

**Universidad Católica de Santa María**  
**Facultad de Ciencias e Ingenierías Físicas y Formales**  
**Escuela Profesional de Ingeniería Mecánica, Mecánica Eléctrica**  
**y Mecatrónica**



“ANÁLISIS MEDIANTE ELEMENTOS DISCRETOS (MED) Y EVALUACIÓN EXPERIMENTAL BAJO LA NORMA ASTM G-99 DEL DESGASTE EN REVESTIMIENTOS DUROS APLICADOS POR PROCESOS DE SOLDADURA EN UÑAS DE ACERO 32MnCrMo6-4-3 DE UNA EXCAVADORA HIDRÁULICA CAT 336D2 L”

Tesis presentada por el Bachiller:

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Para optar el Título Profesional de:

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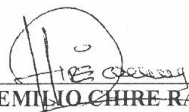
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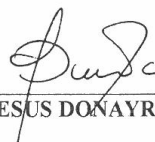
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Arequipa, 16 Setiembre 2019



ING. EMILIO CHIRE RAMIREZ



ING. JESUS DONAYRE CAHUA

**"Hay una fuerza motriz más poderosa que el vapor, la electricidad y la energía atómica:**

**La voluntad" - Albert Einstein.**

El presente trabajo se lo dedico principalmente a Dios por ser mi guía y acompañarme en el transcurso de mi vida, brindándome sabiduría y fuerza para continuar en este proceso de obtener uno de los anhelos más deseados.

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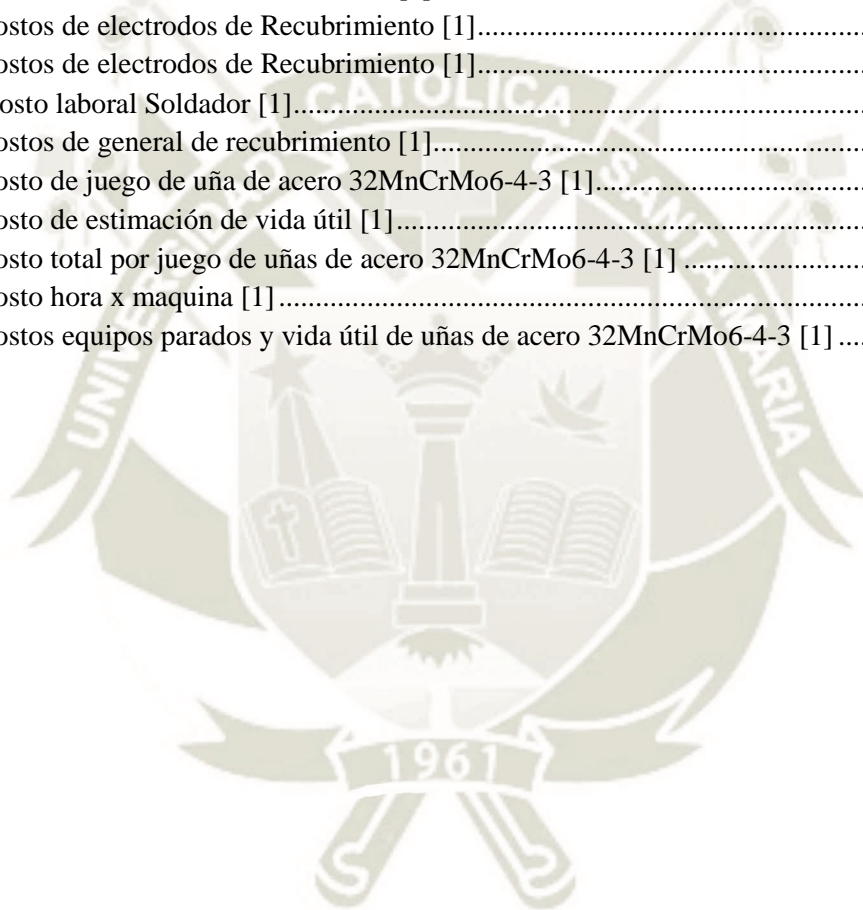
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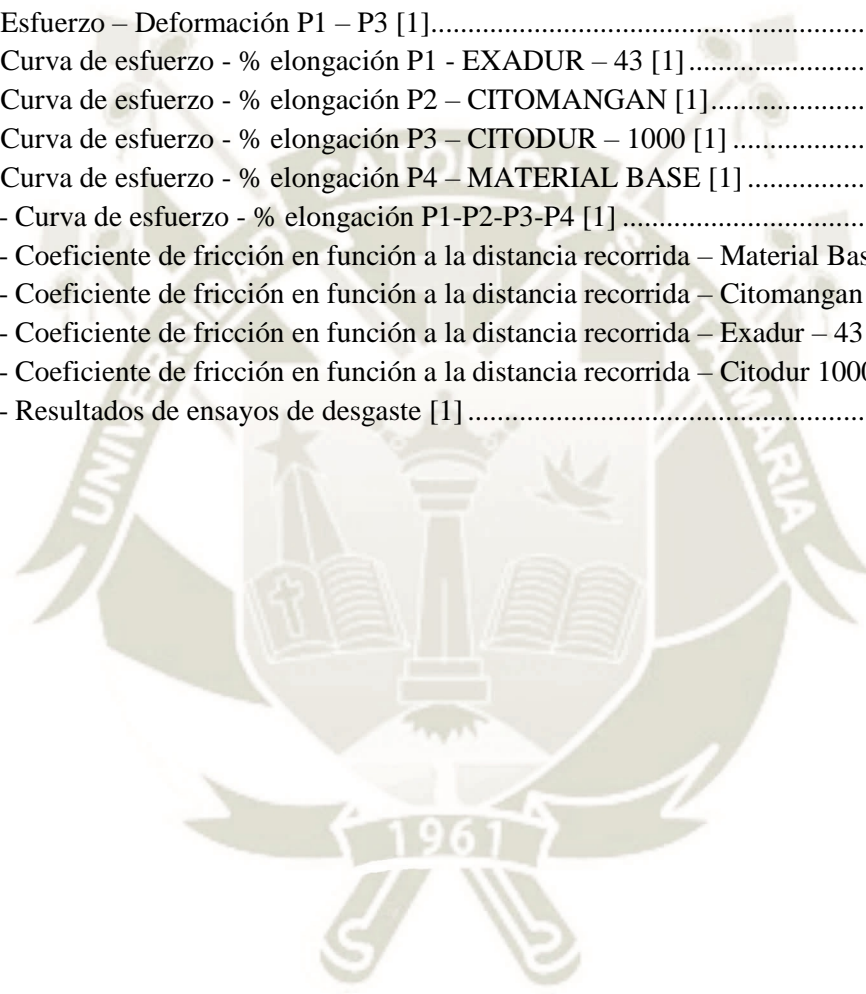
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## RESUMEN

El desgaste de materiales es un fenómeno que afecta a todo tipo de industrias, debido a este gran problema, diferentes investigadores vienen desarrollando estudios para minimizar los efectos del desgaste.

La presente tesis abarca el estudio de 3 recubrimientos duros aplicado en el acero de las uñas de Acero 32MnCrMo6-4-3 (K-130), utilizado en las excavadoras hidráulicas 336D2 L CAT y su incidencia en el desgaste presentado en la mina Barrick – Lagunas norte.

Durante la elaboración de este proyecto se realizarán estudios y pruebas respecto a la resistencia al desgaste de los materiales anteriormente mencionados, mediante la norma ASTM G99 y elementos discretos (MED). Teniendo en cuenta factores como tenacidad, dureza, estructura, corrosión presente, modo y tipo de carga, composición química, rugosidad de la superficie, distancia recorrida, frecuencia de cambio, etc. Expresándolos mediante un marco conceptual y de referencia, la metodología con la cual se procedió en este proyecto y las actividades desarrolladas.

**Palabras claves:** desgaste, uñas de acero, recubrimiento, excavadora hidráulica, elementos discretos, tenacidad, dureza, composición química



## ABSTRACT

The wear of materials is a phenomenon that affects all types of industries, due to this major problem, different researchers are developing studies to minimize the effects of wear.

The present thesis covers the study of 3 hard coatings applied in the steel of the steel nails 32MnCrMo6-4-3 (K-130), used in the hydraulic excavators 336D2 L CAT and its incidence in the wear presented in the mine Barrick - Lagunas Norte.

During the elaboration of this project, studies and tests will be carried out with respect to the wear resistance of the aforementioned materials, by means of the ASTM G99 standard and discrete elements (MED). Taking into account factors such as toughness, hardness, structure, present corrosion, mode and type of load, chemical composition, surface roughness, distance travelled, frequency of change, etc. Expressing them through a conceptual and reference framework, the methodology used in this project and the activities developed.

**Keywords:** wear, steel nails, coating, hydraulic excavator, discrete elements, toughness, hardness, chemical composition



# CAPÍTULO I

## 1. FUNDAMENTACIÓN DEL PROYECTO

### 1.1. Descripción del Problema

De manera general, se define al desgaste como: el daño a una superficie sólida, que implica la pérdida progresiva de material, causada por el movimiento relativo entre la superficie y una sustancia de contacto o sustancias.

En casi todas las empresas relacionadas a la minería hay desgaste de piezas y maquinaria, por lo cual se requiere de minimizar este desgaste y aumentar el ciclo de vida útil de estas piezas obteniendo una mayor relación costo – beneficio. Además de aumentar las horas de producción y la utilidad de los equipos.

Para hacer una buena selección del tipo de revestimiento protector y su aplicación, se necesita saber los tipos de desgaste a los que puede estar sometido la pieza que se quiere proteger.

En este contexto, en el presente tema de tesis, se busca evaluar el efecto en el revestimiento de electrodos duro sobre la microestructura, dureza y resistencia al desgaste de depósitos obtenidos mediante proceso SMAW sobre el acero (32MnCrMo6-4-3) de las uñas K-130 de una excavadora hidráulica CAT 336D2 L, finalmente se determinará cuál de los electrodos proporciona un recargue con mayor resistencia al desgaste.

## 1.2. Justificación

Se ha observado que uno de los problemas que más afecta al área de mantenimiento y oficina técnica es el desgaste prematuro de los elementos de desgaste (Uñas de Acero 32MnCrMo6-4-3) de las excavadoras hidráulicas 336D2 L, y su incidencia en los altos costos por la alta rotación de estas, al no cumplir con el ciclo de vida útil.

Por tal motivo el presente trabajo de investigación se centra en el análisis de revestimientos duros aplicados por procesos de soldadura en las uñas de acero 32MnCrMo6-4-3 (K-130) de una excavadora hidráulica 336D2 L y su incidencia en el desgaste.

Por lo antes expuesto, desde el punto de vista económico, se considera que este estudio es de utilidad tanto para las diferentes empresas del sector minero, por la optimización de costos en compra, cambio de uñas desgastadas, fisuradas, fracturadas con pocas horas de trabajo y paradas no programadas por mantenimiento. Así también optimización de costos por la utilización de los equipos y evitar pérdidas por hora de alquiler no trabajada.

### 1.3. Delimitación del Proyecto

Está limitado al material como es el acero 32MnCrMo6-4-3 de las uñas K-130 de una excavadora hidráulica CAT 336D2 L

Está limitado por la zona geográfica, ya que el estudio está realizado para el contexto operacional mina Lagunas Norte, ubicada en el distrito de Quiruvilca, provincia de Santiago de Chuco, departamento de La Libertad. La zona de trabajo se denomina ALEXA SUR, composición química del material abrasivo afectado a los equipos de carguío y transporte de la compañía.



Figura 1-1 - Excavadora Hidráulica Cat 336 D2 L en operación [1]

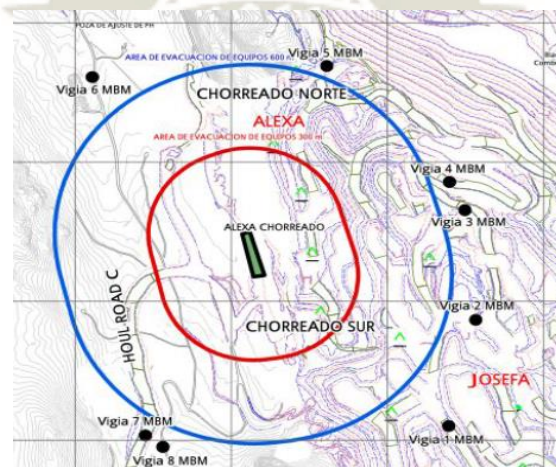


Figura 1-2 - Zona de trabajo Alexa Sur [1]

## 1.4. Objetivos

### 1.4.1. General

Analizar y evaluar el desgaste en revestimientos duros aplicados por procesos de soldadura en uñas de acero 32MnCrMo6-4-3 de una excavadora hidráulica CAT 336D2 L

### 1.4.2. Específicos

- Analizar el desgaste en revestimientos duros aplicados por procesos de soldadura mediante elementos discretos (MED).
- Evaluar el desgaste en revestimientos duros aplicados por procesos de soldadura bajo la norma ASTM G-99.
- Evaluar las pérdidas Volumétricas existentes mediante el desgaste bajo la norma ASTM G-99.
- Realizar el análisis de dureza, metalografía, tensión en cada uno de los procesos de recubrimientos.
- Determinar el tipo de electrodo más adecuado que garantice sus buenas propiedades contra el desgaste.
- Analizar el costo-beneficio del recargue duro aplicado a las uñas de acero 32MnCrMo6-4-3 de las excavadoras Hidráulicas.
- Determinar la influencia de las características del mineral explotado en la mina y de las condiciones de operación de los equipos en el desgaste presentado.

## 1.5.Hipótesis

### 1.5.1. Hipótesis General

Analizando los revestimientos duros aplicados por procesos de soldadura en las uñas de acero 32MnCrMo6-4-3 (K-130) de una excavadora CAT 336D2 L, podemos aumentar la relación costo-beneficio y reducir la compra de elementos de desgaste de las excavadoras debido a la alta rotación de esta.





# CAPÍTULO II



## 2. MARCO TEÓRICO

### 2.1. Aceros

#### 2.1.1. ¿Qué es el Acero?

El Acero es básicamente una aleación o combinación de hierro y carbono (alrededor de 0,05% hasta menos de un 2%). Algunas veces otros elementos de aleación específicos tales como el Cr (Cromo) o Ni (Níquel) se agregan con propósitos determinados.

Ya que el acero es básicamente hierro altamente refinado (más de un 98%), su fabricación comienza con la reducción de hierro (producción de arrabio) el cual se convierte más tarde en acero [2].

El hierro puro es uno de los elementos del acero, por lo tanto, consiste solamente de un tipo de átomos. No se encuentra libre en la naturaleza ya que químicamente reacciona con facilidad con el oxígeno del aire para formar óxido de hierro - herrumbre. El óxido se encuentra en cantidades significativas en el mineral de hierro, el cual es una concentración de óxido de hierro con impurezas y materiales térreos [2].

#### 2.1.2. Clasificación de los aceros.

Los diferentes tipos de acero se clasifican de acuerdo con los elementos de aleación que producen distintos efectos en el Acero [26]:

##### 2.1.2.1. Aceros al Carbono

Más del 90% de todos los aceros son aceros al carbono. Estos aceros contienen diversas cantidades de carbono y menos del 1,65% de manganeso, el 0,60% de silicio y el 0,60% de cobre. Entre los productos fabricados con aceros al carbono figuran máquinas, carrocerías de automóvil, la mayor parte de las estructuras de construcción de acero, cascos de buques, somieres y horquillas [26].

#### 2.1.2.2. Aceros Aleados

Estos aceros contienen una proporción determinada de vanadio, molibdeno y otros elementos, además de cantidades mayores de manganeso, silicio y cobre que los aceros al carbono normales. Estos aceros de aleación se pueden subclasificar en [26]:

##### 2.1.2.2.1. Estructurales

Son aquellos aceros que se emplean para diversas partes de máquinas, tales como engranajes, ejes y palancas. Además, se utilizan en las estructuras de edificios, construcción de chasis de automóviles, puentes, barcos y semejantes. El contenido de la aleación varía desde 0,25% a un 6% [26].

##### 2.1.2.2.2. Para Herramientas

Aceros de alta calidad que se emplean en herramientas para cortar y modelar metales y no metales. Por lo tanto, son materiales empleados para cortar y construir herramientas tales como taladros, escariadores, fresas, terrajas y machos de roscar [26].

##### 2.1.2.2.3. Especiales

Los Aceros de Aleación especiales son los aceros inoxidable y aquellos con un contenido de cromo generalmente superior al 12%. Estos aceros de gran dureza y alta resistencia a las altas temperaturas y a la corrosión se emplean en turbinas de vapor, engranajes, ejes y rodamientos [26].

##### 2.1.2.2.4. Aceros de baja aleación ultrarresistentes

Esta familia es la más reciente de las cuatro grandes clases de acero. Los aceros de baja aleación son más baratos que los aceros aleados convencionales ya que contienen cantidades menores de los costosos elementos de aleación. Sin embargo, reciben un tratamiento especial que les da una resistencia mucho mayor que la del acero al

carbono. Por ejemplo, los vagones de mercancías fabricados con aceros de baja aleación pueden transportar cargas más grandes porque sus paredes son más delgadas que lo que sería necesario en caso de emplear acero al carbono. Además, como los vagones de acero de baja aleación pesan menos, las cargas pueden ser más pesadas. En la actualidad se construyen muchos edificios con estructuras de aceros de baja aleación. Las vigas pueden ser más delgadas sin disminuir su resistencia, logrando un mayor espacio interior en los edificios [26].

#### 2.1.2.2.5. Aceros Inoxidables

Los aceros inoxidables contienen cromo, níquel y otros elementos de aleación, que los mantienen brillantes y resistentes a la herrumbre y oxidación a pesar de la acción de la humedad o de ácidos y gases corrosivos. Algunos aceros inoxidables son muy duros; otros son muy resistentes y mantienen esa resistencia durante largos periodos a temperaturas extremas. Debido a sus superficies brillantes, en arquitectura se emplean muchas veces con fines decorativos. El acero inoxidable se utiliza para las tuberías y tanques de refinerías de petróleo o plantas químicas, para los fuselajes de los aviones o para cápsulas espaciales [26].

### 2.2.Efectos de los elementos de aleación

Los elementos de aleación específicos y sus cantidades determinan el tipo de acero de aleación y sus propiedades particulares [26].

Se puede apreciar en la Tabla 2-1 los efectos principales de algunos de los elementos más comunes.

Tabla 2-1 - Efectos de elementos de aleación [2]

ELEMENTO	APORTACIÓN
ALUMINIO	Empleado en pequeñas cantidades, actúa como un desoxidante para el acero fundido y produce un Acero de Grano Fino.
BORO	Aumenta la templabilidad (la profundidad a la cual un acero puede ser endurecido).
CROMO	Aumenta la profundidad del endurecimiento y mejora la resistencia al desgaste y corrosión. COBRE Mejora significativamente la resistencia a la corrosión atmosférica.
MANGANESO	Elemento básico en todos los aceros comerciales. Actúa como un desoxidante y también neutraliza los efectos nocivos del azufre, facilitando la laminación, moldeo y otras operaciones de trabajo en caliente. Aumenta también la penetración de temple y contribuye a su resistencia y dureza.
MOLIBDENO	Mediante el aumento de la penetración de temple, mejora las propiedades del tratamiento térmico. Aumenta también la dureza y resistencia a altas temperaturas.
NIQUEL	Mejora las propiedades del tratamiento térmico reduciendo la temperatura de endurecimiento y distorsión al ser templado. Al emplearse conjuntamente con el Cromo, aumenta la dureza y la resistencia al desgaste.
SILICIO	Se emplea como desoxidante y actúa como endurecedor en el acero de aleación.
AZUFRE	Normalmente es una impureza y se mantiene a un bajo nivel. Sin embargo, alguna vez se agrega intencionalmente en grandes cantidades (0,06 a 0,30%) para aumentar la maquinabilidad (habilidad para ser trabajado mediante cortes) de los aceros de aleación y al carbono.
TITANIO	Se emplea como un desoxidante y para inhibir el crecimiento granular. Aumenta también la resistencia a altas temperaturas.
TUNGSTENO	Se emplea en muchos aceros de aleación para herramientas, impartiendo una gran resistencia al desgaste y dureza a altas temperaturas.
VANADIO	Imparte dureza y ayuda en la formación de granos de tamaño fino. Aumenta la resistencia a los impactos (resistencia a las fracturas por impacto) y también la resistencia a la fatiga.

### 2.3. Aceros utilizados en elementos de desgaste

#### 2.3.1. Acero 32MnCrMo6-4-3 – Aceros Aleados

Efectos de los elementos de aleación.

Las aleaciones se utilizan principalmente para aumentar la templabilidad de los aceros. No tienen ningún comportamiento durante el temple. Los formadores de carburo de tungsteno tienden a para aumentar la dureza de la martensita templada, como se muestra en la Figura 2-1 [3].

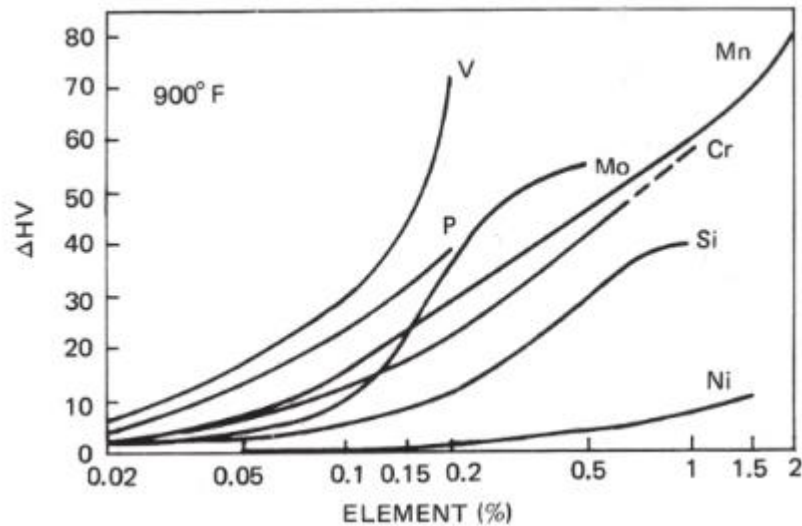


Figura 2-1 - Efecto de los elementos de aleación sobre la dureza de la martensita templada para 1 h a 482°C. [3]

El efecto neto de las aleaciones sobre la dureza Vickers es la suma de las contribuciones de cada elemento. El molibdeno aumenta el tiempo para formar perlita mucho más que el tiempo para formar bainita, por lo que se utiliza en aceros en los que la bainita es un producto deseado. Elementos de aleación aumenta el tiempo necesario para el revenido. Mn, Ni, Cr y Si tienden a promueven la fragilidad del temperamento; Mo, Ti y Zr la retrasan [3].

### 2.3.2. Aplicaciones

Las aleaciones bajas en carbono (0.10-0.25%C) se utilizan principalmente para carburizado partes. Estos incluyen 4023, 4118 y 5015. Partes intrincadas que contienen más del 0,40% C debe ser templado con aceite para evitar que se agriete. El 52100 se utiliza exclusivamente para rodamientos de bolas. Los resortes se fabrican normalmente de las aleaciones 5155 y 5160 [3].

## 2.4. Tribología

La palabra “tribología” viene de la palabra griega tribos que significa fricción, traduciendo la palabra literalmente como la “ciencia de la fricción”. Mientras que el estudio del concepto se remonta a Leonardo da Vinci y sus estudios sobre las leyes de la fricción, la palabra “Tribología” no se había utilizado ampliamente hasta que Peter H. Jost, un ingeniero mecánico británico, acuñó el término en el Reporte Jost del 9 de marzo de 1966 [12].

Jost es considerado el fundador de la disciplina de la tribología, y a partir de su reporte, se puso una mayor atención sobre el tema. Solicitó el establecimiento de Institutos de Tribología, junto con la publicación de un manual sobre tribodiseño e ingeniería [12].

En una entrevista realizada por Jim Fitch, fundador de Noria Corporation, se le pidió a Jost que describiera el momento en que concibió la tribología, señalando que fue en septiembre de 1964 en la Conferencia sobre Lubricación en Trabajos de Hierro y Acero en Cardiff (Reino Unido) del Instituto del Hierro y del Acero/Grupo de Lubricación y Desgaste del ImechE [12]. Fue en esta conferencia donde se discutieron las fallas, particularmente en la maquinaria y equipos dañados en acerías. Después de esto, se le pidió a Jost que formara un comité para “investigar lo relacionado con la educación sobre lubricación, la investigación y las necesidades de la industria” (vea el artículo de Jim Fitch, “Interview with Luminary Professor H. Peter Jost – The Man who Gave Birth to the Word ‘Tribology’”) [12].

Poco después de la publicación del Reporte Jost, el 26 de septiembre de 1966 se estableció formalmente la Comisión de Tribología y fue encargada de varias tareas, incluyendo [12]:

- Asesorar al ministro de tecnología para medir el efecto del progreso tecnológico y los ahorros en el ámbito de la tribología [12].
- Asesorar a los departamentos gubernamentales y otros organismos en asuntos relacionados con la tribología [12].
- Examinar y recomendar a la industria las últimas técnicas en tribología [12].
- Informar anualmente al ministro de tecnología sobre sus propias actividades y sobre las tendencias y desarrollos en tribología que se consideran de importancia tecnológica o económica para la nación [12]

Desde entonces, la tribología se ha convertido en un área interdisciplinaria relacionada con la biología, la química, la ingeniería, las ciencias de los materiales, las matemáticas y la física [4].

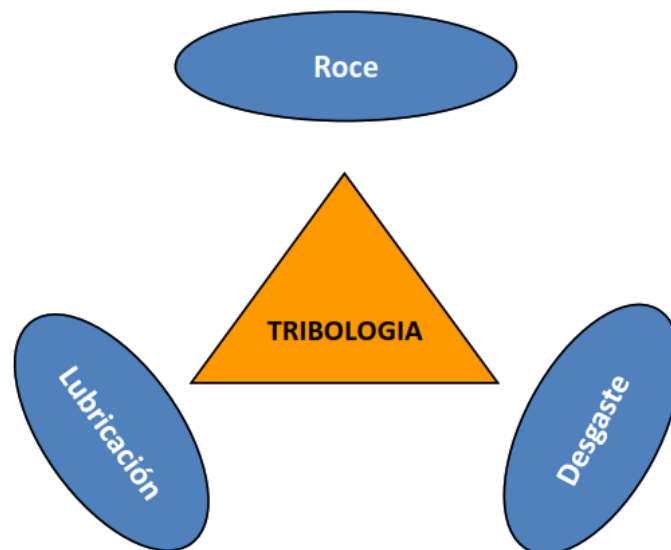


Figura 2-2 - Esquema tribológico [4]

El Perú y otros países de Latinoamérica (ricos en minerales) son el centro de la mayor red de industrias mineras. Estas trabajan bajo altas cargas de calor, polvo y rigor. Las mencionadas condiciones son un reto para la tribología [4].

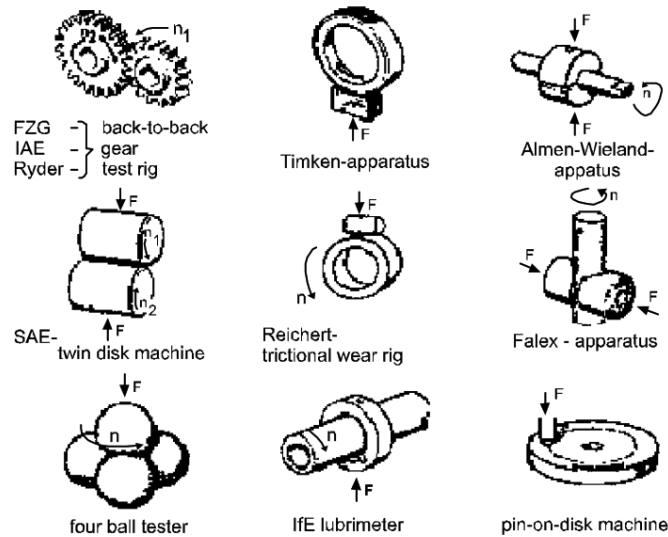


Figura 2-3 - Diferentes Ensayos de Tribológicos [4]

#### 2.4.1. Tribología – Economía.

Las pérdidas por fricción y desgaste representan el 10% del PBI. Los países subdesarrollados pierden un 30% adicional, con los países desarrollados como se puede observar en la Figura 2-4 y la Figura 2-5 [4].

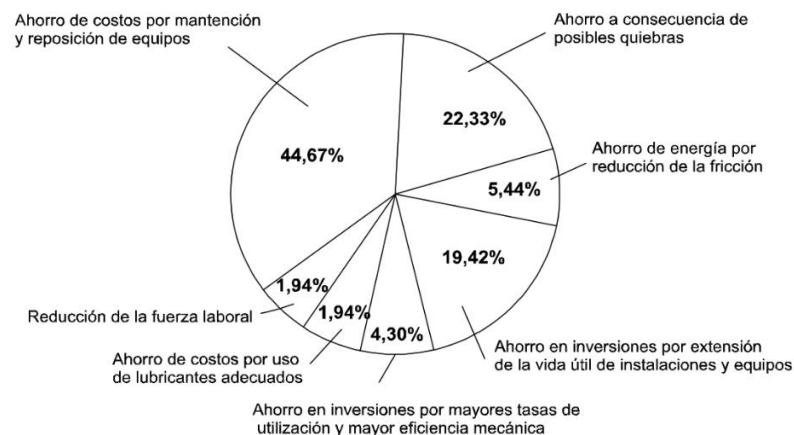


Figura 2-4 - Tribo – pérdidas económicas [4]



Industria	Pérdidas como % del costo de mantenimiento
Metalúrgica	55 a 60%
Hierro y acero	60 a 65%
Minería	70 a 72%
Petroquímica	60 a 65%
Ingeniería	50 a 60%

Figura 2-5 - Pérdidas económicas por Industria [4]

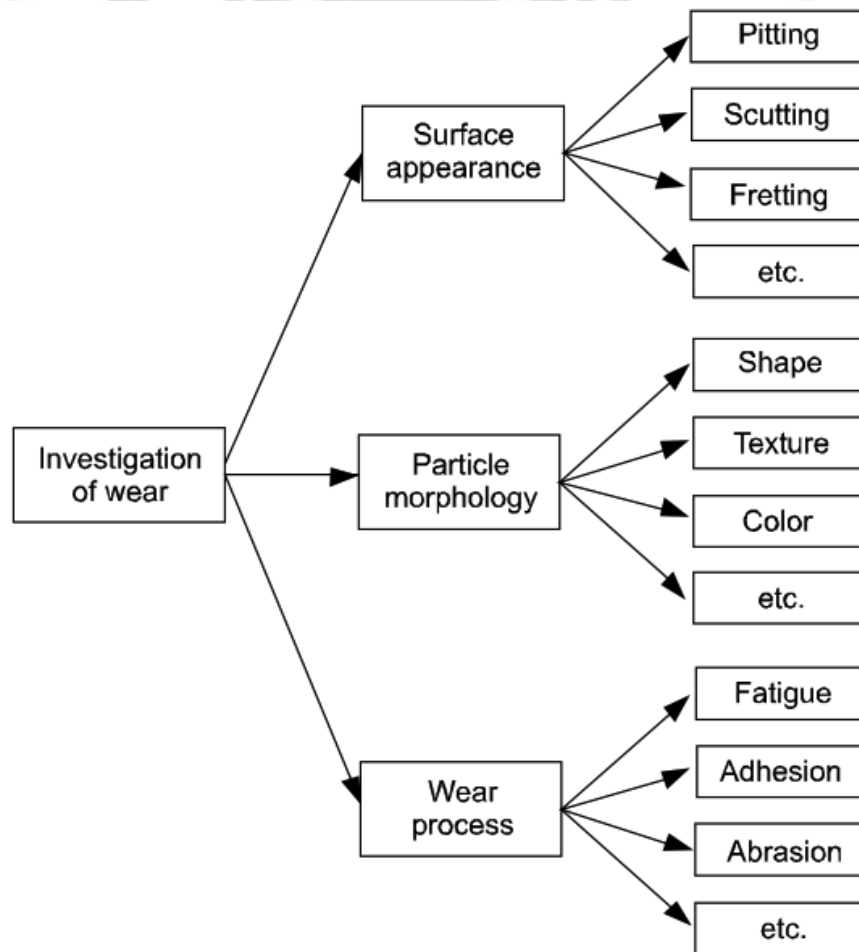


Figura 2-6 - Investigación del desgaste [4]

## 2.5.Desgaste

El desgaste es una de las causas principales de los daños en los componentes y de las consiguientes averías de máquinas y aparatos. Su mitigación mediante la elección del material apropiado, el revestimiento, el diseño de la superficie o la lubricación lo es, por lo tanto, de gran importancia económica [5].

Aunque la fricción y el desgaste siempre aparecen juntos, en la práctica son fenómenos cualitativamente diferentes. Esto ya se puede ver en el hecho de que uno puede imaginar la fricción sin desgaste, al menos en un modelo. Por ejemplo, hay fricción, pero no hay desgaste en el modelo Prandtl-Tomlinson. Incluso se puede prever un desgaste sin fricción: el desgaste ya puede ser causado por un contacto normal sin movimiento tangencial [5].

Los mecanismos físicos de fricción y desgaste, a menudo diferentes, se hacen visibles en el hecho de que la tasa de desgaste de varios pares de fricción (en condiciones idénticas) puede variar en varios órdenes de magnitud [5].

Al mismo tiempo puede observarse que en situaciones específicas, los procesos que conducen a la fricción también causan que el desgaste ocurra al mismo tiempo, por ejemplo, la deformación plástica de los microcontactos. En estos casos, la fricción y el desgaste pueden tener una estrecha correlación [5].

En la mayoría de los casos, la fricción se considera un fenómeno no deseado. Sin embargo, el desgaste también puede ser la base de varios procesos tecnológicos, como el esmerilado, el pulido o el chorro de arena [5].

Es común diferenciar los siguientes tipos fundamentales de desgaste según sus mecanismos físicos [5]:

- El desgaste por abrasión se produce cuando dos cuerpos con durezas muy diferentes están en contacto o cuando el tercer cuerpo contiene partículas duras [5].
- El desgaste del adhesivo se produce incluso en los contactos entre cuerpos con durezas iguales o similares [5].

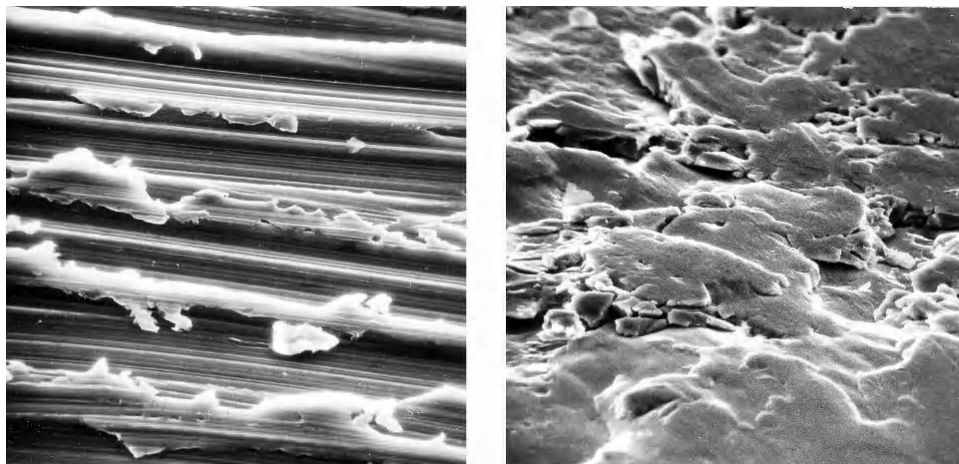


Figura 2-7 - Microestructura de desgaste de Material [5]

### 2.5.1. Desgaste abrasivo

Durante el desgaste por abrasión, las asperezas del material más duro penetran y cortan el material más blando. Las ranuras que se desplazan en el sentido de deslizamiento son, por lo tanto, un signo de desgaste abrasivo [6].

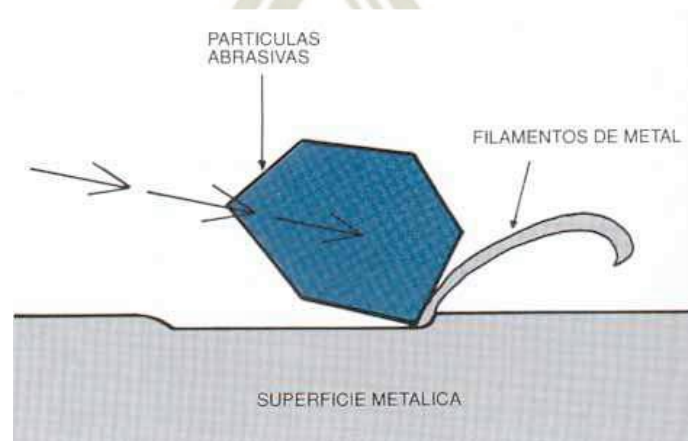


Figura 2-8 - Partícula abrasiva en movimiento [6]

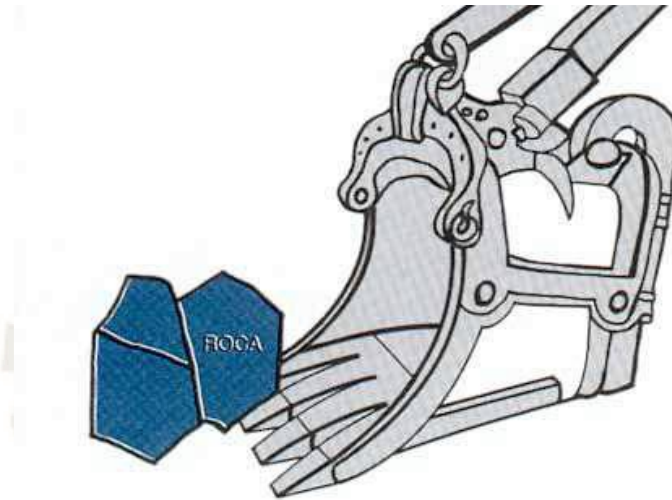


Figura 2-9 - Impacto de Metal con roca a baja velocidad [6]

Causado por el movimiento relativo de partículas duras en la superficie. El grado de abrasión depende de la naturaleza de las partículas abrasivas, (morfología, granulometría, concentración, ángulo incidencia y la velocidad relativa) [6].

- Abrasión pura o de bajo esfuerzo
- Abrasión de alto esfuerzo
- Abrasión por desgarramiento

#### 2.5.1.1. Abrasión pura o de bajo esfuerzo

Abrasivo de granulometría fina/media, ausencia de impacto, ángulos de incidencia pequeños, presiones bajas (abrasivo sobre metal) como ejemplo se tiene en la Figura 2-10 [6].



Figura 2-10 - Partícula abrasiva en Hopper [6]

#### 2.5.1.2. Abrasión de alto esfuerzo

Constituido por partículas pequeñas y que no impactan sobre la superficie de desgaste [6].

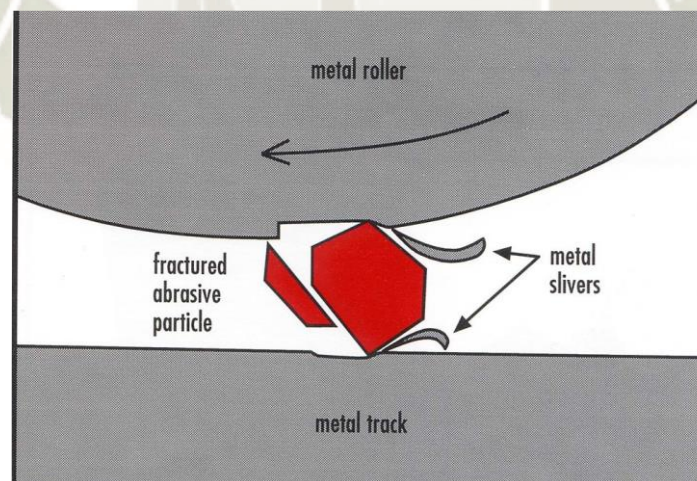


Figura 2-11 - Partícula abrasiva en movimiento [6]

#### 2.5.1.3. Abrasión por desgarramiento

Difiere al anterior en cuanto a que el elemento abrasivo es de mayor tamaño y muchas veces existe impacto [6].

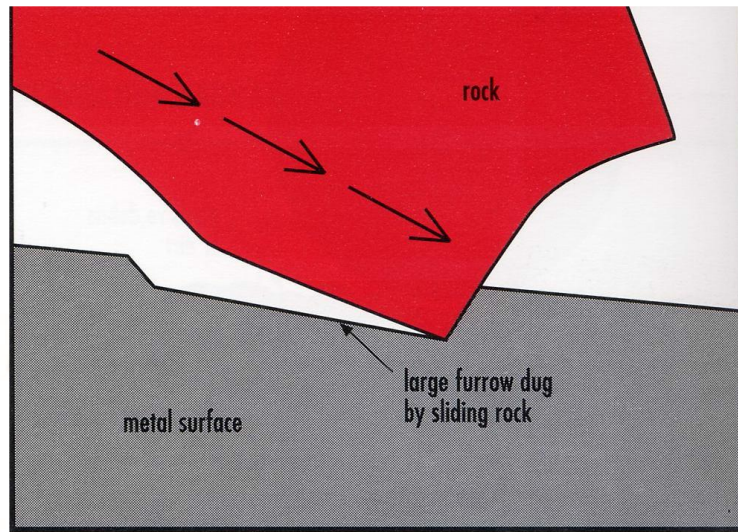


Figura 2-12 - Desgarro de material con partícula abrasiva [6]



Figura 2-13 - Cucharón de excavadora desgarrado con material abrasivo [1]

### 2.5.2. Desgaste por impacto

El desgaste por impacto es causado por colisiones repetitivas entre superficies opuestas. Un ejemplo clásico de esta forma de desgaste se encuentra en las cabezas de los martillos. Esta forma de desgaste implica superficies planas o superficies casi planas con un gran radio de curvatura en comparación con el tamaño de la cicatriz de desgaste. Esta característica distingue el desgaste por impacto del desgaste erosivo, en el que una partícula puntiaguda penetra en la superficie de la pieza. superficie plana. En el desgaste por impacto, la superficie está sometida a un impacto repetitivo por una serie de impulsos de alta tensión de contacto combinada con cierta disipación de energía en cada impacto, como se muestra a continuación esquemáticamente en la Figura 2-14 [7].

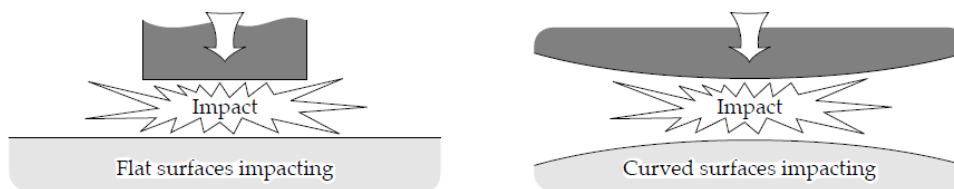


Figura 2-14 - Pulsos de tensión repetitivos bajo el desgaste por impacto [7]

En la medida que la superficie reciba el impacto y pueda absorber energía es que exhibirá resistencia al choque [6].

El empleo de las aleaciones tenaces del tipo aceros al manganeso austeníticos y aceros de baja aleación tratados térmicamente, son los que están dan buenos resultados [6].

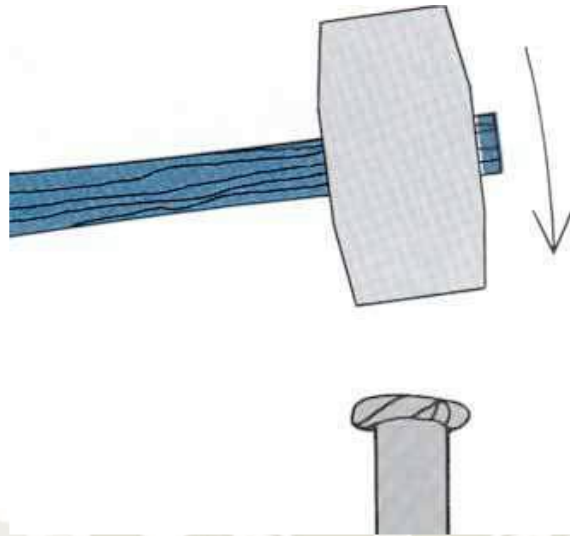


Figura 2-15 - Desgaste por impacto en un cincel [6]

### 2.5.3. Desgaste erosivo

El desgaste erosivo es causado por el impacto de partículas sólidas o líquidas contra la superficie de un objeto. El desgaste erosivo se produce en una gran variedad de maquinaria y los ejemplos típicos como los siguiente: daños en los álabes de las turbinas de gas cuando una aeronave vuela a través de nubes de polvo, y el desgaste de impulsores de bombas en sistemas de procesamiento de lodos minerales. En común con otras formas de desgaste, la resistencia mecánica no garantiza la resistencia al desgaste y un estudio detallado del material se requieren para minimizar el desgaste. Las propiedades de la partícula que se erosiona son también importantes y se reconocen cada vez más como un parámetro relevante en el control de este tipo de desgaste [7].

El desgaste erosivo implica varios mecanismos de desgaste que son controlados en gran medida por el material de las partículas, el ángulo de impacto, la velocidad de impacto y el tamaño de las partículas. Si la partícula es dura y sólida, es posible que se produzca un proceso similar al desgaste abrasivo. Cuando las partículas líquidas son el erodente, la



abrasión no tiene lugar y los mecanismos de desgaste involucrados son el resultado de esfuerzos repetitivos en el impacto [7].

El término "desgaste erosivo" se refiere a un número indeterminado de mecanismos de desgaste que se producen cuando partículas relativamente pequeñas impactan contra componentes mecánicos. Esta definición es empírica por naturaleza y se relaciona más con consideraciones prácticas que con cualquier comprensión fundamental del desgaste. Los mecanismos conocidos de desgaste erosivo se ilustran en la Figura 2-16 [7].

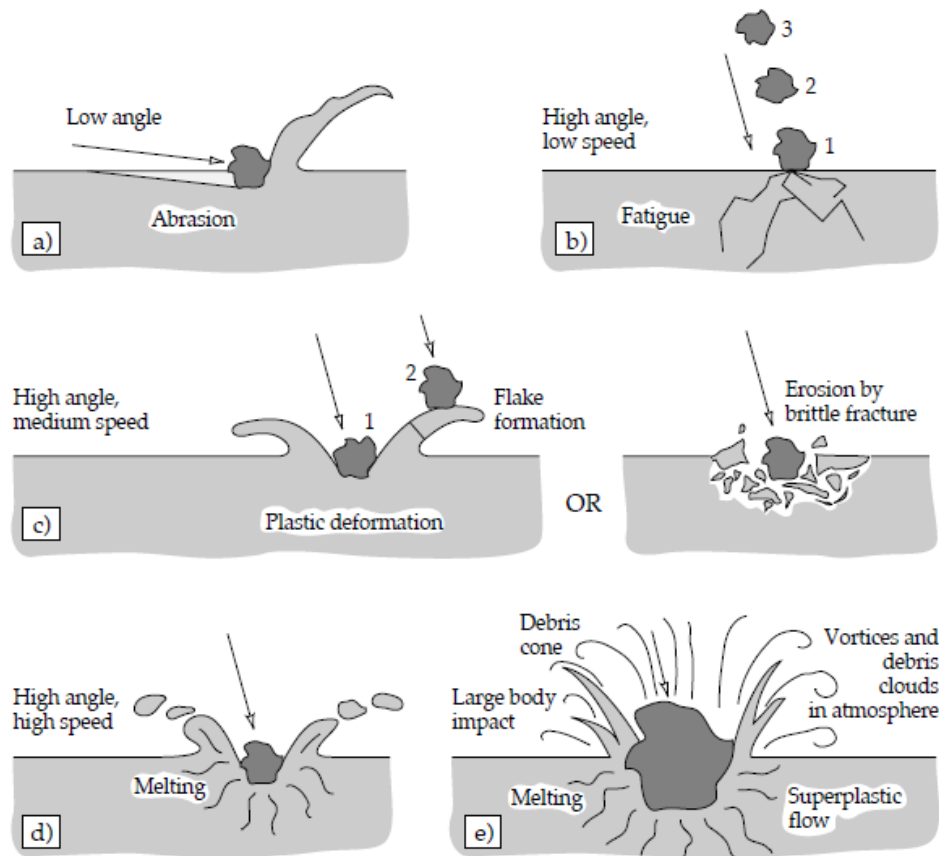


Figura 2-16 - Posibles mecanismos de erosión; a) abrasión en ángulos de bajo impacto, b) fatiga superficial durante un impacto de baja velocidad y alto ángulo de impacto, c) fractura frágil o deformación plástica múltiple, d) fusión de superficie a altas velocidades de impacto, e) erosión macroscópica con efectos secundarios [7]

#### 2.5.4. Desgaste adhesivo

Si los elementos de fricción tienen durezas comparables, entonces otro tipo de desgaste comienza a jugar un papel primordial: el desgaste adhesivo. El desgaste del adhesivo es lo más importante tipo de desgaste en aplicaciones tribológicas en las que se debe minimizar el desgaste y, por lo tanto, deben evitarse las condiciones en las que se produce el desgaste por abrasión [5].

El mecanismo de desgaste adhesivo puede ser imaginado como la soldadura de microfibras de las asperezas seguidas de los elementos de volumen (partículas de desgaste) cerca de la superficie siendo arrancada. Investigamos las condiciones para la soldadura y el desgarro de una partícula según este mecanismo [5].

La propiedad fundamental de los materiales metálicos es que se deforman plásticamente después de superar una tensión crítica. Si el material se carga en tensión, después de una deformación crítica, se produce un fallo. Por el contrario, si se sobrepasa el límite elástico bajo presión, los dos socios se sueldan entre sí. Aunque este efecto no sea perceptible macroscópicamente (similar al caso de la adhesión), es válido para micro contactos individuales, este se puede observar en la Figura 2-17 [5].

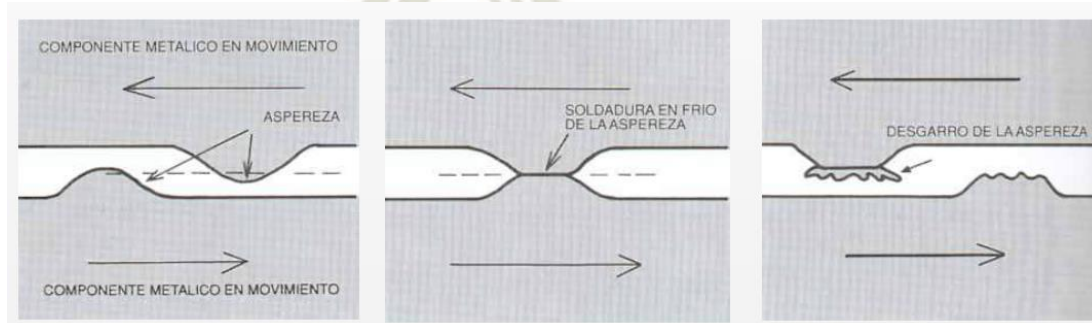


Figura 2-17 - Desgaste producto de la fricción no lubricada entre piezas metálicas [6]

## 2.6.Contexto operacional

### 2.6.1. Ubicación y Accesibilidad

Minera Barrick Misquichilca S.A. (MBM) UEA Lagunas Norte se ubica en el Distrito de Quiruvilca, Provincia de Santiago de Chuco, Departamento de La Libertad, ubicado por carretera aproximadamente a 140 km. al este de Trujillo y a 11 km. al noreste del pueblo de Quiruvilca. La mina se sitúa en la Cordillera Occidental de los Andes Peruanos a una altitud aproximada de 4150 m.s.n.m. encontrándose el área del proyecto entre los 3700 a 4200 m.s.n.m. Se extiende a ambos lados de la divisoria continental entre dos cuencas que drenan hacia en el Océano Atlántico al este y hacia el Océano Pacífico al oeste. Considerando la ubicación, la naciente del Río Chuyuhual fluye al este y la del Río Negro fluye al oeste. El Río Negro desemboca en el RíoPerejil, el cual aguas abajo cambia de nombre a Río Alto Chicama. El área se caracteriza por cerros ondulantes y montañas escarpadas, con terreno cortado por valles abruptos, que reflejan los patrones de erosión asociados con la geología del lecho de roca [8].

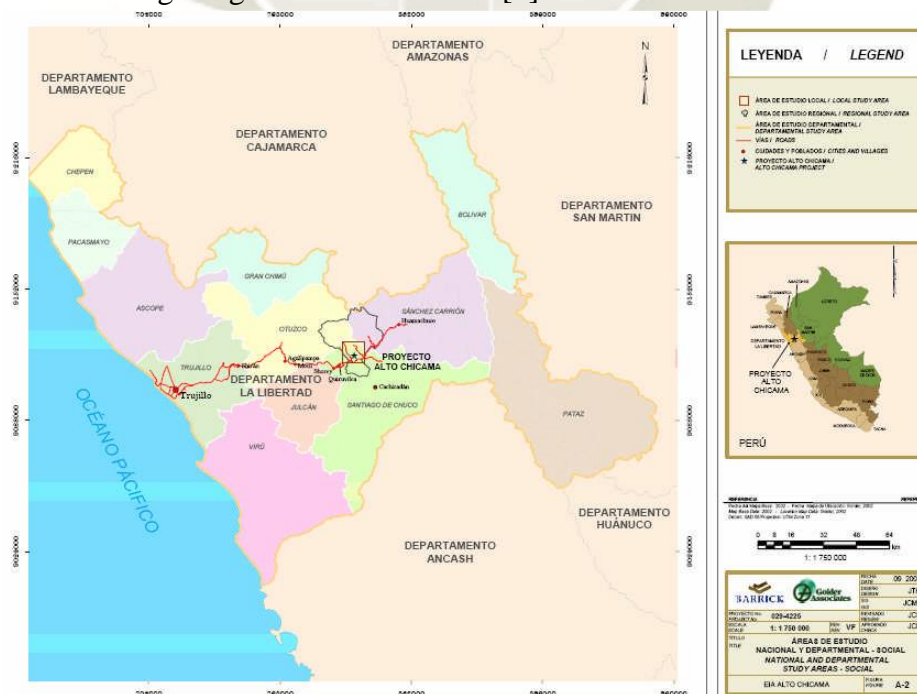


Figura 2-18 - Ubicación y accesibilidad Mina Lagunas Norte [8]

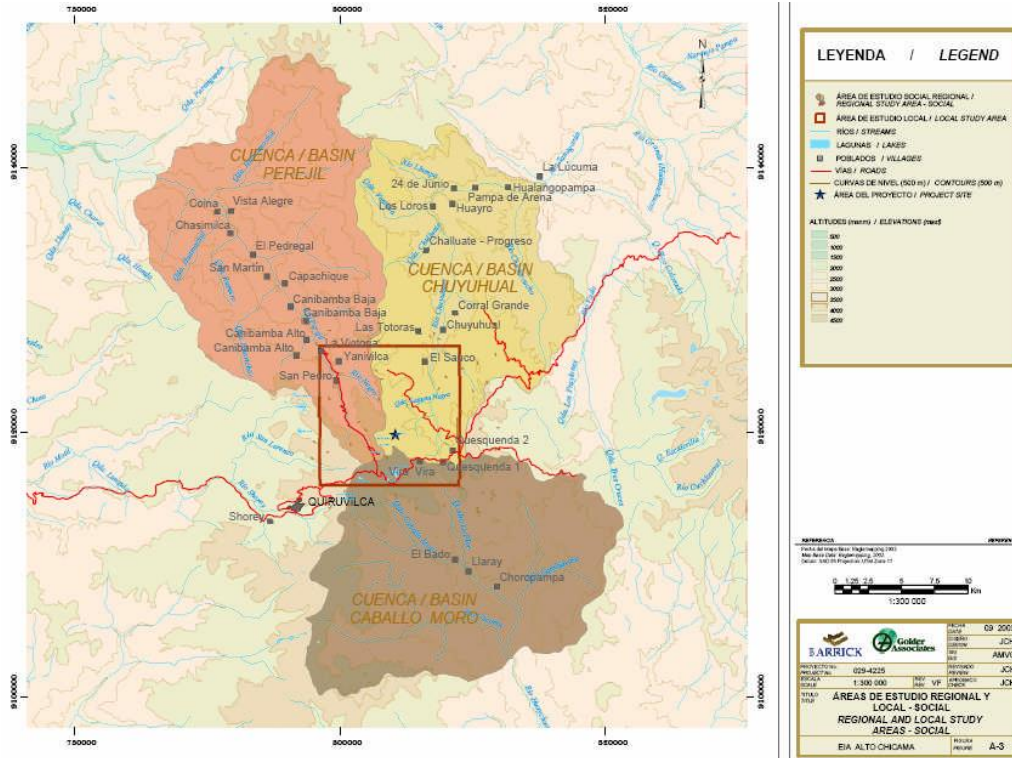


Figura 2-19 - Ubicación y accesibilidad Mina Lagunas Norte [8]

2.6.2. Clasificación de materiales para polígonos y estacas de campo.

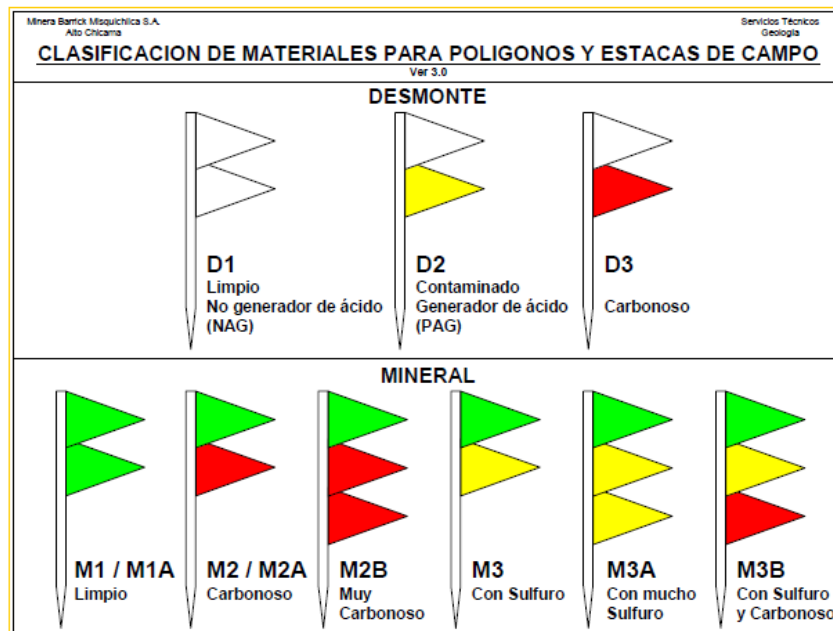


Figura 2-20 - Clasificación de materiales para polígonos y estacas de campo [8]

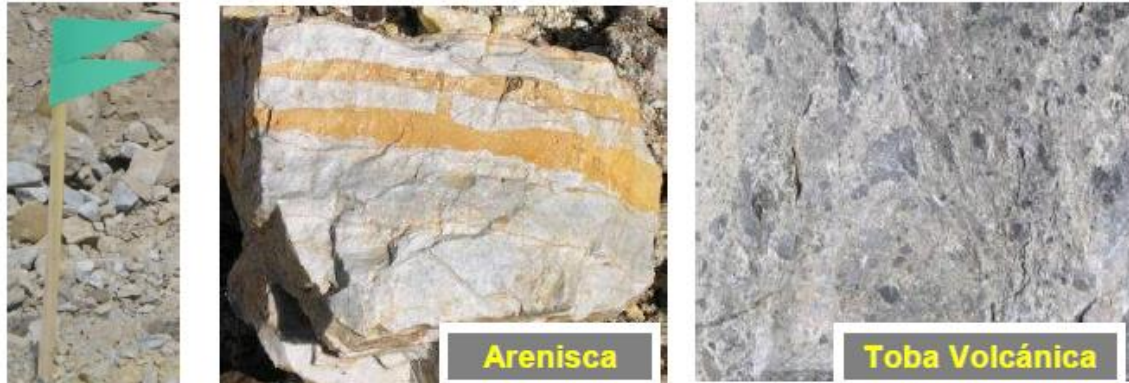


Figura 2-21 - Mineral M2-M2A [8]

M2-M2A: Es el mineral contaminado con material carbonoso, su destino es chancadora cuando es autorizado por metalurgia, de lo contrario va al single pass y stockpile (Figura 2-21). Este tipo de mineral tiene los siguientes valores [8]:

- M2: Au >0.358 gr/TM, TCM>0.05<0.1% y S <0.25% [8].
- M2A: Au >0.352 gr/TM, TCM>0.1%<0.5% y S <0.25% [8].

Generalmente está definido litológicamente por sedimentos carbonosos y por tobas. Su identificación es con dos banderines, el superior de color verde que representa al mineral y el segundo de color rojo que indica que es mineral carbonoso (Figura 2-21) [8].



Figura 2-22 - Mineral M3 [8]

M3: Este mineral es con sulfuro, su destino es single pass chancado (Figura 2-22). Solo en casos extremos será enviado a Stockpile. Este tipo de mineral tiene los siguientes valores [8]:

- M3: Au >0.339 gr/TM, TCM < 0.05% y S > 0.40% [8].

Generalmente está definido litológicamente por brechas y tobas volcánicas con sulfuro. Su identificación es con dos banderines, el superior de color verde que representa al mineral y el siguiente de color amarillo que indica que es mineral con sulfuro [8].

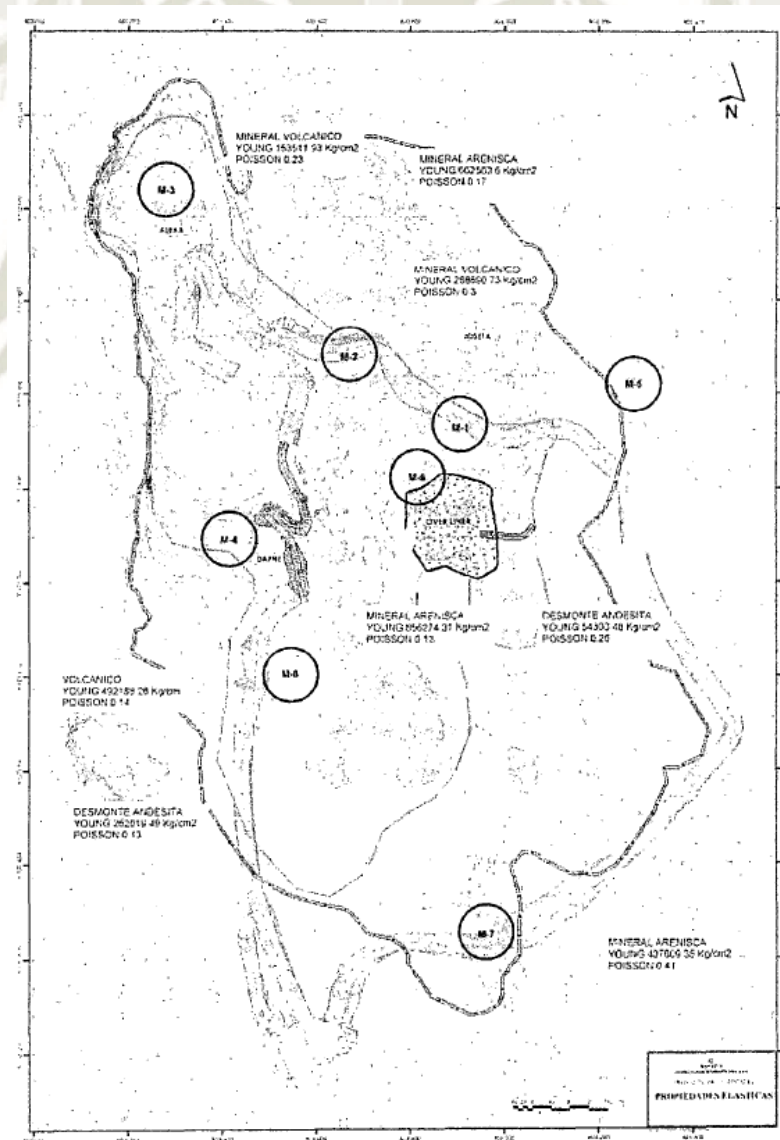


Figura 2-23- Muestras superficiales [9]

### 2.6.3. Ensayos de propiedades elásticas – muestras superficiales

Según la tesis ANÁLISIS TECNICO-ECOLOGICO-ECONOMICO CON LA APLICACIÓN DE EXPLODECK PARA REDUCIR EL CONSUMO DE MEZCLA EXPLOSIVA EN LA COMPAÑÍA MINERA BARRICK MISQUICHILCA LAGUNAS NORTE , se tomaron 8 muestras superficiales, de igual modo de distintos tipos litológicos y fueron enviadas a Lima (PUCP), para ser ensayadas por sus propiedades elásticas (Módulo de Elasticidad, Coeficiente de Poisson), dentro de estos ensayos se determinó también la Resistencia a la Compresión no confinada (Figuras 2-24, 2-25, 2-26) [9].

MUESTRA	CODIGO	MODULO DE ELASTICIDAD kg/cm <sup>2</sup>
M1	VBPMS	288690.73
M3	VBPMS	153511.93
M6	SSAC	856274.31
M7	SSAC	437609.35
M2	SSAC	662580.6
M4	SMSCS	492188.26
M5	LPANF	54300.48
M8	LPANF	262019.49

Figura 2-24 - Resultados de módulo de elasticidad [9]

MUESTRA	CODIGO	COEF. DE POISSON
M1	VBPMS	0.3
M3	VBPMS	0.23
M6	SSAC	0.13
M7	SSAC	0.41
M2	SSAC	0.17
M4	SMSCS	0.14
M5	LPANF	0.26
M8	LPANF	0.13

Figura 2-25 - Resultados de coeficiente de Poisson [9]

MUESTRA	CODIGO	RESISTENCIA A COMPRESION Mpa
M1	VBPMS	63
M3	VBPMS	32
M6	SSAC	220
M7	SSAC	70
M2	SSAC	140
M4	SMSCS	95
M5	LPANF	23
M8	LPANF	100

Figura 2-26 - Resultados a la resistencia a la compresión [9]

#### 2.6.4. Ensayo de Abrasión

Para conocer el porcentaje de desgaste (abrasión) de las rocas; se enviaron a ensayar 7 muestras de distintos lugares de la mina, básicamente de 2 tipos litológicos; Brechas Volcánicas y Areniscas que son las que presentan mayor dureza (Figuras 2-27, 2-28) [9].

**RESULTADOS DE ABRASION**

No Muestra	Zona	Nivel	Tipo de Roca	Coefficiente de Desgaste
M-1	Alexa Norte	4180	Ceniza y Tobas Volcánica	28.10%
M-2	Alex Sur	4180	Arenisca	33.20%
M-3	Dafne	4140	Ceniza y Tobas Volcánica	26.90%
M-4	Dafne	4120	Bx. Volcánica	22.90%
M-5	Dafne	4120	Arenisca	22.30%
M-6	Over Liner		Arenisca	22.00%
M-7	Over Liner		Bx. Volcánica	24.30%

Figura 2-27 - Resultados de ensayo de abrasión [9]

**RESUMEN**

Tipo de Roca	Coefficientes de Desgastes			Prom
Ceniza y Tobas Volcánica	28.00	26.90		27.45%
Bx. Volcánica	22.90	24.30		23.60%
Arenisca	33.20	22.30	22.00	25.83%

Figura 2-28 - Resultados de ensayo de abrasión [9]

#### 2.7. Hardfacing

El recargue o recubrimiento protector consiste en el depósito de una o varias capas de soldadura de características muy especiales en las superficies de piezas desgastadas o deterioradas, evitándose de esta manera el costoso reemplazo de la pieza. Gracias a las capas de recargue o recubrimiento protector, que se aplican a las piezas mediante electrodos de soldadura eléctrica, varillas de soldadura oxi-acetilénica, alambres tubulares u otros procedimientos, es posible [10]:

- Recuperar piezas desgastadas o deterioradas.
- Reparar elementos de máquina.



- Proteger las superficies de las piezas o elementos sujetos a fuerte desgaste, prolongando su vida útil.
- Construir piezas con materiales más baratos, aplicando el recargue protector sólo en las superficies que requieren protección.
- Los recubrimientos protectores se emplean, cuando las piezas deben poseer una o varias de las propiedades siguientes:
  - La abrasión es producida por fricción de la pieza con rocas, arena, cascajo, tierra o cualquier materia no metálica.
  - Resistencia al rozamiento metálico, el cual es producido por la fricción de la pieza con la superficie metálica de otra pieza o elemento mecánico.
  - Resistencia al impacto o choques bruscos e intempestivos.
  - Resistencia a la oxidación.
  - Resistencia a la corrosión causada por acción de sales, ácidos u otros elementos.
  - Resistencia a calor elevado y variaciones de temperatura, etc.

Por supuesto, cualquiera de las piezas puede requerir varias de las propiedades indicadas, de manera que el material de recargue o recubrimiento protector deberá poseer las distintas cualidades necesarias [10].

Normalmente no es posible encontrar un electrodo de recargue o recubrimiento protector, que reúna al máximo y en forma conjunta a todas las propiedades señaladas. Sin embargo, sabiendo seleccionar el electrodo adecuado, se llega a obtener un resultado satisfactorio [10].

La dureza (Rockwell o Brinell) del metal depositado por un electrodo de recubrimiento protector es la, que generalmente se toma como indicación de las cualidades de resistencia al desgaste. Sin embargo, lo que el grado de dureza realmente nos proporciona es una orientación sobre las propiedades del material depositado, ya que materiales diferentes con el mismo grado de dureza pueden tener reacciones completamente distintas al someterlos a las diferentes condiciones de desgaste o de servicio [10].

Muchos de los recubrimientos protectores poseen efectivamente una gran dureza; de allí la expresión "recubrimiento duro". Este término se ha hecho muy común; sin embargo, no es correcta la expresión en todos los casos. Lo importante en una capa de recubrimiento es que tenga las propiedades necesarias, las cuales muchas veces no coinciden con valores de dureza particularmente elevados [10].

#### 2.7.1. Normas AWS A5.13, A5.21

Esta especificación prescribe los requisitos para la clasificación de los electrodos de revestimiento para la soldadura por arco metálico blindado. La clasificación se basa en la composición química del metal de soldadura depositado, excepto en el caso de los electrodos de carburo de tungsteno, donde la clasificación se basa en el rango de malla, cantidad y composición de los gránulos de carburo de tungsteno. Una guía se adjunta al pliego de condiciones como fuente de información sobre las características y aplicaciones del producto clasificado electrodos [11].

## 2.7.2. Especificaciones para electrodos y varillas utilizadas en recubrimientos duros

Esta especificación prescribe los requisitos para la clasificación de los electrodos de revestimiento para la soldadura por arco metálico blindado.

Los electrodos y varillas desnudos sólidos para superficies se clasifican en AWS A5.13:2010, Especificación para electrodos desnudos y varillas para superficies y Varillas para el acabado de superficies [11].

### 2.7.2.1. Utilidad

Para demostrar la utilidad de los electrodos, con el fin de ser clasificados en esta especificación, los electrodos deberán ser capaces de producir los siguientes resultados en las pruebas requeridas [11]:

- a. Para varillas de soldadura, el metal fluirá libremente y sin problemas sobre la superficie de la placa sin escurrir.
- b. Los electrodos deberán funcionar sin problemas y sin salpicaduras excesivas cuando se use dentro de los rangos de corriente recomendado por el fabricante.
- c. La escoria se elimina fácilmente con herramientas de mano.
- d. La superficie de la plataforma de prueba después de ser esmerilado, estarán libres de defectos visibles al ojo desnudo.

#### 2.7.2.2.Fabricación

Los electrodos y varillas pueden ser utilizados por cualquier método para piezas o productos que cumpla los requisitos de esta especificación.

La selección del material o electrodos de aporte depende básicamente de tres factores, que son [11]:

- a. Metal base
- b. Tipo de desgaste
- c. Elección de proceso de soldeo

#### 2.7.2.3.Clasificación [11]:

- a. Excepto los electrodos de carburo de tungsteno, los electrodos de superficie cubiertos por esta especificación A5.13/A5.13M son clasificados de acuerdo con la composición química del metal de aportación no diluido [11].
- b. Los electrodos de carburo de tungsteno se clasifican en función del tamaño y la composición química del tungsteno de carburo [11].
- c. Los electrodos clasificados en una clasificación no se clasificarán en ninguna otra clasificación de la presente especificación [11].

**Table 1**  
**Iron Base Surfacing Electrodes—Chemical Composition Requirements<sup>a</sup>**

AWS Classification	Annex A Reference	UNS Number <sup>e</sup>	Deposit Composition, weight percent <sup>b,c,d</sup>											Other Elements, Total
			C	Mn	Si	Cr	Ni	Mo	V	W	Ti	Nb(Cb)	Fe	
EFe1	A7.1.1	W74001	0.04–0.20	0.5–2.0	1.0	0.5–3.5	—	1.5	—	—	—	—	Rem	1.0
EFe2	A7.1.1	W74002	0.10–0.30	0.5–2.0	1.0	1.8–3.8	1.0	1.0	0.35	—	—	—	Rem	1.0
EFe3	A7.1.2	W74003	0.50–0.80	0.5–1.5	1.0	4.0–8.0	—	1.0	—	—	—	—	Rem	1.0
EFe4	A7.1.3	W74004	1.0–2.0	0.5–2.0	1.0	3.0–5.0	—	—	—	—	—	—	Rem	1.0
EFe5	A7.1.4	W75110	0.30–0.80	1.5–2.5	0.90	1.5–3.0	—	—	—	—	—	—	Rem	1.0
EFe6	A7.1.5	W77510	0.6–1.0	0.4–1.0	1.0	3.0–5.0	—	7.0–9.5	0.5–1.5	0.5–1.5	—	—	Rem	1.0
EFe7	A7.1.6	W77610	1.5–3.0	0.5–2.0	1.5	4.0–8.0	—	1.0	—	—	—	—	Rem	1.0
EFeMn-A	A7.1.7	W79110	0.5–1.0	12–16	1.3	—	2.5–5.0	—	—	—	—	—	Rem	1.0
EFeMn-B	A7.1.7	W79310	0.5–1.0	12–16	1.3	—	—	0.5–1.5	—	—	—	—	Rem	1.0
EFeMn-C	A7.1.7	W79210	0.5–1.0	12–16	1.3	2.5–5.0	2.5–5.0	—	—	—	—	—	Rem	1.0
EFeMn-D	A7.1.7	W79410	0.5–1.0	15–20	1.3	4.5–7.5	—	—	0.4–1.2	—	—	—	Rem	1.0
EFeMn-E	A7.1.7	W79510	0.5–1.0	15–20	1.3	3.0–6.0	1.0	—	—	—	—	—	Rem	1.0
EFeMn-F	A7.1.7	W79610	0.8–1.2	17–21	1.3	3.0–6.0	1.0	—	—	—	—	—	Rem	1.0
EFeMnCr	A7.1.8	W79710	0.25–0.75	12–18	1.3	13–17	0.5–2.0	2.0	1.0	—	—	—	Rem	1.0
EFeCr-A1A	A7.1.9	W74011	3.5–4.5	4.0–6.0	0.5–2.0	20–25	—	0.5	—	—	—	—	Rem	1.0
EFeCr-A2	A7.1.10	W74012	2.5–3.5	0.5–1.5	0.5–1.5	7.5–9.0	—	—	—	—	1.2–1.8	—	Rem	1.0
EFeCr-A3	A7.1.11	W74013	2.5–4.5	0.5–2.0	1.0–2.5	14–20	—	1.5	—	—	—	—	Rem	1.0
EFeCr-A4	A7.1.9	W74014	3.5–4.5	1.5–3.5	1.5	23–29	—	1.0–3.0	—	—	—	—	Rem	1.0
EFeCr-A5	A7.1.12	W74015	1.5–2.5	0.5–1.5	2.0	24–32	4.0	4.0	—	—	—	—	Rem	1.0
EFeCr-A6	A7.1.13	W74016	2.5–3.5	0.5–1.5	1.0–2.5	24–30	—	0.5–2.0	—	—	—	—	Rem	1.0
EFeCr-A7	A7.1.13	W74017	3.5–5.0	0.5–1.5	0.5–2.5	23–30	—	2.0–4.5	—	—	—	—	Rem	1.0
EFeCr-A8	A7.1.14	W74018	2.5–4.5	0.5–1.5	1.5	30–40	—	2.0	—	—	—	—	Rem	1.0
EFeCr-E1	A7.1.15	W74211	5.0–6.5	2.0–3.0	0.8–1.5	12–16	—	—	—	—	4.0–7.0	—	Rem	1.0
EFeCr-E2	A7.1.15	W74212	4.0–6.0	0.5–1.5	1.5	14–20	—	5.0–7.0	1.5	—	—	—	Rem	1.0
EFeCr-E3	A7.1.15	W74213	5.0–7.0	0.5–2.0	0.5–2.0	18–28	—	5.0–7.0	—	3.0–5.0	—	—	Rem	1.0
EFeCr-E4	A7.1.15	W74214	4.0–6.0	0.5–1.5	1.0	20–30	—	5.0–7.0	0.5–1.5	2.0	—	4.0–7.0	Rem	1.0

<sup>a</sup> Solid bare electrodes and rods previously classified in AWS A5.13–80 are now either discontinued or reclassified in AWS A5.21:2001, *Specification for Bare Electrodes and Rods for Surfacing* (see A8 in Annex A).

<sup>b</sup> Single values are maximum. Rem = Remainder.

<sup>c</sup> Electrodes and rods shall be analyzed for the specific elements for which values are shown in this table. If the presence of other elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total does not exceed the limit specified for “Other Elements, Total” in the last column of the table.

<sup>d</sup> Sulfur and phosphorus contents each shall not exceed 0.035%.

<sup>e</sup> SAE HS-1086/ASTM DS-56, *Metals & Alloys in the Unified Numbering System*.

Figura 2-29 - Composición química de electrodos de revestimientos [11]

### 2.7.3. Selección de material de aporte

La selección del electrodo adecuado se inicia con el reconocimiento de los factores que actúan en el desgaste a que está sujeta la pieza, así como de las exigencias de trabajo a que estará sometida [10].

Esta determinación inicial se complementa con el estudio de los aspectos siguientes [10]:

- Influencia de la abrasión, rozamiento, corrosión etc. en el desgaste o deterioro que sufre la pieza, es decir las causas secundarias o paralelas [10].
- Necesidad de maquinado o forjado del depósito de soldadura [10].
- Composición y condición de la pieza a recubrir [10].
- Si las características físicas de la pieza a recubrir no se alteran fuertemente por el calentamiento y/o enfriamiento brusco [10].
- Si la pieza resiste cambios de temperatura violentos y localizados, sin agrietarse o romperse [10].
- Espesor del metal a depositar, ya que debe evitarse la deposición de demasiadas capas con determinados electrodos; en general nunca depositar más de 3 capas de cualquier recargue o recubrimiento protector [10].

#### 2.7.3.1. Materiales de aporte para recubrimientos protectores de piezas sujetas a desgaste.

En el campo de los electrodos para recubrimientos protectores, SOLDEXA fabrica una gran variedad de tipos, tanto convencionales como especiales [10].

Naturalmente existen electrodos SOLDEXA, que cubren dos o más tipos de desgaste, pero jamás se pretenderá que un solo electrodo cubra todas las diversas formas de desgaste o exigencias que se presentan [10].

Por tal motivo, debe analizarse cuál es el factor de desgaste más importante que debemos evitar, a fin de hacer la selección más correcta del electrodo. En algunos casos habrá que sacrificar algunas de las características de resistencia. Por ejemplo, cuando el material está sujeto a impacto combinado con abrasión como es el caso en las uñas de las palas, pondremos un electrodo que, aunque no resista tanto la abrasión, tampoco sea quebradizo y pueda resistir el impacto [10].

Cada uno de los recubrimientos descritos en la Figura 2-29 presentan una microestructura característica principalmente dependiente de su composición química, esto define sus propiedades mecánicas y su aplicación [10].

#### 2.7.3.1.1. Citodur 1000

Electrodo para recargue de gran resistencia a la corrosión oxidación y abrasión severa. El material depositado es una fundición blanca con alto contenido de cromo (36%), por lo que, se recomienda aplicar 2 pases para que el relleno no se desprenda. En la mayoría de los casos, para obtener las características deseadas, es recomendable usar una cama cojín apropiada en función a las características del material base o los desgastes presentes. Gracias a su alto contenido de carburos de cromo, el depósito conserva la resistencia a la abrasión severa aún a temperaturas elevadas (hasta 1000°C). Los cordones que deposita son perfectamente lisos, libres de poros, sin salpicaduras ni inclusiones de escoria. El material de aporte es no maquinable, pero puede ser forjado y templado [10].

## Aplicaciones:

- Para recuperar y recubrir piezas que están expuestas a desgaste por abrasión severa y bajo impacto [10].
- Usado en la industria minera, siderúrgica, construcción, ladrillera, cementera, agrícola y todos aquellos sectores donde los materiales están expuestos a desgaste abrasivo severo [10].
- Ideal para la recuperación y protección de dientes, cucharas, baldes y cubos de draga, sinfines de transporte, paletas de mezcladoras, uñas de palas, bombas de arena, aletas de ventiladores, etc [10].
- Para ollas, moldes y bordes de cucharas de fundición, que sufren desgaste por abrasión o erosión de escorias o metal líquido a temperaturas elevadas [10].

## 2.7.3.1.2. Citomangan

Electrodo que deposita un acero al manganeso con 12,0 – 14,0% Mn. Presenta excelente comportamiento frente a abrasión e impacto severo. El material depositado posee una estructura austenítica de gran tenacidad, que le permite absorber los golpes durante el trabajo. Por las características del CITOMANGAN, requiere estar expuesto a impacto severo para que la superficie se autoendurezca y llegue a una dureza final de 55 HRC. Usar una técnica de soldadura que garantice el mínimo aporte de calor y cuidar que la pieza no sobrepase los 250°C (riesgo de cristalización). Es susceptible al fisuramiento en caliente, riesgo que se incrementa por las elevadas contracciones que presenta este material. Cuando se trata de rellenos considerables, es necesario el empleo



de cordones alternados, alivio de tensiones mecánico y de ser necesario soldar en tinas de agua para extraer el calor aportado [10].

Aplicaciones :

- Para recubrimiento de aceros que van a estar expuestos a desgaste abrasivo combinado con impacto severo [10].
- Utilizado con frecuencia en equipos de minería, movimiento de tierra, construcción y ferrocarril [10].
- Para unir y rellenar piezas de acero al manganeso (13%) [10]
- Las aplicaciones principales son: Relleno de dientes de excavadoras, mandíbulas de trituradoras, forros de molino, cilindros de trapiche, rieles, cruces y desvíos de vías férreas, baldes de draga, zapatas para orugas, etc [10].

#### 2.7.3.1.3. Exadur - 43

Electrodo de máxima resistencia a la abrasión e impacto. El material depositado es aleado al C, Cr, Nb, los carburos están distribuidos en una matriz austenítica que incrementa su resistencia al impacto. El EXADUR - 43 es un electrodo de bajo hidrógeno, cuyo depósito es un recubrimiento protector de excelentes características, de fácil aplicación en posición plana e inclinada ascendente. También es aplicable en posición horizontal. Posee muy poca escoria y es de fácil remoción. Se recomienda aplicar sólo 2 capas. Las fisuras transversales son de alivio de tensiones. Electrodo de alto rendimiento y gran velocidad de deposición [10].

## Aplicaciones:

- Recubrimiento protector extraduro para ser empleado en partes sometidas a abrasión extremadamente [10].
- severa, con impactos moderados, hasta temperaturas que no excedan los 450°C [10].
- Para recuperar tornillos de extrusión para la fabricación de ladrillos refractarios, ladrillos comunes y cemento [10].
- Para reconstruir palas de mezcladoras [10].
- Para tornillos transportadores, paletas, ventiladores, etc [10].
- Para reconstruir conos de trituradoras y chancadoras [10].
- En general empleado en la industria minera, agroindustrial, siderúrgica, cementera, ladrillera, etc [10].

## 2.7.4. Microestructuras resistentes al desgaste

La resistencia al desgaste de metales y aleaciones está en función de la microestructura del metal. Esta, a su vez, depende de la composición química y del ciclo térmico impuesto.

Las tres estructuras metalúrgicas más importantes, presentes en los depósitos de soldadura para Recubrimientos Protectores Especiales, son: Martensita, Austenita y Carburos. Esta última estructura puede encontrarse en forma dispersa o en forma de red. Así mismo tienen diferentes propiedades, y nuestras soldaduras para Recubrimientos Protectores Especiales hacen uso de ellas para obtener la mejor combinación posible de propiedades para los casos específicos de aplicación [10].

#### 2.7.4.1. Martensita

Es la estructura más común y más ampliamente usada en los depósitos de Recubrimientos Protectores; es resistente a todos los tipos de condiciones suavemente abrasivas y algunos ambientes severamente abrasivos.

La martensita tiene una alta dureza, que aumenta con el incremento del carbono. Los depósitos martensíticos tienen moderada ductilidad y mediana resistencia al impacto. La martensita ofrece ventajas al ser usada contra medios de abrasión por rayado, condición que puede considerarse moderada. Las martensitas con más alto porcentaje de carbono presentan excelente resistencia a la abrasión por esmerilado (Figura 2-30) [10].

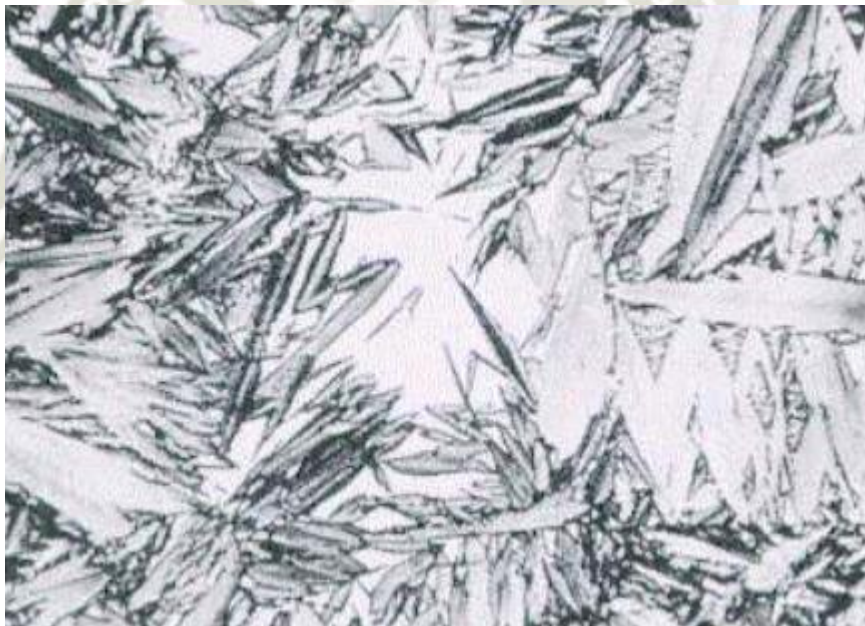


Figura 2-30 - Microestructura de Martensita (x100) [10]

#### 2.7.4.2. Austenita

La austenita es blanda y dúctil; se autoendurece rápidamente durante el trabajo con impacto y posee buenas cualidades de resistencia a la abrasión por raspado. Los depósitos austeníticos tienen un núcleo tenaz y dúctil, que soporta una capa superficial que se endurece durante el trabajo [10].

La austenita es también una fase muy importante en depósitos de alto carbono que contienen carburos y sirve para impartir cierta ductilidad a los mismos. Los depósitos austeníticos son excelentes como cojines amortiguadores, antes de aplicar las capas duras sobrepuestas (Figura 2-31) [10].

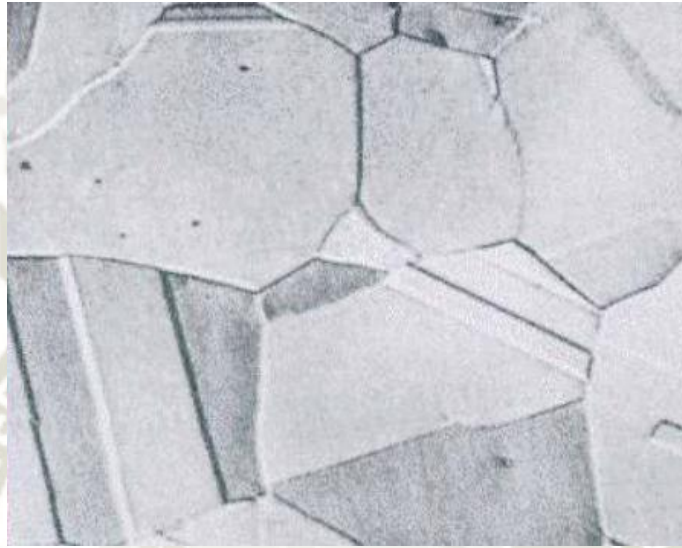


Figura 2-31 - Microestructura de Austenita [10]

#### 2.7.4.3. Carburos de red

La red de carburos se forma por precipitación a partir de una fusión de alto carbono, originando así red continua en el metal solidificado. Este tipo de carburo es una estructura extremadamente dura y frágil, con baja resistencia al impacto. En estos depósitos la estructura de carburo rodea la fase de matriz, que generalmente es austenítica.

Los carburos en red aumentan la resistencia al desgaste; también son efectivos contra la abrasión por esmerilado severo, siempre que el carburo tenga mayor dureza que el abrasivo.

El aumento de la resistencia al desgaste es proporcional a la cantidad de carburo presente, pudiendo alcanzar el depósito por saturación, las propiedades del carburo que son: alta dureza y baja ductilidad, lo que ocasionará depósitos frágiles y susceptibles a rajaduras (Figura 2-32) [10].



Figura 2-32 - Fotomicrografía Carburos en Red [10]

#### 2.7.4.4. Carburos dispersos

Los carburos dispersos están rodeados por metal de ligamento. Un porcentaje relativamente alto puede estar contenido en un depósito de soldadura, antes que la resistencia y ductilidad del depósito alcancen los valores del carburo; la mayor dispersión del carburo en el depósito de soldadura refleja las propiedades del metal de liga, es decir de la matriz. Son propiedades de la matriz las que controlan el empleo del carburo disperso. Al emplear adecuadamente los depósitos con carburos dispersos se obtiene mejores resultados contra todos los tipos de desgaste, aún los combinados (Figura 2-33) [10].



Figura 2-33 - Fotomicrografía carburos dispersos [10]

#### 2.7.4.5. Aplicaciones de recargue de soldadura



Figura 2-34 - Recargue de soldadura en uña de excavadora hidráulica [6]



Figura 2-35 - Recalce de cantonera de tractor Cat - D8T [6]

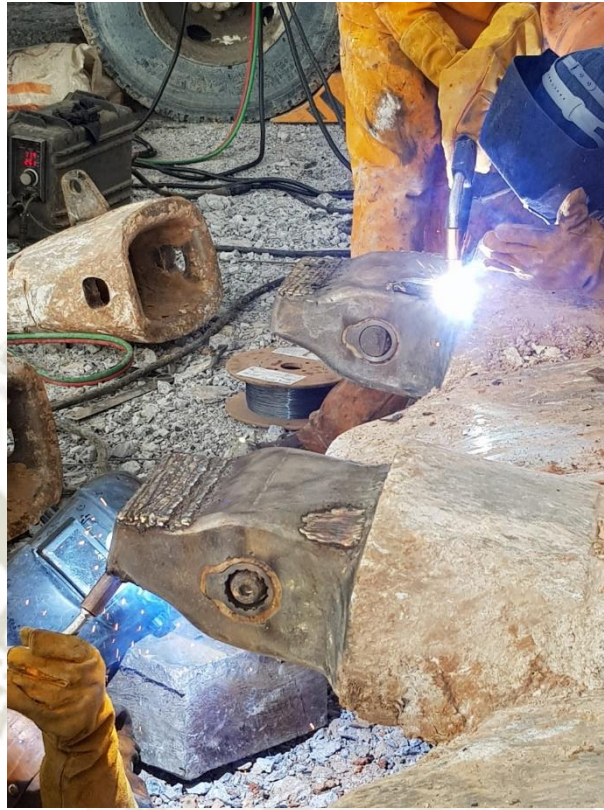


Figura 2-36 - Reforzamiento de nariz de adaptador de una pala hidráulica Cat - 6060S [1]



Figura 2-37 - Recargue de soldadura en hoja de cucharón de cargador frontal de bajo perfil - Scoop Cat 1300G [1]

## 2.8. Ensayos

### 2.8.1. Metalografía

La metalografía es la ciencia que estudia las características microestructurales o constitutivas de un metal o aleación relacionándolas con las propiedades físicas, químicas y mecánicas [13].

Mucha es la información que puede suministrar un examen metalográfico, para ello es necesario obtener muestras que sean representativas y que no presenten alteraciones debidas a la extracción y/o preparación metalográfica [13].

Los pasos que seguir para una preparación metalográfica son los siguientes [13]:

#### 2.8.1.1. Corte metalográfico



Figura 2-38 - Cortadora metalográfica [13]

Cortar la muestra con una sierra metalográfica: es un equipo capaz de cortar con un disco especial de corte por abrasión, mientras suministra un gran caudal de refrigerante, evitando así el sobrecalentamiento de la muestra. De este modo, no se alteran las condiciones microestructurales de la misma [13].



## 2.8.1.2. Includido metalográfica



Figura 2-39 - Includora metalográfica [13]

La muestra cortada se incluye en resina para su mejor tratamiento posterior y almacenado. La inclusión se puede realizar mediante resina en frío: normalmente dos componentes, resina en polvo y un catalizador en líquido, los cuales se mezclan y se vierten sobre un molde con la pieza a incluir ya puesta dentro del mismo. Se debe llenar el molde hasta cubrir su totalidad. La inclusión en frío tiene la ventaja de poder incluir varias piezas en poco tiempo. Asimismo, se le puede dar cualquier forma al molde. Tiene la desventaja de formar una inclusión más bien blanda (comparada con la inclusión en caliente) y es difícil respetar las tolerancias del diámetro de embutición. Si no, se puede incluir en caliente: mediante una includora, que, mediante una resistencia interior calienta la resina (monocomponente) hasta que se deshace. La calidad y dureza de la embutición es óptima. El proceso de embutición es relativamente rápido. No es un proceso recomendado en caso de requerimientos de muchas muestras al cabo del día. Tampoco se recomienda utilizar este método para aquellas piezas que sean frágiles o sensibles al calor [13].

### 2.8.1.3. Pulido metalográfica

Se usa el equipo suelda Metalográfica, se prepara la superficie del material, en su primera fase denominada Desbaste Grueso, se desbasta la superficie de la muestra con papel de lija, de manera uniforme y así sucesivamente disminuyendo el tamaño de grano (N° de papel de lija) hasta llegar al papel de menor tamaño de grano. Desbaste Fino, se requiere de una superficie plana libre de ralladuras la cual se obtiene mediante una rueda giratoria húmeda cubierta con un paño especial cargado con partículas abrasivas cuidadosamente seleccionadas en su tamaño para ello existen gran posibilidad de abrasivos para efectuar el último pulido [13].



Figura 2-40 - Pulidora metalográfica [13]

La etapa del pulimento es ejecutada en general con paños macizos colocados sobre platos giratorios circulares, sobre los cuales son depositadas pequeñas cantidades de abrasivos, en general diamante industrial en polvo fino o bien en suspensión, con granulometrías como por ejemplo de 10, 6, 3, 1, y 0,25 micras. El pulido se realiza sujetando la muestra a tratar con la mano o bien mediante un cabezal automático para pulir varias muestras a la

vez. Este ejerce una presión pre-configurada hacia el disco o paño de desbaste o pulido durante un tiempo concreto. Estos parámetros deben ser configurados según el tipo de material (dureza, estado del pulido, etc.) [13].

#### 2.8.1.4. Ataque químico

Hay una enormidad de ataques químicos, para diferentes tipos de metales y situaciones. En general, el ataque es hecho por inmersión o fregado con algodón embebido en el líquido escogido por la región a ser observada, durante algunos segundos hasta que la estructura o defecto sea revelada. Uno de los más usados es el nital, (ácido nítrico y alcohol), para la gran mayoría de los metales ferrosos. Una guía de los ataques químicos utilizados para revelar las fases y microconstituyentes de metales y aleaciones se pueden ver en la norma ASTM E407 - 07 Standard Practice for Microetching Metals and Alloys [13].

#### 2.8.1.5. Microscopio

Utilización de lupas estereoscópicas (que favorecen la profundidad de foco y permiten, por tanto, visión tridimensional del área observada) con aumentos que pueden variar de 5x a 64X [13].

El principal instrumento para la realización de un examen metalográfico lo constituye el microscopio metalográfico, con el cual es posible examinar una muestra con aumentos que varían entre 50x y 2000x [13].

El microscopio metalográfico, debido a la opacidad de los metales y aleaciones, opera con la luz reflejada por el metal. Por lo que para poder observar la muestra es necesario preparar una probeta y pulir a espejo la superficie. Existe una norma internacional ASTM E3-11 Standard Practice for Preparation of Metallographic Specimens que trata sobre las correctas técnicas de preparación de muestras metalográficas [13].

### 2.8.2. Dureza

La prueba de dureza mide la resistencia a la penetración de un material en la superficie objeto duro. La dureza como un término no se define con precisión. Dureza, dependiendo del contexto, representa la resistencia a los rayones o a la indentación y una medida cualitativa de la fuerza del material. En general, en mediciones de macrodureza, la carga aplicada es ~2N. Se han ideado una variedad de pruebas de dureza, pero las más comúnmente usadas son la prueba Rockwell y la prueba Brinell. Diferentes indentadores utilizados en estas pruebas se muestran en Figura 2-41 [14].

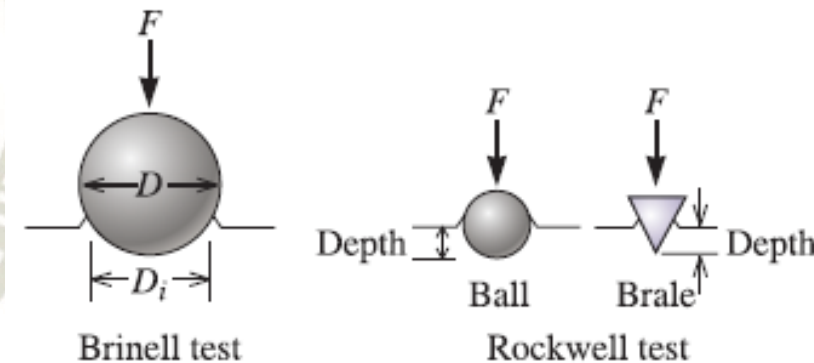


Figura 2-41 - Penetradores para las pruebas de dureza Brinell y Rockwell [14]

#### 2.8.2.1. Brinell

En la prueba de dureza Brinell, una esfera de acero duro (generalmente de 10 mm de diámetro) es forzada en la superficie del material. El diámetro de la impresión, generalmente de 2 a 6 mm, es medido y el número de dureza Brinell (abreviado como HB o BHN) se calcula a partir de la siguiente ecuación 2-1 [14]:

$$DB = \frac{2F}{\pi D \sqrt{D^2 - D_i^2}} \quad \text{Ec 2-1}$$

donde  $F$  es la carga aplicada en kilogramos,  $D$  es el diámetro del penetrador en milímetros, y  $D_i$  es el diámetro de la impresión en milímetros. La dureza Brinell tiene unidades de  $\text{kg/mm}^2$  [14].

#### 2.8.2.2. Rockwell

La prueba de dureza Rockwell utiliza una bola de acero de pequeño diámetro para materiales blandos y un cono de diamante, o Brale, para materiales más duros. La profundidad de penetración del indentador es medido automáticamente por la máquina de prueba y convertido a una dureza Rockwell número (HR). Ya que no es necesaria una medición óptica de las dimensiones de la hendidura, la prueba de Rockwell tiende a ser más popular que la de Brinell. Varias variaciones de la Se utiliza la prueba de Rockwell, incluidas las descritas en la Tabla 6-5. Una prueba Rockwell C (HRC) se utiliza para aceros duros, mientras que para el aluminio se puede seleccionar una prueba Rockwell F (HRF). Las pruebas de Rockwell proporcionan un número de dureza que no tiene unidades [14].

Los números de dureza se utilizan principalmente como base cualitativa para la comparación de materiales (Figura 2-42), las especificaciones de fabricación y tratamiento térmico, el control de calidad y la correlación con otras propiedades de los materiales. Por ejemplo, la dureza Brinell está relacionada a la resistencia a la tracción del acero por la aproximación [14]:

Test	Indenter	Load	Application
Brinell	10-mm ball	3000 kg	Cast iron and steel
Brinell	10-mm ball	500 kg	Nonferrous alloys
Rockwell A	Brale	60 kg	Very hard materials
Rockwell B	1/16-in. ball	100 kg	Brass, low-strength steel
Rockwell C	Brale	150 kg	High-strength steel
Rockwell D	Brale	100 kg	High-strength steel
Rockwell E	1/8-in. ball	100 kg	Very soft materials
Rockwell F	1/16-in. ball	60 kg	Aluminum, soft materials
Vickers	Diamond square pyramid	10 kg	All materials
Knoop	Diamond elongated pyramid	500 g	All materials

Figura 2-42 - Comparación de durezas [14]

$$Tensile\ strength\ (psi) = 500HB$$

donde  $HB$  tiene unidades de  $\frac{kg}{mm^2}$

La dureza se correlaciona bien con la resistencia al desgaste. Para la medición de la resistencia al desgaste se dispone de una prueba independiente. Un material utilizado en la trituración o molienda de minerales debe ser muy duro para asegurar que el material no sea erosionado o desgastado por las materias primas duras. Del mismo modo, los dientes de los engranajes en la transmisión o en el sistema de transmisión de un vehículo deben ser lo suficientemente duros como para que los dientes no se desgasten. Típicamente encontramos que los materiales poliméricos son excepcionalmente blandos, los metales y las aleaciones tienen dureza intermedia, y las cerámicas son excepcionalmente duras. Utilizamos materiales como el compuesto de carburo de tungsteno y cobalto (WC-Co), conocido como "carburo", para aplicaciones de herramientas de corte. También usamos diamantes microcristalinos o diamantes como (DLC) para herramientas de corte y otras aplicaciones [14].

La prueba de dureza Knoop (HK) es una prueba de microdureza, que forma pequeñas hendiduras, que se necesita un microscopio para obtener la medida. En estos ensayos, la carga es inferior a 2 N. La prueba de Vickers, que utiliza un indentador de pirámide de

diamante, puede ser como una prueba de macrodureza o de microdureza. Los ensayos de microdureza son adecuados para materiales que pueden tener una superficie que tiene una dureza más alta que el material a granel, materiales en qué áreas muestran diferentes niveles de dureza, o muestras que no son macroscópicas plano [14].

#### 2.8.2.2.1. Cálculo del número de dureza rockwell

Numero de dureza Rockwell: un número derivado del incremento neto en la profundidad del indentador cuando la fuerza en el indentador es incrementada desde una fuerza previa (preliminar específico) hasta una fuerza total (específica) y luego retornada al valor de fuerza previa [15].

Para un indentador de diamante esférico cónico:

$$\text{Dureza Rockwell} : 100 - \frac{h}{0.002} \quad \text{Ec 2-2}$$

$$\text{Dureza Superficial de Rockwell} : 100 - \frac{h}{0.001} \quad \text{Ec 2-3}$$

Para un indentador de bola:

$$\text{Dureza Rockwell} : 130 - \frac{h}{0.002} \quad \text{Ec 2-4}$$

$$\text{Dureza Superficial de Rockwell} : 100 - \frac{h}{0.001} \quad \text{Ec 2-5}$$

El promedio de las mediciones de dureza está determinado por:

$$\bar{H} = \frac{H1 + H2 + H3 \dots + Hn}{n} \quad \text{Ec 2-6}$$

Y su error es:

$$E = H - Hstd \quad \text{Ec 2-7}$$

Donde  $H_{std}$  es un promedio de dureza certificada, estandarizado según el material utilizado [15].

### 2.8.3. Tracción

La prueba de tracción es popular ya que las propiedades obtenidas se pueden aplicar al diseño de diferentes componentes. La prueba de tracción mide la resistencia de un material a una carga estática o lentamente fuerza aplicada. Las tasas de deformación en una prueba de tracción son típicamente pequeñas ( $10^{-4}$  a  $10^{-2}$  s $^{-1}$ ). Una prueba de configuración se muestra en la Figura 2-43; una muestra típica tiene un diámetro de 0,505 pulgadas y un instrumento longitud de 2 pulg. La muestra se coloca en la máquina de prueba y una fuerza  $F$ , llamada carga, está aplicada. Una máquina de prueba universal en la que las pruebas de tracción y compresión pueden ser realizadas a menudo se utiliza. Un medidor de tensión o extensómetro se utiliza para medir la cantidad que la muestra se estira entre las marcas del medidor cuando se aplica la fuerza. Por lo tanto, el cambio en longitud de la muestra ( $\Delta l$ ) se mide con respecto a la longitud original ( $l_0$ ). La información sobre la resistencia, el módulo de Young y la ductilidad de un material puede ser obtenida a partir de dicha prueba de tracción. Por lo general, se realiza una prueba de tracción en metales, aleaciones, y plásticos. Las pruebas de tracción se pueden usar para cerámica; sin embargo, estos no son muy populares porque la muestra puede fracturarse mientras se alinea. La siguiente discusión principalmente se aplica a las pruebas de tracción de metales y aleaciones [14].



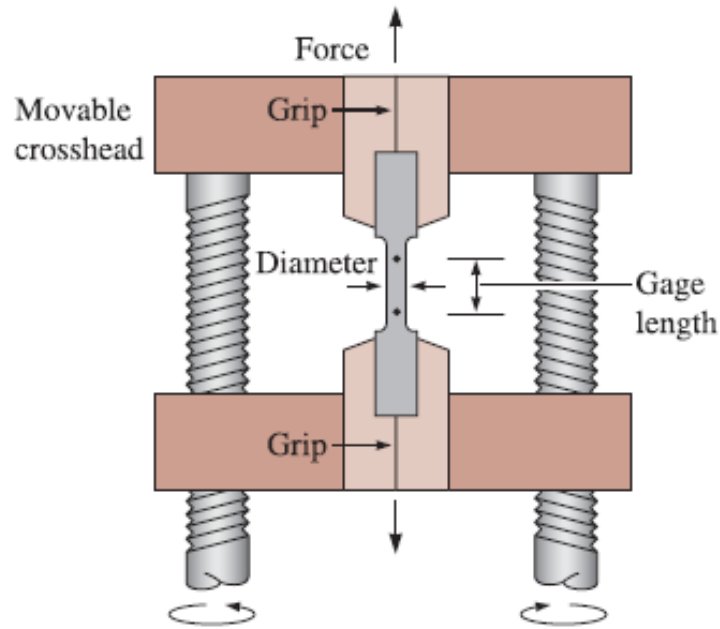


Figura 2-43 - Se aplica una fuerza unidireccional a una muestra en la prueba de tracción por medio de la cruceta móvil. El movimiento de la cruceta puede ser realizado con tornillos o un mecanismo hidráulico [14]

### 2.8.3.1. Esfuerzo y deformación Ingenieril

Se aplican los resultados de una prueba única a todos los tamaños y secciones transversales de especímenes para un material dado si convertimos la fuerza en esfuerzo y la distancia entre las marcas de calibración para deformar. El esfuerzo ingenieril y la deformación ingenieril se definen por las siguientes ecuaciones 2-8 y 2-9 [14]:

$$\text{Esfuerzo Ingenieril} = S = \frac{F}{A_0} \quad \text{Ec 2-8}$$

$$\text{Deformación Ingenieril} = e = \frac{\Delta l}{l_0} \quad \text{Ec 2-9}$$

donde  $A_0$  es el área de sección transversal original de la muestra antes de que comience la prueba,  $l_0$  es la distancia original entre las marcas del medidor, y  $\Delta l$  es el cambio en la longitud después de que la fuerza  $F$  es aplicado [14].

La Figura 2-44 muestra cualitativamente las curvas de tensión y deformación para un metal típico (a), (b) material termoplástico, (c) elastómero, y (d) cerámica (o vidrio) en condiciones relativamente pequeñas tasas de deformación. Las escalas en esta figura son cualitativas y diferentes para cada material [14].

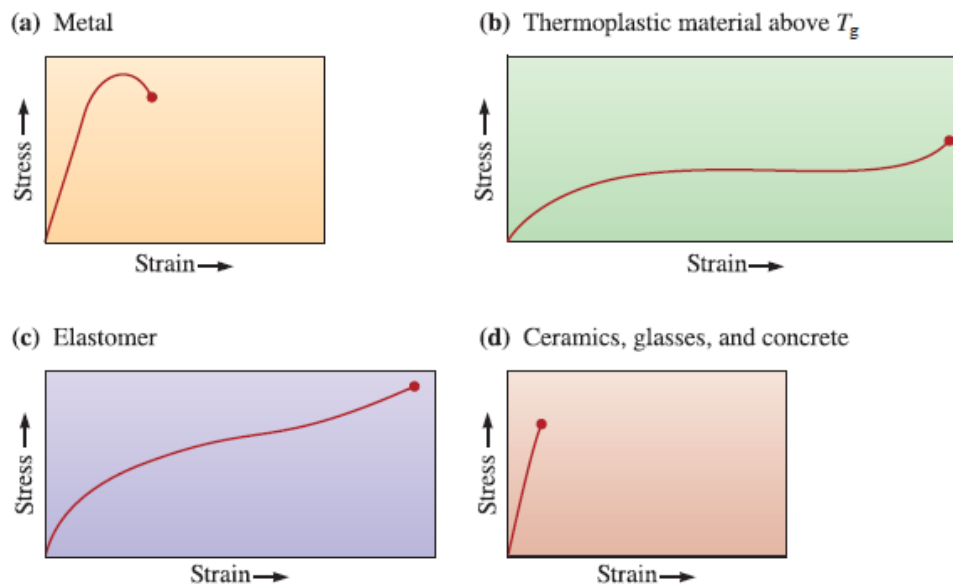


Figura 2-44 - Curvas de esfuerzo y deformación para diferentes materiales. Tenga en cuenta que estos son cualitativos. Las magnitudes de las tensiones y las tensiones no deben ser comparadas [14]

### 2.8.3.2. Medición de las dimensiones de las muestras de ensayo:

Probetas estándar para la prueba de tensión rectangular - Estas formas de probetas se muestran en la Figura 2-45. Para determinar el área de la sección transversal, la dimensión de la anchura central se medirá con una precisión de 0,005 pulg. (0,13 mm) para el modelo de 8 pulgadas (200 mm) de longitud de calibre y 0,001 pulg. (0,025 mm) para la muestra de longitud de calibre 2" (50 mm) en la Figura 2-45. La dimensión del espesor central se medirá con una precisión de 0,001 pulgadas para ambas muestras [16].

Probetas de prueba de tensión redondas estándar: estas Las formas de las muestras se muestran en las Figura 2-46. Para determinar el área de la sección transversal, el diámetro deberá ser medida en el centro de la longitud del gálibo con precisión 0,001 pulg. (0,025 mm) [16].

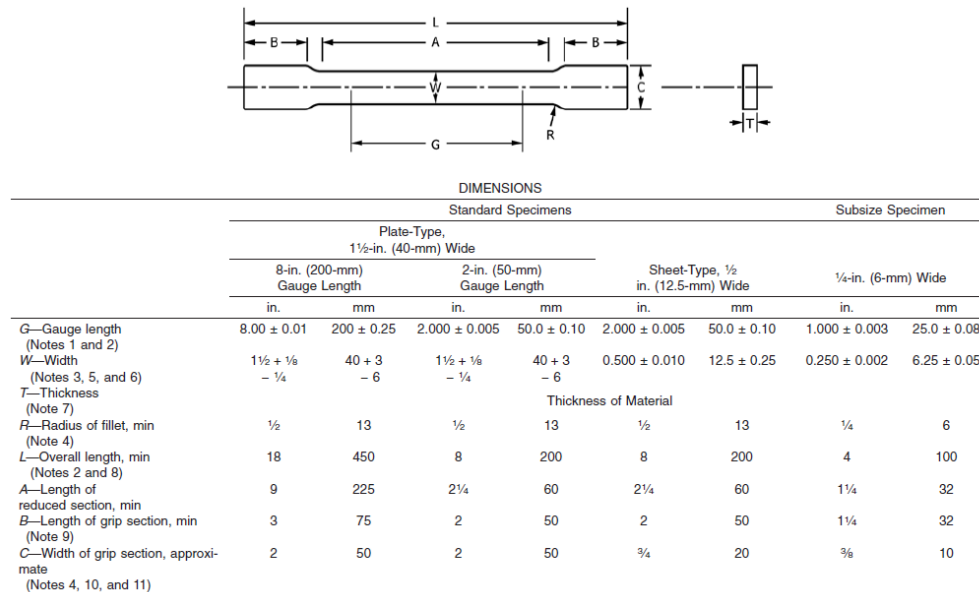


Figura 2-45 - Muestras de prueba de tensión rectangular [16]

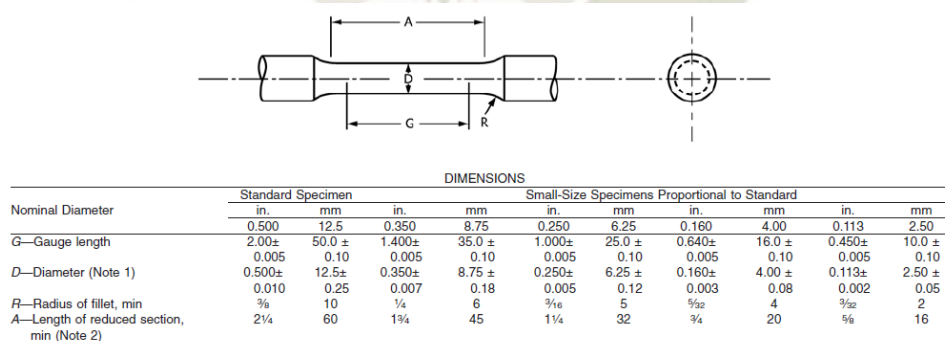


Figura 2-46 - Estándar de 0.500 pulg. (12.5 mm) Muestra de prueba de tensión redonda con 2 pulg. (50 mm) de longitud de calibre y ejemplos de muestras de tamaño pequeño [16]

## 2.8.4. Desgaste

### 2.8.4.1. Ensayo de tribología– Norma ASTM G99

Este método de ensayo abarca un procedimiento de laboratorio para determinar el desgaste de los materiales durante el deslizamiento mediante un aparato pin-on-disk. Los materiales se prueban en pares bajo condiciones nominalmente no abrasivas. Las principales áreas de atención experimental en el uso de este tipo de aparatos para se describen las medidas de desgaste. El coeficiente de fricción puede también ser determinado [17].

Este método de prueba estándar utiliza un conjunto específico de pruebas parámetros (carga, velocidad de deslizamiento, materiales, etc.) que fueron entonces utilizado en un estudio interlaboratorios (ILS), cuyos resultados son los siguientes (Figura 2-47 y 2-48). (Esto satisface la forma ASTM en que "Las instrucciones para realizar la prueba deben incluir todas de los detalles esenciales en cuanto a aparatos, muestras de prueba, y los cálculos necesarios para lograr un resultado satisfactorio. precisión y sesgo.") Cualquier usuario debe informar de que "siguió los requisitos de la norma ASTM G99", cuando esto sea cierto [17].

NOTE 1—See Note 4 for information.

	Composition (weight%)	Microstructure	Hardness (HV 10)	Roughness <sup>A</sup>	
				$R_z$ (mean) ( $\mu\text{m}$ )	$R_a$ (mean) ( $\mu\text{m}$ )
Steel ball (100 Cr6) (AISI 52 100) <sup>B</sup> Diameter 10 mm	1.35 to 1.65 Cr ← 0.95 to 1.10 C 0.15 to 0.35 Si 0.25 to 0.45 Mn	martensitic with minor carbides and austenite	838 ± 21	0.100	0.010
Steel disc (100 Cr6) (AISI 52 100) <sup>C</sup> Diameter 40 mm	← <0.030 P <0.030 S	martensitic with minor carbides and austenite	852 ± 14	0.952	0.113
Alumina ball, diameter = 10 mm <sup>D</sup>	← 95 % Al <sub>2</sub> O <sub>3</sub> (with addi- tives of TiO <sub>2</sub> ,	equi-granular alpha alumina with very minor secondary	1610 ± 101 (HV 0.2)	1.369	0.123
Alumina disc, diameter = 40.6 mm <sup>D</sup>	← MgO, and ZnO)	phases	1599 ± 144 (HV 0.2)	0.968	0.041

<sup>A</sup> Measured by stylus profilometry.  $R_z$  is maximum peak-to-valley roughness.  $R_a$  is arithmetic average roughness.

<sup>B</sup> Standard ball-bearing balls (SKF).

<sup>C</sup> Standard spacers for thrust bearings (INA).

<sup>D</sup> Manufactured by Compagnie Industrielle des Ceramiques Electroniques, France.

Figura 2-47 - Características de las muestras de prueba de desgaste entre laboratorios [17]

Results (ball) (disk)	Specimen Pairs			
	Steel-steel	Alumina-steel	Steel-alumina	Alumina-alumina
Ball wear scar diameter (mm)	2.11 ± 0.27 (2.11 ± 0.27)	NM	2.08 ± 0.35 (2.03 ± 0.41)	0.3± 0.06 (0.3 ± 0.06)
Ball wear volume (10 <sup>-3</sup> mm <sup>3</sup> )	198 (198)	...	186 (169)	0.08 (0.08)
Number of values	102 (102)	...	60 (64)	56 (59)
Disk wear scar width (mm)	NM	0.64 ± 0.12 (0.64 ± 0.12)	NM	NM
Disk wear volume (10 <sup>-3</sup> mm <sup>3</sup> )	...	480 (480)	...	...
Number of values	...	60 (60)	...	...
Friction coefficient	0.60 ± 0.11	0.76 ± 0.14	0.60 ± 0.12	0.41 ± 0.08
Number of values	109	75	64	76

<sup>A</sup> Test conditions:  $F = 10\text{ N}$ ;  $v = 0.1\text{ ms}^{-1}$ ,  $T = 23^{\circ}\text{C}$ ; relative humidity range 12 to 78 %; laboratory air; sliding distance 1000 m; wear track (nominal) diameter = 32 mm; materials: steel = AISI 52 100; and alumina =  $\alpha\text{-Al}_2\text{O}_3$ .

Figura 2-48 - Resultados de la prueba Inter laboratorio [17]

Para el ensayo de desgaste pin-on-disk se necesitan dos probetas. Uno de ellos, un pasador con una punta de radio está posicionado perpendicularmente a la otra, normalmente un disco circular plano. Una pelota, rígidamente se utiliza a menudo como espécimen de alfiler. La máquina de prueba hace que la probeta de disco o la probeta de pasador giren sobre el centro del disco. En cualquier caso, la trayectoria de deslizamiento es un círculo en la superficie del disco. El plano del plato ya sea horizontal o verticalmente [17].

La probeta se presiona contra el disco a una distancia de carga especificada, normalmente por medio de un brazo o una palanca y pesos adjuntos. Se han utilizado otros métodos de carga, tales como hidráulico o neumático [17].

Los resultados de desgaste se informan como pérdida de volumen en milímetros cúbicos para el pasador y el disco por separado. Cuando se prueban dos materiales diferentes, se recomienda que cada material se pruebe tanto en la posición del pasador como en la del disco [17].

La cantidad de desgaste se determina mediante la medición de dimensiones lineales de ambas muestras antes y después del ensayo, o bien pesando ambas muestras antes y después del ensayo. Si se utilizan medidas lineales de desgaste, el cambio de longitud o de forma cambio del perno, y el cambio de profundidad o forma del disco de desgaste (en milímetros) están determinadas por cualquier técnica metrológica, como la medición electrónica de distancia o el perfilado del palpador. Las medidas lineales de desgaste se convierten en desgaste volumen (en milímetros cúbicos) utilizando la geometría apropiada relaciones. Las medidas lineales de desgaste se utilizan con frecuencia en ya que la pérdida de masa es a menudo demasiado pequeña para medirla con precisión. Si se mide la pérdida de masa, el valor de pérdida de masa se convierte a pérdida de volumen (en milímetros cúbicos) utilizando un valor apropiado para la densidad del espécimen [17].

Los resultados de desgaste suelen obtenerse mediante la realización de una prueba para una distancia de deslizamiento seleccionada y para valores de carga seleccionados y velocidad. En la Figura 2-49 se presenta un conjunto de condiciones de prueba que se utilizaron en una serie de mediciones inter-laboratorios. Se pueden seleccionar otras condiciones de prueba dependiendo del propósito de la prueba. En tales casos, el usuario debe reportar sus resultados como "siguiendo el procedimiento de ASTM G99" [17].

Normal Force (N)	10
Sliding Speed (m/s)	0.1
Sliding Distance (m)	1000
Pin-end Diameter, spherical (mm)	10
Environment	air
Temperature, nominal (°C)	23
Humidity, (%RH)	12–78
Track Diameter (mm)	25–35

Figura 2-49 - Parámetros de prueba utilizados para pruebas Inter laboratorios [17]

#### 2.8.4.1.1. Descripción general

La Figura 2-50 muestra un dibujo esquemático de un típico sistema de prueba de desgaste pin-on-disk. Un tipo de sistema típico consiste en un husillo accionado y un mandril para sosteniendo el disco giratorio, un dispositivo de palanca para sostener el pasador, y accesorios para permitir que la probeta de pasador sea forzada contra el espécimen de disco giratorio con una carga controlada.

Otro tipo de sistema carga un pasador que gira alrededor del centro del disco contra un disco estacionario. En cualquier caso, la pista de desgaste del disco es un círculo, que implica múltiples pasadas de desgaste en la misma pista.

El sistema puede tener un sistema de medición de la fuerza de fricción, para ejemplo, una célula de carga, que permite que el coeficiente de fricción sea determinado [17].

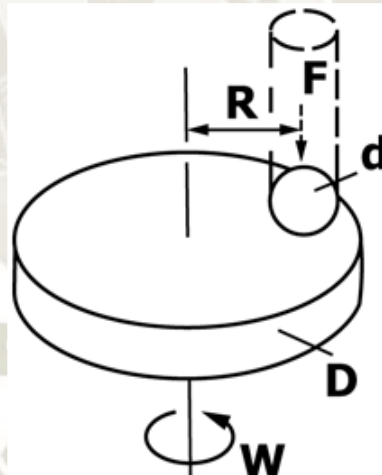


Figura 2-50 - Sistema de prueba de desgaste pin-on-disk [17]

Motor Drive-A motor de velocidad variable, capaz de mantener se requiere una velocidad constante (61 % de la velocidad nominal del motor a plena carga) bajo carga. El motor debe montarse de manera que su vibración no afecte al ensayo. Las velocidades de rotación están típicamente en el rango de 0.3 a 3 rad/s (60 a 600 r/min) [17].

Contador de revoluciones-La máquina debe estar equipada con un contador de revoluciones o su equivalente que registre el número de revoluciones del disco, y preferiblemente tenga la capacidad de apagar la máquina después de un número preseleccionado de revoluciones [17].

Portamuestras y brazo de palanca - En un sistema típico, el portamuestras estacionario se fija a un brazo de palanca que tiene un pivote. La adición de pesas, como una opción de carga, produce una fuerza de prueba proporcional a la masa de las pesas aplicadas. Lo ideal es que el pivote del brazo esté situado en el plano del contacto de desgaste para evitar fuerzas de carga extrañas debidas a la fricción de deslizamiento [17]. El soporte del pasador y el brazo deben ser de construcción sustancial para reducir el movimiento vibratorio durante la prueba [17].

Sistemas de medición de desgaste: los instrumentos para obtener medidas lineales de desgaste deben tener una sensibilidad de  $2,5 \mu\text{m}$  o superior [17].

Cualquier balanza utilizada para medir la pérdida de masa de la muestra de ensayo deberá tener una sensibilidad de  $0,1 \text{ mg}$  o superior; en situaciones de bajo desgaste puede ser necesaria una sensibilidad mayor [17].

#### 2.8.4.1.2. Cálculo y elaboración de informes

Las medidas de desgaste deben ser reportadas como la pérdida de volumen en milímetros cúbicos para el pasador y el disco, por separado [17].

Utilice las siguientes ecuaciones 2-10, 2-11 para calcular el volumen pérdidas cuando el pasador tiene inicialmente una forma de extremo esférica de radio  $R$  y el disco es inicialmente plano, bajo las condiciones que sólo uno de los dos miembros lleva un desgaste significativo [17]:



***pin (extremo esférico) pérdida de volumen, mm<sup>3</sup>***

$$= \frac{\pi(\text{wear scar diameter,mm})^4}{64 (\text{sphere radius,mm})} \quad \text{Ec 2-10}$$

asumiendo que no hay un desgaste significativo del disco. Esta es una relación geométrica aproximada que es correcta al 1 % para (diámetro de la marca de desgaste/radio de la esfera) <0,3, y es correcta al 5 % para (diámetro de la marca de desgaste/radio de la esfera) <0,7. La ecuación exacta se encuentra en el apéndice X1 de la norma ASTM G99 -17 [17].

***pérdida de volumen de disco, mm<sup>3</sup>***

$$= \frac{\pi(\text{wear track radius,mm})(\text{track width,mm})^3}{6 (\text{sphere radius,mm})} \quad \text{Ec 2-11}$$

asumiendo que no hay un desgaste significativo de las clavijas. Esta es una relación geométrica aproximada que es correcta al 1 % para (anchura de la vía de desgaste/radio de la esfera) <0,3, y al 5 % para (anchura de la vía de desgaste/radio de la esfera) <0,8. La ecuación exacta se encuentra en el Apéndice X1 de la norma ASTM G99-17 [17].

Mientras que los resultados de pérdida de masa pueden ser usados internamente en laboratorios para comparar materiales de densidades equivalentes, este método de prueba reporta desgaste como pérdida de volumen para que no haya confusión causada por variaciones en la densidad. Tenga cuidado al usar y reportar el mejor valor de densidad disponible para los materiales probados cuando calcule la pérdida de volumen de la pérdida de masa medida [17].

Utilice la siguiente ecuación 2-12 para la conversión de masa pérdida a pérdida de volumen [17].

$$\mathbf{volume\ loss, mm^3 = \frac{mass\ loss, g}{density, g/cm^3} * 1000} \quad \text{Ec 2-12}$$

## 2.9.Descripción de la Excavadora Hidráulica CAT 336D2L

Es una unidad mecánica hidráulica que está compuesta por dos bastidores. Un bastidor principal en cual están montados los bastidores del tren de rodamiento con motores de propulsión y el bastidor superior. Un bastidor superior o de rotación en cual está montado la cabina, el motor, bombas hidráulicas, motores de rotación, cojinetes de rotación, la pluma, el brazo y la cuchara. El accionamiento obtenido en la excavadora está basado en la hidráulica, la fuerza necesaria para mover estas bombas lo proporciona el motor Diésel con que está equipado [18].

### Funciones de Equipo

- Carga de camiones en excavaciones de corte
- Carga de materiales para planta de agregados y asfalto
- Carga de material sub-base para carreteras
- Alcantarillado y postura de tubería
- Grandes movimientos de tierra



Figura 2-51 - Excavadora Hidráulica Cat 336D2 L [19]

### 2.9.1. Especificaciones de la Excavadora Hidráulica CAT 336D2/D2 L

#### Especificaciones de la Excavadora Hidráulica 336D2/D2 L

##### Motor

Modelo del motor	Cat C9 ACERT	
Potencia del motor (ISO 14396)	209 kW	280 hp
Potencia neta (SAE J1349/ISO 9249)	200 kW	268 hp
Calibre	112 mm	4,41"
Carrera	149 mm	5,87"
Cilindrada	8,8 L	537 pulg <sup>3</sup>

- El Cat C9 cumple con las emisiones de escape equivalentes a las regulaciones de emisiones Tier 2 de la EPA de EE.UU., Stage II de la Unión Europea y Tier 2 de China.
- La potencia neta publicada es la potencia disponible en el volante cuando el motor está equipado con ventilador, filtro de aire, silenciador y alternador.
- El Motor C9 probado en terreno puede trabajar eficazmente en altitudes de hasta 2.300 m (7.546 pies).

##### Pesos

Peso en orden de trabajo		
Tren de rodaje estándar*	34.489 kg	76.035 lb
Tren de rodaje largo**	37.086 kg	81.761 lb

- \*Tren de rodaje estándar, con brazo de alcance de 2,8 m (9' 2"), zapatas de 600 m (24"), contrapeso de 6,0 tons métricas (6,6 tons EE.UU.).
- \*\*Tren de rodaje largo con brazo de excavación de gran volumen de 2,55 m (8' 4"), zapatas de 800 m (32"), contrapeso de 6,0 tons métricas (6,6 tons EE.UU.).

##### Mecanismo de giro

Velocidad de giro	8,98 rpm	
Par de giro	108,6 kN·m	80.142 lb·pie

##### Mando

Rendimiento en pendientes	30°/70 %	
Velocidad máxima de desplazamiento	4,85 km/h	3,0 mph
Tracción máxima en la barra de tiro	300,5 kN	67.555 lb-pie

##### Sistema hidráulico

Sistema principal: flujo máximo (cada uno)	265 L/min	70 gal EE.UU.
Sistema de rotación: flujo máximo	265 L/min	70 gal EE.UU.
Presión máxima: equipo	35.000 kPa	5.076 lb/pulg <sup>2</sup>
Presión máxima: desplazamiento	35.000 kPa	5.076 lb/pulg <sup>2</sup>
Presión máxima: giro	29.000 kPa	4.061 lb/pulg <sup>2</sup>
Sistema piloto: flujo máximo	40 L/min	10,6 gal EE.UU./min
Sistema piloto: presión máxima	4.000 kPa	580,2 lb/pulg <sup>2</sup>
Cilindro de la pluma: calibre	150 mm	5,9"
Cilindro de la pluma: carrera	1.440 mm	56,7"
Cilindro del brazo: calibre	170 mm	6,7"
Cilindro del brazo: carrera	1.738 mm	68,4"
Cilindro del cucharón: calibre	150 mm	5,9"
Cilindro del cucharón: carrera	1.151 mm	45,3"

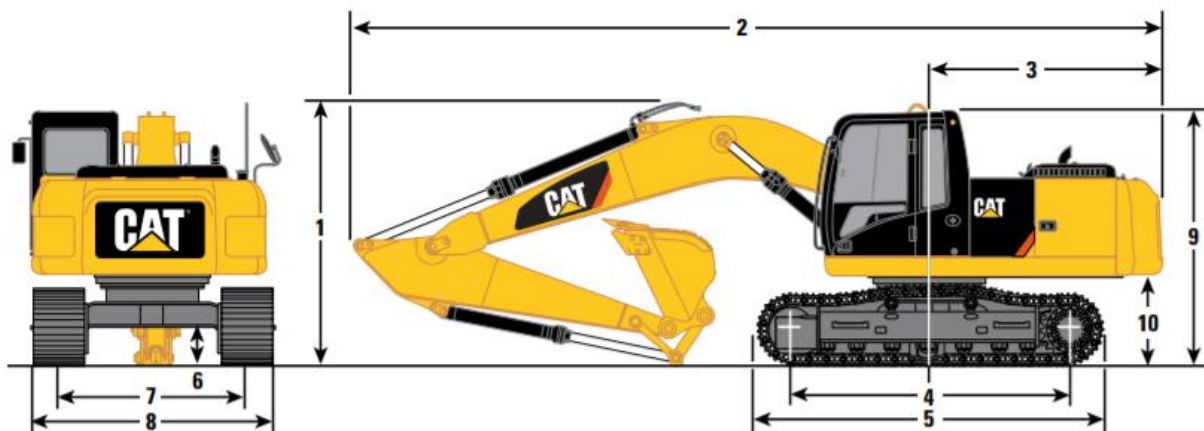
##### Capacidades de llenado de servicio

Capacidad del tanque de combustible	620 L	163,79 gal EE.UU.
Sistema de enfriamiento	40 L	10,57 gal EE.UU.
Aceite del motor	40 L	10,57 gal EE.UU.
Mando de giro	19 L	5,02 gal EE.UU.
Mando final (cada uno)	8 L	2,11 gal EE.UU.
Capacidad de aceite del sistema hidráulico (tanque incluido)	410 L	108,31 gal EE.UU.
Aceite del tanque hidráulico	175 L	46,2 gal EE.UU.

Figura 2-52 - Especificaciones de la Excavadora Hidráulica 336D2/D2 L [19]

### Dimensiones

Todas las dimensiones son aproximadas.



Opciones de pluma	Pluma de alcance de servicio pesado 6,50 m (21' 4")			Pluma para excavación de gran volumen 6,18 m (20' 3")	
Opciones de brazos	R3.9DB (12' 10")	R3.2DB (10' 6")	R2.8DB (9' 2")	M2.55TB (8' 4")	M2.15TB (7' 1")
<b>1</b> Altura de embarque*	3.700 mm (12' 2")	3.340 mm (11' 0")	3.570 mm (11' 9")	3.650 mm (12' 0")	3.680 mm (12' 1")
<b>2</b> Longitud de embarque	11.200 mm (36' 9")	11.150 mm (36' 7")	11.210 mm (36' 9")	10.910 mm (35' 10")	11.200 mm (36' 9")
<b>3</b> Radio de giro de la cola	3.500 mm (11' 6")	3.500 mm (11' 6")	3.500 mm (11' 6")	3.500 mm (11' 6")	3.500 mm (11' 6")
<b>4</b> Longitud hasta el centro de los rodillos					
Tren de rodaje estándar	3.610 mm (11' 10")	3.610 mm (11' 10")	3.610 mm (11' 10")	3.610 mm (11' 10")	3.610 mm (11' 10")
Tren de rodaje largo	4.040 mm (13' 3")	4.040 mm (13' 3")	4.040 mm (13' 3")	4.040 mm (13' 3")	4.040 mm (13' 3")
<b>5</b> Longitud de la rueda					
Tren de rodaje estándar	4.590 mm (15' 1")	4.590 mm (15' 1")	4.590 mm (15' 1")	4.590 mm (15' 1")	4.590 mm (15' 1")
Tren de rodaje largo	5.020 mm (16' 6")	5.020 mm (16' 6")	5.020 mm (16' 6")	5.020 mm (16' 6")	5.020 mm (16' 6")
<b>6</b> Espacio libre sobre el suelo**	450 mm (1' 6")	450 mm (1' 6")	450 mm (1' 6")	450 mm (1' 6")	450 mm (1' 6")
<b>7</b> Entrevía					
Tren de rodaje estándar	2.590 mm (8' 6")	2.590 mm (8' 6")	2.590 mm (8' 6")	2.590 mm (8' 6")	2.590 mm (8' 6")
Tren de rodaje largo	2.590 mm (8' 6")	2.590 mm (8' 6")	2.590 mm (8' 6")	2.590 mm (8' 6")	2.590 mm (8' 6")
<b>8</b> Ancho de transporte: tren de rodaje largo o estándar					
Zapatas de 600 mm (24")	3.190 mm (10' 6")	3.190 mm (10' 6")	3.190 mm (10' 6")	3.190 mm (10' 6")	3.190 mm (10' 6")
Zapatas de 700 mm (28")	3.290 mm (10' 10")	3.290 mm (10' 10")	3.290 mm (10' 10")	3.290 mm (10' 10")	3.290 mm (10' 10")
Zapatas de 800 mm (32")	3.390 mm (11' 2")	3.390 mm (11' 2")	3.390 mm (11' 2")	3.390 mm (11' 2")	3.390 mm (11' 2")
<b>9</b> Altura de la cabina*	3.140 mm (10' 4")	3.140 mm (10' 4")	3.140 mm (10' 4")	3.140 mm (10' 4")	3.140 mm (10' 4")
<b>10</b> Espacio libre del contrapeso**	1.220 mm (4' 0")	1.220 mm (4' 0")	1.220 mm (4' 0")	1.220 mm (4' 0")	1.220 mm (4' 0")

\*Incluye la altura de las orejetas de las zapatas.

\*\*Sin incluir la altura de las orejetas de las zapatas.

Figura 2-53 - Especificaciones de la Excavadora Hidráulica 336D2/D2 L [19]

### 2.9.2. Partes de la excavadora Hidráulica CAT 336D2/D2 L



1. Punto de Unión entre brazo y pluma
2. Cilindro hidráulico del cucharon
3. Brazo
4. Eslabón de articulación
5. Cucharon
6. Trenes de Rodaje
7. Chasis o Bastidor
8. Compartimiento del motor
9. Cabina de operador
10. Cilindro hidráulico de Pluma
11. Pluma o Boom
12. Cilindro hidráulico del brazo

Figura 2-54 - Partes de la excavadora Hidráulica 336D2/D2 L [1]

2.9.2.1. Cucharón 3.2 yd<sup>3</sup>

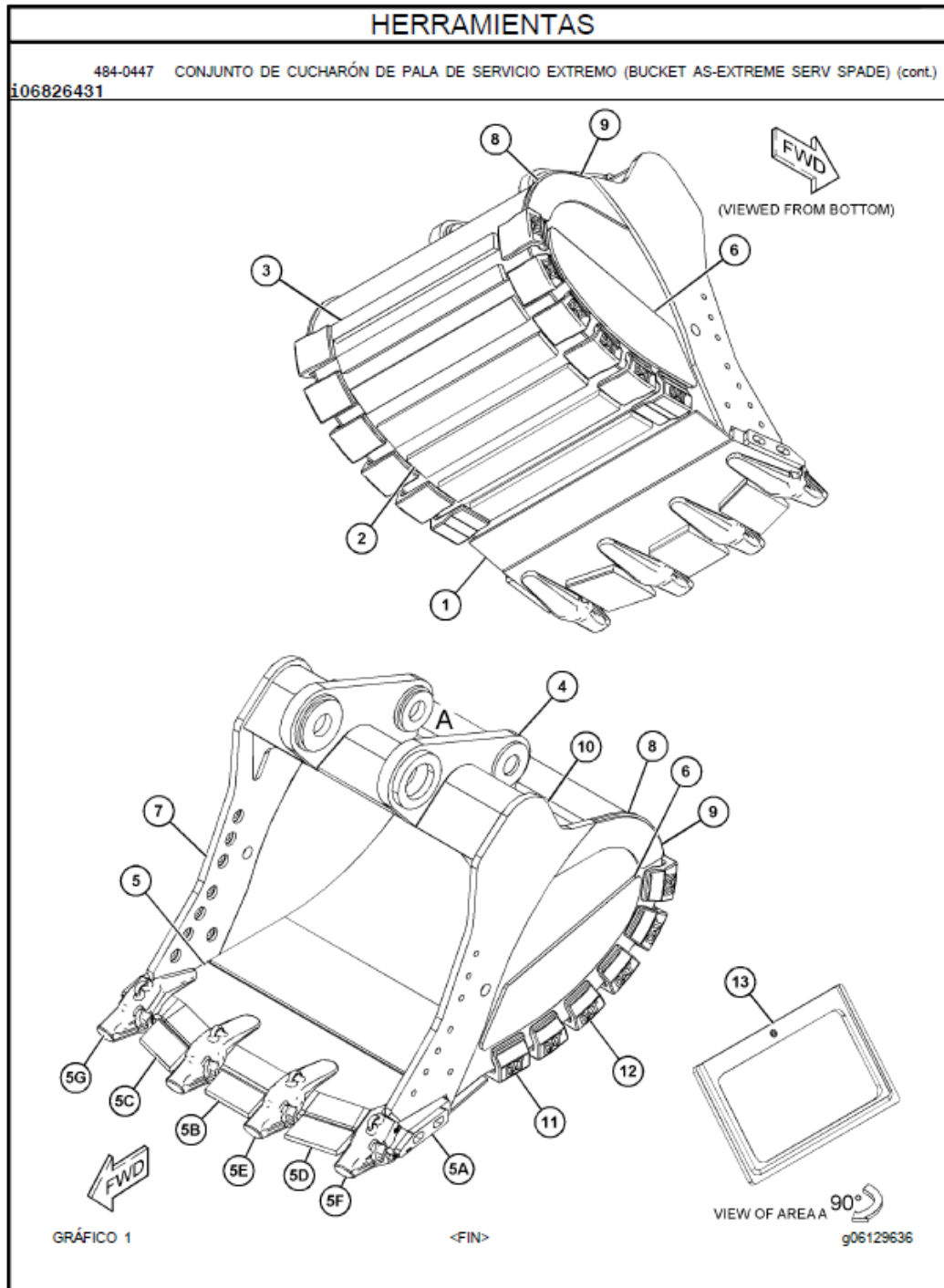


Figura 2-55 - Cucharón 3.2 yd<sup>3</sup> de excavadora hidráulica Cat 336D2 L [20]

2.9.2.1.1. Conjunto de piezas del Cucharón

HERRAMIENTAS						
<b>484-0447 CONJUNTO DE CUCHARÓN DE PALA DE SERVICIO EXTREMO-FAMILIA TB (BUCKET AS-EXTREME SERV SPADE-FAMILIA TB)</b> NO. DE SERIE: MBP1-UP 1.550 MM (61 PULG) DE ANCHO X 2 M <sup>3</sup> (2,59 YD <sup>3</sup> ) DE CAPACIDAD. ADAPTADORES K-130, CANTIDAD 4 PARTE DE 494-0470 GRUPO DE CUCHARÓN Y AJUSTADOR						
SMCS-6529						i06826431
NOTA	NO NO	GRÁFICO REF	NÚMERO DE LA PIEZA	QTY	NOMBRE DE LA PIEZA 1 2 3 4 5 6 (NIVEL DEL PRODUCTO)	VER PAGINA
	1	1	352-8952	1	PLACA DE DESGASTE (PLATE-WEAR)	
	2	1	369-0878	5	PLACA DE DESGASTE (PLATE-WEAR)	
	3	1	369-0879	2	PLACA DE DESGASTE (PLATE-WEAR)	
	4	1	482-1096	1	CONJUNTO DE PLACA DE BISAGRA (PLATE AS-HINGE)	
	5	1	484-0405	1	CONJUNTO DE BORDE (EDGE AS)	
	5A	1	271-8391	2	BLOQUE DE DESGASTE (BLOCK-WEAR)	
	5B	1	369-2473	1	CUCHILLA (EDGE-CUTTING)	
	5C	1	369-2474	1	CUCHILLA (EDGE-CUTTING)	
	5D	1	369-2475	1	CUCHILLA (EDGE-CUTTING)	
	5E	1	469-4316	2	ADAPTADOR (K-130, 2 CORREAS, CENTRAL) (ADAPTER (K-130, 2-STRAP, CENTER))	
	5F	1	469-4319	1	ADAPTADOR (K-130, 2 CORREAS, LADO DERECHO) (ADAPTER (K-130, 2-STRAP, RH))	
	5G	1	469-4320	1	ADAPTADOR (K-130, 2 CORREAS, LADO IZQUIERDO) (ADAPTER (K-130, 2-STRAP, LH))	
	6	1	369-0877	2	PLACA DE DESGASTE (PLATE-WEAR)	
	7	1	494-0979	1	PLACA (LADO IZQUIERDO) (PLATE (LH))	
	8	1	494-0981	2	PLACA LATERAL (PLATE-SIDE)	
	9	1	494-0982	2	PLACA DE DESGASTE (PLATE-WEAR)	
	10	1	494-0980	1	PLACA (LADO DERECHO) (PLATE (RH))	
	11	1	138-6529	2	CUBIERTA PROTECTORA (TALÓN, RECTO) (SHROUD (HEEL, STRAIGHT))	
	12	1	138-6551	10	CUBIERTA PROTECTORA (TALÓN, CURVO) (SHROUD (HEEL, CURVED))	
	13	1	285-3254	1	PLACA (PROTECTOR) (PLATE (PROTECTOR))	

Figura 2-56 - Conjuntos de piezas de cucharón [20]

2.9.2.1.2. Uña K-130 (32MnCrMo6-4-3)

**229-7123 GRUPO DE PUNTA DE PENETRACIÓN PLUS-K-130,  
CÁNCAMO DE LEVANTAMIENTO (TIP GP-PENETRATION PLUS-K-130, CÁNCAMO  
DE LEVANTAMIENTO)  
NO. DE SERIE: MBP1-UP**

SMCS-6805						i06615094	
NOTA	NO NO	GRÁFICO REF	NÚMERO DE LA PIEZA	QTY	NOMBRE DE LA PIEZA 1 2 3 4 5 6 (NIVEL DEL PRODUCTO)	VER PAGINA	
	1	1	220-9130	1	RETENEDOR DE HERRAMIENTA DE CORTE (K-130) (RETAINER-G.E.T. (K-130))		
	2	1	467-9813	1	PUNTA DE PENETRACIÓN PLUS (K-130, CÁNCAMO DE LEVANTAMIENTO) (TIP-PENETRATION PLUS (K-130, LIFTING EYE))		

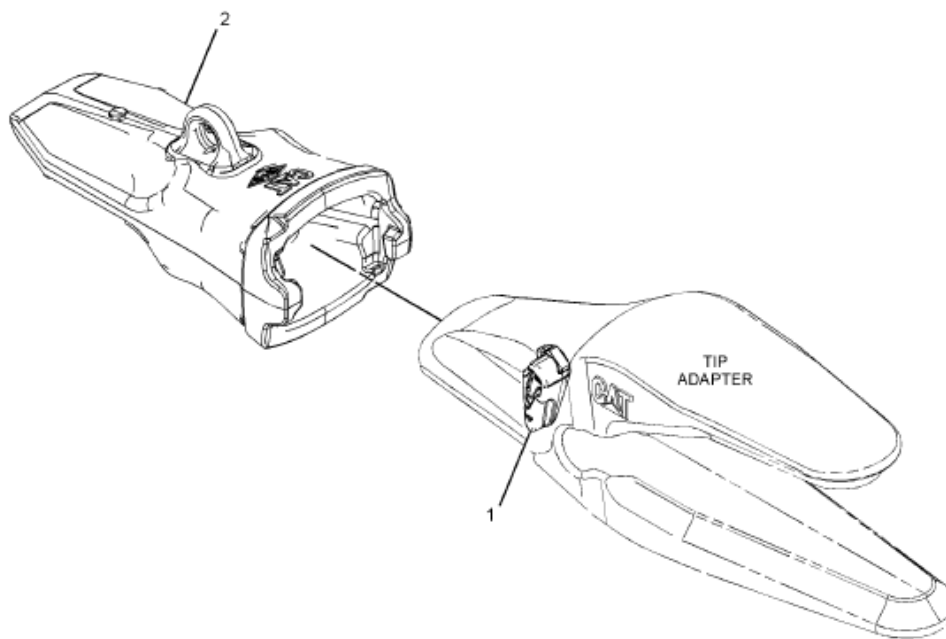


GRÁFICO 1

<FIN>

g01258043

Figura 2-57 - Uña K-130 (32MnCrMo6-4-3) de excavadora hidráulica Cat 336D2 L [20]



## 2.10. Elementos discretos (EDEM)

### 2.10.1. El método de los elementos discretos

Cuando se trata de simular sistemas de partículas, se pueden identificar dos enfoques principales de modelado: continuo (euleriano) y discreto (lagrangiano) [21].

#### 2.10.1.1. Continuo

En el enfoque del continuo, el comportamiento constitutivo de la materia granular se describe mediante leyes constitutivas, comúnmente expresadas en forma de ecuaciones diferenciales que relacionan variables de campo mecánicas (por ejemplo, tensión y deformación) [21].

El modelado de una sustancia con este enfoque asume que es continua y llena completamente el espacio que ocupa. Como resultado, el comportamiento de las partículas individuales es ignorado. Las ecuaciones constitutivas resultantes se resuelven numéricamente (p. ej. Método de elementos finitos) [21].

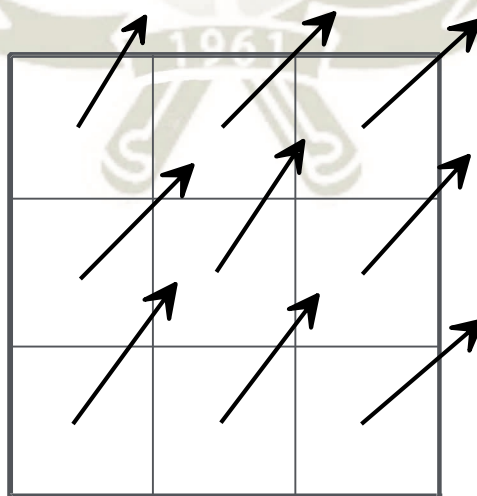


Figura 2-58 - Método continuo [21]

### 2.10.1.2. Discreto

En contraste con el enfoque continuo, los enfoques discretos modelan cada partícula como una entidad distinta y representan el material granular como un conjunto idealizado de partículas. El comportamiento general del sistema (macroscópico) resulta de las interacciones individuales de las partículas [21].

Esto hace que el enfoque discreto sea muy bueno para investigar fenómenos que ocurren en la escala de longitud del diámetro de las partículas y para simular el comportamiento a granel de las partículas [21].

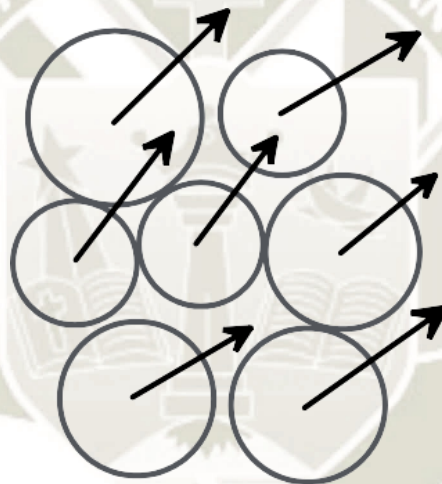


Figura 2-59 - Método discreto [21]

### 2.10.1.3. Acoplamiento dem y cosimulaciones

#### 2.10.1.3.1. DEM-MBD

El acoplamiento DEM con paquetes de dinámica multicuerpo (MBD) permite a los usuarios realizar simulaciones con control programático del movimiento de la geometría y la física, lo que permite la implementación de movimientos de cuerpos rígidos y complejos [21].

Las fuerzas de materiales a granel que actúan sobre las superficies de los equipos calculadas por el software DEM pueden ser recuperadas por el código acoplado para obtener una cinemática de equipo realista [21].

#### 2.10.1.3.2. DEM-CFD

DEM también puede utilizarse en combinación con la dinámica de fluidos computacional (CFD) para investigar el comportamiento de las partículas en fase fluida. El movimiento sólido y fluido se resuelve mediante las ecuaciones de movimiento de Newton para partículas discretas y las ecuaciones de Navier-Stokes para el fluido continuo [21].

El acoplamiento se basa en el intercambio continuo de información entre el software DEM y CFD. Se pueden utilizar varios modelos de arrastre para la interacción partícula-fluido [21].

#### 2.10.1.3.3. DEM-FEA

El software DEM puede proporcionar fuerzas y distribuciones de presión realistas del material que actúa sobre el equipo. Estas cargas pueden ser utilizadas como insumos en el análisis estructural o de fatiga en cualquier software de análisis de elementos finitos (FEA) [21].

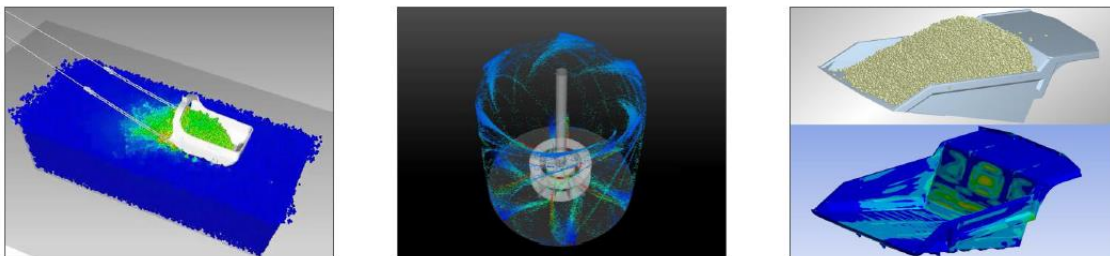


Figura 2-60 - Simulación DEM-MBD de una cuchara de arrastre (Cortesía de VR Steel), modelo DEM-CFD de dinámica de flotación de partículas (Cortesía de la Universidad de Utah) y acoplamiento DEM-FEA utilizado para analizar las cargas de la cuchara del camión volquete (Cortesía de Austin Engineering) [21]



# CAPÍTULO III

### 3. INGENIERÍA DE PROYECTO

3.1. Análisis mediante elementos discretos al desgaste de las uñas 32MnCrMo6-4-3 y sus Revestimientos aplicados mediante Elementos Discretos.

En este capítulo se realizó una simulación del desgaste del cucharón en general, uñas de Acero 32MnCrMo6-4-3 y los revestimientos aplicados a las uñas (Citomangan, Exadur 43, Citodur – 1000) en el orden descrito. Para verificar el desgaste, se utilizó el Software de Elementos Discretos EDEM.

#### 3.1.1. Secuencia de Simulación EDEM

Los pasos por seguir fueron los siguientes:

##### 3.1.1.1. EDEM Creator: creando materiales

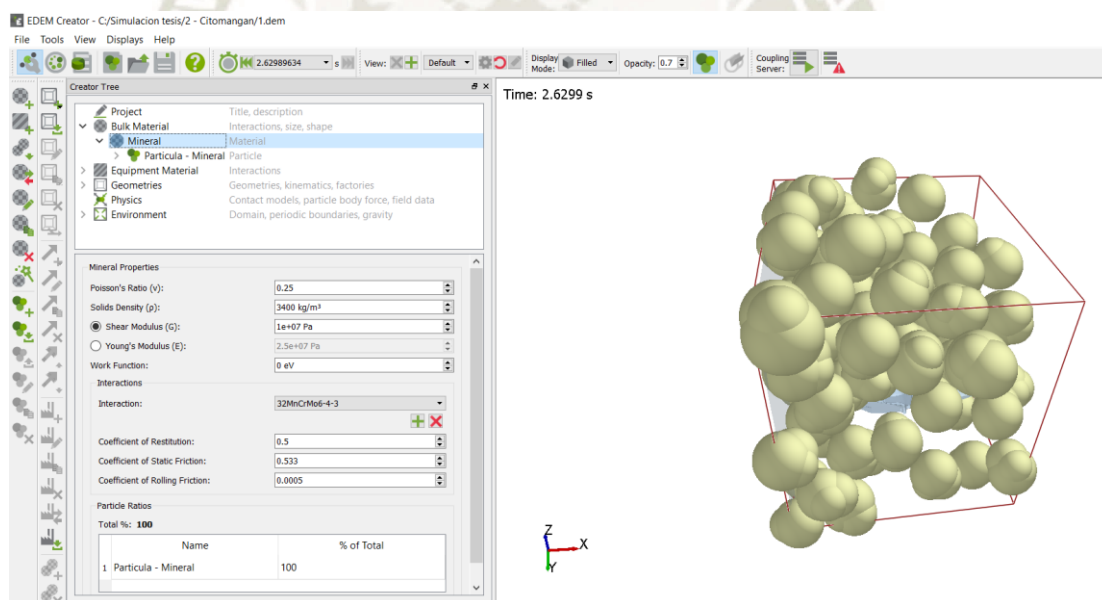


Figura 3-1 - Creación de mineral a simular [1]

Acá la principal interacción que tendrá será el mineral será con el Acero 32MnCrMo6-4-

3.

### 3.1.1.2. Creación de partículas multiesfera

Las dimensiones del mineral están dadas en la siguiente Figura 3-2:

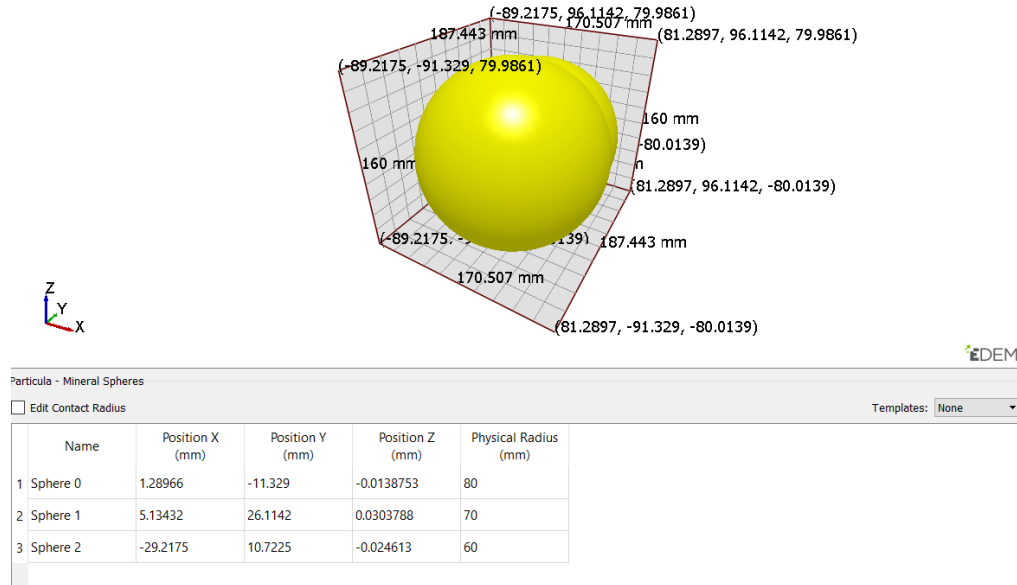


Figura 3-2 - Dimensiones de partícula de mineral [1]

Colocando las dimensiones de nuestras partículas de los minerales, el software calcula las propiedades de esta, y se puede visualizar en la siguiente Figura 3-3.

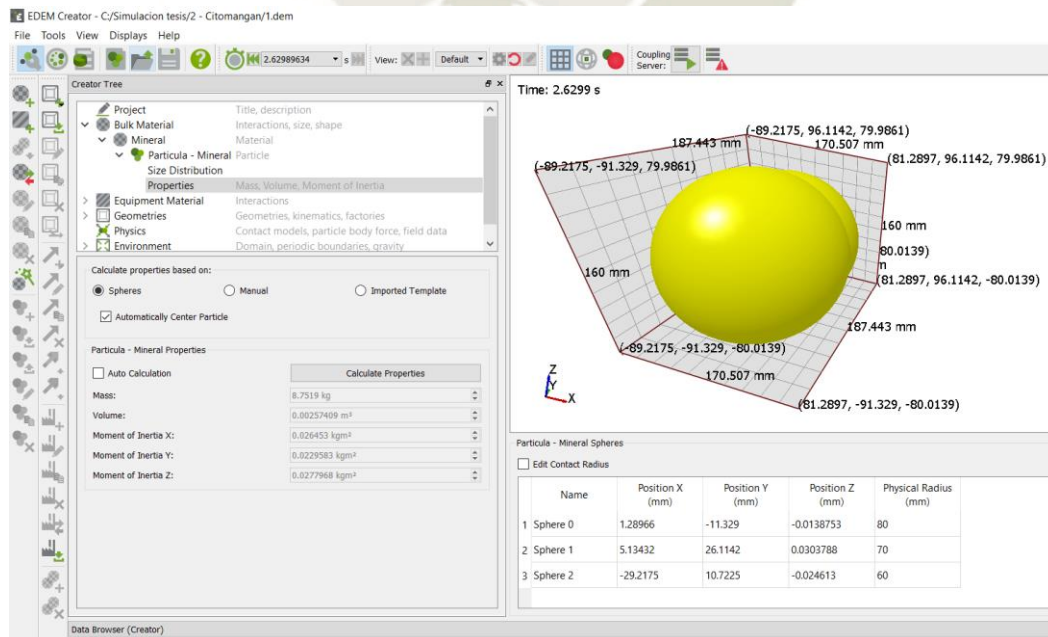


Figura 3-3 - Propiedades de partícula de mineral [1]

### 3.1.1.3. EDEM Creator: Creación del Material del equipo.

En este paso se tuvo que colocar propiedades diferentes ya que se tiene diferentes propiedades de los resultados de Ensayos de Tracción según la norma ASTM A 370-18, y el ensayo de desgaste ASTM G-99.

### 3.1.1.4. Material Base – 32MnCrMo6-4-3

Las propiedades del material se pueden visualizar en la siguiente Figura 3-4.

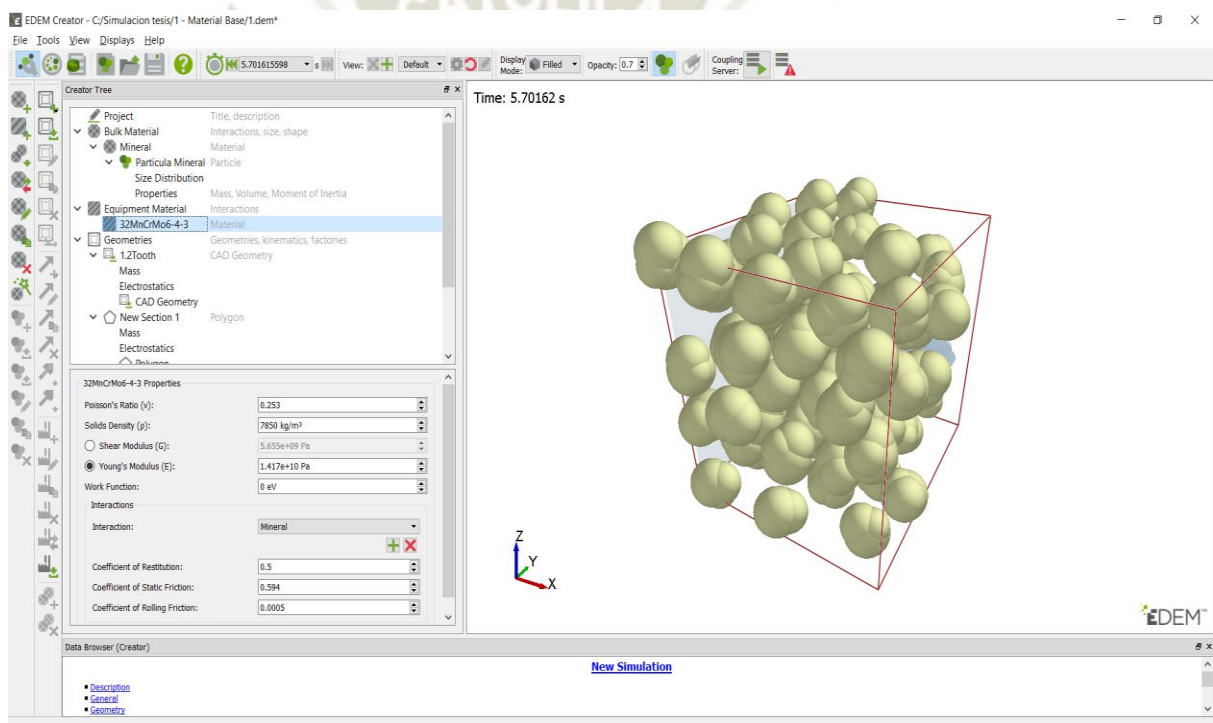


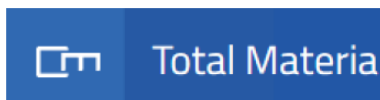
Figura 3-4 - Propiedades Material base – 32MnCrMo6-4-3 [1]

En este material se tiene las siguientes propiedades:

Coefficiente de Poisson que será igual a 0.253, y el módulo de Young  $1.417 \cdot 10^{10}$ , estas propiedades son resultados del ensayo de tracción que se describe en el capítulo 4.4 Ensayo de Tracción, la densidad  $7850 \text{ kg/m}^3$  esta propiedad se tomó como referencia a Total materia que se puede visualizar en la siguiente Figura 3-5.

2/8/2019

Total Materia :: Physical Properties



The world's most comprehensive materials database

### Saarstahl - 32MnCrMo6-4-3

Standard / Country: PROPRIETARY  
Subgroup: Saarlager AG

#### Physical Properties

[Official](#) [Other Sources](#) [Similar Materials](#) [Typical](#)

Density,  $\rho$  [Kg/dm<sup>3</sup>]

Value	Comment
7.85	Typical property value for mild carbon low-alloyed steels. This value is not provided by standard, it is indicative and cannot be used for design purposes.

Figura 3-5 - Propiedades Físicas del Material base – 32MnCrMo6-4-3 [22]

Para el coeficiente de restitución se pondrá un valor aproximado de 0.5 ya que este valor comprende entre 0 y 1 indica en un choque inelástico.

El coeficiente de fricción es igual 0.594 y es el resultado del ensayo de desgaste realizado en el capítulo 4.5, se puede visualizar en la siguiente Figura 3-6.

#### Base - 32MnCrMo6-4-3

##### Standard parameters

###### Instrument

- Standard tribometer
- Serial number: 1000059319
- Tribometer / Version 7.3.17
- Date of measurement: 8/1/2019 1:43:48 PM

###### Static partner

- Coating: -
- Substrate: WC
- Dimension: 6.00 [mm]
- Geometry: Ball

###### Sample

- Coating: -
- Substrate: Base 2
- Cleaning: -
- Supplier: -

###### Environment

- Temperature: 20.50 [°C]
- Atmosphere: Air
- Humidity: 10.00 [%]

###### Sequence

- Sequence count: 1
- Single-way mode
- Radius: 8.00 [mm]
- Lin. Speed: 25.00 [cm/s]
- Acquisition rate: 5.0 [Hz]
- Cycles sampled: 1/1
- Pause: 0 [s]
- Homing at begin: Yes
- Normal load: 10.00 [N]
- Unload at end: No
- Stop condit.: 905.00 [m]  
Or  $\mu > 0.80$
- Effective Stop: Meters

Sample	Static partner	Calculations
Worn track section: 76997.1 [ $\mu\text{m}^2$ ] Young's Modulus: 14.2 [GPa] Poisson ratio: 0.250	Worn cap diameter: 897.4 [ $\mu\text{m}$ ] Young's Modulus: 600.0 [GPa] Poisson ratio: 0.300	Sample Wear Rate: 0.0004277 [ $\text{mm}^3/\text{N/m}$ ] Partner Wear Rate: 1.182E-006 [ $\text{mm}^3/\text{N/m}$ ] Max Herzian Stress: 0.3607 [GPa]

Start : 0.003 min : 0.003 max : 0.662 mean : 0.594 std. dev. : 0.075

Figura 3-6 - Resultados ensayo de desgaste – Base 32MnCrMo6-4-3 [1]



El coeficiente por fricción será igual a 0.0005 a la rodadura, según la Figura 3-7 a continuación en el que tomamos como referencia un contacto acero con acero.

Material	Rolling friction
Steel on Steel	0.0005m
Wood on Steel	0.0012m
Wood on Wood	0.0015m
Iron on Iron	0.00051m
Iron on Granite	0.0021m
Iron on Wood	0.0056m
Polymer on Steel	0.002m
Hard rubber on Steel	0.0077m
Hard rubber on Concrete	0.01 - 0.02m
Rubber on Concrete	0.015 - 0.035m

Note: Values for rolling friction from various sources are not consistent and these values should only be used for approximate calculations. Remember also the coefficient of rolling friction is dependent on the cylinder radius and therefore has units of length (metres).

Figura 3-7 - Coeficiente de fricción a la rodadura [15]

### 3.1.1.5. Material Base – Citomangan

Las propiedades del material fueron obtenidas se puede visualizar en la siguiente Figura 3-8.

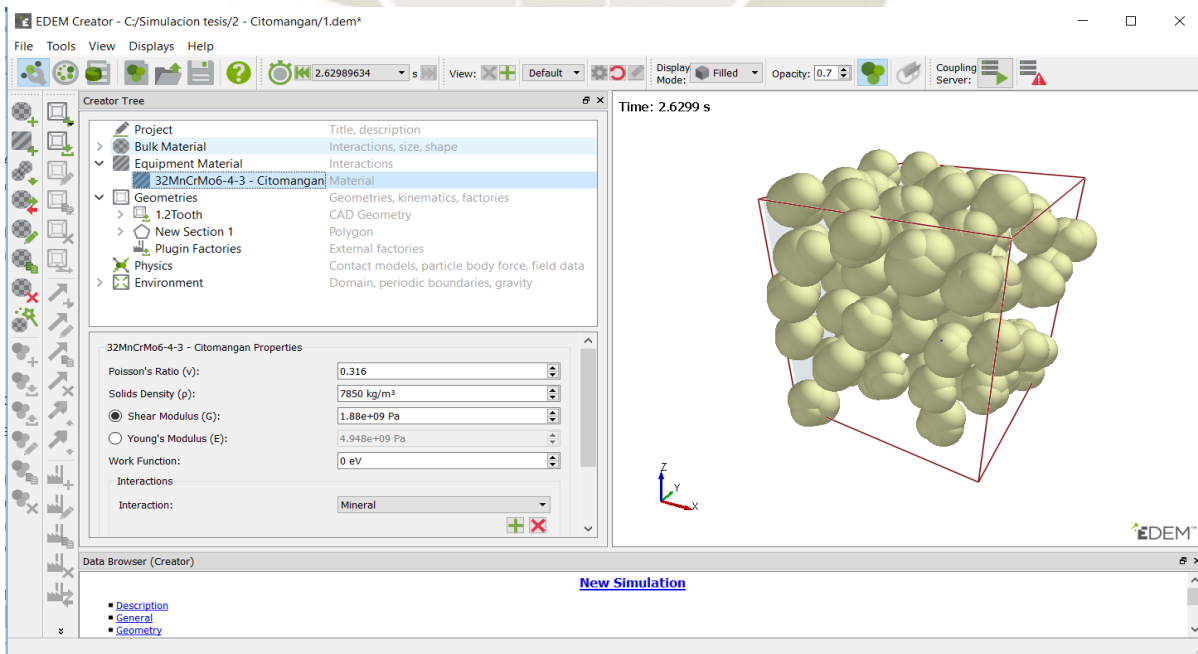
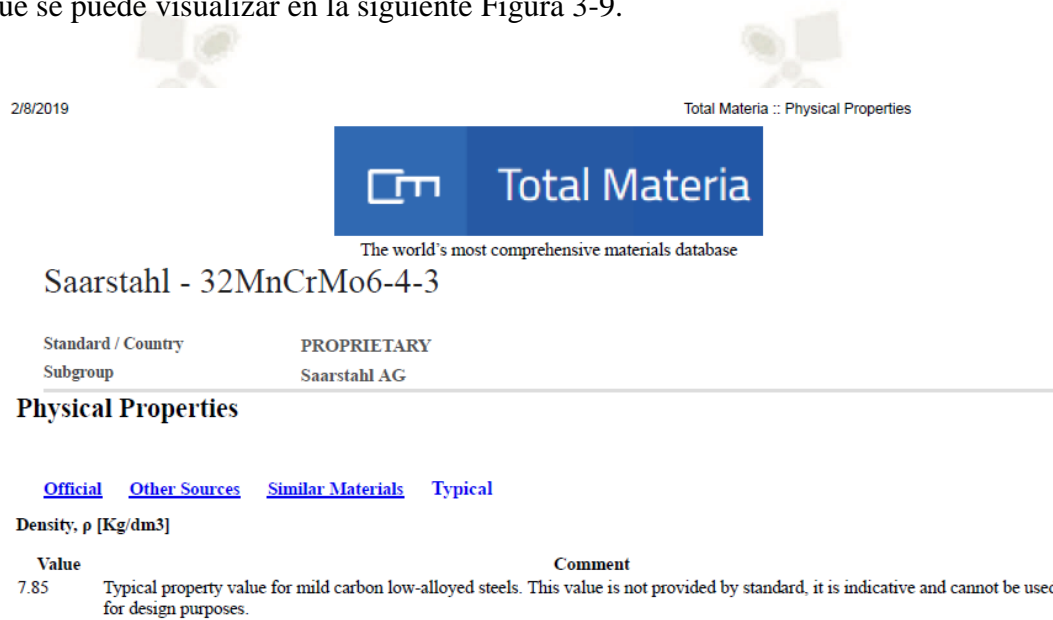


Figura 3-8 - Propiedades Material base – Citomangan [1]

En este material tiene las siguientes propiedades:

Coefficiente de Poisson que será igual a 0.316, y el módulo de Young  $1.88 \cdot 10^9$ , estas propiedades son resultados del ensayo de tracción que se describe en el capítulo 4.4 Ensayo de Tracción, la densidad  $7850 \text{ kg/m}^3$  esta propiedad se tuvo como referencia a Total materia que se puede visualizar en la siguiente Figura 3-9.



2/8/2019 Total Materia :: Physical Properties

**Total Materia**  
The world's most comprehensive materials database

**Saarstahl - 32MnCrMo6-4-3**

Standard / Country	PROPRIETARY
Subgroup	Saarstahl AG

**Physical Properties**

[Official](#) [Other Sources](#) [Similar Materials](#) [Typical](#)

Density,  $\rho$  [Kg/dm3]

Value	Comment
7.85	Typical property value for mild carbon low-alloyed steels. This value is not provided by standard, it is indicative and cannot be used for design purposes.

Figura 3-9 - Propiedades Físicas del Material base – 32MnCrMo6-4-3 [22]

Para el coeficiente de restitución se pondrá un valor aproximado de 0.5 ya que este valor comprende entre 0 y 1 indica en un choque inelástico.

El coeficiente de fricción es igual 0.533 y es el resultado del ensayo de desgaste realizado en el capítulo 4.5, se puede visualizar en la siguiente Figura 3-10.

**Muestra A - Citomangan**

Standard parameters

<p><b>Instrument</b></p> <ul style="list-style-type: none"> <li>- Standard tribometer</li> <li>- Serial number: 1000059319</li> <li>- Tribometer / Version 7.3.17</li> <li>- Date of measurement: 7/31/2019 4:34:40 PM</li> </ul> <p><b>Static partner</b></p> <ul style="list-style-type: none"> <li>- Coating: -</li> <li>- Substrate: WC</li> <li>- Dimension: 6.00 [mm]</li> <li>- Geometry: Ball</li> </ul> <p><b>Sample</b></p> <ul style="list-style-type: none"> <li>- Coating: -</li> <li>- Substrate: Muestra A</li> <li>- Cleaning: -</li> <li>- Supplier: -</li> </ul>	<p><b>Environment</b></p> <ul style="list-style-type: none"> <li>- Temperature: 21.20 [°C]</li> <li>- Atmosphere: Air</li> <li>- Humidity: 10.00 [%]</li> </ul> <p><b>Sequence</b></p> <ul style="list-style-type: none"> <li>- Sequence count: 1</li> <li>- Single-way mode</li> <li>- Radius: 8.01 [mm]</li> <li>- Lin. Speed: 25.00 [cm/s]</li> <li>- Acquisition rate: 5.0 [Hz]</li> <li>- Cycles sampled: 1/1</li> <li>- Pause: 0 [s]</li> <li>- Homing at begin: Yes</li> <li>- Normal load: 10.00 [N]</li> <li>- Unload at end: No</li> <li>- Stop condit.: 905.00 [m]</li> <li>Or <math>\mu &gt; 0.80</math></li> <li>- Effective Stop: Meters</li> </ul>
--	---

<p><b>Sample</b></p> <ul style="list-style-type: none"> <li>Worn track section: 72936.0 [<math>\mu\text{m}^2</math>]</li> <li>Young's Modulus: 5.0 [GPa]</li> <li>Poisson ratio: 0.320</li> </ul>	<p><b>Static partner</b></p> <ul style="list-style-type: none"> <li>Worn cap diameter: 747.0 [<math>\mu\text{m}</math>]</li> <li>Young's Modulus: 600.0 [GPa]</li> <li>Poisson ratio: 0.300</li> </ul>	<p><b>Calculations</b></p> <ul style="list-style-type: none"> <li>Sample Wear Rate: 0.0004056 [<math>\text{mm}^3/\text{N/m}</math>]</li> <li>Partner Wear Rate: 5.661E-007 [<math>\text{mm}^3/\text{N/m}</math>]</li> <li>Max Hertzian Stress: 0.186 [GPa]</li> </ul>
---	--	---

Start : 0.034	min : 0.018	max : 0.641	mean : 0.533	std. dev. : 0.060
---------------	-------------	-------------	--------------	-------------------

Figura 3-10 - Resultados ensayo de desgaste – Base Citomangan [1]

El coeficiente por fricción será igual a 0.0005 a la rodadura, según la Figura 3-11 a continuación en el que tomamos como referencia un contacto acero con acero.

Material	Rolling friction
Steel on Steel	0.0005m
Wood on Steel	0.0012m
Wood on Wood	0.0015m
Iron on Iron	0.00051m
Iron on Granite	0.0021m
Iron on Wood	0.0056m
Polymer on Steel	0.002m
Hard rubber on Steel	0.0077m
Hard rubber on Concrete	0.01 - 0.02m
Rubber on Concrete	0.015 - 0.035m

Note: Values for rolling friction from various sources are not consistent and these values should only be used for approximate calculations. Remember also the coefficient of rolling friction is dependent on the cylinder radius and therefore has units of length (metres).

Figura 3-11 - Coeficiente de fricción a la rodadura [15]

### 3.1.1.6. Material Base – Exadur – 43

Las propiedades del material fueron obtenidas se puede visualizar en la siguiente Figura

3-12.

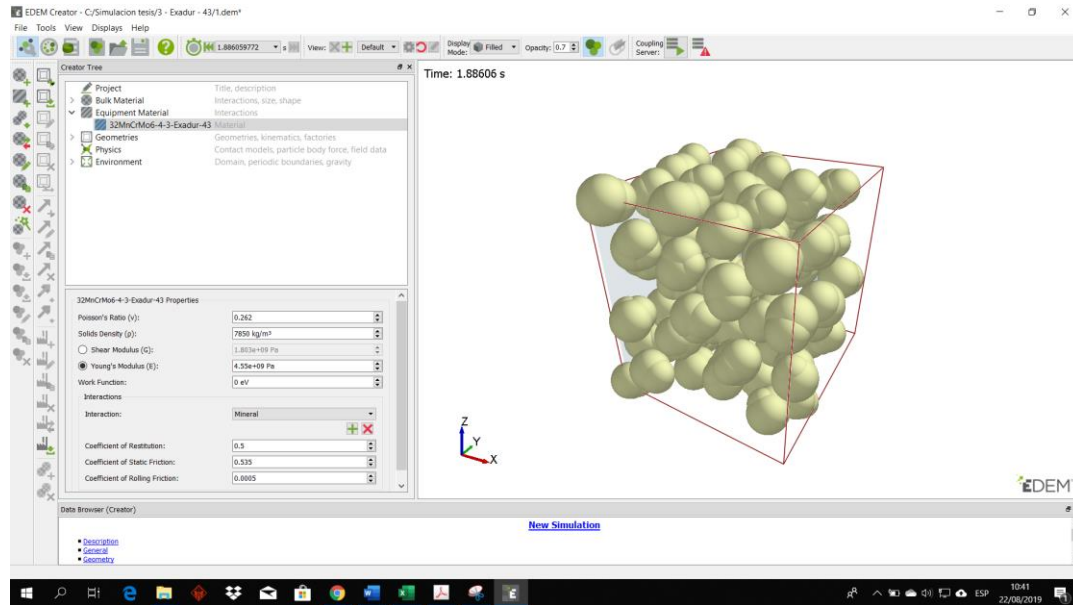


Figura 3-12 - Propiedades Material base – Exadur 43 [1]

En este material tiene las siguientes propiedades:

Coefficiente de Poisson que será igual a 0.262 y el módulo de Young  $4.55 \cdot 10^9$ , estas propiedades son resultados del ensayo de tracción que se describe en el capítulo 4.4 Ensayo de Tracción, a densidad  $7850 \text{ kg/m}^3$  esta propiedad se tuvo como referencia a Total materia que se puede visualizar en la siguiente Figura 3-13.

2/8/2019 Total Materia :: Physical Properties

The world's most comprehensive materials database

Saarstahl - 32MnCrMo6-4-3

Standard / Country	PROPRIETARY
Subgroup	Saarstahl AG

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**Physical Properties**

[Official](#) [Other Sources](#) [Similar Materials](#) [Typical](#)

Density,  $\rho$  [Kg/dm3]

Value	Comment
7.85	Typical property value for mild carbon low-alloyed steels. This value is not provided by standard, it is indicative and cannot be used for design purposes.

Figura 3-13 - Propiedades Físicas del Material base – 32MnCrMo6-4-3 [22]

Para el coeficiente de restitución se pondrá un valor aproximado de 0.5 ya que este valor comprende entre 0 y 1 indica en un choque inelástico.

El coeficiente de fricción es igual 0.535 y es el resultado del ensayo de desgaste realizado en el capítulo 4.5, se puede visualizar en la siguiente Figura 3-14.

Muestra B - Exadur - 43		
Standard parameters		
<b>Instrument</b> - Standard tribometer - Serial number: 1000059319 - Tribometer / Version 7.3.17 - Date of measurement: 8/1/2019 3:13:30 PM	<b>Environment</b> - Temperature: 20.50 [°C] - Atmosphere: Air - Humidity: 10.00 [%]	<b>Sequence</b> - Sequence count: 1 - Single-way mode - Radius: 8.01 [mm] - Lin. Speed: 25.00 [cm/s] - Acquisition rate: 5.0 [Hz] - Cycles sampled: 1/1 - Pause: 0 [s] - Homing at begin: Yes - Normal load: 10.00 [N] - Unload at end: No - Stop condit.: 905.00 [m] Or $\mu > 0.80$ - Effective Stop: Meters
<b>Static partner</b> - Coating: - - Substrate: WC - Dimension: 6.00 [mm] - Geometry: Ball	<b>Sample</b> - Coating: - - Substrate: Muestra B2 - Cleaning: - - Supplier: -	
<b>Sample</b> Worn track section: 24821.5 [ $\mu\text{m}^2$ ] Young's Modulus: 4.6 [GPa] Poisson ratio: 0.260	<b>Static partner</b> Worn cap diameter: 634.3 [ $\mu\text{m}$ ] Young's Modulus: 600.0 [GPa] Poisson ratio: 0.300	<b>Calculations</b> Sample Wear Rate: 0.000138 [ $\text{mm}^3/\text{N}/\text{m}$ ] Partner Wear Rate: 2.937E-007 [ $\text{mm}^3/\text{N}/\text{m}$ ] Max Hertzian Stress: 0.1715 [GPa]
Start : -0.010 min : -0.010 max : 0.639 mean : 0.535 std. dev. : 0.160		

Figura 3-14 - Resultados ensayo de desgaste – Base Exadur 43 [1]

El coeficiente por fricción será igual a 0.0005 a la rodadura, según la Figura 3-15 a continuación en el que tomamos como referencia un contacto acero con acero.

Material	Rolling friction
Steel on Steel	0.0005m
Wood on Steel	0.0012m
Wood on Wood	0.0015m
Iron on Iron	0.00051m
Iron on Granite	0.0021m
Iron on Wood	0.0056m
Polymer on Steel	0.002m
Hard rubber on Steel	0.0077m
Hard rubber on Concrete	0.01 - 0.02m
Rubber on Concrete	0.015 - 0.035m

Note: Values for rolling friction from various sources are not consistent and these values should only be used for approximate calculations. Remember also the coefficient of rolling friction is dependent on the cylinder radius and therefore has units of length (metres).

Figura 3-15 - Coeficiente de fricción a la rodadura [15]

### 3.1.1.7. Material Base – Citodur 1000

Las propiedades del material fueron obtenidas se puede visualizar en la siguiente Figura 3-

16.

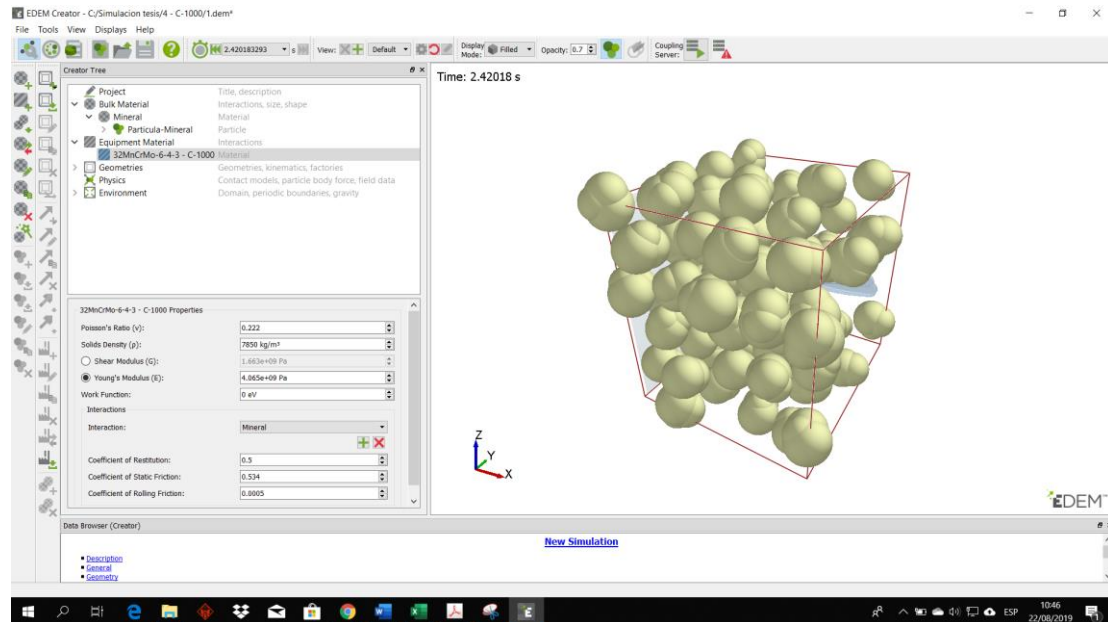


Figura 3-16 - Propiedades Material base – Citodur 1000 [1]

En este material tiene las siguientes propiedades:

Coefficiente de Poisson que será igual a 0.262 y el módulo de Young  $4.065 \cdot 10^9$ , estas propiedades son resultados del ensayo de tracción que se describe en el capítulo 4.4 Ensayo de Tracción, la densidad  $7850 \text{ kg/m}^3$  esta propiedad se tuvo como referencia a Total materia que se puede visualizar en la siguiente Figura 3-17.

2/8/2019 Total Materia :: Physical Properties

The world's most comprehensive materials database

Saarstahl - 32MnCrMo6-4-3

Standard / Country	PROPRIETARY
Subgroup	Saarstahl AG

**Physical Properties**

[Official](#) [Other Sources](#) [Similar Materials](#) [Typical](#)

Density, ρ [Kg/dm3]

Value	Comment
7.85	Typical property value for mild carbon low-alloyed steels. This value is not provided by standard, it is indicative and cannot be used for design purposes.

Figura 3-17 - Propiedades Físicas del Material base – 32MnCrMo6-4-3 [22]

Para el coeficiente de restitución se pondrá un valor aproximado de 0.5 ya que este valor comprende entre 0 y 1 indica en un choque inelástico.

El coeficiente de fricción es igual 0.534 y es el resultado del ensayo de desgaste realizado en el capítulo 4.5, se puede visualizar en la siguiente Figura 3-18.

Muestra C - Citodur 1000		
Standard parameters		
<b>Instrument</b> - Standard tribometer - Serial number: 1000059319 - Tribometer / Version 7.3.17 - Date of measurement: 8/1/2019 12:33:36 PM	<b>Environment</b> - Temperature: 20.50 [°C] - Atmosphere: Air - Humidity: 10.00 [%]	<b>Sequence</b> - Sequence count: 1 - Single-way mode - Radius: 8.00 [mm] - Lin. Speed: 25.00 [cm/s] - Acquisition rate: 5.0 [Hz] - Cycles sampled: 1/1 - Pause: 0 [s] - Homing at begin: Yes - Normal load: 10.00 [N] - Unload at end: No - Stop condit.: 905.00 [m] Or $\mu > 0.80$ - Effective Stop: Meters
<b>Static partner</b> - Coating: - - Substrate: WC - Dimension: 6.00 [mm] - Geometry: Ball	<b>Sample</b> - Coating: - - Substrate: Muestra C - Cleaning: - - Supplier: -	
<b>Sample</b> Worn track section: 53006.0 [ $\mu\text{m}^2$ ] Young's Modulus: 4.1 [GPa] Poisson ratio: 0.220	<b>Static partner</b> Worn cap diameter: 976.3 [ $\mu\text{m}$ ] Young's Modulus: 600.0 [GPa] Poisson ratio: 0.300	<b>Calculations</b> Sample Wear Rate: 0.0002944 [ $\text{mm}^3/\text{N}/\text{m}$ ] Partner Wear Rate: 1.657E-006 [ $\text{mm}^3/\text{N}/\text{m}$ ] Max Herzian Stress: 0.1569 [GPa]
Start : 0.021    min : -0.027    max : 0.585    mean : 0.534    std. dev. : 0.099		

Figura 3-18 - Resultados ensayo de desgaste – Base Exadur 43 [1]

El coeficiente por fricción será igual a 0.0005 a la rodadura, según la Figura 3-19 a continuación en el que tomamos como referencia un contacto acero con acero.

Material	Rolling friction
Steel on Steel	0.0005m
Wood on Steel	0.0012m
Wood on Wood	0.0015m
Iron on Iron	0.00051m
Iron on Granite	0.0021m
Iron on Wood	0.0056m
Polymer on Steel	0.002m
Hard rubber on Steel	0.0077m
Hard rubber on Concrete	0.01 - 0.02m
Rubber on Concrete	0.015 - 0.035m

Note: Values for rolling friction from various sources are not consistent and these values should only be used for approximate calculations. Remember also the coefficient of rolling friction is dependent on the cylinder radius and therefore has units of length (metres).

Figura 3-19 - Coeficiente de fricción a la rodadura [15]

### 3.1.1.8. EDEM Creator: sección de geometrías

Las secciones de geometría se utilizan para crear el entorno en el que actúa el Mineral. En este paso se procedió a importar dos Geometrías, el cucharón con todas las piezas, esto para poder visualizar las partes más afectadas (Desgaste), y el adaptador con la uña K -130. Cabe recalcar que se trabajó en mm y se unió todas las piezas en una sola geometría. Se pueden visualizar en las siguientes Figuras 3-20 y 3-21

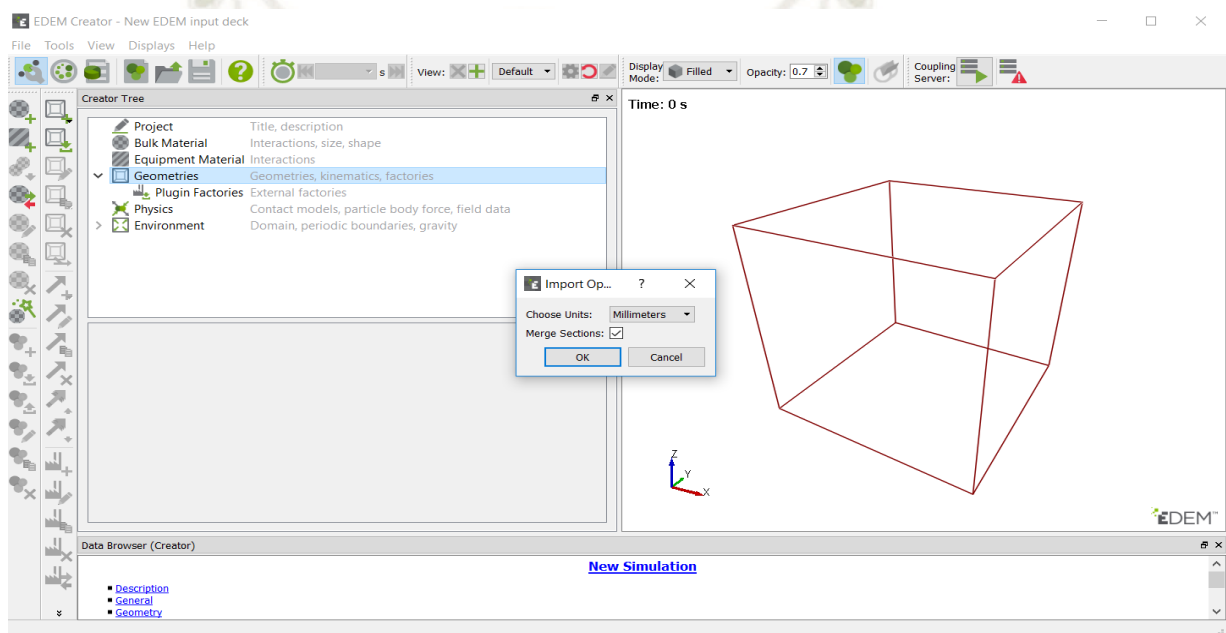


Figura 3-20 - Importación de geometría [1]

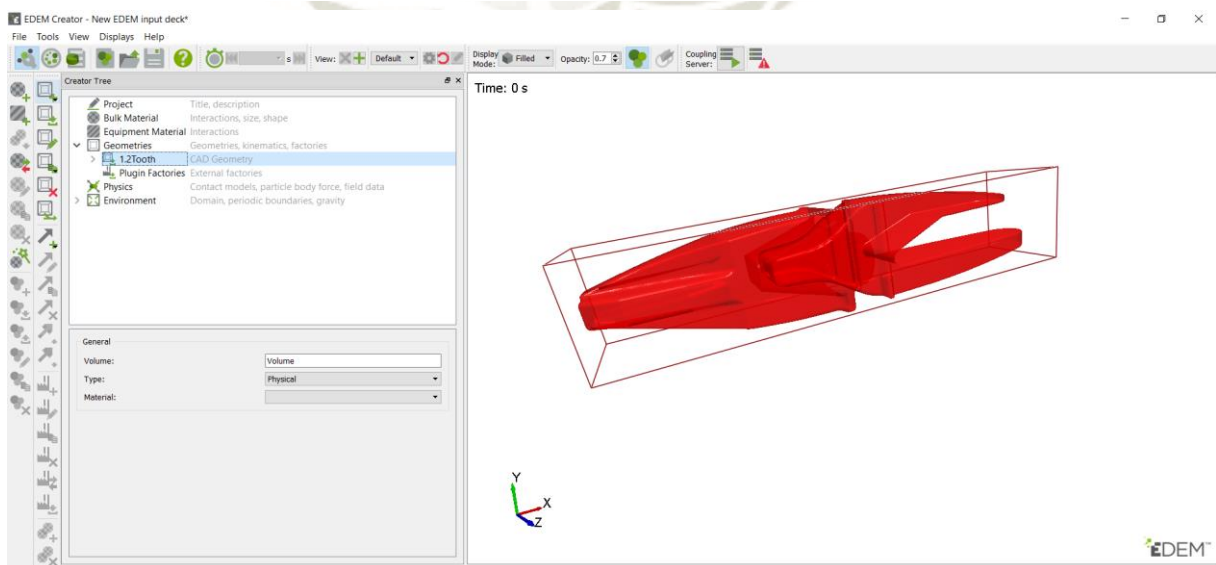


Figura 3-21 - Importación de geometría – uña y adaptador [1]



### 3.1.1.9. Creación de piezas de geometría incorporada

En este paso se procede a crear una geometría virtual, 500 mm x 200 mm de color rojo transparente. Esta geometría nos servirá para la creación del mineral y la interacción con el material Acero. Se puede observar en las siguientes Figuras 3-22 y 3-23.

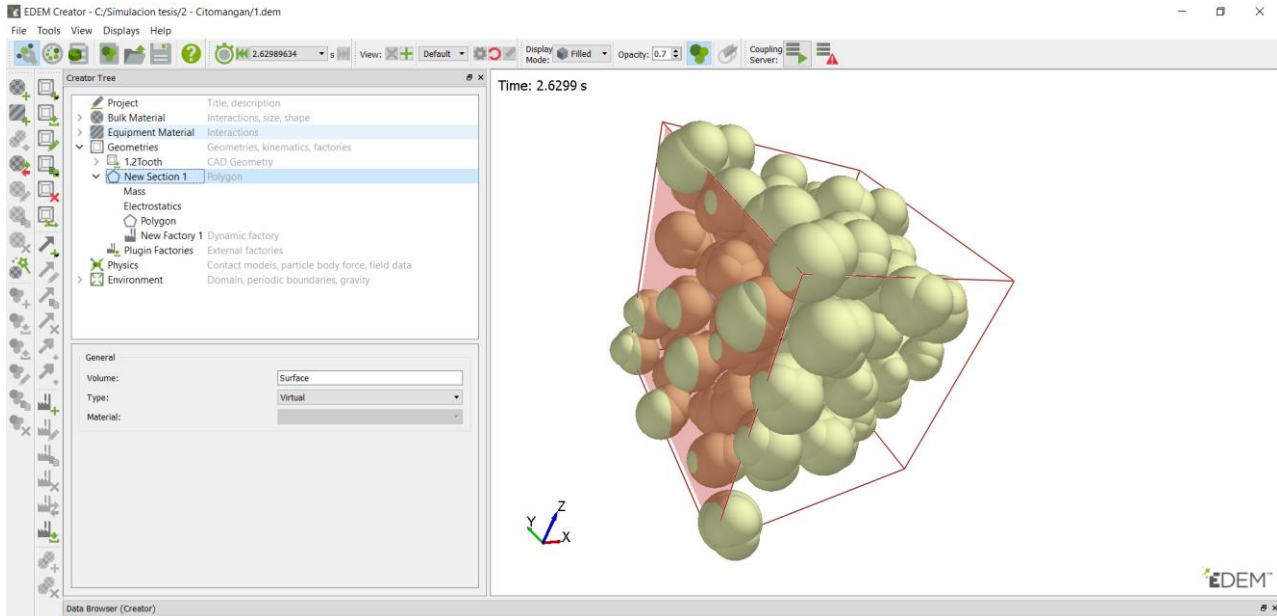


Figura 3-22 - Creación de geometría virtual [1]

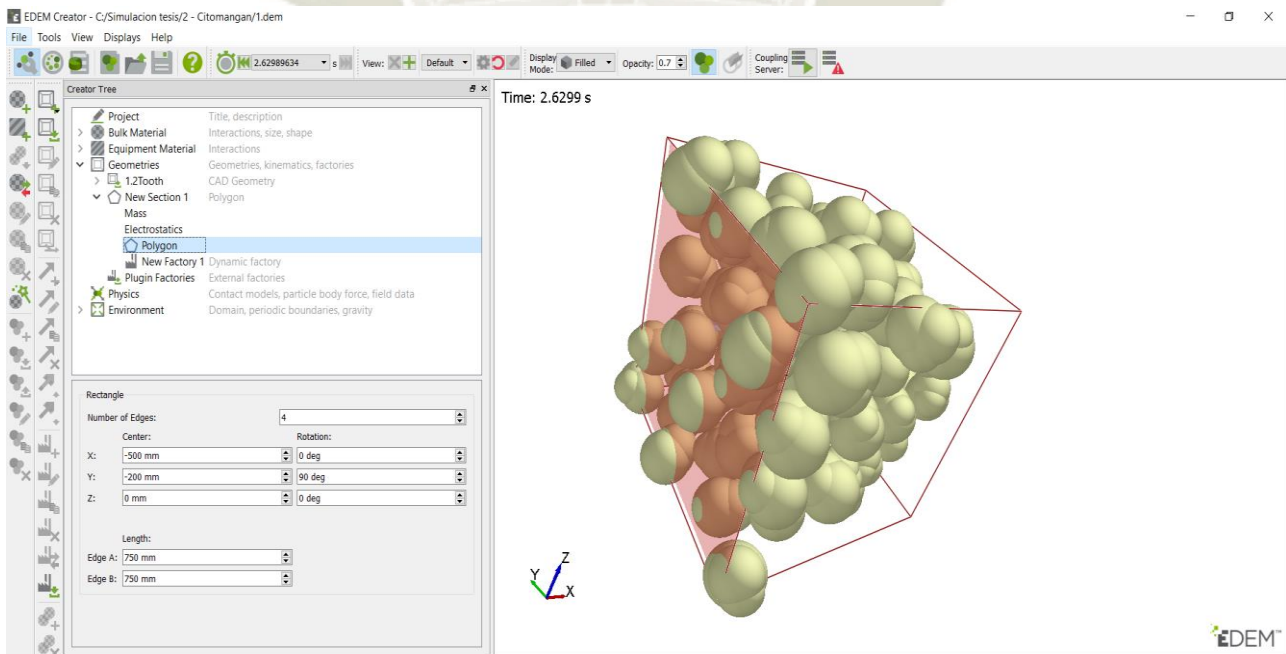


Figura 3-23 - Parámetros de geometría virtual [1]

### 3.1.1.10. EDEM Creator: Crear fábricas

Las fábricas de partículas se utilizan para definir dónde, cuándo y cómo aparecen las partículas en una simulación. Cualquier superficie o volumen virtual (físico o virtual) puede convertirse en una fábrica de partículas. Las fábricas sólo pueden crearse si se ha definido un Material a granel. Una simulación puede tener cualquier número de fábricas de partículas.

### 3.1.1.11. Parámetros de fabrica

En este paso se procedió a colocar las propiedades de fábrica de partículas, que se puede visualizar en la siguiente Figura 3-24. Se puede observar que se elige una velocidad de partículas de 3 m/s. Todas estas propiedades se repiten en las demás simulaciones.

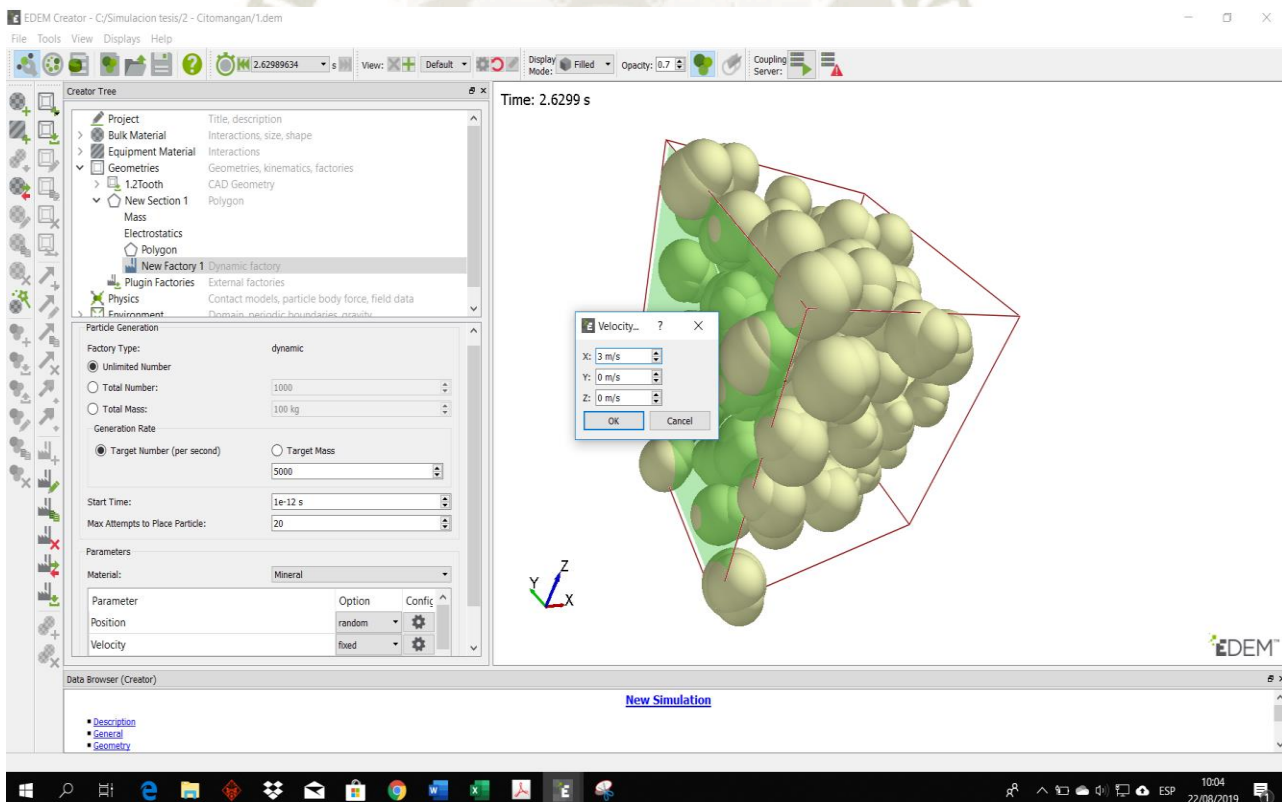


Figura 3-24 - Parámetros de fábrica de partículas [1]

3.1.1.12. EDEM Creator: Sección de física

El software tiene varias interacciones físicas que se pueden agregar (Figura 3-25). Por ejemplo:

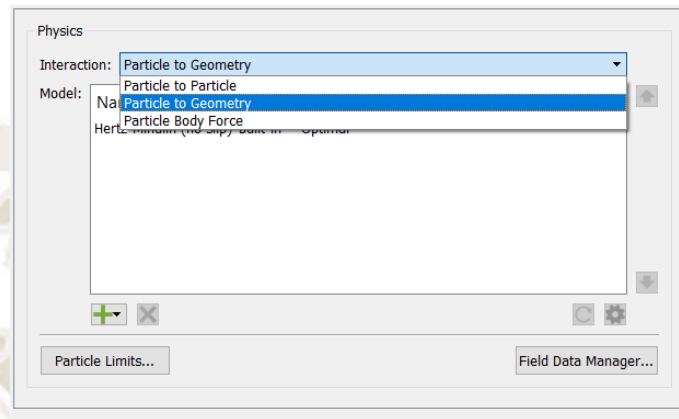


Figura 3-25 - Interacción - modelo de contacto de partícula a geometría [1]

En este caso se elige la interacción - modelo de contacto de partícula a geometría. Luego se elige modelo de contacto que describe cómo se comportan los elementos cuando entran en contacto entre sí (Figura 3-26). Cabe resaltar que un modelo de contacto solo se puede añadir una vez. Entre los modelos de contacto tenemos a elegir:

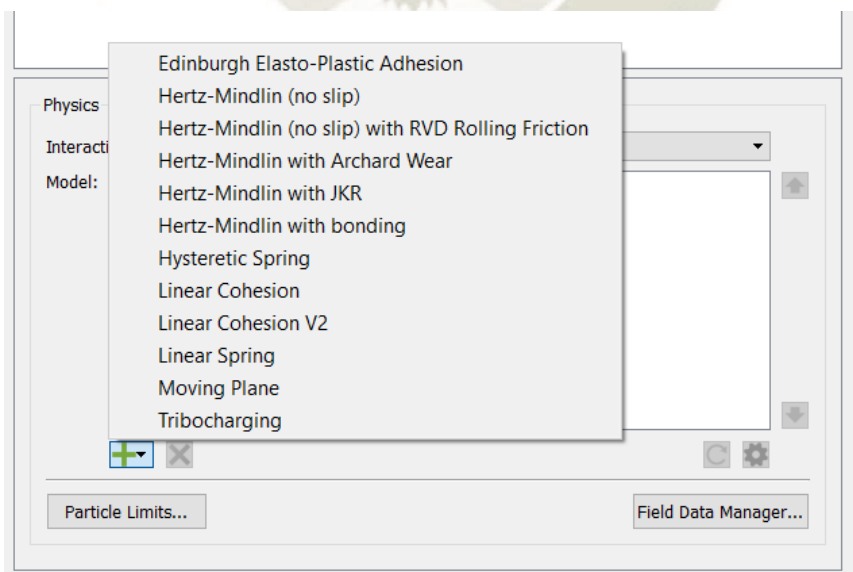


Figura 3-26 - Modelo de contacto [1]

Para calcular el desgaste, se eligió el modelo de contacto Hertz-Mindlin with Archard Wear, este nos permite dar una estimación de la profundidad de desgaste de las superficies geométricas. El modelo se basa en el trabajo de John F. Archard (Archard 1953) y utiliza la idea de que la cantidad de material eliminado de la superficie será proporcional al trabajo de fricción realizado por las partículas que se mueven sobre la superficie.

La ecuación de Archard está dada por:

$$Q = W * Fn * dt \quad \text{Ec 3-1}$$

En donde:

Q = Es el volumen de material eliminado

W = es una constante de desgaste originalmente:

dt = Es la distancia tangencial desplazada

La constante de desgaste es igual a:

$$W = \frac{K}{H} \quad \text{Ec 3-2}$$

Donde K es una constante sin dimensión y H es una medida de la dureza de la superficie más blanda.

Como la ecuación predice un volumen de material a ser removido, esto se reordena para dar una profundidad por elemento en EDEM:

$$\text{wear depth} = \frac{Q}{A} \quad \text{Ec 3-3}$$

### 3.1.1.13. Wear Rate

Se tiene diferentes ratios de desgaste de Archard para los diferentes materiales a interactuar con el mineral. Estos ratios de desgaste se obtuvieron del Capítulo 4.5 Ensayo de desgaste.

Estos datos se pueden visualizar en la siguiente Tabla 3-1.

Tabla 3-1 - Tasa de desgaste ensayos de desgaste [1]

Material	k masas / Maquina	
	k por masas mm <sup>3</sup> /N*mm	k por Maquina mm <sup>3</sup> /N*mm
Base	1.13E-08	4.28E-07
Citomangan (A)	9.85E-09	4.06E-07
Exadur 43 (B)	5.63E-09	1.38E-07
C-1000 (C)	7.04E-09	2.94E-07

#### 3.1.1.13.1. Coeficiente de Archard Material Base – EDEM

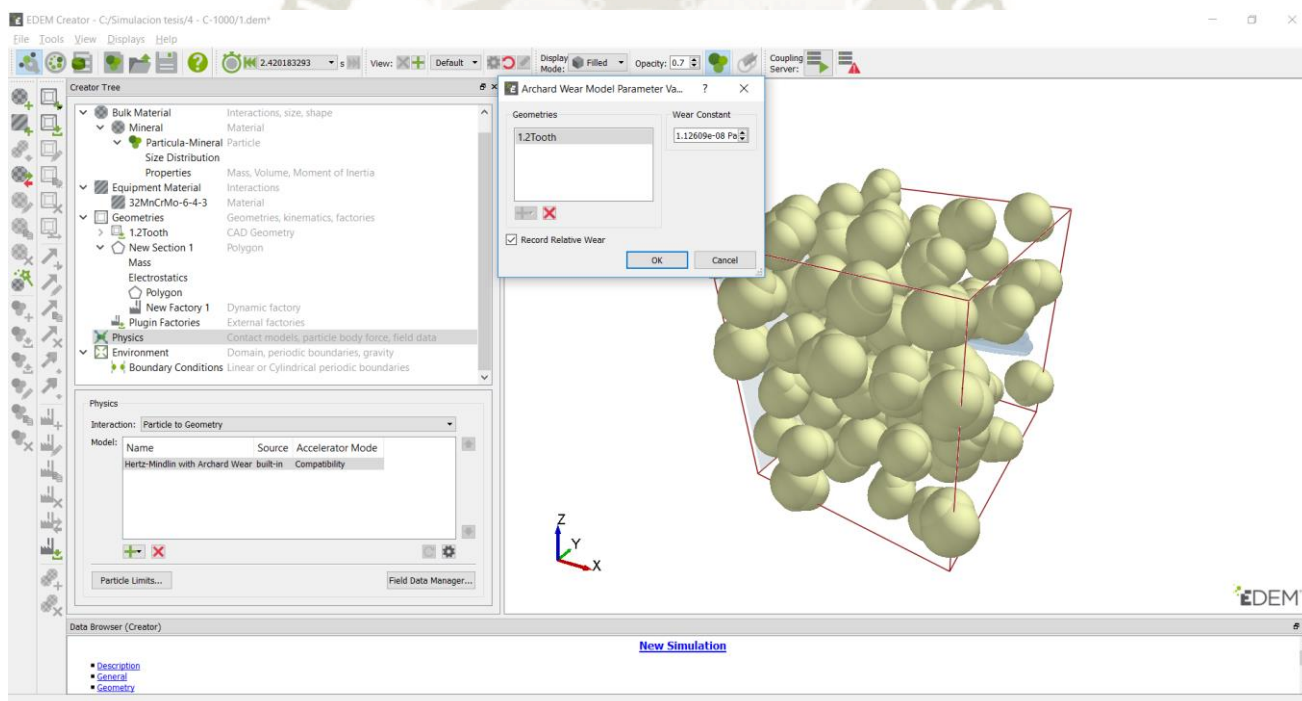


Figura 3-27 - Coeficiente de Archard Material Base – EDEM [1]

### 3.1.1.13.2. Coeficiente de Archard Citomangan – EDEM

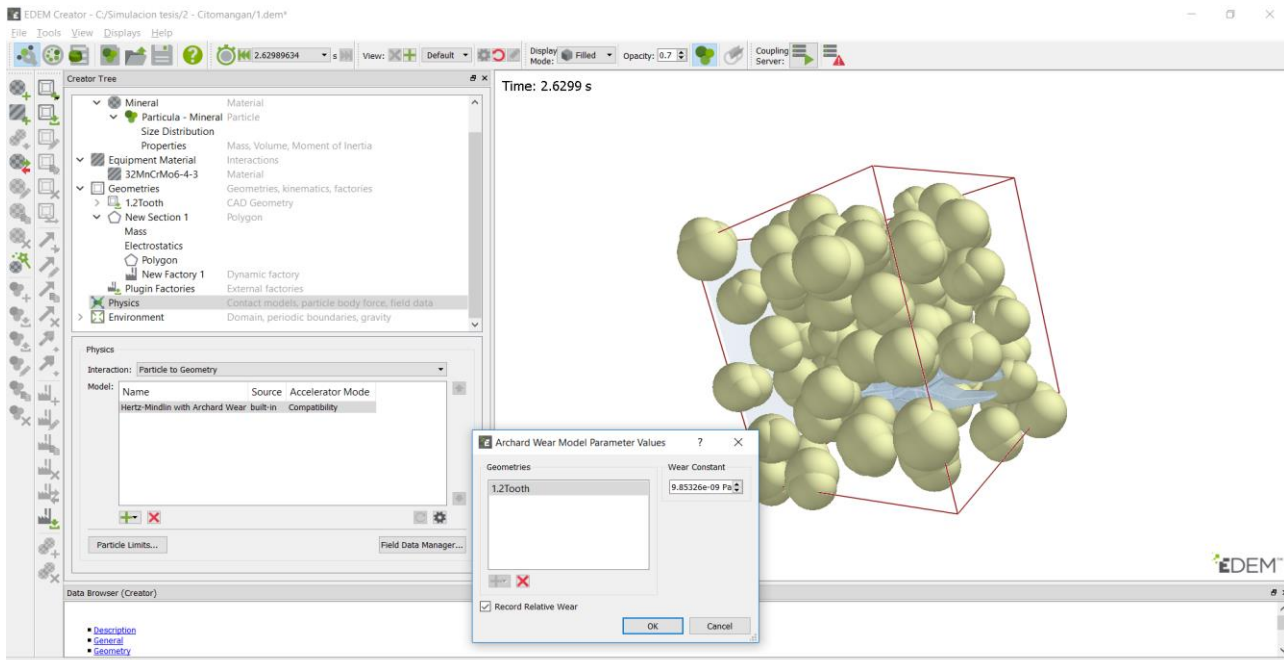


Figura 3-28 - Coeficiente de Archard Citomangan – EDEM [1]

### 3.1.1.13.3. Coeficiente de Archard Exadur - 43 – EDEM

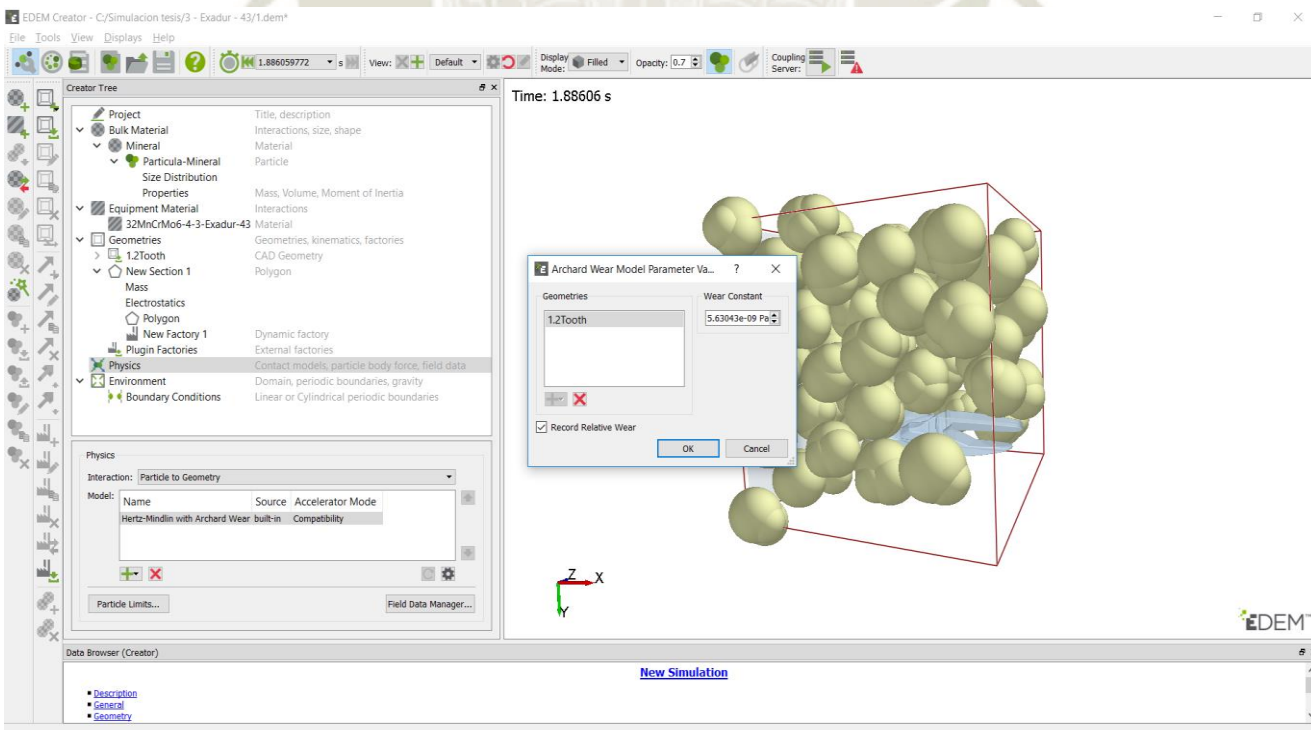


Figura 3-29 - Coeficiente de Archard Exadur - 43 – EDEM [1]

### 3.1.1.13.4. Coeficiente de Archard Citodur - 1000– EDEM

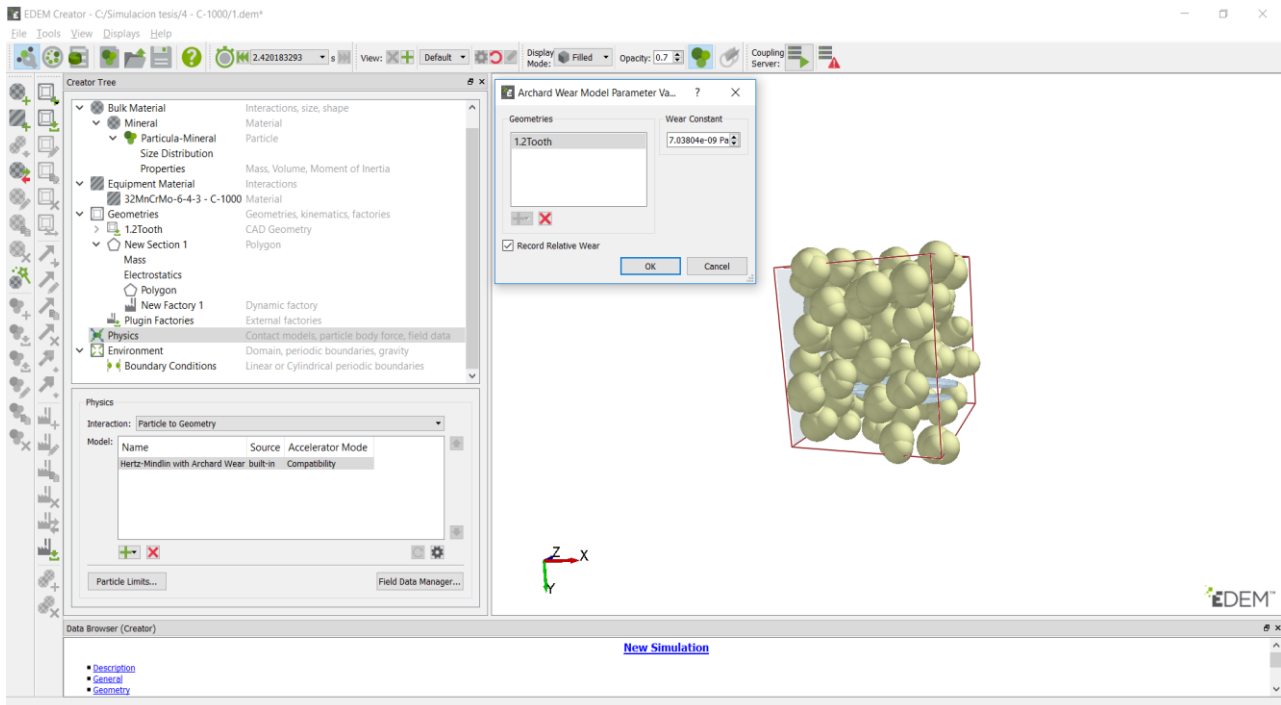


Figura 3-30 - Coeficiente de Archard Citodur 1000– EDEM [1]

### 3.1.1.14. Simulador EDEM

Luego de acabar con la opción creador, se procede a ir al árbol de simulador, en donde se coloca las siguientes propiedades que se pueden visualizar en la siguiente Figura 3-31.

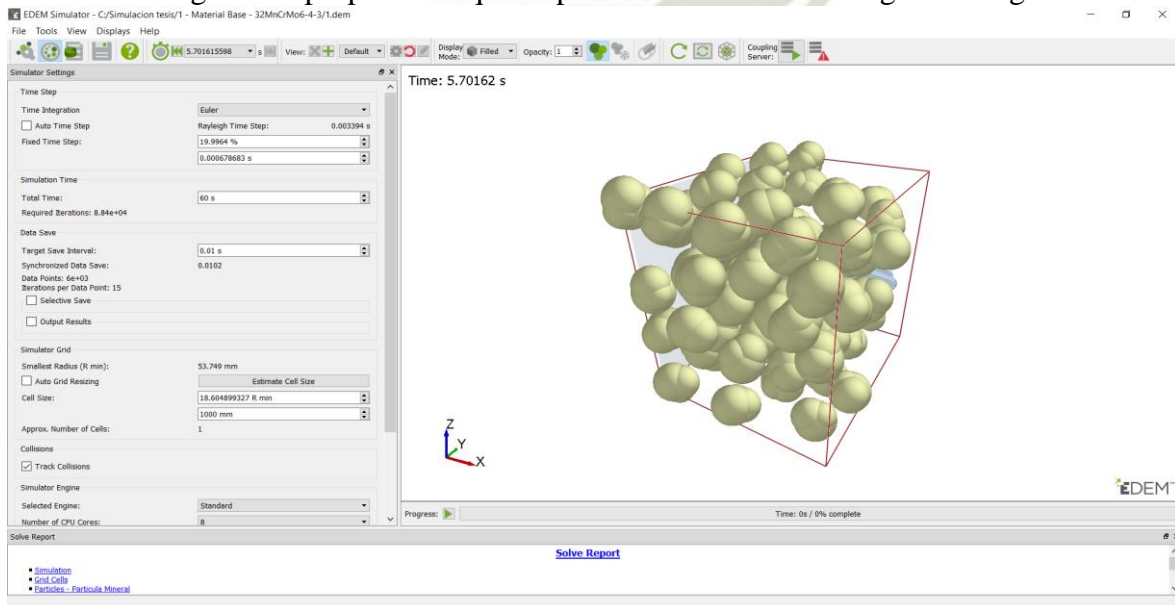


Figura 3-31 - Simulador de Edem [1]

En donde se elige un fixed time Step del 20%. El time Step es la cantidad de tiempo entre iteraciones (cálculos) en el Simulador. La simulación se coloca 60 s para poder obtener el desgaste total.

### 3.1.1.15. Descripción general del analista del EDEM

Luego de colocar los parámetros del Simulador, se procede a ir al árbol del analista, El árbol de analistas se muestra en el lado izquierdo de la ventana EDEM. Tiene cinco secciones: Visualización, configuración de selecciones, herramientas, recorte y campo (opcional, dependiendo de la licencia). Se tiene como ejemplo en la siguiente Figura 3-32.

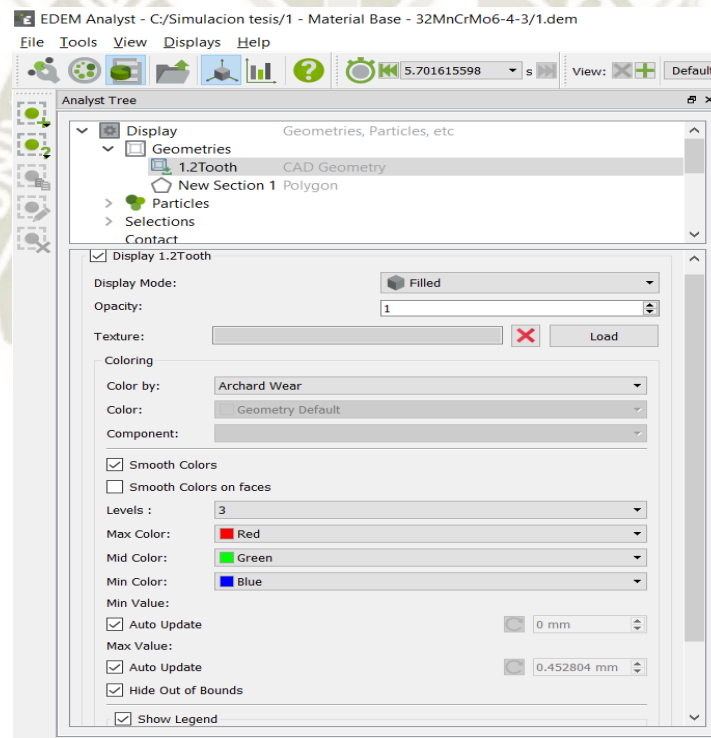


Figura 3-32 - Analista EDEM [1]

En donde se coloca Archard Wear para la geometría y se pincha en el cuadro de Auto Update para que calcule el desgaste total en el tiempo propuesto. Se puede colocar los colores de desgaste según corresponda. Este modelo de se aplico para todas las simulaciones.



### 3.2. Evaluación experimental.

Lo objetivo de este punto es describir la metodología realizada en la evaluación de las muestras preparadas de esta tesis. Los resultados de cada ensayo se mostrarán en el siguiente capítulo.

La Figura 3-33 se presenta un esquema de las actividades y ensayos realizados en las probetas.

Materiales y equipos utilizados:

- Electrodo de Recargue (Citodur 1000, Exadur – 43, Citomangan) donde la composición química se describe en la Tabla 3-6
- Fuente de poder para proceso SMAW y parámetros de soldeo (figura 3-49)
- Probetas de ensayo (9 probetas para los ensayos de Dureza, Metalografía, 4 probetas para los ensayos de tracción, 4 probetas para los ensayos de desgaste)
- Equipo de dureza Rockwell C (carga desde 60kgf hasta 150 kgf) Marca Time Group INC modelo HRC -150 con rango de medición de 20-88HRA, 20-100HRB, 20-70HRC.
- Microscopio Metalúrgico Invertido Óptico, Time Group INC, DX40TV con resolución 20x/100x.
- Equipos de desbaste y set de lijas para preparación de muestras metalográficas.
- Equipo de tracción INSTRON modelo 23-100.
- Tribómetro pin-on-disk - Anton Paar (TRB3) de 0.2 rpm to 2000 rpm, según la norma ASTM G-99, ASTM G-133, DIN 50324.
- Balanza con una precisión de 0.0001 gramos . Marca Mettler Toledo y Modelo – ML-T.
- Microscopio compuesto de binoculares, Motic, BA310POL con resolución 4x/60x
- Equipo de pulidora Metalográfica.

Los ensayos de Metalografía y dureza se realizaron en las instalaciones del laboratorio de Materiales de la universidad Católica de Santa María, y los ensayos de tracción y desgaste se realizaron en las instalaciones del laboratorio de materiales de la Universidad Nacional de San Agustín. Los pasos se describen a continuación:

- Se realizó el corte y mecanizado de las probetas a ensayar según la norma ASTM G65 en la empresa TALLER LÍDER S.A, se produjeron en total 14 probetas.
- Se realizó la preparación de los cupones de soldadura en la empresa Taller Lider S.A. Se agrupó en series (C-1000, E-43 y CITOMANGAN) según el elemento aleante a evaluar tal como se puede observar en la Figura 3-38.
- Se realizó el análisis de composición química a una muestra de cada serie, esta se llevó a cabo en la empresa VOESTALPINE HIGH PERFORMANCE METALS DEL PERÚ S.A. El objetivo de la realización de la composición química de cada muestra fue tener una mayor exactitud del porcentaje de elementos químicos que poseen y corroborarlo con la Data Sheet de cada soldadura. Se puede observar en la Ficha 4-1.
- Se realizó la preparación para el análisis metalográfico a todas las muestras, la superficie evaluada fue la transversal respecto al cordón de soldadura. La preparación metalográfica se hizo según la norma ASTM E3-11. Se puede observar en la Figura 3-69.

- Se realizó la preparación para el ensayo de dureza a todas las muestras, la superficie evaluada fue la transversal respecto al cordón de soldadura. El ensayo de dureza se realizó según la norma ASTM E18-15. Se puede observar en la Figura 3-69.
- Se realizó el corte y mecanizado para la unión de soldadura de 04 muestras, una de cada serie, en la empresa TALLER LÍDER S.A. Luego se procedió al mecanizado de estas muestras para la realización del ensayo de tracción según la norma ASTM A370 – 18. Se puede observar en la Figura 3-41.
- Se realizó el corte y mecanizado de 04 muestras en la empresa TALLER LÍDER S.A. para el ensayo de desgaste según la norma ASTM G99-17. Se puede observar en la Figura 3-44.

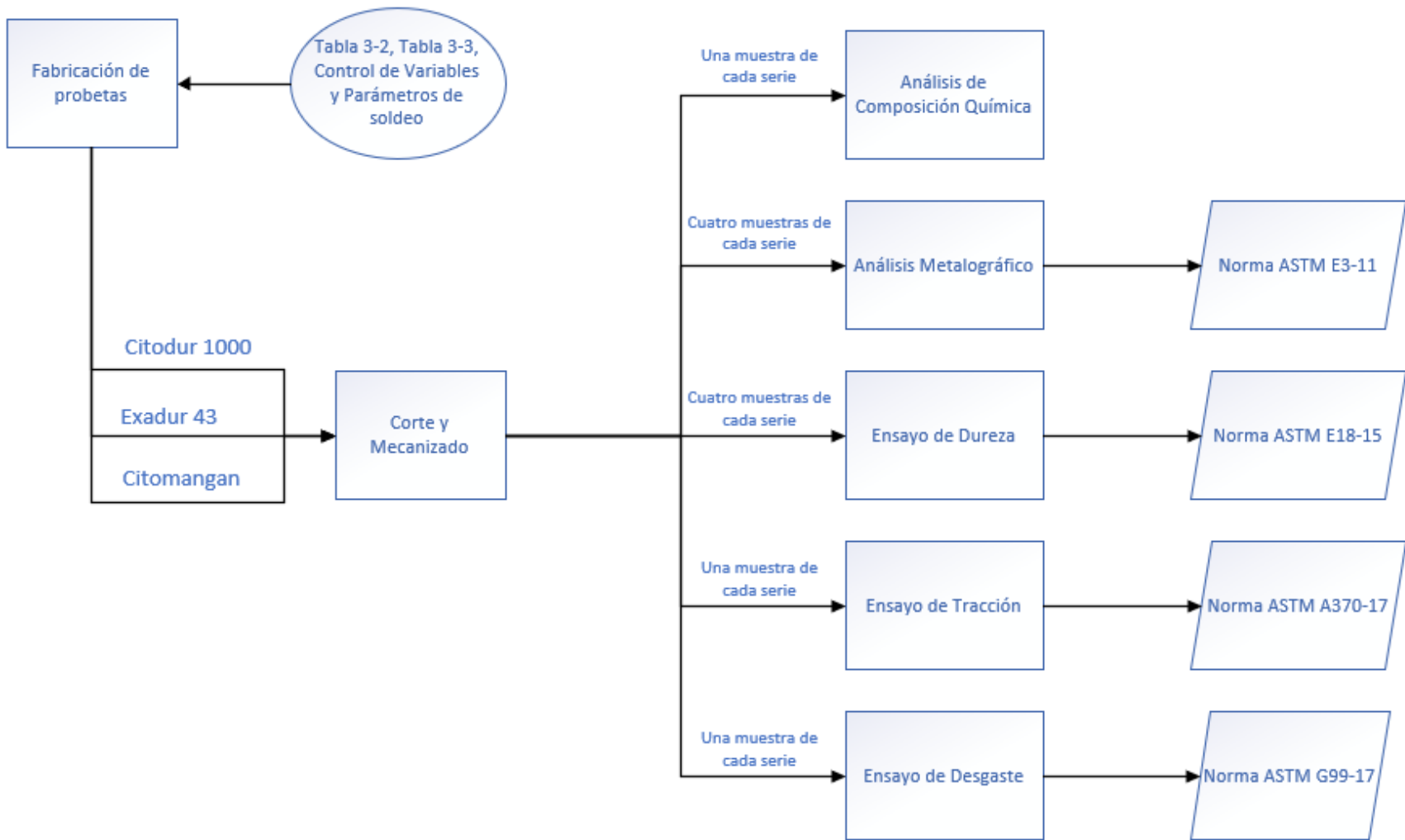


Figura 3-33 - Esquema del Procedimiento Experimental [1]

### 3.2.1. Fabricación de las probetas

#### 3.2.1.1. Probetas de Desgaste según la norma ASTM G65-16, metalografía y dureza

Las probetas se obtuvieron de una uña de acero 32MnCrMo6-4-3 (Figura 3-35), se realizó mediante Corte con Disco (Figura 3-36) y fresado (Figura 3-37) para obtener el correcto dimensionamiento, paralelepípedos con sus lados rectificadas (Tabla 3-2). Según la norma ASTM G-65 (Figura 3-34).

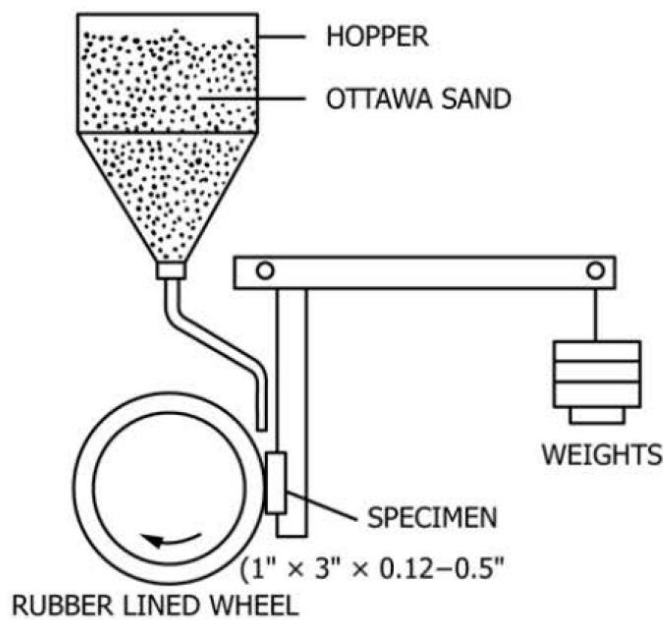


Figura 3-34 - Diagrama esquemático del aparato de prueba [23]

Tabla 3-2 - Medidas de la probeta de desgaste según la norma ASTM G65-16 [23]

Medidas	in	mm
Largo	3	76.2
Ancho	1	25.4
Espesor	0.5	12.7



Figura 3-35 - Uña de acero 32MnCrMo6-4-3 [1]



Figura 3-36 - Corte con disco Manual [1]

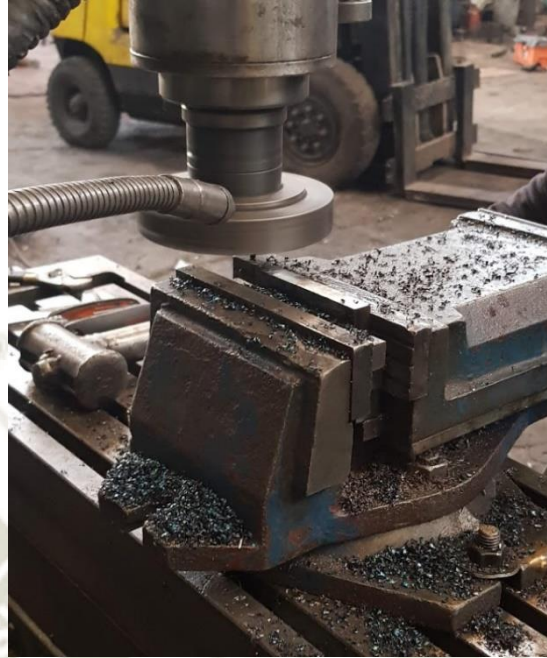


Figura 3-37 - Fresado de Probetas de desgaste [1]



Figura 3-38 - Probetas de desgaste de Acero 32MnCrMo6-4-3 culminadas según la norma ASTM G65-16 [1]

### 3.2.1.2. Probetas de Tracción según la norma ASTM A370-18

Las probetas se obtuvieron de una ña de acero 32MnCrMo6-4-3 (Figura 3-35), se realizó mediante Corte con Disco y fresado para obtener el correcto dimensionamiento (Tabla 3-3). Según la norma ASTM A370 - 18 (Figura 3-39).

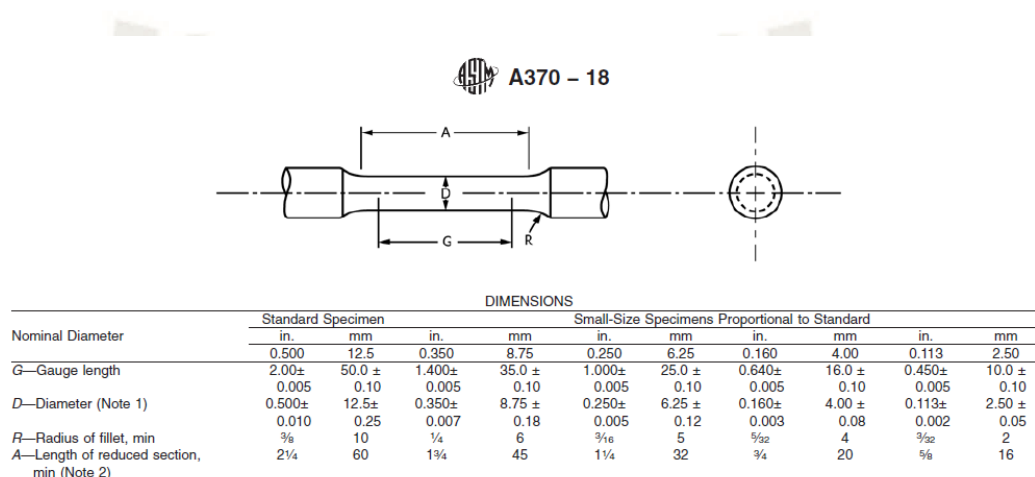


Figura 3-39 - Muestra de prueba de tensión redonda estándar de 0,500 pulgadas (12,5 mm) con una longitud de calibre de 2 pulgadas (50 mm) y ejemplos de muestras de tamaño pequeño. Proporcional a las muestras estándar [16]

Tabla 3-3 - Medidas de la probeta de tracción según la norma ASTM A370 – 18 [16]

Diámetro Nominal	Especificaciones estándar	
	in	Mm
		0.350
(G) - Longitud	1.400	35.000
(D) - Diámetro	0.350	8.750
(R) - Radio	1/4	6.000
(A) - Longitud de Sección	1 3/4	45.000





Figura 3-40 - Probetas de Tracción de Acero 32MnCrMo6-4-3 listos para la aplicación de soldadura [1]



Figura 3-41 - Torneado de Probetas de Tracción de Acero 32MnCrMo6-4-3 después de la aplicación unión de la soldadura de Recargue [1]



Figura 3-42 - Probetas de Tracción de Acero 32MnCrMo6-4-3 culminadas según la norma ASTM A370 – 18 [1]

### 3.2.1.3. Probetas de Desgaste según la norma ASTM G99-17

Las probetas se obtuvieron de una uña de acero 32MnCrMo6-4-3 (Figura 3-35), se realizó mediante Corte con Disco y fresado para obtener el correcto dimensionamiento (Tabla 3-4). Según la norma ASTM G-99-17.

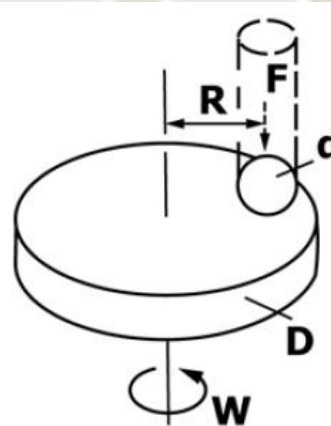


Figura 3-43 - Esquema del sistema de prueba de desgaste Pin-on-Disk [17]

Tabla 3-4 - Medidas de la probeta según la norma ASTM G99-17 [17]

Diámetro Nominal	Especificaciones estándar
	mm
(D) - Diámetro	30 – 100
(R) - Espesor	2 – 10



Figura 3-44 - Probetas de Desgaste de Acero 32MnCrMo6-4-3 después del recargue de Soladura Según la norma ASTM G-99 -17 [1]

3.2.2. Selección del metal base y el material de aporte probetas y elaboración de procedimiento de soldadura.

#### 3.2.2.1. Datos metal base – 32MnCrMo6-4-3

Acero endurecido al aire para la producción de componentes de forja de alta resistencia.

Sin tratamiento de temple clásico en el sector de la automoción (Tabla 3-5).

Tabla 3-5 - Material Saerstahl - 32MnCrMo6-4-3 [22]

#	MATERIAL	ESTÁNDAR	PAÍS / PRODUCTOR	TIPO
1	Saerstahl - 32MnCrMo6-4-3	PROPRIETARY	Saerstahl AG	Metal / Aceros aleados y al carbono

3.2.2.2. Composición química y propiedades mecánicas del metal base – Composición química del acero 32MnCrMo6-4-3 (Tabla 3-6).

Tabla 3-6 - Saarstahl - 32MnCrMo6-4-3 - Composición química [22]

Criterios	Min.	Max	Aprox	Número CAS
C	0.28	0.36	-	7440-44-0
Mn	1.4	1.8	-	7439-96-5
P	-	0.025	-	7723-14-0
S	-	0.04	-	7704-34-9
Si	-	0.5	-	7440-21-3
Cr	0.8	1.2	-	7440-47-3
Mo	0.25	0.4	-	7439-98-7

3.2.2.3. Conformado en caliente y tratamiento térmico (Tabla 3-7).

Tabla 3-7 - Conformado en caliente y tratamiento térmico [22]

Proceso	Temperaturas
Conformado en caliente:	1050 - 1250°C
Normalizado:	850 - 880°C/Luft
Temple:	500 - 700°C/Luft

3.2.2.4. Propiedades mecánicas del acero 32MnCrMo6-4-3 (Tabla 3-8).

Tabla 3-8 - Propiedades mecánicas del acero 32MnCrMo6-4-3 [22]

Propiedades del Componente	Estado: forjado y templado al aire libre - Diámetro de la pieza: Ø 50 mm
Fuerza elástica Rp0.2[N/mm <sup>2</sup> ]	min. 800
Resistencia a la tracción Rm[N/mm <sup>2</sup> ]	min. 1150
Alargamiento de rotura A5[%]	min. 12
Reducción de la superficie Z[%].	min. 38
Energía de impacto de barra entallada ISO-V[J] a temperatura ambiente	min. 12
Dureza	min. 330 HB max. 250 HB



Figura 3-45 - Cucharon de excavadora 336D2 L con 04 uñas de Acero 32MnCrMo6-4-3 [1]

### 3.2.2.5. Composición química, propiedades mecánicas y aplicaciones de material de aporte

#### 3.2.2.5.1. Electrodo de Recubrimiento Protector – Citodur 1000

Tabla 3-9 - Clasificación de electrodo Citodur 1000 [10]

Clasificación AWS A5.13 / ASME SFA-5.13	DIN 8555 E10
EFeCr-A8	UM 60 CGRZ

Tabla 3-10 - Análisis Químico Citodur 1000 [10]

C	Mn	Si	P	S	Mo	Ni	Cr	Cu	Otros
4.00	1.10	0.60	máx. 0.020	máx. 0.020	-	-	36.00	-	-

Tabla 3-11 - Propiedades Mecánicas Citodur 1000 [10]

Tratamiento Térmico	Resistencia a la Tracción [MPa (psi)]	Límite de Fluencia [MPa (psi)]	Elongación en 2" [%]	Energía Absorbida ISO-V [°C (°F)] [J (Ft-Lbf)]	Dureza
Sin tratamiento	-	-	-	-	58 - 62 HRC

### 3.2.2.5.2. Electrodo de Recubrimiento Protector – Citomangan

Tabla 3-12 - Clasificación de electrodo Citomangan [10]

Clasificación AWS A5.13 / ASME SFA-5.13	DIN 8555 E10
EFe Mn-B	E 7 - UM - 200 KP

Tabla 3-13 - Análisis Químico Citomangan [10]

C	Mn	Si	P	S	Mo	Ni	Cr	Cu	Otros
1.00	12.00 – 14.00	0.60	máx. 0.020	máx. 0.020	-	-	-	-	-

Tabla 3-14 - Propiedades Mecánicas Citomangan [10]

Tratamiento Térmico	Resistencia a la Tracción [MPa (psi)]	Límite de Fluencia [MPa (psi)]	Elongación en 2" [%]	Energía Absorbida ISO-V [°C (°F)] [J (Ft-Lbf)]	Dureza
Sin tratamiento Auto endurecido	-	-	-	-	19 - 28 HRC 50 - 60 HRC

### 3.2.2.5.3. Electrodo de Recubrimiento Protector – Exadur – 43

Tabla 3-15 - Clasificación de electrodo Exadur – 43 [10]

Clasificación AWS A5.13 / ASME SFA-5.13	DIN 8555 E10
E Fe Cr-A2	E 10-UM-65-GRZ

Tabla 3-16 - Análisis Químico Exadur – 43 [10]

C	Mn	Si	P	S	Mo	Ni	Cr	Cu	Otros
3.40	1.10	0.60	máx. 0.020	máx. 0.020	-	-	22.00	-	8%Nb

Tabla 3-17 - Propiedades Mecánicas Exadur – 43 [10]

Tratamiento Térmico	Resistencia a la Tracción [MPa (psi)]	Límite de Fluencia [MPa (psi)]	Elongación en 2" [%]	Energía Absorbida ISO-V [°C (°F)] [J (Ft-Lbf)]	Dureza
Sin tratamiento	-	-	-	-	60 - 62 HRC

### 3.2.2.6. Selección de la máquina de soldar

Para el proceso de soldadura se utilizó la máquina de soldar multiproceso Miller XMT 425 SERIES, alimentación trifásica, con salida nominal (con ciclo de trabajo al 100%) de 5 a 425 A a 10 - 38 VCD (Figura 3-46).



Figura 3-46 - Máquina de soldar multiproceso Miller XMT 425 SERIES, alimentación trifásica, de 5 a 425 A a 10 - 38 VCD [1]

Voltage Range in CV Mode	Amperage Range in CC Mode	Rated Output	IP Rating	Amps Input at Rated Output, 50/60 Hz						Max. Open-Circuit Voltage	Dimensions	Net Weight
				230 V	400 V	460 V	575 V	KVA	KW			
10-38 V	5-425 A	275 A at 21 VDC, 100% duty cycle 425 A at 27 VDC, 30% duty cycle	IP23	36.1	20.6	17.8	14.1	14.2	13.6	75 V	H: 432 mm (17 in.) W: 318 mm (12.5 in.) D: 610 mm (24 in.)	36.3 kg (80 lb.) without aux. pwr. 43 kg (94.8 lb.) with aux. pwr.

Figura 3-47 - Especificaciones de Máquina de soldar Miller XMT 425 SERIES [1]



### 3.2.2.7. Procedimiento de Soldadura

#### 3.2.2.7.1. Especificación del procedimiento de soldadura - Ensayo de desgaste (AWS D1.1/D1.1M:2008)

Nombre de la Compañía	"ANÁLISIS MEDIANTE ELEMENTOS DISCRETOS (MED) Y EVALUACIÓN EXPERIMENTAL BAJO LA NORMA ASTM G-65 DEL DESGASTE ABRASIVO EN REVESTIMIENTOS DUROS APLICADOS POR PROCESOS DE SOLDADURA EN UÑAS DE ACERO 32MnCrMo6-4-3 DE UNA EXCAVADORA HIDRÁULICA CAT 336D2 L"	
Proceso de Soldadura	SMAW	
Material Base	Especificación del material:	32MnCrMo6-4-3
	Espesor:	0.5 in
Material de Aporte	Especificación AWS:	Clasificación AWS A5.13 / ASME SFA-5.13
	Clasificación AWS:	EFeCr-A8
	Especificación DIN:	DIN 8555 E10
	Clasificación DIN:	UM 60 CGRZ
	Diámetro y longitud del electrodo:	∅ 4 mm (5/32 in) x 35 cm
Precalentamiento	T° Pre calentamiento:	100 a 120 °C
	T° Interpase:	150 °C - 350 °C. Las repeticiones sin pre calentamiento
Posición	Plana 1G	
Características Eléctricas	Amperaje:	150 - 160 A
	CCEP (corriente continua con electrodo positivo)	
Técnica	Arrastre sin oscilación	
	Pasadas múltiples por cara, de 1 y 3 capas. Las repeticiones de 2 - 3 capas	
	La limpieza entre pasadas se hará con escobilla metálica y picota. Si es necesario se utilizará esmeril.	
Tratamiento Térmico Post Soldadura	Enfriamiento lento utilizando cal industrial que cubrirá la probeta.	

Tabla 3-18 - Especificación del procedimiento de soldadura (Desgaste - Citodur 1000) [1]

PROCEDIMIENTO DE SOLDADURA								
Pase o Capa	Proceso	Metal de Aporte		Corriente		Voltaje (V)	Velocidad de avance Clase (cm/min)	Detalles de la junta
		Clase	Diámetro (in)	Tipo y polaridad	Amperaje (A)			
1	SMAW	EFeCr-A8	5/32	CCEP	150 - 160 A	20 - 30	25-30 cm/min	
2	SMAW	EFeCr-A8	5/32	CCEP	150 - 160 A	20 - 30	25-30 cm/min	
3	SMAW	EFeCr-A8	5/32	CCEP	150 - 160 A	20 - 30	25-30 cm/min	

Nombre de la Compañía	"ANÁLISIS MEDIANTE ELEMENTOS DISCRETOS (MED) Y EVALUACIÓN EXPERIMENTAL BAJO LA NORMA ASTM G-65 DEL DESGASTE ABRASIVO EN REVESTIMIENTOS DUROS APLICADOS POR PROCESOS DE SOLDADURA EN UÑAS DE ACERO 32MnCrMo6-4-3 DE UNA EXCAVADORA HIDRÁULICA CAT 336D2 L"	
Proceso de Soldadura	SMAW	
Material Base	Especificación del material:	32MnCrMo6-4-3
	Espesor:	0.5 in
Material de Aporte	Especificación AWS:	Clasificación AWS A5.13 / ASME SFA-5.13
	Clasificación AWS:	EFe Mn-B
	Especificación DIN:	DIN 8555 E10
	Clasificación DIN:	E 7 - UM - 200 KP
	Diámetro y longitud del electrodo:	∅ 5 mm (3/16 in) x 35 cm
Precalentamiento	T° Pre calentamiento:	100 a 120 °C
	T° Interfase:	150 °C - 350 °C. Las repeticiones sin pre calentamiento
Posición	Plana 1G	
Características Eléctricas	Amperaje:	170 - 220 A
	CCEP (corriente continua con electrodo positivo)	
Técnica	Arrastre sin oscilación	
	Pasadas múltiples por cara, de 1 y 3 capas. Las repeticiones de 2 - 3 capas	
	La limpieza entre pasadas se hará con escobilla metálica y picota. Si es necesario se utilizará esmeril.	
Tratamiento Térmico Post Soldadura	Enfriamiento lento utilizando cal industrial que cubrirá la probeta.	

Tabla 3-19 - Especificación del procedimiento de soldadura (Desgaste -Citomangan) [1]

PROCEDIMIENTO DE SOLDADURA								
Pase o Capa	Proceso	Metal de Aporte		Corriente		Voltaje (V)	Velocidad de avance Clase (cm/min)	Detalles de la junta
		Clase	Diámetro (in)	Tipo y polaridad	Amperaje (A)			
1	SMAW	EFe Mn-B	3/16	CCEP	170 - 220 A	20 - 30	25-30 cm/min	
2	SMAW	EFe Mn-B	3/16	CCEP	170 - 220 A	20 - 30	25-30 cm/min	
3	SMAW	EFe Mn-B	3/16	CCEP	170 - 220 A	20 - 30	25-30 cm/min	

Nombre de la Compañía	"ANÁLISIS MEDIANTE ELEMENTOS DISCRETOS (MED) Y EVALUACIÓN EXPERIMENTAL BAJO LA NORMA ASTM G-65 DEL DESGASTE ABRASIVO EN REVESTIMIENTOS DUROS APLICADOS POR PROCESOS DE SOLDADURA EN UÑAS DE ACERO 32MnCrMo6-4-3 DE UNA EXCAVADORA HIDRÁULICA CAT 336D2 L"	
Proceso de Soldadura	SMAW	
Material Base	Especificación del material:	32MnCrMo6-4-3
	Espesor:	0.5 in
Material de Aporte	Especificación AWS:	Clasificación AWS A5.13 / ASME SFA-5.13
	Clasificación AWS:	E Fe Cr-A2
	Especificación DIN:	DIN 8555 E10
	Clasificación DIN :	E 10-UM-65-GRZ
Precalentamiento	T° Precalentamiento:	100 a 120 °C
	T° Interpase:	150 °C - 350 °C. Las repeticiones sin precalentamiento
Posición	Plana 1G	
Características Eléctricas	Amperaje:	90 - 130 A
	CCEP (corriente continua con electrodo positivo)	
Técnica	Arrastre sin oscilación	
	Pasadas múltiples por cara, de 1 y 3 capas. Las repeticiones de 2 - 3 capas	
	La limpieza entre pasadas se hará con escobilla metálica y picota. Si es necesario se utilizará esmeril.	
Tratamiento Térmico Post Soldadura	Enfriamiento lento utilizando cal industrial que cubrirá la probeta.	

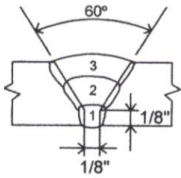
Tabla 3-20 - Especificación del procedimiento de soldadura (Desgaste - Exadur 43) [1]

PROCEDIMIENTO DE SOLDADURA								
Pase o Capa	Proceso	Metal de Aporte		Corriente		Voltaje (V)	Velocidad de avance Clase (cm/min)	Detalles de la junta
		Clase	Diámetro (in)	Tipo y polaridad	Amperaje (A)			
1	SMAW	EFe Cr-A2	1/8	CCEP	90 - 130 A	20 - 30	25-30 cm/min	
2	SMAW	EFe Cr-A2	1/8	CCEP	90 - 130 A	20 - 30	25-30 cm/min	
3	SMAW	EFe Cr-A2	1/8	CCEP	90 - 130 A	20 - 30	25-30 cm/min	

3.2.2.7.2. Especificación del procedimiento de soldadura – Ensayo de tracción (AWS  
D1.1/D1.1M:2008)

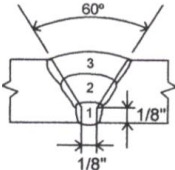
Nombre de la Compañía	“ANÁLISIS MEDIANTE ELEMENTOS DISCRETOS (MED) Y EVALUACIÓN EXPERIMENTAL BAJO LA NORMA ASTM G-65 DEL DESGASTE ABRASIVO EN REVESTIMIENTOS DUROS APLICADOS POR PROCESOS DE SOLDADURA EN UÑAS DE ACERO 32MnCrMo6-4-3 DE UNA EXCAVADORA HIDRÁULICA CAT 336D2 L”	
Proceso de Soldadura	SMAW	
Tipo	Manual	
Diseño de Unión	Tipo de Unión	A tope
	Tipo de Soldadura	Ranura en V
	Abertura de Raíz	3.2 mm
	Ángulo de Ranura	60°
	Soporte	No
	Limpieza de Raíz	Si
Material Base	Especificación del material:	32MnCrMo6-4-3
	Espesor:	25.4 mm
Material de Aporte	Especificación AWS:	Clasificación AWS A5.13 / ASME SFA-5.13
	Clasificación AWS:	EFeCr-A8
	Especificación DIN:	DIN 8555 E10
	Clasificación DIN:	UM 60 CGRZ
	Diámetro y longitud del electrodo:	Ø 4 mm (5/32 in) x 35 cm
Pre calentamiento	T° Pre calentamiento:	100 a 120 °C
	T° Interpase:	150 °C - 350 °C. Las repeticiones sin pre calentamiento
Posición	Plana 1G	
Características Eléctricas	Amperaje:	150 - 160 A
	CCEP (corriente continua con electrodo positivo)	
Técnica	Arrastre con oscilación	
	Pasadas múltiples, de 1 y 3 capas. Las repeticiones de 2 - 3 capas	
	La limpieza entre pasadas se hará con escobilla metálica y picota. Si es necesario se utilizará esmeril.	
Tratamiento Térmico Post Soldadura	Enfriamiento lento utilizando cal industrial que cubrirá la probeta.	

Tabla 3-21 - Especificación del procedimiento de soldadura (Tracción - Citodur 1000) [1]

PROCEDIMIENTO DE SOLDADURA								
Pase o Capa	Proceso	Metal de Aporte		Corriente		Voltaje (V)	Velocidad de avance Clase (cm/min)	Detalles de la junta
		Clase	Diámetro (in)	Tipo y polaridad	Amperaje (A)			
1	SMAW	EFeCr-A8	5/32	CCEP	150 - 160 A	20 - 30	25-30 cm/min	
2	SMAW	EFeCr-A8	5/32	CCEP	150 - 160 A	20 - 30	25-30 cm/min	
3	SMAW	EFeCr-A8	5/32	CCEP	150 - 160 A	20 - 30	25-30 cm/min	

Nombre de la Compañía	"ANÁLISIS MEDIANTE ELEMENTOS DISCRETOS (MED) Y EVALUACIÓN EXPERIMENTAL BAJO LA NORMA ASTM G-65 DEL DESGASTE ABRASIVO EN REVESTIMIENTOS DUROS APLICADOS POR PROCESOS DE SOLDADURA EN UÑAS DE ACERO 32MnCrMo6-4-3 DE UNA EXCAVADORA HIDRÁULICA CAT 336D2 L"	
Proceso de Soldadura	SMAW	
Tipo	Manual	
Diseño de Unión	Tipo de Unión	A tope
	Tipo de Soldadura	Ranura en V
	Abertura de Raíz	3.2 mm
	Ángulo de Ranura	60°
	Soporte	No
	Limpieza de Raíz	Si      Esmeril
Material Base	Especificación del material:	32MnCrMo6-4-3
	Espesor:	25.4 mm
Material de Aporte	Especificación AWS:	Clasificación AWS A5.13 / ASME SFA-5.13
	Clasificación AWS:	EFe Mn-B
	Especificación DIN:	DIN 8555 E10
	Clasificación DIN:	E 7 - UM - 200 KP
	Diámetro y longitud del electrodo:	∅ 5 mm (3/16 in) x 35 cm
Precalentamiento	T° Pre calentamiento:	100 a 120 °C
	T° Interfase:	150 °C - 350 °C. Las repeticiones sin pre calentamiento
Posición	Plana 1G	
Características Eléctricas	Amperaje:	170 - 220 A
	CCEP (corriente continua con electrodo positivo)	
Técnica	Arrastre con oscilación	
	Pasadas múltiples, de 1 y 3 capas. Las repeticiones de 2 - 3 capas	
	La limpieza entre pasadas se hará con escobilla metálica y picota. Si es necesario se utilizará esmeril.	
Tratamiento Térmico Post Soldadura	Enfriamiento lento utilizando cal industrial que cubrirá la probeta.	

Tabla 3-22 - Especificación del procedimiento de soldadura (Tracción - Citomangan) [1]

PROCEDIMIENTO DE SOLDADURA								
Pase o Capa	Proceso	Metal de Aporte		Corriente		Voltaje (V)	Velocidad de avance Clase (cm/min)	Detalles de la junta 
		Clase	Diámetro (in)	Tipo y polaridad	Amperaje (A)			
1	SMAW	EFe Mn-B	3/16	CCEP	170 - 220 A	20 - 30	25-30 cm/min	
2	SMAW	EFe Mn-B	3/16	CCEP	170 - 220 A	20 - 30	25-30 cm/min	
3	SMAW	EFe Mn-B	3/16	CCEP	170 - 220 A	20 - 30	25-30 cm/min	

Nombre de la Compañía	"ANÁLISIS MEDIANTE ELEMENTOS DISCRETOS (MED) Y EVALUACIÓN EXPERIMENTAL BAJO LA NORMA ASTM G-65 DEL DESGASTE ABRASIVO EN REVESTIMIENTOS DUROS APLICADOS POR PROCESOS DE SOLDADURA EN UÑAS DE ACERO 32MnCrMo6-4-3 DE UNA EXCAVADORA HIDRÁULICA CAT 336D2 L"	
Proceso de Soldadura	SMAW	
Tipo	Manual	
Diseño de Unión	Tipo de Unión	A tope
	Tipo de Soldadura	Ranura en V
	Abertura de Raíz	3.2 mm
	Ángulo de Ranura	60°
	Soporte	No
	Limpieza de Raíz	Si
Material Base	Especificación del material:	32MnCrMo6-4-3
	Espesor:	25.4 mm
Material de Aporte	Especificación AWS:	Clasificación AWS A5.13 / ASME SFA-5.13
	Clasificación AWS:	E Fe Cr-A2
	Especificación DIN:	DIN 8555 E10
	Clasificación DIN:	E 10-UM-65-GRZ
	Diámetro y longitud del electrodo:	∅ 3.25 mm (1/8 in) x 35 cm
Precalentamiento	T° Pre calentamiento:	100 a 120 °C
	T° Interfase:	150 °C - 350 °C. Las repeticiones sin pre calentamiento
Posición	Plana 1G	
Características Eléctricas	Amperaje:	90 - 130 A
	CCEP (corriente continua con electrodo positivo)	
Técnica	Arrastre con oscilación	
	Pasadas múltiples, de 1 y 3 capas. Las repeticiones de 2 - 3 capas	
	La limpieza entre pasadas se hará con escobilla metálica y picota. Si es necesario se utilizará esmeril.	
Tratamiento Térmico Post Soldadura	Enfriamiento lento utilizando cal industrial que cubrirá la probeta.	

Tabla 3-23 - Especificación del procedimiento de soldadura (Tracción – Exadur-43) [1]

PROCEDIMIENTO DE SOLDADURA								
Pase o Capa	Proceso	Metal de Aporte		Corriente		Voltaje (V)	Velocidad de avance Clase (cm/min)	
		Clase	Diámetro (in)	Tipo y polaridad	Amperaje (A)			
1	SMAW	E Fe Cr-A2	1/8	CCEP	90 - 130 A	20 - 30	25-30 cm/min	
2	SMAW	E Fe Cr-A2	1/8	CCEP	90 - 130 A	20 - 30	25-30 cm/min	
3	SMAW	E Fe Cr-A2	1/8	CCEP	90 - 130 A	20 - 30	25-30 cm/min	

### 3.2.2.7.3. Especificación del procedimiento de soldadura – Ensayo de tracción (AWS D1.1/D1.1M:2008)

Para la aplicación del recubrimiento, se seleccionó el mínimo y el máximo amperaje recomendado en la ficha técnica del fabricante. Para conocer la influencia de este parámetro en el depósito final del recubrimiento, que definirá la microestructura, el valor de dureza y el comportamiento de resistencia al desgaste abrasivo.

El mínimo y máximo valor de amperaje para la aplicación de recubrimiento y la unión de tope del electrodo Citodur 1000 fue de 150 a 160 A para un diámetro de 5/32 (Tabla 3-24).

Tabla 3-24 - Parámetro de soldeo Recomendado – Citodur 1000 [10]

Para corriente alterna(AC) o continua (DC): Electrodo al polo positivo DCEP							
Diámetro	[mm]	1,60	2,50	3,25	4,00	5,00	6,30
	[pulgadas]	1/16	3/32	1/8	5/32	3/16	1/4
Amperaje mínimo	-	-	-	120	150	180	-
Amperaje máximo	-	-	-	140	160	230	-



Figura 3-48 - Máquina de soldar multiproceso Miller XMT 425 SERIES – 160 A [1]

El mínimo y máximo valor de amperaje para la aplicación de recubrimiento y la unión de tope del electrodo Citomangan fue de 170 a 220 A para un diámetro de 3/16 (Tabla 3-25).

Tabla 3-25 - Parámetro de soldeo Recomendado – Citomangan [10]

Para corriente alterna(AC) o continua (DC): Electrodo al polo positivo DCEP							
Diámetro	[mm]	1,60	2,50	3,25	4,00	5,00	6,30
	[pulgadas]	1/16	3/32	1/8	5/32	3/16	1/4
Amperaje mínimo		-	-	110	140	170	-
Amperaje máximo		-	-	135	175	220	-





Figura 3-49 - Máquina de soldar multiproceso Miller XMT 425 SERIES – 220 A [1]

El mínimo y máximo valor de amperaje para la aplicación de recubrimiento y la unión de tope del electrodo Exadur 43 fue de 90 a 130 A para un diámetro de 1/8 (Tabla 3-26).

Tabla 3-26 - Parámetro de soldeo Recomendado – Exadur 43 [10]

Para corriente alterna(AC) o continua (DC): Electrodo al polo positivo DCEP							
Diámetro	[mm]	1,60	2,50	3,25	4,00	5,00	6,30
	[pulgadas]	1/16	3/32	1/8	5/32	3/16	1/4
Amperaje mínimo		-	-	90	120	160	-
Amperaje máximo		-	-	130	180	220	-



Figura 3-50 - Máquina de soldar multiproceso Miller XMT 425 SERIES – 122 A [1]

#### 3.2.2.7.4. Especificación del procedimiento de soldadura – Ensayo de tracción (AWS D1.1/D1.1M:2008)

La recomendación del fabricante es la aplicación de depósitos de soldadura (recubrimiento y unión) son 1 a 3 capas como máximo.

#### 3.2.2.7.5. Temperatura de precalentamiento y temperatura de interpase

Consiste en llevar la pieza a una temperatura determinada, antes de iniciar la soldadura propiamente dicha. Se consiguen principalmente dos efectos, que posibilitan la ejecución de una buena soldadura:

Se evita que las zonas frías absorban violentamente el calor de la zona soldada, enfriándola rápidamente y, en consecuencia, produciendo zonas duras y quebradizas.

Al estar caliente toda la plancha en el momento de terminarse la soldadura, el enfriamiento de toda la pieza es uniforme en todo el conjunto y se produce en forma lenta, ya que no existe absorción de calor de la zona soldada por las zonas frías del resto de la pieza.

La necesidad de precalentamiento es determinada por la composición química del material base y el espesor del material a Soldar.

Para el correcto monitoreo la temperatura de precalentamiento se utilizará un pirómetro o termómetro infrarrojo digital con láser marca SKF modelo TKTL 10, con gama de temperaturas desde  $-60$  a  $+625$  °C, con una precisión de rango total de  $0$  a  $625$  °C  $\pm 2\%$ .

Para el presente estudio se ha determinado dos temperaturas de precalentamiento con valores mínimo y máximo:  $100$  y  $120$  °C respectivamente. Una vez aplicado el cordón se cubrirá con cal Industrial para disminuir la velocidad de enfriamiento. Para reducir el aporte de calor, se realizará entre pases de cordones de soldadura a  $130$  °C.

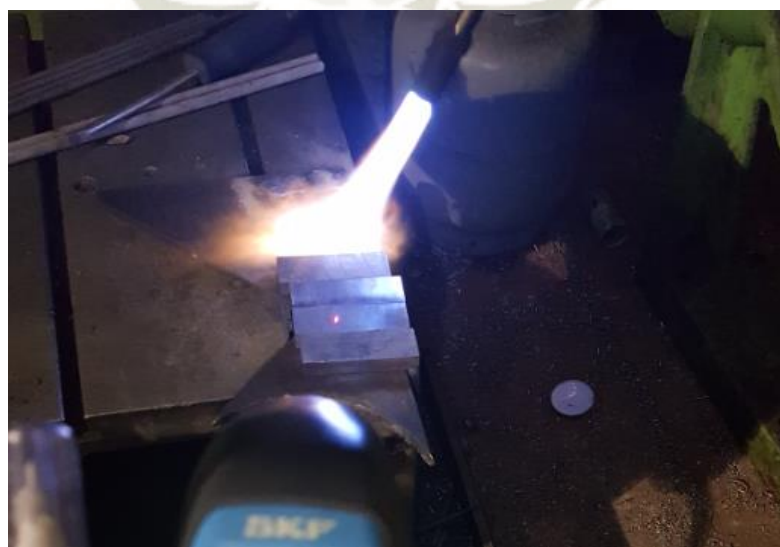


Figura 3-51 - Precalentamiento del metal base (Desgaste), utilizando un equipo de Oxiacetileno [1]



Figura 3-52 - Monitoreo del precalentamiento del metal base (Desgaste), utilizando pirómetro SKF modelo TKTL 10 [1]



Figura 3-53 - Precalentamiento del metal base (Tracción), utilizando un equipo de Oxiacetileno [1]



Figura 3-54 - Monitoreo del precalentamiento del metal base (Tracción), utilizando pirómetro SKF modelo TKTL 10 [1]



Figura 3-55 - Aplicación de soldadura de Recargue sobre el material base (Desgaste) [1]



Figura 3-56 - Monitoreo de la soldadura de Recargue sobre el material base (Desgaste), utilizando pirómetro SKF modelo TKTL 10 [1]



Figura 3-57 - Aplicación de la soldadura de Recargue sobre el material base (Tracción) [1]



Figura 3-58 - Monitoreo de la soldadura de Recargue sobre el material base (Tracción), utilizando pirómetro SKF modelo TKTL 10 [1]



Figura 3-59 - Probetas de Desgaste con soldadura de Recargue [1]



Figura 3-60 - Probeta de Tracción unido con soldadura de Recargue [1]

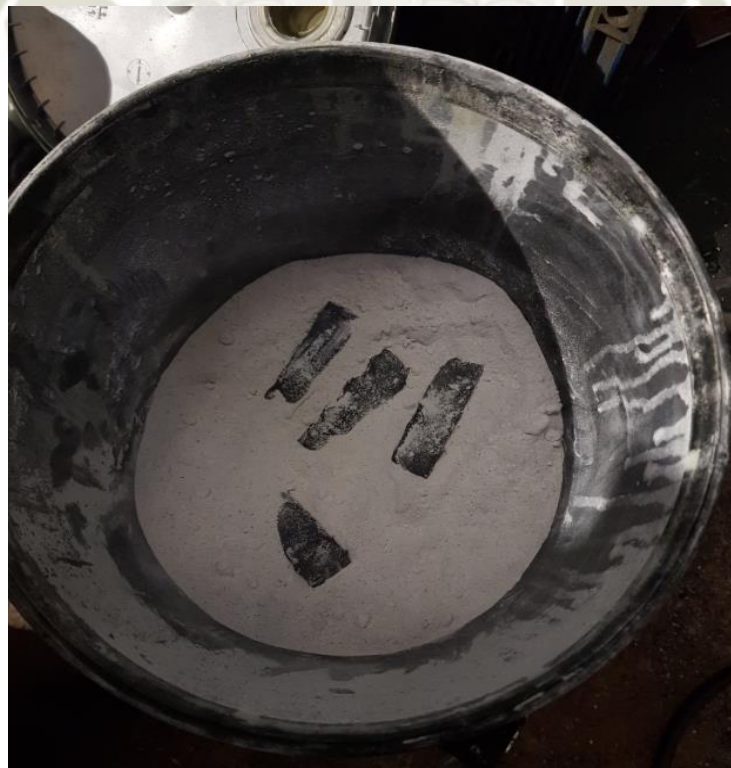


Figura 3-61 - Probeta de desgaste con recargue en recipiente con cal industrial [1]





Figura 3-62 - Probetas de tracción con recargue en recipiente con cal industrial [1]

### 3.2.3. Análisis Químico - Composición Química

Debido a que no se conoce con exactitud la composición química del material base y la composición química del recargue de soldadura en el metal base, se mandó a realizar un análisis químico de 04 probetas (Material base, P1 – E43, P2 – CTMG, P3 – C1000), en la empresa voestalpine High Performance Metals del Perú S.A.

El método utilizado fue espectrometría de emisión óptica (arco/chispa) con un equipo alemán SPECTRO.

La superficie de análisis fue acondicionada en cada uno de los Análisis de composición química.

### 3.2.3.1. Material base



Figura 3-63 - Uña de acero Excavadora hidráulica Cat 336 D2 L [1]

### 3.2.3.2. Recubrimiento - Exadur - 43



Figura 3-64 - Probeta con soldadura de recargue Exadur 43 (P1) [1]

### 3.2.3.3. Recubrimiento - Citomangan

voestalpine High Performance Metals del Perú S.A.



REGISTRO FOTOGRÁFICO



**CÓDIGO P-2 CTMG**  
**MATERIAL DE APORTE (SOLDADURA).**

Figura 3-65 - Probeta con soldadura de recargue Citomangan (P2) [1]

### 3.2.3.4. Recubrimiento – Citodur 1000

voestalpine High Performance Metals del Perú S.A.



REGISTRO FOTOGRÁFICO



**CÓDIGO P-3 C-1000.**  
**MATERIAL DE APORTE (SOLDADURA).**

Figura 3-66 - Probeta con soldadura de recargue Citodur 1000 (P3) [1]

### 3.2.4. Análisis Metalográfico

Se preparó las muestras la evaluación metalográfica, según la norma ASTM E3-11 “Standard Practice for Preparation of Metallographic Specimens” que se describe en la siguiente Tabla 3-27. Se dividió en las siguientes etapas:

3.2.4.1.Desbaste grueso: Se trabajó papel lijar al agua, marca ABRALIT:

- Lijar #100
- Lijar #220
- Lijar #400
- Lijar #600

3.2.4.2.Desbaste fino: Se trabajó con papel lijar al agua:

- Lijar #1000, marca ABRALIT
- Lijar #1200, marca ABRALIT
- Lijar #2000, marca ASALITE

3.2.4.3.Pulido fino: En una pulidora de disco con paño de pulido, con pasta de alúmina 0,5 micrones.

Tabla 3-27 - Preparación método 2 para materiales duros  $\geq 45$  (450 HV) [24]

Superficie	Lubricante	Tipo de Abrasivo Tamaño ANSI	Tiempo (s)	Fuerza N(lbf) <sup>A</sup>	Plato RPM <sup>B</sup>	Rotación
Papel/piedra lija plano	Agua	120-320 (P120-400) Polvo SiC/Al <sub>2</sub> O <sub>3</sub>	15 - 45	20-30 (5-8)	200-300 <sup>C</sup>	CO <sup>D</sup>
Disco rígido de lija fina	Lubricante compatible	6-15 $\mu$ m diamante	180 - 300	20-30 (5-8)	100-150	CO
Pulido áspero bajo	Lubricante compatible	3-6 $\mu$ m diamante	120 - 300	20-30 (5-8)	100-150	CO
Pulido final	Lubricante compatible	1 $\mu$ m diamante	60 - 120	10-20 (3-5)	100-150	CO
Gamuza sintética <sup>E</sup>	Agua	0.04 $\mu$ m silice coloidal 0.05 $\mu$ m alumina	30 - 60	10-20 (3-5)	100-150	CONTRA <sup>F</sup>



Figura 3-67 - Desbaste grueso de probetas para ensayo metalográfico [1]



Figura 3-68 - Pulido de probetas para ensayo metalográficos [1]



Figura 3-69 - Probeta con pulido final [1]

#### 3.2.4.4. Reactivo Químico

El Estudio Metalográfico se realizó con un Microscopio Metalúrgico Invertido Óptico, Time Group INC, DX40TV con una resolución 20x/100x.

Los reactivos químicos empleados para revelar la microestructura en las probetas metalográficas fueron preparados según lo especificado en la norma ASTM E 407-07 “Standard Practice for Microetching Metals and Alloys”.

Para revelar la microestructura de las muestras, se usaron los siguientes reactivos que se muestra en la siguiente Tabla 3-28:

Tabla 3-28 - Reactivos utilizados para la metalografía [25]

Reactivo	Composición Química
Nital al 3%	3 mL de HNO <sub>3</sub> y 97 mL de Alcohol
Vilella	1 g Acido Picrico, 5 mL HCL, 100 mL Etanol

El Nital al 3% se utilizó para contrastar los granos de ferrita con los de perlita. Este reactivo revela los límites de grano de la ferrita, que son equiaxiales claros, y oscurece a la perlita. Asimismo, permite revelar la existencia de redes de carburos en los límites de grano. También se puede visualizar la austenita retenida y martensita con el Nital. La Vilella que revela constituyentes como carburos, fase sigma y ferrita delta, además de revelar la estructura de los granos.



Figura 3-70 - Preparación del Reactivo químico [1]



Figura 3-71 - Visualización de las microestructuras con el microscopio Metalúrgico Invertido Óptico, Time Group INC, DX40TV con una resolución 20x/100x [1]

### 3.2.5. Ensayo de dureza

El ensayo de dureza se llevó a cabo empleando un durómetro dureza Rockwell C, marca Time Group INC modelo HRC -150 (Figura 3-75) teniendo en consideración lo establecido en la norma ASTM E18 -15 “Standard Test Methods for Rockwell Hardness of Metallic Materials”

Las probetas que se emplearon para el ensayo son como las que se muestran en la (Figura 3-72). En donde se puede apreciar que cada probeta tiene un corte transversal que está conformado por tres elementos principales: la soldadura o recargue, la zona afectada por el calor (ZAC) y el metal base (DIN 32MnCrMo 6-4-3).

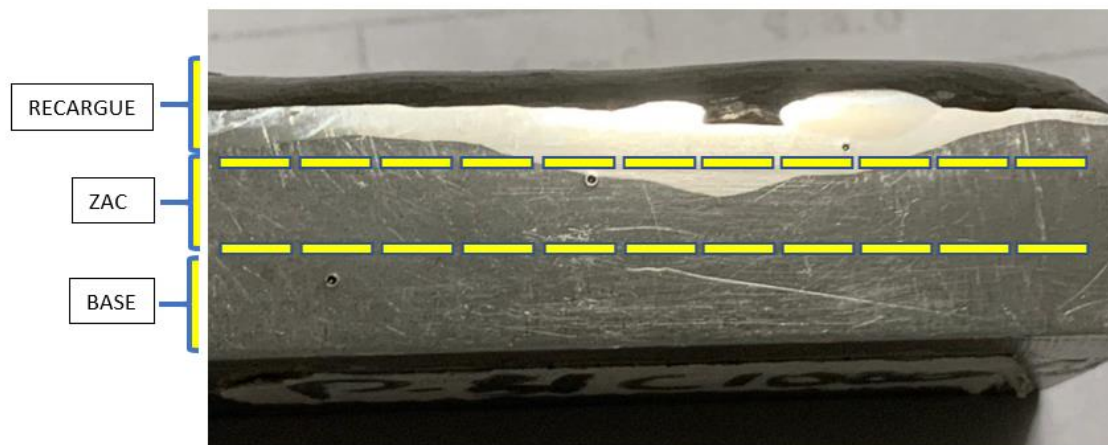


Figura 3-72 - Línea de Barrido de Dureza [1]

Como se puede observar en la figura, se trazó una línea de barrido y se tomó las durezas a lo largo de esta. Siendo el extremo izquierdo la primera medida tomada que corresponde al material Base (DIN 32MnCrMo 6-4-3), luego se tomó en la zona central que corresponde a la zona ZAC y por último se tomó al recargue Duro. Los resultados obtenidos son se muestran en el capítulo 4.3 de esta tesis.



El procedimiento se realizó aplicando una precarga de 10 kgf y luego se le añadió una carga de 140 kgf, dando en total una carga de 150kgf. El tiempo total del ensayo por probeta fue de 10 segundos.



Figura 3-73 - Durómetro dureza Rockwell C, marca Time Group INC modelo HRC -150 [1]

### 3.2.6. Ensayo de Tracción

El ensayo de tensión se llevó a cabo empleando el equipo marca INSTRON modelo 23-100 (Figura 3-75), teniendo en consideración lo establecido en la norma ASTM A370-18 “Standard Test Methods and Definitions for Mechanical Testing of Steel Products”

El primer paso a realizar fue la demarcación de longitud inicial y la toma de medida de diámetro inicial de todas las probetas (Figura 3-74), se hallará también el área de la sección transversal.



Figura 3-74 - Demarcación de longitud inicial [1]

Teniendo como resultado de los valores obtenidos en la siguiente Tabla 3-29:

Tabla 3-29 - Valores obtenidos de las muestras de tracción [1]

Probeta	Díámetro Inicial (mm)	Longitud Inicial (mm)	Área mm <sup>2</sup>
1 Exadur - 43	8.89	36.7	62.07
2 Citomangan	8.86	38.42	61.65
3 C-1000	8.69	37.76	59.31
4 Base	7.95	61.64	49.64

Luego se procede a montar las probetas en la máquina de tensión, esta cuenta con un par de mordazas que permite tener un mejor agarre.

Las muestras se someten a una fuerza a lo largo de su eje longitudinal principal a velocidad constante hasta que se produzca la rotura.

El equipo de tracción cuenta con el software Bluehill® instalado, este permite registrar las fuerzas y los valores de incrementos entre las mordazas (Figura 3-76).



Figura 3-75 - Máquina de tracción INSTRON modelo 23-100 [1]

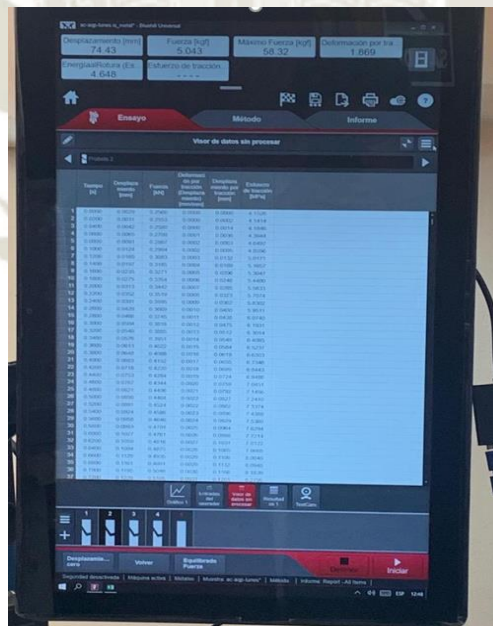


Figura 3-76 - Software Bluehill® [1]

En total se realizaron 04 ensayos de tracción, 03 de unión de soldadura y 01 de material base (Figura 3-77).



Figura 3-77 - Muestras de tracción ensayadas [1]

### 3.2.7. Ensayo de desgaste

El ensayo de Desgaste se llevó a cabo empleando el equipo TRB<sup>3</sup>: Pin-on-disk tribometer marca ANTON PAAR modelo TRB3 (Figura 3-78), teniendo en consideración lo establecido en la norma ASTM G99-17 “Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus”



Figura 3-78 - Tribómetro marca ANTON PAAR modelo TRB3 [1]

El indentador (billa) que se utilizó para nuestros ensayos fue carburo de wolframio (WC) con radio de 6 mm y dureza de 75 HRC (Figura 3-79)

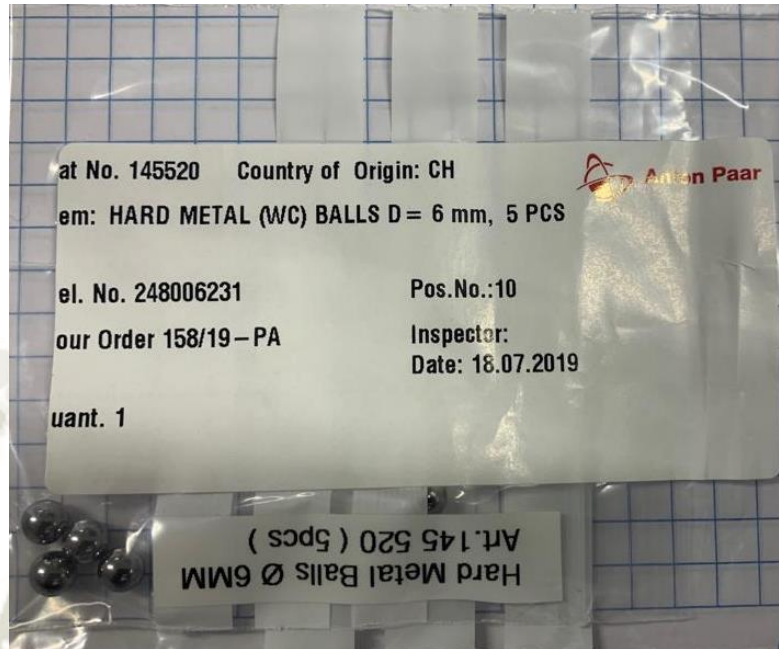


Figura 3-79 - Indentador (billa) carburo de wolframio (WC) con radio de 6 mm y dureza de 75 HRC [1]

Los parámetros de ensayo en todos los ensayos se muestran en la siguiente Tabla 3-30:

Tabla 3-30 - Variables de ensayo de desgaste [1]

Principales Variables del Ensayo	
Variable	Rango
Radio de giro	8 mm
Velocidad Lineal	25 cm/s
Distancia	905 m
Carga	10 N

A continuación, se relacionan los pasos para la ejecución de un ensayo de desgaste con la máquina “pin” sobre disco”:

1. Realización de pulido de superficie de ensayo.

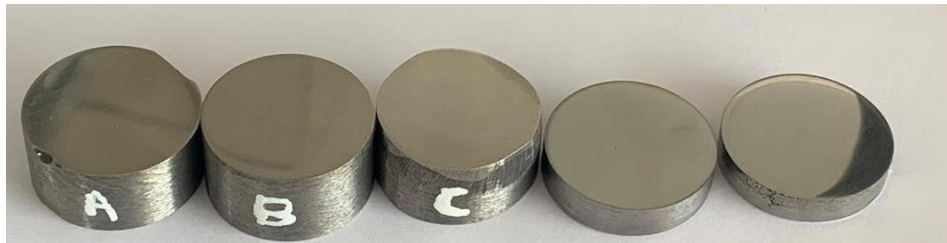


Figura 3-80 - Probetas de ensayo de desgaste pulidas [1]

2. Pesaje en balanza de probetas de desgaste y billas de contacto.



Figura 3-81 - Pesaje en balanza de probetas de desgaste [1]



Figura 3-82 - Pesaje en balanza de billas de contacto [1]

3. Montaje de la probeta de desgaste en el porta-muestras del equipo para el ensayo de desgaste.

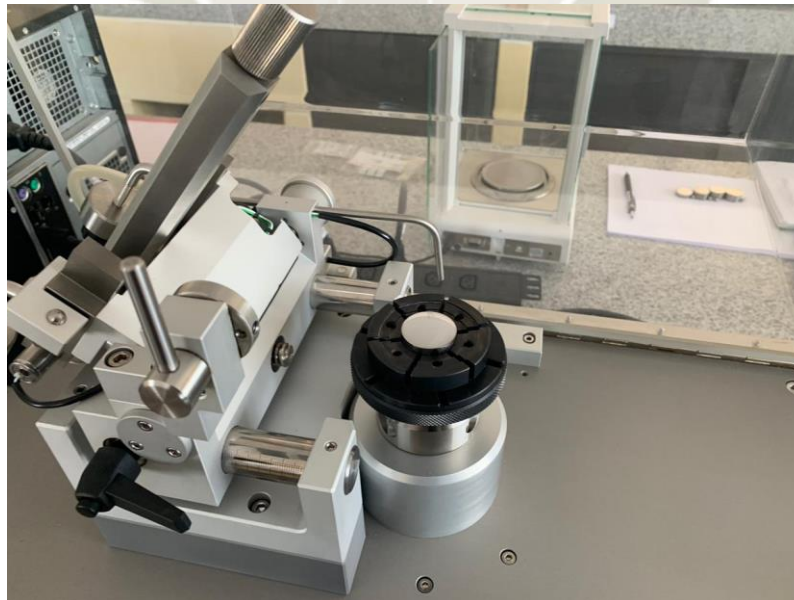


Figura 3-83 - Montaje de la probeta de desgaste en el porta-muestra del tribómetro [1]

4. Selección del radio desde el centro del disco hasta el apoyo de la probeta de ensayo, distancia del ensayo, fuerza de aplicación y velocidad lineal.

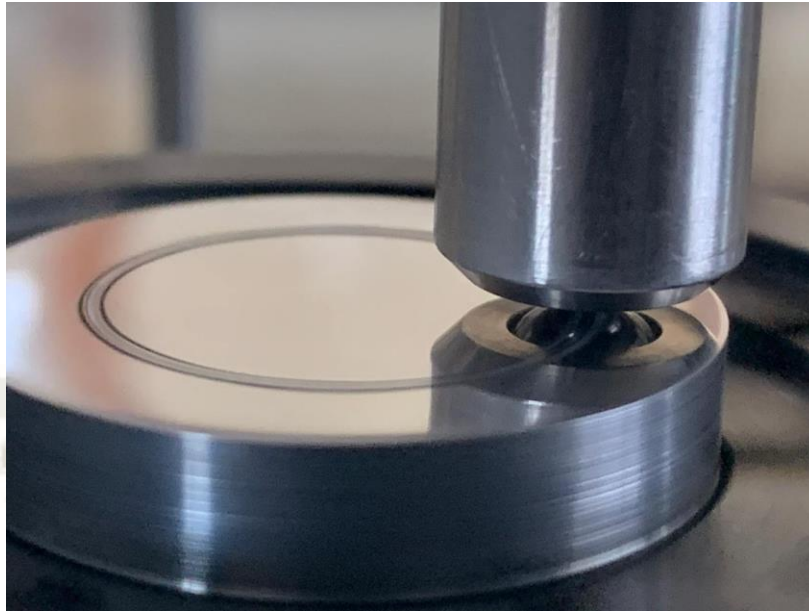


Figura 3-84 - Ensayo de desgaste ASTM G-99 [1]

5. Realización del ensayo de desgaste, durante el tiempo calculado de la distancia total.

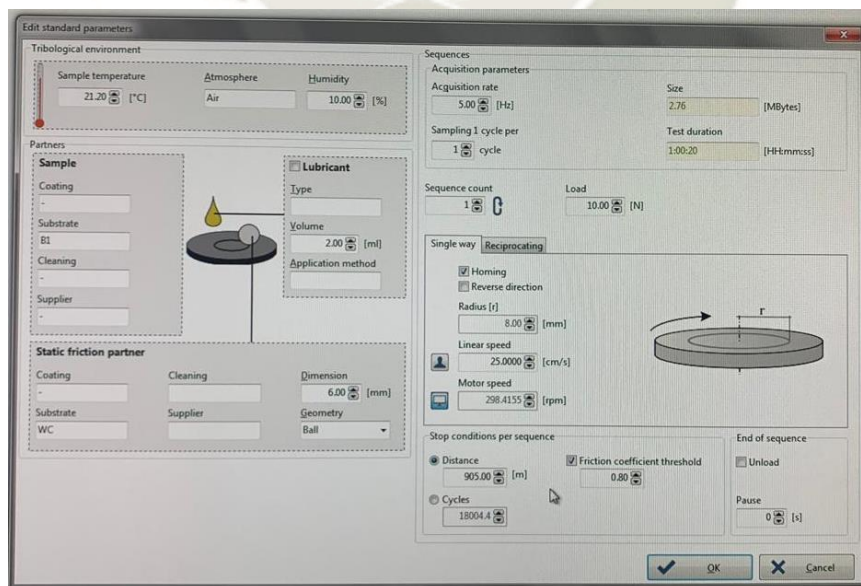


Figura 3-85 - Parámetros de ensayo de desgaste ASTM G-99 [1]



6. Extracción la probeta del porta-muestras del equipo.



Figura 3-86 - Probeta de desgaste ensayada [1]

7. Pesaje en una balanza Balanza marca Mettler Toledo , Modelo – ML-T de las probetas de desgaste y billas ensayadas.



Figura 3-87 - Pesaje en balanza de probetas de desgaste ensayadas [1]



Figura 3-88 - Pesaje en balanza de billas de contacto ensayadas [1]

8. Medición del Wear Track y el diámetro de desgaste de la billa en un microscopio compuesto de binoculares, Motic, BA310POL con resolución 4x/60x

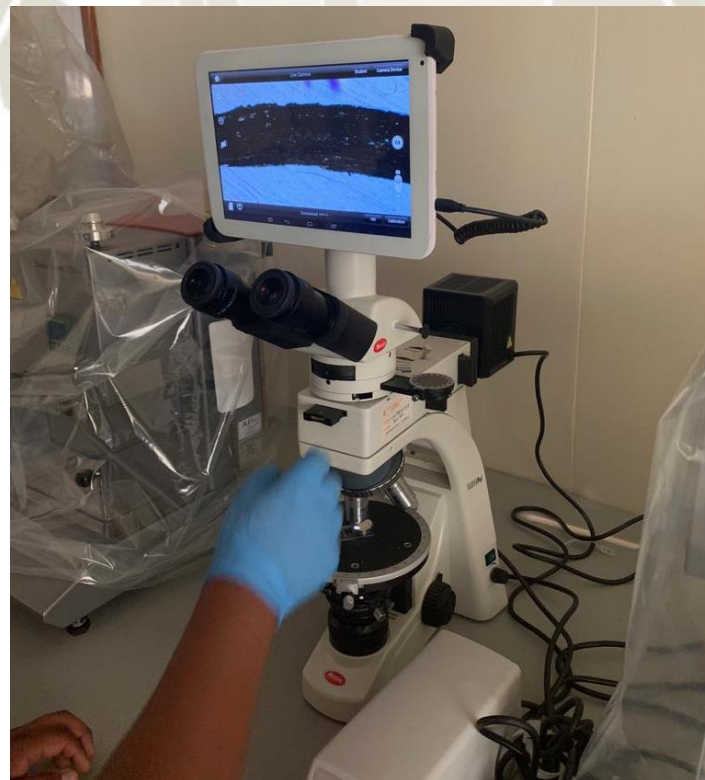


Figura 3-89 - Medición de Wear Track de probeta de desgaste ensayada [1]



# CAPÍTULO IV

## 4. RESULTADOS Y DISCUSIÓN

### 4.1. Análisis de composición química

Los resultados de composición química del material Base y Recargues fueron dadas por la empresa voestalpine High Performance Metals del Perú S.A en los siguientes informes Técnicos: CERT-DCM-2018-086 – BASE, CERT-DCM-2018-169-P1 (E-43), CERT-DCM-2018-169-P2 (CTMG), CERT-DCM-2018-169-P3 (C-1000).

#### 4.1.1. CERT-DCM-2018-086 – Material BASE

Acero de mediano carbono y baja aleación (Manganeso – Cromo – Molibdeno), similar químicamente con la designación DIN 32MnCrMo 6-4-3 (W<sub>Nr</sub>° 1.7910), los elementos químicos y la cantidad en % se observa en la siguiente Figura 4-1.

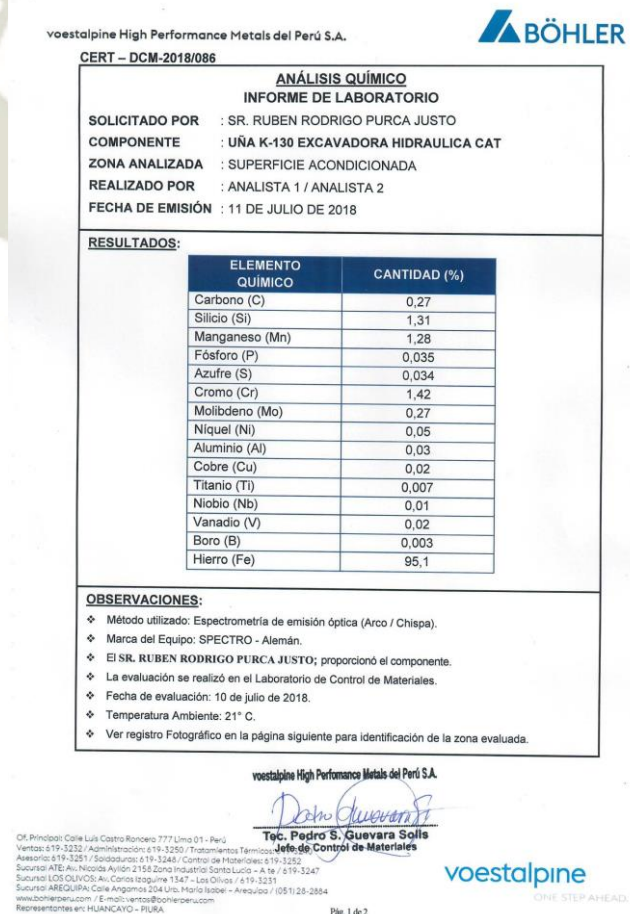
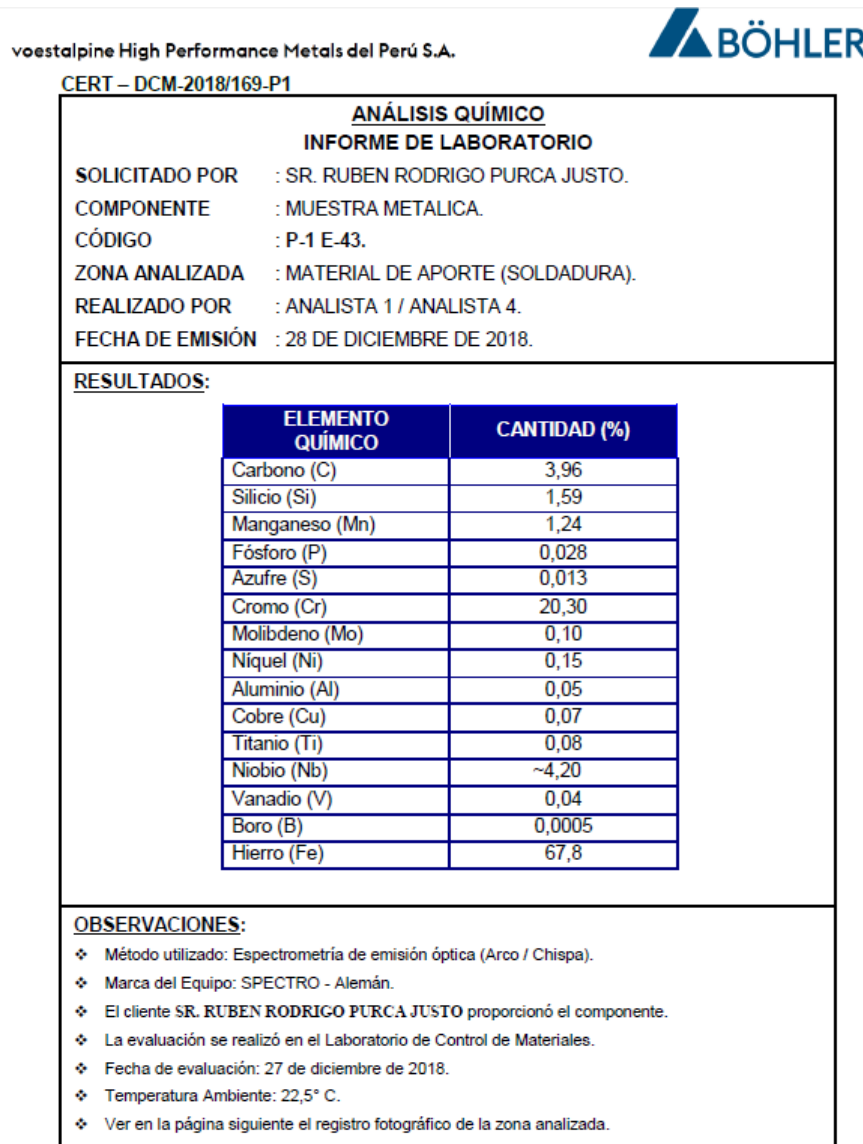


Figura 4-1 - Composición química del material Base (CERT-DCM-2018-086) [1]

4.1.2. CERT-DCM-2018-169-P1 (E-43)

Material de alto carbono y alta aleación (Cromo – Niobio), similar químicamente con la designación EXADUR 43, los elementos químicos y la cantidad en % se observa en la siguiente Figura 4-2.



Of. Principal: Calle Luis Castro Roncero 777 Lima 01 - Perú  
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 Sucursal LOS OLIVOS: Av. Carlos Izaguirre 1347 - Los Olivos / 619-3231  
 Sucursal AREQUIPA: Calle Angamos 204 Urb. María Isabel - Arequipa / (051)28-2884  
 www.bohlerperu.com / E-mail: ventas@bohlerperu.com  
 Representantes en: HUANCAYO - PIURA

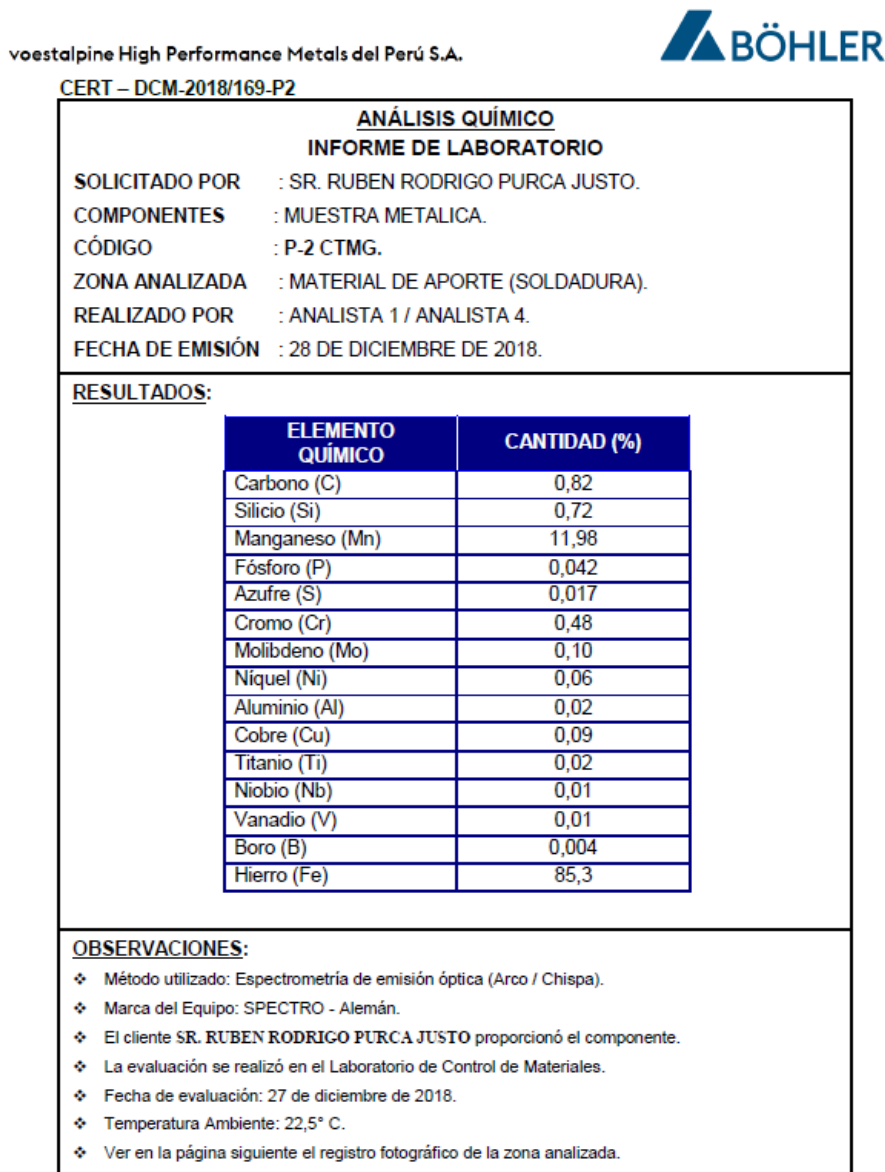
  
ONE STEP AHEAD.

Fig. 1 de 2

Figura 4-2 - Composición química del recargue duro Exadur 43 sobre el material base (CERT-DCM-2018-169-P1) [1]

4.1.3. CERT-DCM-2018-169-P2 (CITOMANGAN)

Material de alto carbono y alta aleación (Manganeso), similar químicamente con la designación CITOMANGAN, los elementos químicos y la cantidad en % se observa en la siguiente Figura 4-3.



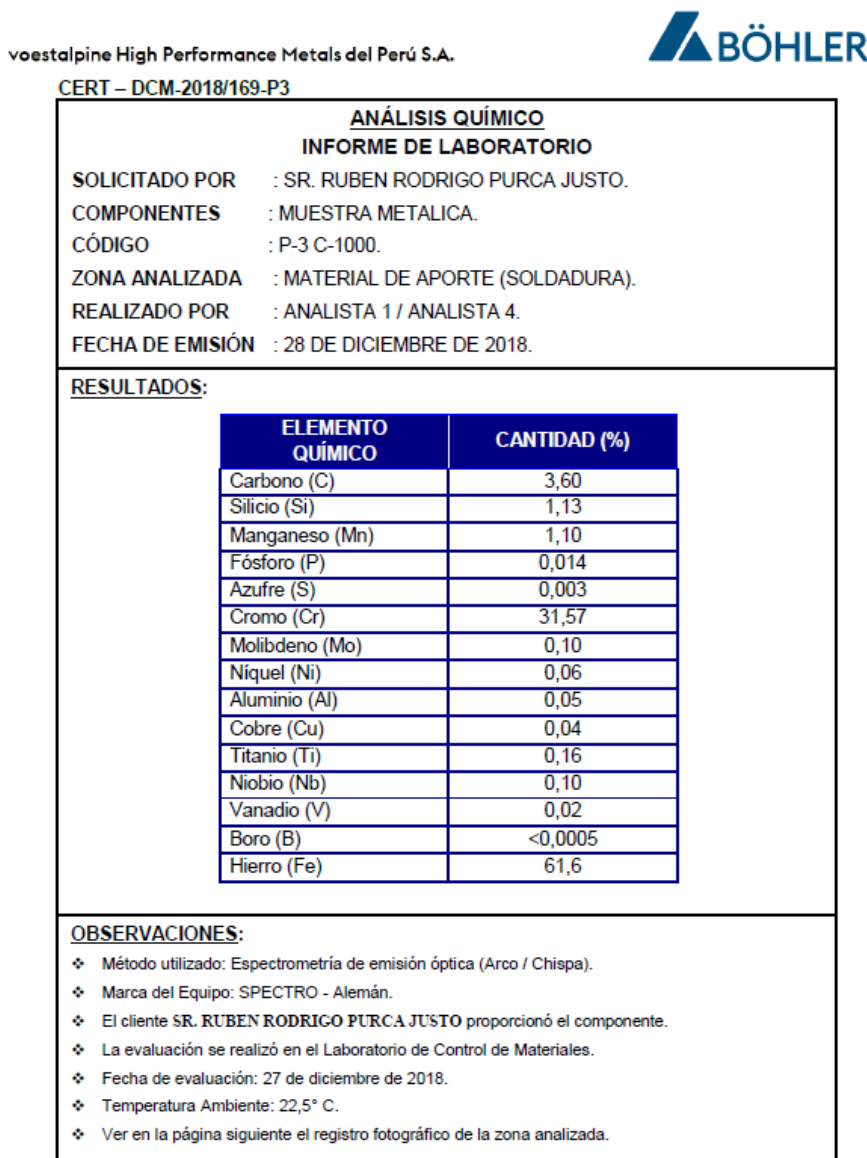
Of. Principal: Calle Luis Castro Roncero 777 Lima 01 - Perú  
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 Asesoría: 619-3251 / Soldadores: 619-3248 / Control de Materiales: 619-3252  
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Figura 4-3 - Composición química del recargue duro (CITOMANGAN) sobre el material base (CERT-DCM-2018-169-P2) [1]

4.1.4. CERT-DCM-2018-169-P3 (C-1000)

Material de alto carbono y alta aleación (Cromo), similar químicamente con la designación CITODUR 1000, los elementos químicos y la cantidad en % se observa en la siguiente Figura 4-4.



Of. Principal: Calle Luis Castro Rencera 777 Lima 01 - Perú  
 Ventas: 619-3232 / Administración: 619-3220 / Tratamientos Térmicos: 619-3240  
 Asesoría: 619-3251 / Soldaduras: 619-3248 / Control de Materiales: 619-3252  
 Sucursal ATE: Av. Nicolás Ayllón 2158 Zona Industrial Santa Lucía - A. to / 619-3247  
 Sucursal LIMA: Av. Corles Inga s/n 1347 - Lino Olivos / 619-3233  
 Sucursal AREQUIPA: Calle Angamos 204 Urb. María Isobel - Arequipa / 051126-2684  
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Figura 4-4 - Composición química del recargue duro (CITODUR 1000) sobre el material base (CERT-DCM-2018-169-P3) [1]

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<b>REPORTE DE COMPOSICIÓN QUÍMICA POR - Espectrometría de emisión óptica (Arco / Chispa)</b>																
Tipo de Estudio	De laboratorio				Ensayo N°	1, 2, 3, 4										
Fecha:	28 DE DICIEMBRE DE 2018				Probeta N°	Base, P-1, P-2, P-3										
Parte Especificada:	Material Base y aporte Revestimientos Duros															
Solicitado Por:	Ruben Purca	Dirección		Asoc. De Viv Los Olmos Arequipa, Peru												
Centro de estudios y análisis:	Laboratorio de Control de Materiales - voestalpine High Performance Metals del Perú S.A															
Realizado Por:	Analista 1/ Analista 2		Revisado Por:		Pedro Guevara Solis											
<b>PARÁMETROS DEL ENSAYO DE ESPECTROMETRÍA</b>																
Tipo de Ensayo:	Espectrometría de emisión óptica (Arco / Chispa).	Equipo utilizado:		SPECTRO - Alemán.												
Temperatura del Ensayo:	22,5° C.	BASE		P1-E43												
		P-2 CTMG		P-3 C-1000												
<b>RESULTADOS</b>																
Probeta	Tipo de Recargue	C	Si	Mn	P	S	Cr	Mo	Ni	Al	Cu	Ti	Nb	V	B	Fe
P-0 BASE	Sin Recargue	0.27	1.31	1.28	0.035	0.034	1.42	0.27	0.05	0.03	0.02	0.007	0.01	0.02	0.003	95.1
P-1 (E-43)	Exadur 43	3.96	1.59	1.24	0.028	0.013	20.3	0.1	0.15	0.05	0.07	0.08	4.2	0.04	0.0005	67.8
P-2 (CTMG)	Citomangan	0.82	0.72	11.98	0.042	0.017	0.48	0.1	0.06	0.02	0.09	0.02	0.01	0.01	0.004	85.3
P-3 (C-1000)	Citodur 1000	3.6	1.13	1.1	0.014	0.003	31.57	0.1	0.06	0.05	0.04	0.16	0.1	0.02	0.0005	61.6



#### 4.2. Análisis metalográfico

A continuación, se detalla los resultados de acuerdo con el código designado en la siguiente

Tabla 4-1.

Tabla 4-1 - Resumen de Resultados de Micrografías [1]

N°	Cód. Muestra	Ensayo/Propiedad	Zona Examinada	Reactivo Usado	Resultados
1	MP-007	Metalográfico de Acero DIN 32MnCrMo6-4-3	BASE	Nital	Micrografías 1
2	MP-008	C1000 Metalográfico de Acero DIN 32MnCrMo6-4-3	BASE	Nital	Micrografías 2
3	MP-009	C1000 Metalográfico de Acero DIN 32MnCrMo6-4-3	ZAC	Nital	Micrografías 3
4	MP-010	C1000 Metalográfico de Acero DIN 32MnCrMo6-4-3	RECUBRIMIENTO	Nital	Micrografías 4
5	MP-011	CTMG Metalográfico de Acero DIN 32MnCrMo6-4-3	BASE	Nital	Micrografías 5
6	MP-012	CTMG Metalográfico de Acero DIN 32MnCrMo6-4-3	ZAC	Nital	Micrografías 6
7	MP-013	CTMG Metalográfico de Acero DIN 32MnCrMo6-4-3	RECUBRIMIENTO	Nital	Micrografías 7
8	MP-014	E43 Metalográfico de Acero DIN 32MnCrMo6-4-3	BASE	Nital	Micrografías 8
9	MP-015	E43 Metalográfico de Acero DIN 32MnCrMo6-4-3	ZAC	Nital	Micrografías 9
10	MP-016	E43 Metalográfico de Acero DIN 32MnCrMo6-4-3	RECUBRIMIENTO	Nital	Micrografías 10
11	MP-017	Metalográfico de Acero DIN 32MnCrMo6-4-3	BASE	Vilella	Micrografías 11
12	MP-018	C1000 Metalográfico de Acero DIN 32MnCrMo6-4-3	BASE	Vilella	Micrografías 12
13	MP-019	C1000 Metalográfico de Acero DIN 32MnCrMo6-4-3	ZAC	Vilella	Micrografías 13
14	MP-020	C1000 Metalográfico de Acero DIN 32MnCrMo6-4-3	RECUBRIMIENTO	Vilella	Micrografías 14
15	MP-021	CTMG Metalográfico de Acero DIN 32MnCrMo6-4-3	BASE	Vilella	Micrografías 15
16	MP-022	CTMG Metalográfico de Acero DIN 32MnCrMo6-4-3	ZAC	Vilella	Micrografías 16
17	MP-023	CTMG Metalográfico de Acero DIN 32MnCrMo6-4-3	RECUBRIMIENTO	Vilella	Micrografías 17
18	MP-024	E43 Metalográfico de Acero DIN 32MnCrMo6-4-3	BASE	Vilella	Micrografías 18
19	MP-025	E43 Metalográfico de Acero DIN 32MnCrMo6-4-3	ZAC	Vilella	Micrografías 19
20	MP-026	E43 Metalográfico de Acero DIN 32MnCrMo6-4-3	RECUBRIMIENTO	Vilella	Micrografías 20

En las siguientes Fichas 4-2 al 4-9, se presenta los parámetros y los resultados de ensayo metalográficos.


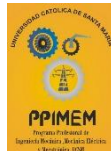
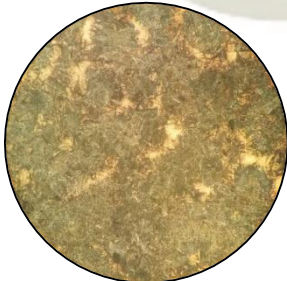
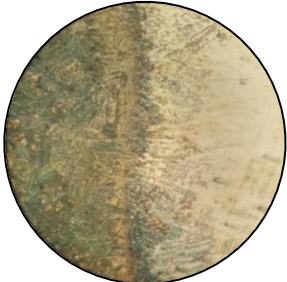
Ficha 4-2 - Análisis metalográfico (Micrografía 1) [1]

		UNIVERSIDAD CATÓLICA DE SANTA MARÍA, ESCUELA PROFESIONAL DE INGENIERIA MECÁNICA, MECÁNICA ELÉTRICA Y MECÁTRONICA			
<b>ENSAYO METALOGRÁFICO</b>					
Tipo de Estudio		De laboratorio		Ensayo N°	
Fecha:		17/01/2019		Micrografías 1	
Parte Especificada:		PROBETA MATERIAL BASE - DIN 32MnCrMo 6-4-3 (WNR° 1.7910)			
Solicitado Por:		Ruben Purca		Dirección	
Centro de estudios y análisis:		Laboratorio de Ingeniería de Materiales de la Universidad Católica de Santa María			
Realizado Por:		Ruben Purca		Revisado Por:	
				Ing. Emilio Chire	
<b>PARAMETROS AMBIENTALES DEL LUGAR DURANTE EL ENSAYO</b>					
Tipo de Ensayo:		Ensayo Metalográfico		Iluminación:	
				Buena	
Temperatura del Ensayo:		22,5° C.		Tipo de probeta:	
				Rectangular	
				Espec. del material:	
		Acero de mediano carbono y baja aleación (Manganeso – Cromo – Molibdeno)			
<b>PARÁMETROS DEL ENSAYO METALOGRÁFICO</b>					
Preparación de la superficie:		Lijar #100; Lijar #220; Lijar #400 ,Lijar #600, Lijar #1000, Lijar #1200, Lijar #2000			
Tiempo de ataque:		10 segundos		Ataque químico:	
				Nital	
<b>RESULTADO</b>					
1- 20X			1 - 100X		

Ficha 4-3 - Análisis metalográfico (Micrografías 2,3,4) [1]

		UNIVERSIDAD CATÓLICA DE SANTA MARÍA, ESCUELA PROFESIONAL DE INGENIERIA MECÁNICA, MECÁNICA ELÉTRICA Y MECÁTRONICA			
<b>ENSAYO METALOGRAFICO</b>					
Tipo de Estudio		De laboratorio		Ensayo N°	
Fecha:		17/01/2019		Micrografías 2,3,4	
Parte Especificada:		PROBETA CON UNION DE RECARGUE CITODUR - 1000			
Solicitado Por:		Ruben Purca		Dirección	
Centro de estudios y análisis:		Laboratorio de Ingeniería de Materiales de la Universidad Católica de Santa María			
Realizado Por:		Ruben Purca		Revisado Por:	
				Ing. Emilio Chire	
<b>PARAMETROS AMBIENTALES DEL LUGAR DURANTE EL ENSAYO</b>					
Tipo de Ensayo:		Ensayo Metalográfico		Iluminación:	
				Buena	
Temperatura del Ensayo:		22,5° C.		Tipo de probeta:	
				Rectangular	
		Espec. del material:		Unión de Acero de mediano carbono y baja aleación (Manganeso – Cromo – Molibdeno) con Soldadura CITODUR - 1000	
<b>PARÁMETROS DEL ENSAYO METALOGRAFICO</b>					
Preparación de la superficie:		Lijar #100; Lijar #220; Lijar #400, Lijar #600, Lijar #1000, Lijar #1200, Lijar #2000			
Tiempo de ataque:		10 segundos		Ataque químico:	
				Nital	
<b>RESULTADO</b>					
2				4	
3				La figura 2 corresponde al material Base La figura 3 corresponde a la zona ZAC La figura 4 corresponde a la zona de Recargue	

Ficha 4-4 - Análisis metalográfico (Micrografías 5,6,7) [1]

		UNIVERSIDAD CATÓLICA DE SANTA MARÍA, ESCUELA PROFESIONAL DE INGENIERIA MECÁNICA, MECÁNICA ELÉCTRICA Y MECÁTRONICA			
<b>ENSAYO METALOGRAFICO</b>					
Tipo de Estudio		De laboratorio		Ensayo N°	
Fecha:		17/01/2019		Micrografías 5,6,7	
Parte Especificada:		PROBETA CON UNIÓN DE RECARGUE CITOMANGAN			
Solicitado Por:		Ruben Purca		Dirección	
Centro de estudios y análisis:		Laboratorio de Ingeniería de Materiales de la Universidad Católica de Santa María			
Realizado Por:		Ruben Purca		Revisado Por:	
				Ing. Emilio Chire	
<b>PARAMETROS AMBIENTALES DEL LUGAR DURANTE EL ENSAYO</b>					
Tipo de Ensayo:		Ensayo Metalográfico		Iluminación:	
				Buena	
Temperatura del Ensayo:		22,5° C.		Tipo de probeta:	
				Rectangular	
		Espec. del material:		Unión de Acero de mediano carbono y baja aleación (Manganeso – Cromo – Molibdeno) con Soldadura CITOMANGAN	
<b>PARÁMETROS DEL ENSAYO METALOGRAFICO</b>					
Preparación de la superficie:		Lijar #100; Lijar #220; Lijar #400, Lijar #600, Lijar #1000, Lijar #1200, Lijar #2000			
Tiempo de ataque:		10 segundos		Ataque químico:	
				Nital	
<b>RESULTADO</b>					
5				7	
6				La figura 5 corresponde al material Base La figura 6 corresponde a la zona ZAC La figura 7 corresponde a la zona de Recargue	

Ficha 4-5 - Análisis metalográfico (Micrografías 8,9,10) [1]

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<b>ENSAYO METALGRÁFICO</b>					
Tipo de Estudio		De laboratorio		Ensayo N°	Micrografías 8,9,10
Fecha:		17/01/2019		Probeta N°	E43 Metalográfico de Acero DIN 32MnCrMo6-4-3
Parte Especificada:			PROBETA CON UNIÓN DE RECARGUE EXADUR - 43		
Solicitado Por:		Ruben Purca	Dirección	Asoc. De Viv Los Olmos Arequipa, Perú	
Centro de estudios y análisis:			Laboratorio de Ingeniería de Materiales de la Universidad Católica de Santa María		
Realizado Por:		Ruben Purca	Revisado Por:	Ing. Emilio Chire	
<b>PARAMETROS AMBIENTALES DEL LUGAR DURANTE EL ENSAYO</b>					
Tipo de Ensayo:		Ensayo Metalográfico	Iluminación:	Buena	
Temperatura del Ensayo:		22,5° C.	Tipo de probeta:	Rectangular	
			Espec. del material:	Unión de Acero de mediano carbono y baja aleación (Manganeso – Cromo – Molibdeno) con Soldadura EXADUR -43	
<b>PARÁMETROS DEL ENSAYO METALGRÁFICO</b>					
Preparación de la superficie:			Lijar #100; Lijar #220; Lijar #400, Lijar #600, Lijar #1000, Lijar #1200, Lijar #2000		
Tiempo de ataque:			10 segundos	Ataque químico:	Nital
<b>RESULTADO</b>					
8				10	
9				La figura 8 corresponde al material Base  La figura 9 corresponde a la zona ZAC  La figura 10 corresponde a la zona de Recargue	

Ficha 4-6 - Análisis metalográfico (Micrografías 11) [1]

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<b>ENSAYO METALOGRÁFICO</b>					
Tipo de Estudio		De laboratorio		Ensayo N°	Micrografías 11
Fecha:		17/01/2019		Probeta N°	BASE
Parte Especificada:			PROBETA MATERIAL BASE - DIN 32MnCrMo6-4-3 (WNR° 1.7910)		
Solicitado Por:		Ruben Purca	Dirección	Asoc. De Viv Los Olmos Arequipa, Perú	
Centro de estudios y análisis:			Laboratorio de Ingeniería de Materiales de la Universidad Católica de Santa María		
Realizado Por:		Ruben Purca	Revisado Por:	Ing. Emilio Chire	
<b>PARAMETROS AMBIENTALES DEL LUGAR DURANTE EL ENSAYO</b>					
Tipo de Ensayo:		Ensayo Metalográfico	Iluminación:	Buena	
Temperatura del Ensayo:		22,5° C.		Tipo de probeta:	
				Rectangular	
		Espec. del material:	Acero de mediano carbono y baja aleación (Manganeso – Cromo – Molibdeno)		
<b>PARÁMETROS DEL ENSAYO METALOGRÁFICO</b>					
Preparación de la superficie:			Lijar #100; Lijar #220; Lijar #400 ,Lijar #600, Lijar #1000, Lijar #1200, Lijar #2000		
Tiempo de ataque:		10 segundos	Ataque químico:	Vilella	
<b>RESULTADO</b>					
11 - 20X			11 -100X		

Ficha 4-7 - Análisis metalográfico (Micrografías 12,13,14) [1]

		UNIVERSIDAD CATÓLICA DE SANTA MARÍA, ESCUELA PROFESIONAL DE INGENIERIA MECÁNICA, MECÁNICA ELÉCTRICA Y MECÁTRONICA			
<b>ENSAYO METALGRÁFICO</b>					
Tipo de Estudio		De laboratorio		Ensayo N°	
Fecha:		17/01/2019		Probeta N°	
				Micrografías 12,13,14	
				C1000 Metalográfico de Acero DIN 32MnCrMo6- 4-3	
Parte Especificada:			PROBETA CON UNION DE RECARGUE CITODUR - 1000		
Solicitado Por:		Ruben Purca	Dirección	Asoc. De Viv Los Olmos Arequipa, Perú	
Centro de estudios y análisis:			Laboratorio de Ingeniería de Materiales de la Universidad Católica de Santa María		
Realizado Por:		Ruben Purca	Revisado Por:	Ing. Emilio Chire	
<b>PARAMETROS AMBIENTALES DEL LUGAR DURANTE EL ENSAYO</b>					
Tipo de Ensayo:		Ensayo Metalográfico	Iluminación:	Buena	
Temperatura del Ensayo:		22,5° C.	Tipo de probeta:	Rectangular	
			Espec. del material:	Unión de Acero de mediano carbono y baja aleación (Manganeso – Cromo – Molibdeno) con Soldadura CITODUR - 1000	
<b>PARÁMETROS DEL ENSAYO METALGRÁFICO</b>					
Preparación de la superficie:			Lijar #100; Lijar #220; Lijar #400, Lijar #600, Lijar #1000, Lijar #1200, Lijar #2000		
Tiempo de ataque:		10 segundos	Ataque químico:	Vilella	
<b>RESULTADO</b>					
12				14	
13				La figura 12 corresponde al material Base La figura 13 corresponde a la zona ZAC La figura 14 corresponde a la zona de Recargue	

Ficha 4-8 - Análisis metalográfico (Micrografías 15,16,17) [1]

		UNIVERSIDAD CATÓLICA DE SANTA MARÍA, ESCUELA PROFESIONAL DE INGENIERIA MECÁNICA, MECÁNICA ELÉCTRICA Y MECÁTRONICA			
<b>ENSAYO METALGRÁFICO</b>					
Tipo de Estudio		De laboratorio		Ensayo N°	
Fecha:		17/01/2019		Probeta N°	
				Micrografías 15,16,17 CTMG Metalográfico de Acero DIN 32MnCrMo6- 4-3	
Parte Especificada:			PROBETA CON UNIÓN DE RECARGUE CITOMANGAN		
Solicitado Por:		Ruben Purca		Dirección	
				Asoc. De Viv Los Olmos Arequipa, Perú	
Centro de estudios y análisis:			Laboratorio de Ingeniería de Materiales de la Universidad Católica de Santa María		
Realizado Por:		Ruben Purca		Revisado Por:	
				Ing. Emilio Chire	
<b>PARAMETROS AMBIENTALES DEL LUGAR DURANTE EL ENSAYO</b>					
Tipo de Ensayo:		Ensayo Metalográfico		Iluminación:	
				Buena	
Temperatura del Ensayo:		22,5° C.		Tipo de probeta:	
				Rectangular	
				Espec. del material:	
				Unión de Acero de mediano carbono y baja aleación (Manganeso – Cromo – Molibdeno) con Soldadura CITOMANGAN	
<b>PARÁMETROS DEL ENSAYO METALGRÁFICO</b>					
Preparación de la superficie:			Lijar #100; Lijar #220; Lijar #400, Lijar #600, Lijar #1000, Lijar #1200, Lijar #2000		
Tiempo de ataque:			10 segundos		Ataque químico:
					Villela
<b>RESULTADO</b>					
15				17	
16				La figura 15 corresponde al material Base  La figura 16 corresponde a la zona ZAC  La figura 17 corresponde a la zona de Recargue	



Ficha 4-9 - Análisis metalográfico (Micrografías 18,19,20) [1]

		UNIVERSIDAD CATÓLICA DE SANTA MARÍA, ESCUELA PROFESIONAL DE INGENIERIA MECÁNICA, MECÁNICA ELÉTRICA Y MECÁTRONICA			
<b>ENSAYO METALOGRÁFICO</b>					
Tipo de Estudio		De laboratorio		Ensayo N°	Micrografías 18,19,20
Fecha:		17/01/2019		Probeta N°	E43 Metalográfico de Acero DIN 32MnCrMo 6-4-3
Parte Especificada:			PROBETA CON UNIÓN DE RECARGUE EXADUR - 43		
Solicitado Por:		Ruben Purca	Dirección	Asoc. De Viv Los Olmos Arequipa, Perú	
Centro de estudios y análisis:			Laboratorio de Ingeniería de Materiales de la Universidad Católica de Santa María		
Realizado Por:		Ruben Purca	Revisado Por:	Ing. Emilio Chire	
<b>PARAMETROS AMBIENTALES DEL LUGAR DURANTE EL ENSAYO</b>					
Tipo de Ensayo:		Ensayo Metalográfico	Iluminación:	Buena	
Temperatura del Ensayo:		22,5° C.	Tipo de probeta:	Rectangular	
			Espec. del material:	Unión de Acero de mediano carbono y baja aleación (Manganeso – Cromo – Molibdeno) con Soldadura EXADUR -43	
<b>PARÁMETROS DEL ENSAYO METALOGRÁFICO</b>					
Preparación de la superficie:			Lijar #100; Lijar #220; Lijar #400, Lijar #600, Lijar #1000, Lijar #1200, Lijar #2000		
Tiempo de ataque:		10 segundos	Ataque químico:	Villela	
<b>RESULTADO</b>					
18				20	
19				La figura 18 corresponde al material Base  La figura 19 corresponde a la zona ZAC  La figura 20 corresponde a la zona de Recargue	

En las siguientes Fichas 4-10 al 4-29, se presenta los análisis de las micrografías obtenidas.

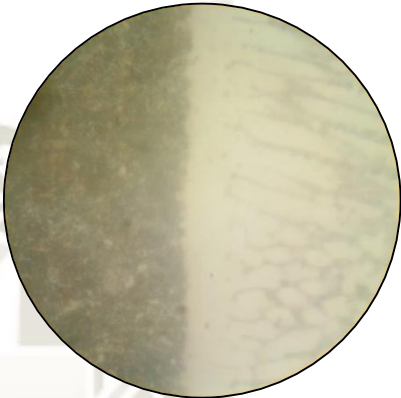
Ficha 4-10 - Evaluación micrografía 1 [1]

EVALUACIÓN DE LA MICROESTRUCTURA			
Ataque Químico	Nital	Ensayo N°	Micrografías 1 - BASE
Parte Especificada:	Acero de mediano carbono y baja aleación (Manganeso – Cromo – Molibdeno)		
Determinación del tamaño de grano		Microestructura	
Método (ASTM E 112)	Planimétrico	Ferrita $\alpha$	
$NA = f * (Ni + \frac{Nint}{2})$ $NA = 2 * (150 + \frac{80}{2})$ $NA = 530$ $G = 3.321918 * \log(NA) - 2.954$ $G = 3.321918 * \log(530) - 2.954$ $G = 6.0952 = 6$		Carburo C	
INTERPRETACIÓN			
<p>Este presenta una estructura del tipo martensítica, se observa también estructura de agujas, las cuales son producto del proceso de fundición. Se presenta ferrita acicular (parte clara) la cual disminuye su espesor a medida que aumenta la profundidad. En el también se encuentra carburos de cromo dispersos (parte oscura).</p>			

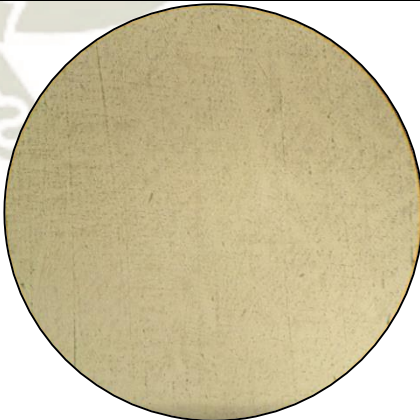
Ficha 4-11 - Evaluación micrografía 2 [1]

EVALUACIÓN DE LA MICROESTRUCTURA			
Ataque Químico	Nital	Ensayo N°	Micrografías 2 - BASE
Parte Especificada:	Unión de Acero de mediano carbono y baja aleación (Manganeso – Cromo – Molibdeno) con Soldadura CITODUR - 1000		
Determinación del tamaño de grano		Microestructura	
Método (ASTM E 112)	Planimétrico	Ferrita $\alpha$	
$NA = f * (Ni + \frac{Nint}{2})$ $NA = 2 * (180 + \frac{40}{2})$ $NA = 400$ $G = 3.321918 * \log(NA) - 2.954$ $G = 3.321918 * \log(400) - 2.954$ $G = 5.689 = 6$		Carburo C	
INTERPRETACIÓN			
<p>Este presenta una estructura del tipo martensítica, se observa también estructura de agujas, las cuales son producto del proceso de fundición. Se presenta ferrita acicular (parte clara) la cual disminuye su espesor a medida que aumenta la profundidad. En el también se encuentra carburos de cromo, molibdeno y manganeso dispersos (parte oscura).</p>			

Ficha 4-12 - Evaluación micrografía 3 [1]

EVALUACIÓN DE LA MICROESTRUCTURA			
Ataque Químico	Nital	Ensayo N°	Micrografías 3 - ZAC
Parte Especificada:	Unión de Acero de mediano carbono y baja aleación (Manganeso – Cromo – Molibdeno) con Soldadura CITODUR - 1000		
Determinación del tamaño de grano		Microestructura	
Método (ASTM E 112)	Planimétrico		
$NA = f * (Ni + \frac{Nint}{2})$ $NA = 2 * (370 + \frac{40}{2})$ $NA = 780$ $G = 3.321918 * \log(NA) - 2.954$ $G = 3.321918 * \log(780) - 2.954$ $G = 6.6533 = 7$			
INTERPRETACIÓN			
Cerca de la intercara metal base-recubrimiento, se observa una estructura con crecimiento dendrítico ocasionada por el rápido enfriamiento característico del proceso de soldadura eléctrica.			

Ficha 4-13 - Evaluación micrografía 4 [1]

EVALUACIÓN DE LA MICROESTRUCTURA			
Ataque Químico	Nital	Ensayo N°	Micrografías 4 - RECUBRIMIENTO
Parte Especificada:	Unión de Acero de mediano carbono y baja aleación (Manganeso – Cromo – Molibdeno) con Soldadura CITODUR - 1000		
Determinación del tamaño de grano		Microestructura	
Método (ASTM E 112)	Planimétrico		
$NA = f * (Ni + \frac{Nint}{2})$ $NA = 2 * (450 + \frac{120}{2})$ $NA = 1020$ $G = 3.321918 * \log(NA) - 2.954$ $G = 3.321918 * \log(1020) - 2.954$ $G = 7.0403 = 7$			
INTERPRETACIÓN			
Se aprecia una zona en donde se encuentran carburos alargados (carburos primarios) inmersos en una matriz martensítica. Los cuales no presentan una orientación preferente respecto a la intercara o a la superficie			

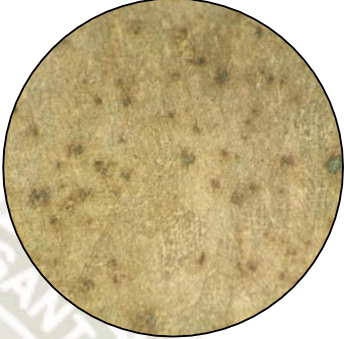
Ficha 4-14 - Evaluación micrografía 5 [1]

EVALUACIÓN DE LA MICROESTRUCTURA			
Ataque Químico	Nital	Ensayo N°	Micrografías 5 - BASE
Parte Especificada:	Unión de Acero de mediano carbono y baja aleación (Manganeso – Cromo – Molibdeno) con Soldadura CITOMANGAN		
Determinación del tamaño de grano		Microestructura	
Método (ASTM E 112)	Planimétrico	Ferrita $\alpha$  Carburo C	
$NA = f * \left(Ni + \frac{Nint}{2}\right)$ $NA = 2 * \left(240 + \frac{130}{2}\right)$ $NA = 610$ $G = 3.321918 * \log(NA) - 2.954$ $G = 3.321918 * \log(610) - 2.954$ $G = 6.2986 = 6$			
INTERPRETACIÓN			
Este presenta una estructura del tipo martensítica, se observa también estructura de agujas, las cuales son producto del proceso de fundición. Se presenta ferrita acicular (parte clara) la cual disminuye su espesor a medida que aumenta la profundidad. En el también se encuentra carburos de cromo, molibdeno y manganeso dispersos (parte oscura).			

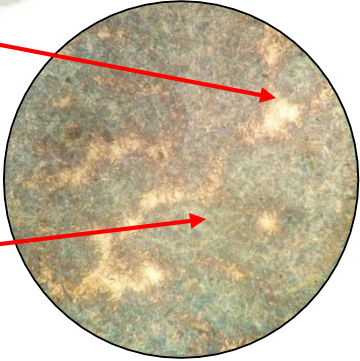
Ficha 4-15 - Evaluación micrografía 6 [1]

EVALUACIÓN DE LA MICROESTRUCTURA			
Ataque Químico	Nital	Ensayo N°	Micrografías 6 - ZAC
Parte Especificada:	Unión de Acero de mediano carbono y baja aleación (Manganeso – Cromo – Molibdeno) con Soldadura CITOMANGAN		
Determinación del tamaño de grano		Microestructura	
Método (ASTM E 112)	Planimétrico		
$NA = f * \left(Ni + \frac{Nint}{2}\right)$ $NA = 2 * \left(380 + \frac{120}{2}\right)$ $NA = 880$ $G = 3.321918 * \log(NA) - 2.954$ $G = 3.321918 * \log(880) - 2.954$ $G = 6.8273 = 7$			
INTERPRETACIÓN			
Cerca de la intercara metal base-recubrimiento, se observa una estructura con crecimiento de perlita, el carbono tiende a difundirse al carburo y dejar a la ferrita.			

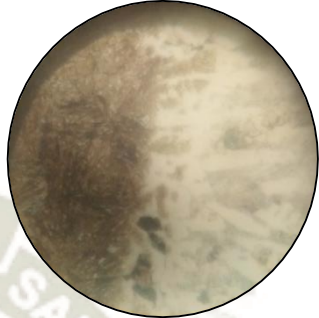
Ficha 4-16 - Evaluación micrografía 7 [1]

EVALUACIÓN DE LA MICROESTRUCTURA			
Ataque Químico	Nital	Ensayo N°	Micrografías 7 - RECUBRIMIENTO
Parte Especificada:	Unión de Acero de mediano carbono y baja aleación (Manganeso – Cromo – Molibdeno) con Soldadura CITOMANGAN		
Determinación del tamaño de grano		Microestructura	
Método (ASTM E 112)	Planimétrico		
$NA = f * \left( Ni + \frac{Nint}{2} \right)$ $NA = 2 * \left( 650 + \frac{330}{2} \right)$ $NA = 1630$ $G = 3.321918 * \log(NA) - 2.954$ $G = 3.321918 * \log(1630) - 2.954$ $G = 7.7166 = 8$			
INTERPRETACIÓN			
<p>Se puede observar una estructura austenítica con precipitación de pequeños carburos, distribuidos en grupos, en el borde de grano y en el interior del mismo. Además, se observan otro tipo de carburos, de mayor tamaño que los anteriores, en el interior del grano austenítico, que pueden explicarse por el mayor contenido en carbono y molibdeno que tiene este acero con respecto a los demás. Se observa también la mezcla laminar de ferrita (parte clara) y carburo (parte oscura) que se forma a partir de la austenita. (Perlita)</p>			

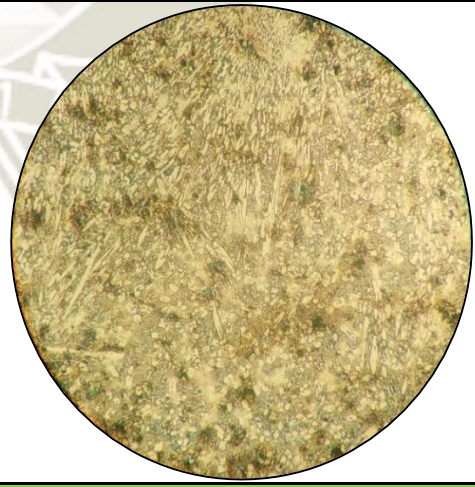
Ficha 4-17 - Evaluación micrografía 8 [1]

EVALUACIÓN DE LA MICROESTRUCTURA			
Ataque Químico	Nital	Ensayo N°	Micrografías 8 - BASE
Parte Especificada:	Unión de Acero de mediano carbono y baja aleación (Manganeso – Cromo – Molibdeno) con Soldadura EXADUR - 43		
Determinación del tamaño de grano		Microestructura	
Método (ASTM E 112)	Planimétrico	<p>Ferrita <math>\alpha</math></p>  <p>Carburo C</p>	
$NA = f * \left( Ni + \frac{Nint}{2} \right)$ $NA = 2 * \left( 265 + \frac{120}{2} \right)$ $NA = 650$ $G = 3.321918 * \log(NA) - 2.954$ $G = 3.321918 * \log(650) - 2.954$ $G = 6.3902 = 6$			
INTERPRETACIÓN			
<p>Este presenta una estructura del tipo martensítica, se observa también estructura de agujas, las cuales son producto del proceso de fundición. Se presenta ferrita acicular (parte clara) la cual disminuye su espesor a medida que aumenta la profundidad. En el también se encuentra carburos de cromo, molibdeno y manganeso dispersos (parte oscura).</p>			

Ficha 4-18 - Evaluación micrografía 9 [1]

EVALUACIÓN DE LA MICROESTRUCTURA			
Ataque Químico	Nital	Ensayo N°	Micrografías 9 - ZAC
Parte Especificada:	Unión de Acero de mediano carbono y baja aleación (Manganeso – Cromo – Molibdeno) con Soldadura EXADUR - 43		
Determinación del tamaño de grano		Microestructura	
Método (ASTM E 112)	Planimétrico		
$NA = f * \left( Ni + \frac{Nint}{2} \right)$ $NA = 2 * \left( 590 + \frac{320}{2} \right)$ $NA = 1500$ $G = 3.321918 * \log(NA) - 2.954$ $G = 3.321918 * \log(1500) - 2.954$ $G = 7.5967 = 8$			
INTERPRETACIÓN			
Cerca de la intercara metal base-recubrimiento, se observa una estructura con crecimiento de perlita, el carbono tiende a difundirse al carburo y dejar a la ferrita.			

Ficha 4-19 - Evaluación micrografía 10 [1]

EVALUACIÓN DE LA MICROESTRUCTURA			
Ataque Químico	Nital	Ensayo N°	Micrografías 10 - RECUBRIMIENTO
Parte Especificada:	Unión de Acero de mediano carbono y baja aleación (Manganeso – Cromo – Molibdeno) con Soldadura EXADUR - 43		
Determinación del tamaño de grano		Microestructura	
Método (ASTM E 112)	Planimétrico		
$NA = f * \left( Ni + \frac{Nint}{2} \right)$ $NA = 2 * \left( 230 + \frac{120}{2} \right)$ $NA = 580$ $G = 3.321918 * \log(NA) - 2.954$ $G = 3.321918 * \log(580) - 2.954$ $G = 6.2258 = 6$			
INTERPRETACIÓN			
Este presenta una estructura del tipo austenítica. Con carburos de Cromo y Niobio. También se observa mezcla laminar de ferrita (parte clara) y carburos (parte oscura) se forma a partir de la austenita.			

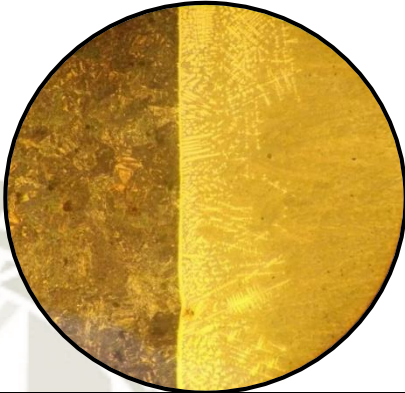
Ficha 4-20 - Evaluación micrografía 11 [1]

EVALUACIÓN DE LA MICROESTRUCTURA			
Ataque Químico	Vilella	Ensayo N°	Micrografías 11 - BASE
Parte Especificada:	PROBETA MATERIAL BASE - DIN 32MnCrMo 6-4-3 (WNR° 1.7910)		
Determinación del tamaño de grano		Microestructura	
Método (ASTM E 112)	Planimétrico		
$NA = f * \left( Ni + \frac{Nint}{2} \right)$ $NA = 2 * \left( 230 + \frac{120}{2} \right)$ $NA = 580$ $G = 3.321918 * \log(NA) - 2.954$ $G = 3.321918 * \log(580) - 2.954$ $G = 6.2258 = 6$			
INTERPRETACIÓN			
<p>Este presenta una estructura del tipo martensítica, se observa también estructura de agujas, las cuales son producto del proceso de fundición. Se presenta ferrita acicular (parte clara) la cual disminuye su espesor a medida que aumenta la profundidad. En el también se encuentra carburos de cromo, molibdeno y manganeso dispersos (parte oscura).</p>			


Ficha 4-21 - Evaluación micrografía 12 [1]

EVALUACIÓN DE LA MICROESTRUCTURA			
Ataque Químico	Vilella	Ensayo N°	Micrografías 12 - BASE
Parte Especificada:	Unión de Acero de mediano carbono y baja aleación (Manganeso – Cromo – Molibdeno) con Soldadura CITODUR - 1000		
Determinación del tamaño de grano		Microestructura	
Método (ASTM E 112)	Planimétrico		
$NA = f * \left( Ni + \frac{Nint}{2} \right)$ $NA = 2 * \left( 230 + \frac{110}{2} \right)$ $NA = 570$ $G = 3.321918 * \log(NA) - 2.954$ $G = 3.321918 * \log(570) - 2.954$ $G = 6.2007 = 6$			
INTERPRETACIÓN			
<p>Este presenta una estructura del tipo martensítica, se observa también estructura de agujas, las cuales son producto del proceso de fundición. Se presenta ferrita acicular (parte clara) la cual disminuye su espesor a medida que aumenta la profundidad. En el también se encuentra carburos de cromo, molibdeno y manganeso dispersos (parte oscura).</p>			

Ficha 4-22 - Evaluación micrografía 13 [1]

EVALUACIÓN DE LA MICROESTRUCTURA			
Ataque Químico	Vilella	Ensayo N°	Micrografías 13 - ZAC
Parte Especificada:	Unión de Acero de mediano carbono y baja aleación (Manganeso – Cromo – Molibdeno) con Soldadura CITODUR - 1000		
Determinación del tamaño de grano		Microestructura	
Método (ASTM E 112)	Planimétrico		
$NA = f * \left( Ni + \frac{Nint}{2} \right)$ $NA = 2 * \left( 345 + \frac{190}{2} \right)$ $NA = 880$ $G = 3.321918 * \log(NA) - 2.954$ $G = 3.321918 * \log(880) - 2.954$ $G = 6.8273 = 7$			
INTERPRETACIÓN			
Cerca de la intercara metal base-recubrimiento, se observa una estructura con crecimiento dendrítico ocasionada por el rápido enfriamiento característico del proceso de soldadura eléctrica.			

Ficha 4-23 - Evaluación micrografía 14 [1]

EVALUACIÓN DE LA MICROESTRUCTURA			
Ataque Químico	Vilella	Ensayo N°	Micrografías 14 - RECUBRIMIENTO
Parte Especificada:	Unión de Acero de mediano carbono y baja aleación (Manganeso – Cromo – Molibdeno) con Soldadura CITODUR - 1000		
Determinación del tamaño de grano		Microestructura	
Método (ASTM E 112)	Planimétrico		
$NA = f * \left( Ni + \frac{Nint}{2} \right)$ $NA = 2 * \left( 550 + \frac{340}{2} \right)$ $NA = 1440$ $G = 3.321918 * \log(NA) - 2.954$ $G = 3.321918 * \log(1440) - 2.954$ $G = 7.5378 = 8$			
INTERPRETACIÓN			
Se aprecia una zona en donde se encuentran carburos alargados (carburos primarios) inmersos en una matriz martensítica. Los cuales no presentan una orientación preferente respecto a la intercara o a la superficie			




Ficha 4-24 - Evaluación micrografía 15 [1]

EVALUACIÓN DE LA MICROESTRUCTURA			
Ataque Químico	Vilella	Ensayo N°	Micrografías 15 - BASE
Parte Especificada:	Unión de Acero de mediano carbono y baja aleación (Manganeso – Cromo – Molibdeno) con Soldadura CITOMANGAN		
Determinación del tamaño de grano		Microestructura	
Método (ASTM E 112)	Planimétrico	Ferrita $\alpha$	
$NA = f * \left( Ni + \frac{Nint}{2} \right)$ $NA = 2 * \left( 260 + \frac{140}{2} \right)$ $NA = 660$ $G = 3.321918 * \log(NA) - 2.954$ $G = 3.321918 * \log(660) - 2.954$ $G = 6.4122 = 6$		Carburo C	
INTERPRETACIÓN			
<p>Este presenta una estructura del tipo martensítica, se observa también estructura de agujas, las cuales son producto del proceso de fundición. Se presenta ferrita acicular (parte clara) la cual disminuye su espesor a medida que aumenta la profundidad. En el también se encuentra carburos de cromo, molibdeno y manganeso dispersos (parte oscura).</p>			

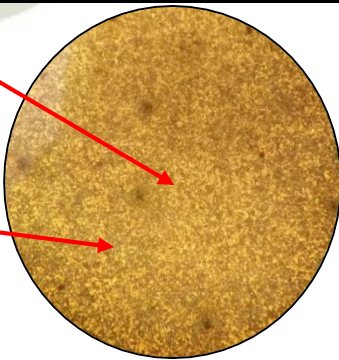
Ficha 4-25 - Evaluación micrografía 16 [1]

EVALUACIÓN DE LA MICROESTRUCTURA			
Ataque Químico	Vilella	Ensayo N°	Micrografías 16 - ZAC
Parte Especificada:	Unión de Acero de mediano carbono y baja aleación (Manganeso – Cromo – Molibdeno) con Soldadura CITOMANGAN		
Determinación del tamaño de grano		Microestructura	
Método (ASTM E 112)	Planimétrico		
$NA = f * \left( Ni + \frac{Nint}{2} \right)$ $NA = 2 * \left( 460 + \frac{2660}{2} \right)$ $NA = 1180$ $G = 3.321918 * \log(NA) - 2.954$ $G = 3.321918 * \log(1180) - 2.954$ $G = 7.2505 = 7$			
INTERPRETACIÓN			
<p>Cerca de la intercara metal base-recubrimiento, se observa una estructura con crecimiento de perlita, el carbono tiende a difundirse al carburo y dejar a la ferrita.</p>			

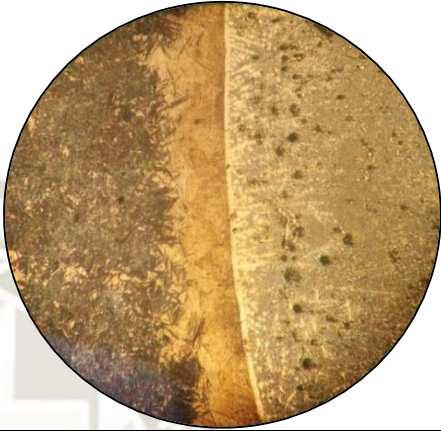
Ficha 4-26 - Evaluación micrografía 17 [1]

EVALUACIÓN DE LA MICROESTRUCTURA			
Ataque Químico	Vilella	Ensayo N°	Micrografías 17 - RECUBRIMIENTO
Parte Especificada:	Unión de Acero de mediano carbono y baja aleación (Manganeso – Cromo – Molibdeno) con Soldadura CITOMANGAN		
Determinación del tamaño de grano		Microestructura	
Método (ASTM E 112)	Planimétrico		
$NA = f * \left( Ni + \frac{Nint}{2} \right)$ $NA = 2 * \left( 680 + \frac{360}{2} \right)$ $NA = 1720$ $G = 3.321918 * \log(NA) - 2.954$ $G = 3.321918 * \log(1720) - 2.954$ $G = 7.7941 = 8$			
INTERPRETACIÓN			
<p>Se puede observar una estructura austenítica con precipitación de pequeños carburos, distribuidos en grupos, en el borde de grano y en el interior del mismo. Además, se observan otro tipo de carburos, de mayor tamaño que los anteriores, en el interior del grano austenítico, que pueden explicarse por el mayor contenido en carbono y molibdeno que tiene este acero con respecto a los demás. Se observa también la mezcla laminar de ferrita (parte clara) y carburo (parte oscura) que se forma a partir de la austenita. (Perlita)</p>			


Ficha 4-27 - Evaluación micrografía 18 [1]

EVALUACIÓN DE LA MICROESTRUCTURA			
Ataque Químico	Vilella	Ensayo N°	Micrografías 18 - BASE
Parte Especificada:	Unión de Acero de mediano carbono y baja aleación (Manganeso – Cromo – Molibdeno) con Soldadura EXADUR - 43		
Determinación del tamaño de grano		Microestructura	
Método (ASTM E 112)	Planimétrico	<p>Ferrita <math>\alpha</math></p>  <p>Carburo C</p>	
$NA = f * \left( Ni + \frac{Nint}{2} \right)$ $NA = 2 * \left( 290 + \frac{120}{2} \right)$ $NA = 700$ $G = 3.321918 * \log(NA) - 2.954$ $G = 3.321918 * \log(700) - 2.954$ $G = 6.4971 = 6$			
INTERPRETACIÓN			
<p>Este presenta una estructura del tipo martensítica, se observa también estructura de agujas, las cuales son producto del proceso de fundición. Se presenta ferrita acicular (parte clara) la cual disminuye su espesor a medida que aumenta la profundidad. En el también se encuentra carburos de cromo, molibdeno y manganeso dispersos (parte oscura).</p>			

Ficha 4-28 - Evaluación micrografía 19 [1]

EVALUACIÓN DE LA MICROESTRUCTURA			
Ataque Químico	Vilella	Ensayo N°	Micrografías 19 - ZAC
Parte Especificada:	Unión de Acero de mediano carbono y baja aleación (Manganeso – Cromo – Molibdeno) con Soldadura EXADUR - 43		
Determinación del tamaño de grano		Microestructura	
Método (ASTM E 112)	Planimétrico		
$NA = f * (Ni + \frac{Nint}{2})$ $NA = 2 * (390 + \frac{230}{2})$ $NA = 1010$ $G = 3.321918 * \log(NA) - 2.954$ $G = 3.321918 * \log(1010) - 2.954$ $G = 7.0261 = 7$			
INTERPRETACIÓN			
Cerca de la intercara metal base-recubrimiento, se observa una estructura con crecimiento de perlita, el carbono tiende a difundirse al carburo y dejar a la ferrita.			

Ficha 4-29 - Evaluación micrografía 20 [1]

EVALUACIÓN DE LA MICROESTRUCTURA			
Ataque Químico	Vilella	Ensayo N°	Micrografías 20 - RECUBRIMIENTO
Parte Especificada:	Unión de Acero de mediano carbono y baja aleación (Manganeso – Cromo – Molibdeno) con Soldadura EXADUR - 43		
Determinación del tamaño de grano		Microestructura	
Método (ASTM E 112)	Planimétrico		
$NA = f * (Ni + \frac{Nint}{2})$ $NA = 2 * (620 + \frac{210}{2})$ $NA = 1450$ $G = 3.321918 * \log(NA) - 2.954$ $G = 3.321918 * \log(1450) - 2.954$ $G = 7.5478 = 8$			
INTERPRETACIÓN			
Este presenta una estructura del tipo austenítica. Con carburos de Cromo y Niobio. También se observa mezcla laminar de ferrita (parte clara) y carburos (parte oscura) se forma a partir de la austenita.			

#### 4.3. Ensayo de dureza

Los resultados de Dureza Rockwell C según la norma ASTM E18 -15 se muestran en la siguiente Tabla 4-2.

Tabla 4-2 - Resultados de Barrido de dureza [1]

N°	Cód. Muestra	Ensayo/Propiedad	Zona Examinada	Resultados	Observaciones
1	DP-009	BASE 1 Dureza Rockwell C	BASE	58.77 HRC	T° de trabajo 21°C
2	DP-010	C1000 1 Dureza Rockwell C	BASE	57.40 HRC	T° de trabajo 21°C
3	DP-011	C1000 1 Dureza Rockwell C	ZAC	61.20 HRC	T° de trabajo 21°C
4	DP-012	C1000 1 Dureza Rockwell C	RECUBRIMIENTO	71.20 HRC	T° de trabajo 21°C
5	DP-013	C1000 2 Dureza Rockwell C	BASE	52.10 HRC	T° de trabajo 21°C
6	DP-014	C1000 2 Dureza Rockwell C	ZAC	62.00 HRC	T° de trabajo 21°C
7	DP-015	C1000 2 Dureza Rockwell C	RECUBRIMIENTO	67.80 HRC	T° de trabajo 21°C
8	DP-016	C1000 3 Dureza Rockwell C	BASE	49.10 HRC	T° de trabajo 21°C
9	DP-017	C1000 3 Dureza Rockwell C	ZAC	63.00 HRC	T° de trabajo 21°C
10	DP-018	C1000 3 Dureza Rockwell C	RECUBRIMIENTO	71.20 HRC	T° de trabajo 21°C
11	DP-019	C1000 4 Dureza Rockwell C	BASE	55.00 HRC	T° de trabajo 21°C
12	DP-020	C1000 4 Dureza Rockwell C	ZAC	60.30 HRC	T° de trabajo 21°C
13	DP-021	C1000 4 Dureza Rockwell C	RECUBRIMIENTO	70.00 HRC	T° de trabajo 21°C
14	DP-022	CTMG 1 Dureza Rockwell C	BASE	51.40 HRC	T° de trabajo 21°C
15	DP-023	CTMG 1 Dureza Rockwell C	ZAC	58.50 HRC	T° de trabajo 21°C
16	DP-024	CTMG 1 Dureza Rockwell C	RECUBRIMIENTO	63.90 HRC	T° de trabajo 21°C
17	DP-025	CTMG 2 Dureza Rockwell C	BASE	55.90 HRC	T° de trabajo 21°C
18	DP-026	CTMG 2 Dureza Rockwell C	ZAC	54.20 HRC	T° de trabajo 21°C
19	DP-027	CTMG 2 Dureza Rockwell C	RECUBRIMIENTO	64.00 HRC	T° de trabajo 21°C
20	DP-028	CTMG 3 Dureza Rockwell C	BASE	51.30 HRC	T° de trabajo 21°C
21	DP-029	CTMG 3 Dureza Rockwell C	ZAC	54.30 HRC	T° de trabajo 21°C
22	DP-030	CTMG 3 Dureza Rockwell C	RECUBRIMIENTO	63.50 HRC	T° de trabajo 21°C
23	DP-031	CTMG 4 Dureza Rockwell C	BASE	52.70 HRC	T° de trabajo 21°C
24	DP-032	CTMG 4 Dureza Rockwell C	ZAC	56.10 HRC	T° de trabajo 21°C
25	DP-033	CTMG 4 Dureza Rockwell C	RECUBRIMIENTO	63.00 HRC	T° de trabajo 21°C
26	DP-034	E43 1 Dureza Rockwell C	BASE	58.40 HRC	T° de trabajo 21°C
27	DP-035	E43 1 Dureza Rockwell C	ZAC	61.70 HRC	T° de trabajo 21°C
28	DP-036	E43 1 Dureza Rockwell C	RECUBRIMIENTO	70.10 HRC	T° de trabajo 21°C
29	DP-037	E43 2 Dureza Rockwell C	BASE	56.20 HRC	T° de trabajo 21°C
30	DP-038	E43 2 Dureza Rockwell C	ZAC	61.50 HRC	T° de trabajo 21°C
31	DP-039	E43 2 Dureza Rockwell C	RECUBRIMIENTO	67.30 HRC	T° de trabajo 21°C
32	DP-040	E43 3 Dureza Rockwell C	BASE	58.40 HRC	T° de trabajo 21°C
33	DP-041	E43 3 Dureza Rockwell C	ZAC	60.30 HRC	T° de trabajo 21°C
34	DP-042	E43 3 Dureza Rockwell C	RECUBRIMIENTO	72.80 HRC	T° de trabajo 21°C
35	DP-043	E43 4 Dureza Rockwell C	BASE	56.80 HRC	T° de trabajo 21°C
36	DP-044	E43 4 Dureza Rockwell C	ZAC	57.90 HRC	T° de trabajo 21°C
37	DP-045	E43 4 Dureza Rockwell C	RECUBRIMIENTO	71.50 HRC	T° de trabajo 21°C

En la Tablas 4-3, 4-4, 4-5 y 4-6 se pueden apreciar los resultados de los barridos dureza de las probetas Material Base, (Citodur 1000), Citomangan y Exadur 43 respectivamente.

Tabla 4-3 - Barrido de dureza probeta sin Recargue [1]

PROBETA SIN RECARGUE						
N°	Cód. Muestra	Ensayo/Propiedad	Zona Examinada	Resultados	Promedio (HRC)	Observaciones
1	DP-009	BASE 1 Dureza Rockwell C	BASE	58.77	58.77	T° de trabajo 21°C

Tabla 4-4 - Barrido de dureza probeta con Recargue C-1000. [1]

PROBETA CON RECARGUE CITODUR – 1000						
N°	Cód. Muestra	Ensayo/Propiedad	Zona Examinada	Resultados (HRC)	Promedio (HRC)	Observaciones
1	DP-010	C1000 1 Dureza Rockwell C	BASE	57.4	53.4	T° de trabajo 21°C
2	DP-013	C1000 2 Dureza Rockwell C	BASE	52.1		T° de trabajo 21°C
3	DP-016	C1000 3 Dureza Rockwell C	BASE	49.1		T° de trabajo 21°C
4	DP-019	C1000 4 Dureza Rockwell C	BASE	55		T° de trabajo 21°C
5	DP-011	C1000 1 Dureza Rockwell C	ZAC	61.2	61.6	T° de trabajo 21°C
6	DP-014	C1000 2 Dureza Rockwell C	ZAC	62		T° de trabajo 21°C
7	DP-017	C1000 3 Dureza Rockwell C	ZAC	63		T° de trabajo 21°C
8	DP-020	C1000 4 Dureza Rockwell C	ZAC	60.3		T° de trabajo 21°C
9	DP-012	C1000 1 Dureza Rockwell C	RECUBRIMIENTO	71.2	70.1	T° de trabajo 21°C
10	DP-015	C1000 2 Dureza Rockwell C	RECUBRIMIENTO	67.8		T° de trabajo 21°C
11	DP-018	C1000 3 Dureza Rockwell C	RECUBRIMIENTO	71.2		T° de trabajo 21°C
12	DP-021	C1000 4 Dureza Rockwell C	RECUBRIMIENTO	70		T° de trabajo 21°C

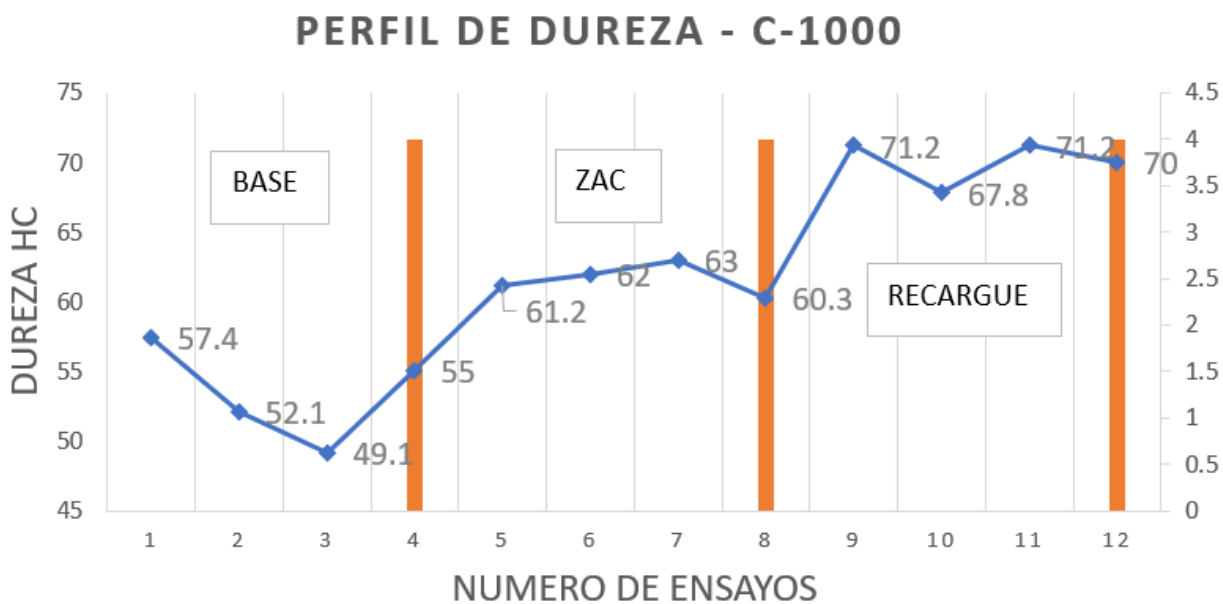
Tabla 4-5 - Barrido de dureza probeta con Recargue CITOMANGAN [1]

PROBETA CON RECARGUE CITOMANGAN						
N°	Cód. Muestra	Ensayo/Propiedad	Zona Examinada	Resultados (HRC)	Promedio (HRC)	Observaciones
1	DP-022	CTMG 1 Dureza Rockwell C	BASE	51.4	52.8	T° de trabajo 21°C
2	DP-025	CTMG 2 Dureza Rockwell C	BASE	55.9		T° de trabajo 21°C
3	DP-028	CTMG 3 Dureza Rockwell C	BASE	51.3		T° de trabajo 21°C
4	DP-031	CTMG 4 Dureza Rockwell C	BASE	52.7		T° de trabajo 21°C
5	DP-023	CTMG 1 Dureza Rockwell C	ZAC	58.5	55.8	T° de trabajo 21°C
6	DP-026	CTMG 2 Dureza Rockwell C	ZAC	54.2		T° de trabajo 21°C
7	DP-029	CTMG 3 Dureza Rockwell C	ZAC	54.3		T° de trabajo 21°C
8	DP-032	CTMG 4 Dureza Rockwell C	ZAC	56.1		T° de trabajo 21°C
9	DP-024	CTMG 1 Dureza Rockwell C	RECUBRIMIENTO	63.9	63.6	T° de trabajo 21°C
10	DP-027	CTMG 2 Dureza Rockwell C	RECUBRIMIENTO	64		T° de trabajo 21°C
11	DP-030	CTMG 3 Dureza Rockwell C	RECUBRIMIENTO	63.5		T° de trabajo 21°C
12	DP-033	CTMG 4 Dureza Rockwell C	RECUBRIMIENTO	63		T° de trabajo 21°C

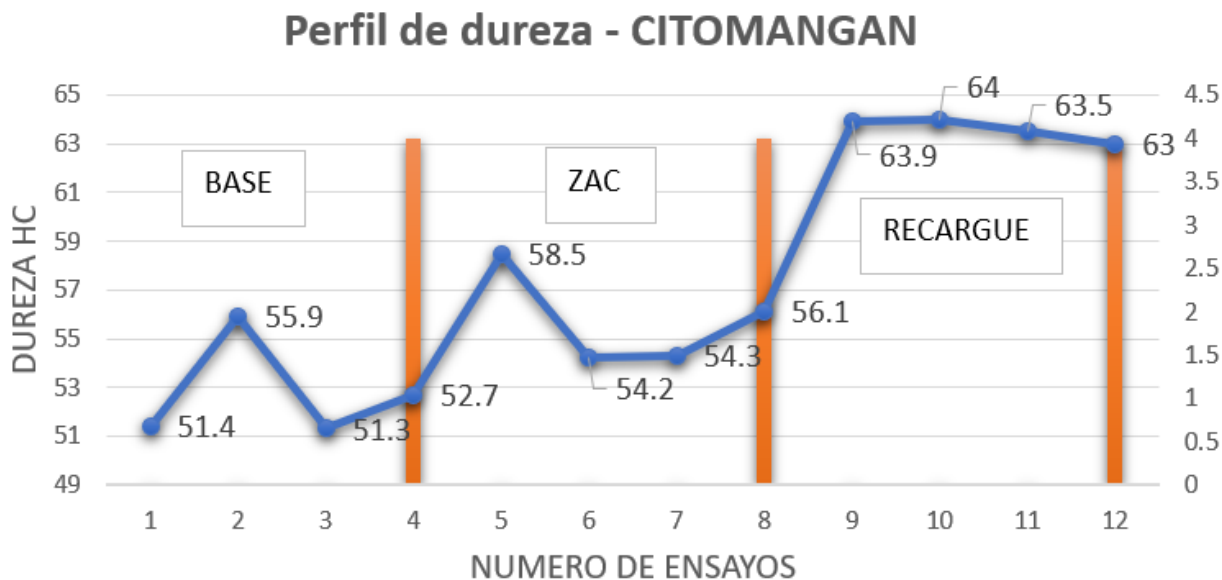
Tabla 4-6 - Barrido de dureza probeta con Recargue EXADUR – 43 [1]

PROBETA CON RECARGUE EXADUR - 43						
N°	Cód. Muestra	Ensayo/Propiedad	Zona Examinada	Resultados (HRC)	Promedio (HRC)	Observaciones
1	DP-034	E43 1 Dureza Rockwell C	BASE	58.4	57.5	T° de trabajo 21°C
2	DP-037	E43 2 Dureza Rockwell C	BASE	56.2		T° de trabajo 21°C
3	DP-040	E43 3 Dureza Rockwell C	BASE	58.4		T° de trabajo 21°C
4	DP-043	E43 4 Dureza Rockwell C	BASE	56.8		T° de trabajo 21°C
5	DP-035	E43 1 Dureza Rockwell C	ZAC	61.7	60.4	T° de trabajo 21°C
6	DP-038	E43 2 Dureza Rockwell C	ZAC	61.5		T° de trabajo 21°C
7	DP-041	E43 3 Dureza Rockwell C	ZAC	60.3		T° de trabajo 21°C
8	DP-044	E43 4 Dureza Rockwell C	ZAC	57.9		T° de trabajo 21°C
9	DP-036	E43 1 Dureza Rockwell C	RECUBRIMIENTO	70.1	70.4	T° de trabajo 21°C
10	DP-039	E43 2 Dureza Rockwell C	RECUBRIMIENTO	67.3		T° de trabajo 21°C
11	DP-042	E43 3 Dureza Rockwell C	RECUBRIMIENTO	72.8		T° de trabajo 21°C
12	DP-045	E43 4 Dureza Rockwell C	RECUBRIMIENTO	71.5		T° de trabajo 21°C

Con los datos obtenidos de los barridos de dureza, se pueden obtener los perfiles de dureza que muestran las Gráficas 4-1, 4-2 y 4-3 para las diferentes probetas.

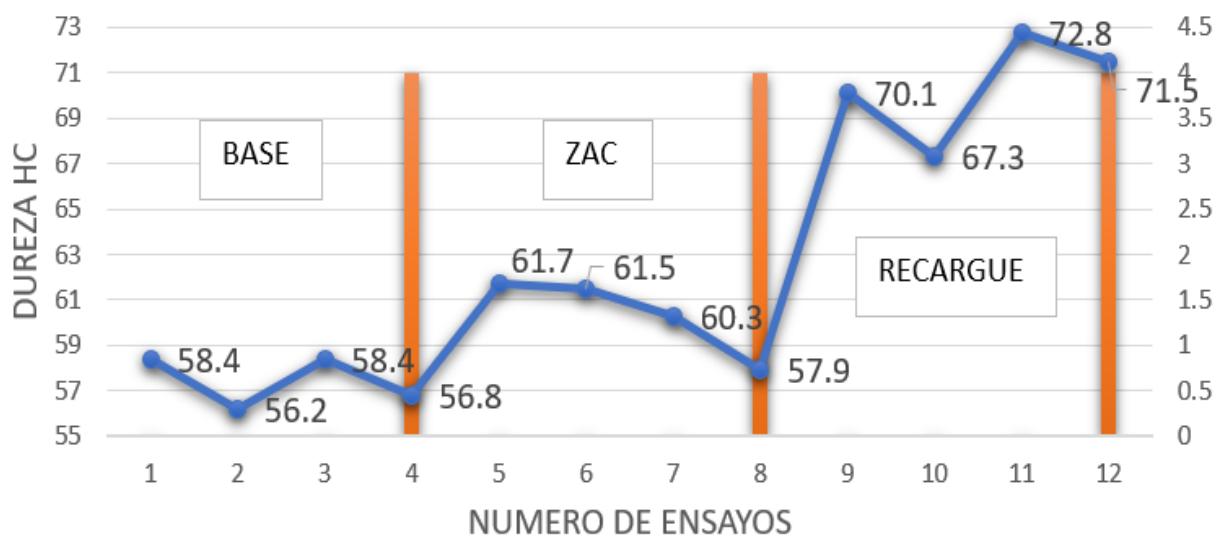


Gráfica 4-1 - Perfil de dureza de la probeta C-1000 [1]



Gráfica 4-2 - Perfil de dureza de la probeta CITOMANGAN [1]

### Perfil de dureza - EXADUR 43

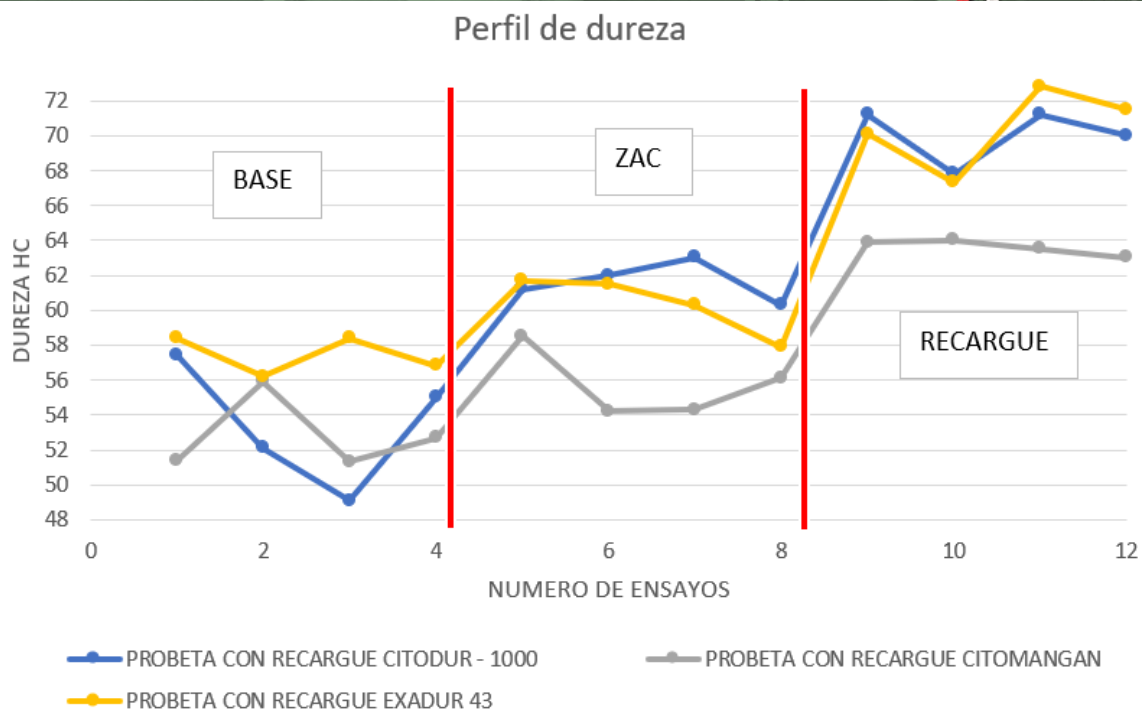


Gráfica 4-3 - Perfil de dureza de la probeta EXADUR 43 [1]

Como es de esperarse el perfil de dureza para los tres casos muestra una dureza elevada en las zonas donde existe recargue duro y esta disminuye conforme se acerca al metal base. Los valores de dureza promedio obtenidos para las probetas C-1000, CITOMANGAN y EXADUR 43 son 70.1 HRC, 63.6 HRC Y 70.4 HRC respectivamente (Gráfica 4-4).

Por otro lado, en la Figura 4-5 se puede apreciar una comparación de los perfiles de dureza de las probetas con los diferentes Recargues Duros.





Gráfica 4-4 - Comparación de perfiles de Dureza [1]

Con los resultados de los barridos de dureza se puede apreciar claramente que se tiene la siguiente relación de durezas correspondiente a la Figura 4-5.

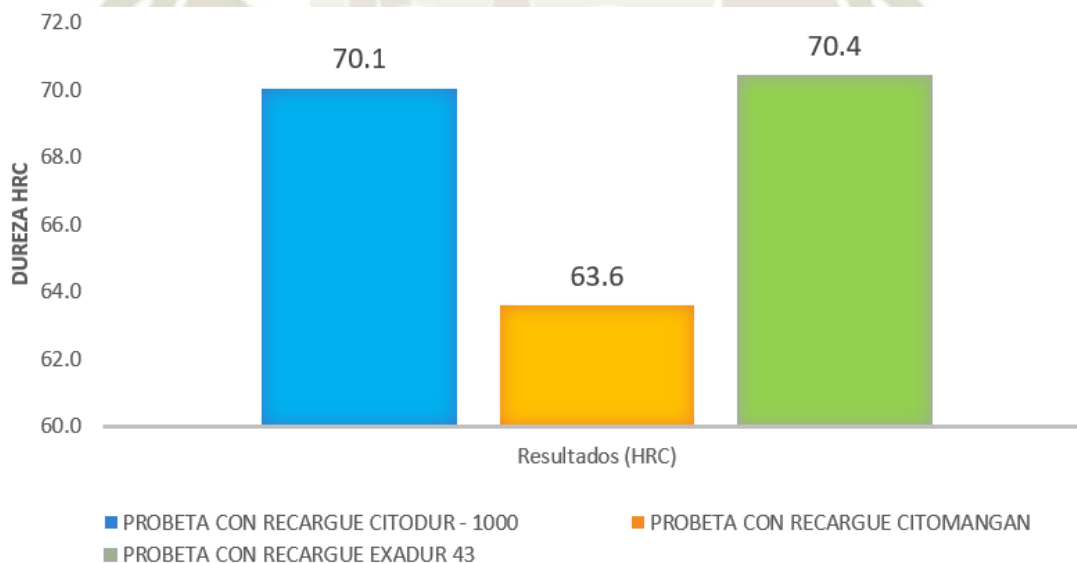



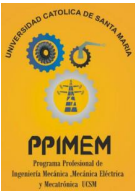
Figura 4-5 - Representación de los valores de dureza de cada recargue [1]

Se puede observar que los valores promedio de dureza son elevados en la zona de recargue, pero se tiene que recalcar que estos están afectados por la dilución del metal base y efectos de revenido entre pases. Los resultados de dureza varían de acuerdo a la composición química de los recubrimientos y su microestructura. Por ejemplo, se tiene a la probeta con Recargue EXADUR 43 con una dureza promedio de 70.4 HRC, esto se debe a que posee una estructura austenítica con carburos de Cr, Nb. Los carburos están distribuidos en una matriz austenítica que incrementa su resistencia al impacto. En la composición química dio como resultado que tiene un 20.3% de Cromo, este componente el cromo provee resistencia a la corrosión atmosférica y al desgaste, sin embargo, el efecto no siempre es consistente y depende de aplicaciones individuales. Se tiene a la probeta con Recargue C-1000 con una dureza de promedio de 70.1 HRC, esto se debe a que posee una estructura austenítica con carburos de C Mn Si Cr, se tiene también que esta composición contiene un 31.57 % de Cromo. Cabe resaltar que ambas probetas Exadur 43 y Citodur 1000 contienen un valor similar de % Carbono, que son 3.96 % y 3.6 % (ficha 4-1), con el incremento en el porcentaje de carbono se aumenta la resistencia al desgaste del acero austenítico. Por último se tiene se tiene a la probeta con Recargue CITOMANGAN con una dureza de promedio de 63.6 HRC, material depositado posee una estructura austenítica de gran tenacidad, que le permite absorber los golpes durante el trabajo, se tiene en el resultado de composición química que contiene 11.98% de Manganeso, esta estabiliza la austenita retardando la transformación martensítica, incrementa la resistencia a la tracción, el límite elástico, la resistencia a la fatiga y a la fluencia lenta, la forjabilidad, la resistencia al desgaste, En cambio, disminuye la maquinabilidad, la embutibilidad, las conductividades térmica y eléctrica y la sensibilidad a la fractura frágil.

#### 4.4. Ensayo de tracción

Las Fichas 4-30 al 4-37 que se presentan a continuación son los parámetros y resultados de los ensayos de tracción realizados a las probetas P1-EXADUR – 42, P2 – CITOMANGAN, P3 – C – 1000 y P-4 MATERIAL BASE según la norma ASTM E370 – 18 “Standard Test Methods and Definitions for Mechanical Testing of Steel Products”.

Ficha 4-30 - Parámetros generales del ensayo - P-1 - EXADUR-43 [1]

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<b>ENSAYO DE TRACCIÓN</b>					
Tipo de Estudio	De laboratorio		Ensayo N°	1	
Fecha:	03 DE JULIO DEL 2019		Probeta N°	P-1 - EXADUR-43	
Parte Especificada:	PROBETA CON UNIÓN DE RECARGUE EXADUR - 43				
Solicitado Por:	Ruben Purca	Dirección	Asoc. De Viv Los Olmos Arequipa, Perú		
Centro de estudios y análisis:	Laboratorio de Ingeniería de Materiales de la Universidad Nacional de San Agustín				
Realizado Por:	Ruben Purca	Revisado Por:	Ing. Guido Quispe Ampuero		
<b>PARÁMETROS DEL ENSAYO DE TRACCIÓN</b>					
Tipo de Ensayo:	Ensayo de Tracción	Equipo utilizado:	Marca INSTRON modelo 23-100		
Temperatura del Ensayo:	22,5° C.	Tipo de probeta:	Cilíndrica	Norma:	ASTM E370 - 18
		Espec. del material:	Unión de Acero de mediano carbono y baja aleación (Manganeso – Cromo – Molibdeno) con Soldadura EXADUR -43		

Ficha 4-31 - Parámetros generales del ensayo - P-2 – CITOMANGAN [1]

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<b>ENSAYO DE TRACCIÓN</b>						
Tipo de Estudio	De laboratorio		Ensayo N°	2		
Fecha:	03 DE JULIO DEL 2019		Probeta N°	P-2 - CITOMANGAN		
Parte Especificada:	PROBETA CON UNIÓN DE RECARGUE CITOMANGAN					
Solicitado Por:	Ruben Purca	Dirección	Asoc. De Viv Los Olmos Arequipa, Perú			
Centro de estudios y análisis:	Laboratorio de Ingeniería de Materiales de la Universidad Nacional de San Agustín					
Realizado Por:	Ruben Purca	Revisado Por:	Ing. Guido Quispe Ampuero			
<b>PARÁMETROS DEL ENSAYO DE TRACCIÓN</b>						
Tipo de Ensayo:	Ensayo de Tracción	Equipo utilizado:	Marca INSTRON modelo 23-100			
Temperatura del Ensayo:	22,5° C.	Tipo de probeta:	Cilíndrica	Norma:	ASTM E370 - 18	
		Espec. del material:	Unión de Acero de mediano carbono y baja aleación (Manganeso – Cromo – Molibdeno) con Soldadura CITOMANGAN			

Ficha 4-32 - Parámetros generales del ensayo - P-3 - CITODUR 1000 [1]

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<b>ENSAYO DE TRACCIÓN</b>						
Tipo de Estudio	De laboratorio		Ensayo N°	3		
Fecha:	03 DE JULIO DEL 2019		Probeta N°	P-3 - CITODUR 1000		
Parte Especificada:	PROBETA CON UNION DE RECARGUE CITODUR - 1000					
Solicitado Por:	Ruben Purca	Dirección	Asoc. De Viv Los Olmos Arequipa, Perú			
Centro de estudios y análisis:	Laboratorio de Ingeniería de Materiales de la Universidad Nacional de San Agustín					
Realizado Por:	Ruben Purca	Revisado Por:	Ing. Guido Quispe Ampuero			
<b>PARÁMETROS DEL ENSAYO DE TRACCIÓN</b>						
Tipo de Ensayo:	Ensayo de Tracción	Equipo utilizado:	Marca INSTRON modelo 23-100			
Temperatura del Ensayo:	22,5° C.	Tipo de probeta:	Cilíndrica	Norma:	ASTM E370 - 18	
		Espec. del material:	Unión de Acero de mediano carbono y baja aleación (Manganeso – Cromo – Molibdeno) con Soldadura CITODUR - 1000			

Ficha 4-33 - Parámetros generales del ensayo - P-4 - MATERIAL BASE [1]

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<b>ENSAYO DE TRACCIÓN</b>					
Tipo de Estudio	De laboratorio		Ensayo N°	4	
Fecha:	03 DE JULIO DEL 2019		Probeta N°	P-4 MATERIAL BASE	
Parte Especificada:	PROBETA MATERIAL BASE - DIN 32MnCrMo6-4-3 (WNR° 1.7910)				
Solicitado Por:	Ruben Purca	Dirección	Asoc. De Viv Los Olmos Arequipa, Perú		
Centro de estudios y análisis:	Laboratorio de Ingeniería de Materiales de la Universidad Nacional de San Agustín				
Realizado Por:	Ruben Purca	Revisado Por :	Ing. Guido Quispe Ampuero		
<b>PARÁMETROS DEL ENSAYO DE TRACCIÓN</b>					
Tipo de Ensayo:	Ensayo de Tracción	Equipo utilizado:	Marca INSTRON modelo 23-100		
Temperatura del Ensayo:	22,5° C.	Tipo de probeta:	Cilíndrica	Norma:	ASTM E370 - 18
		Espec. del material:	Acero de mediano carbono y baja aleación (Manganeso – Cromo – Molibdeno) - DIN 32MnCrMo 6-4-3 (WNR° 1.7910)		

Ficha 4-34 - Resultado del ensayo de Tracción - P-1 - EXADUR-43 [1]

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<b>ENSAYO DE TRACCIÓN</b>					
Tipo de Estudio		De laboratorio		Ensayo N° 1	
Fecha:		03 DE JULIO DEL 2019		Probeta N° P-1 - EXADUR-43	
<b>PÁRAMETROS DE LA PROBETA PARA EL ENSAYO DE TRACCIÓN</b>					
Longitud total (A):		45 mm			
Diámetro de calibre (D):		8.89 mm			
Longitud de calibre (G):		36.7 mm			
<b>RESULTADOS</b>					
#	Desplazamiento (mm)	$\sigma$ (Mpa)	#	Desplazamiento (mm)	$\sigma$ (Mpa)
1	0.000389538	4.3058	21	1.779716339	173.6795
2	0.104280127	8.2625	22	1.868459929	187.8087
3	0.175738319	11.3304	23	1.957827219	202.189
4	0.264838309	14.9048	24	2.046749009	216.6216
5	0.353938299	18.8509	25	2.135848999	231.3127
6	0.442949189	23.2766	26	2.224948989	246.1565
7	0.532049179	28.1991	27	2.314138079	261.1351
8	0.621238269	33.973	28	2.403148969	276.2548
9	0.710249159	40.7601	29	2.492159859	291.4914
10	0.799616449	48.3904	30	2.581348949	306.7051
11	0.888449139	56.3663	31	2.670359839	322.1874
12	0.977727329	65.1987	32	2.759638029	338.5114
13	1.066649119	74.7986	33	2.812919823	348.3473
14	1.155838209	85.1758	34	2.818889522	349.4576
15	1.244849099	96.3241	35	2.821918922	350.0373
16	1.334038189	108.1593	36	2.824681022	350.5917
17	1.423049079	120.3736	37	2.827710421	351.1038
18	1.512059969	133.0012	38	2.830739821	351.6571
19	1.601338159	146.1199	39	2.83439292	299.5477
20	1.690259949	159.6819	40	2.83670952	202.2854

Ficha 4-35 - Resultado del ensayo de Tracción - P-2 – CITOMANGAN [1]

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<b>ENSAYO DE TRACCIÓN</b>					
Tipo de Estudio		De laboratorio		Ensayo N° 2	
Fecha:		03 DE JULIO DEL 2019		Probeta N° P-2 - CITOMANGAN	
<b>PÁRAMETROS DE LA PROBETA PARA EL ENSAYO DE TRACCIÓN</b>					
Longitud total (A):		45 mm			
Diámetro de calibre (D):		8.86 mm			
Longitud de calibre (G):		38.42 mm			
<b>RESULTADOS</b>					
#	Desplazamiento (mm)	$\sigma$ (Mpa)	#	Desplazamiento (mm)	$\sigma$ (Mpa)
1	0.004247365	4.1526	21	1.544990965	151.3078
2	0.078764565	7.6294	22	1.622445565	164.7109
3	0.156219165	10.3336	23	1.699668265	178.5085
4	0.233519165	13.2295	24	1.776968265	192.5607
5	0.310973765	16.6005	25	1.854190965	206.7741
6	0.388119165	20.6841	26	1.931413665	221.2058
7	0.465573765	25.1537	27	2.008868265	235.8133
8	0.542641865	30.0953	28	2.086090965	250.5839
9	0.620096465	35.6549	29	2.163622865	265.4256
10	0.697241865	42.0011	30	2.240690965	280.3265
11	0.772145565	48.9231	31	2.318068265	295.6841
12	0.849368265	56.5448	32	2.395290965	311.0801
13	0.926668265	64.5538	33	2.472668265	326.5033
14	1.003890965	73.1756	34	2.575709165	346.8155
15	1.083741865	82.9885	35	2.872077365	399.8094
16	1.158568265	92.8919	36	2.977669165	415.076
17	1.235790965	103.637	37	3.070351865	423.9267
18	1.313322865	114.7922	38	3.08411265	322.5679
19	1.390390965	126.4836	39	3.130104765	287.8999
20	1.467768265	138.6266	40	3.292357465	144.2063

Ficha 4-36 - Resultado del ensayo de Tracción - P-3 - CITODUR 1000 [1]

		UNIVERSIDAD CATÓLICA DE SANTA MARIA, ESCUELA PROFESIONAL DE INGENIERIA MECÁNICA, MECÁNICA ELÉTRICA Y MECÁTRONICA			
<b>ENSAYO DE TRACCIÓN</b>					
Tipo de Estudio		De laboratorio		Ensayo N° 3	
Fecha:		03 DE JULIO DEL 2019		Probeta N° P-3 - CITODUR 1000	
<b>PÁRAMETROS DE LA PROBETA PARA EL ENSAYO DE TRACCIÓN</b>					
Longitud total (A):	45 mm				
Diámetro de calibre (D):	8.69 mm				
Longitud de calibre (G):	37.76 mm				
<b>RESULTADOS</b>					
#	Desplazamiento (mm)	$\sigma$ (Mpa)	#	Desplazamiento (mm)	$\sigma$ (Mpa)
1	0.027993863	4.2445	21	2.768102863	192.9217
2	0.158803863	7.4239	22	2.905195863	214.223
3	0.296102863	9.6883	23	3.042803863	236.3763
4	0.433298863	12.3463	24	3.179896863	258.9355
5	0.570803863	14.8511	25	3.317298863	281.9764
6	0.707999863	18.3171	26	3.454700863	305.298
7	0.845298863	22.4626	27	3.591896863	329.4414
8	0.982803863	27.4744	28	3.729504863	354.5905
9	1.119999863	33.0435	29	3.866597863	380.1444
10	1.257401863	39.1407	30	4.003999863	406.3189
11	1.394803863	47.0201	31	4.114003863	427.5889
12	1.531896863	56.6606	32	4.148302863	434.3239
13	1.669504863	67.2162	33	4.186000863	441.6532
14	1.806597863	78.8359	34	4.203098863	445.0481
15	1.943999863	91.5793	35	4.247697863	453.8529
16	2.081401863	105.185	36	4.257894863	455.8514
17	2.218597863	120.172	37	4.275198863	459.2742
18	2.356102863	136.8826	38	4.288897863	461.9911
19	2.493298863	154.3128	39	4.295901863	463.3573
20	2.630700863	172.9446	40	4.304450863	259.2567

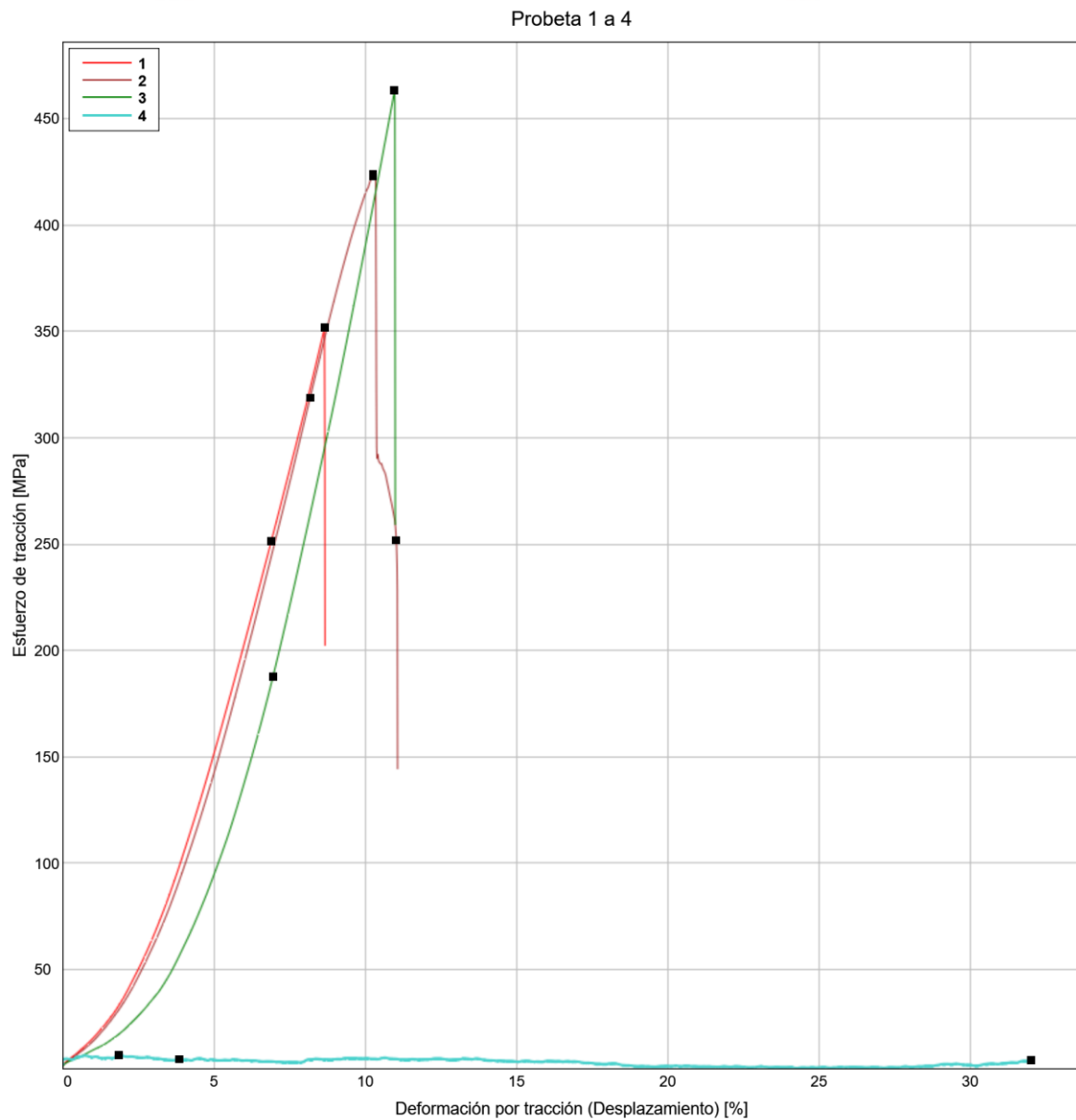


Ficha 4-37 - Resultado del ensayo de Tracción - P-4 - MATERIAL BASE [1]

		UNIVERSIDAD CATÓLICA DE SANTA MARIA, ESCUELA PROFESIONAL DE INGENIERIA MECÁNICA, MECÁNICA ELÉTRICA Y MECÁTRONICA			
<b>ENSAYO DE TRACCIÓN</b>					
Tipo de Estudio		De laboratorio		Ensayo N° 4	
Fecha:		03 DE JULIO DEL 2019		Probeta N° P-4 MATERIAL BASE	
<b>PÁRAMETROS DE LA PROBETA PARA EL ENSAYO DE TRACCIÓN</b>					
Longitud total (A):		45 mm			
Diámetro de calibre (D):		7.95 mm			
Longitud de calibre (G):		61.64 mm			
<b>RESULTADOS</b>					
#	Desplazamiento (mm)	$\sigma$ (Mpa)	#	Desplazamiento (mm)	$\sigma$ (Mpa)
1	0.0021321	4.28683219	21	1.7258883	468.9324339
2	0.00142395	8.83650244	22	1.81016025	504.0485177
3	0.17192735	13.02631789	23	1.89784105	507.6721038
4	0.2581842	17.56525753	24	1.9842705	511.8728666
5	0.34444105	23.99137546	25	2.07044105	516.9898501
6	0.4307842	32.34542632	26	2.15674105	524.159957
7	0.51704105	42.06876805	27	2.24312735	532.8886037
8	0.6032979	55.60028404	28	2.32942735	543.5149425
9	0.6895979	72.4998025	29	2.41572735	558.3818233
10	0.7758979	91.78368418	30	2.5020705	575.9088115
11	0.8621979	113.6541848	31	2.5882842	596.1194277
12	0.94854105	138.7949202	32	2.6744979	618.7097463
13	1.0347979	166.9038072	33	2.76084105	645.1366374
14	1.12114105	197.7122557	34	2.8759221	684.1616981
15	1.20752735	231.840473	35	2.9277021	703.5670036
16	1.29374105	268.0476106	36	3.0183171	693.4900937
17	1.38004105	305.2783833	37	3.03415315	693.0484045
18	1.4662979	343.4344814	38	3.05710895	669.3379836
19	1.55264105	383.9848063	39	3.0585329	613.0803219
20	1.63885475	425.8578143	40	3.06	511.8165308

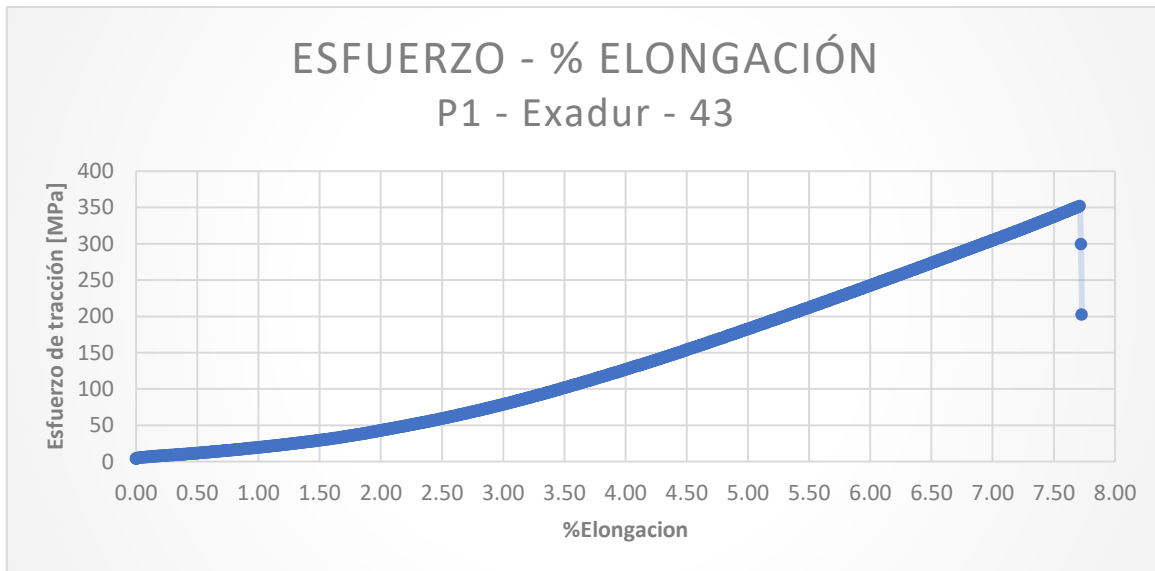
#### 4.4.1. Interpretación de resultados

La siguiente Gráfica 4-5 nos muestra la representación Esfuerzo Deformación de las 03 probetas realizada por el equipo INSTRON modelo 23-100 según los datos obtenidos de los ensayos.



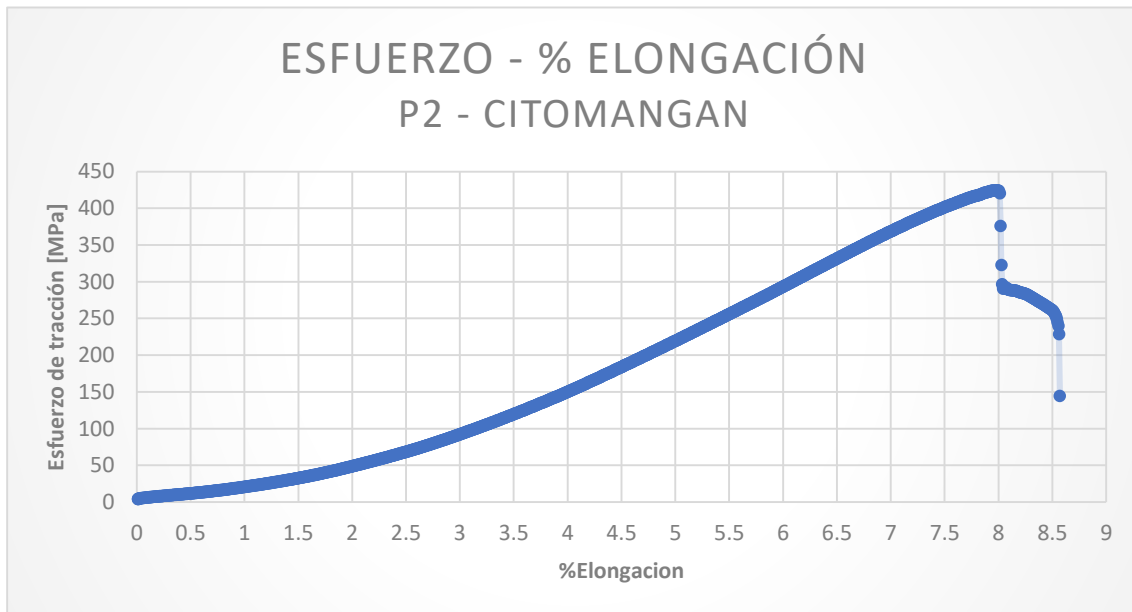
Gráfica 4-5 - Esfuerzo - Deformación P1 - P3 [1]

Se elaboró un conjunto de Gráficas del 4-6 al 4-9. En ellas se representa las curvas esfuerzo vs % elongación para cada material.



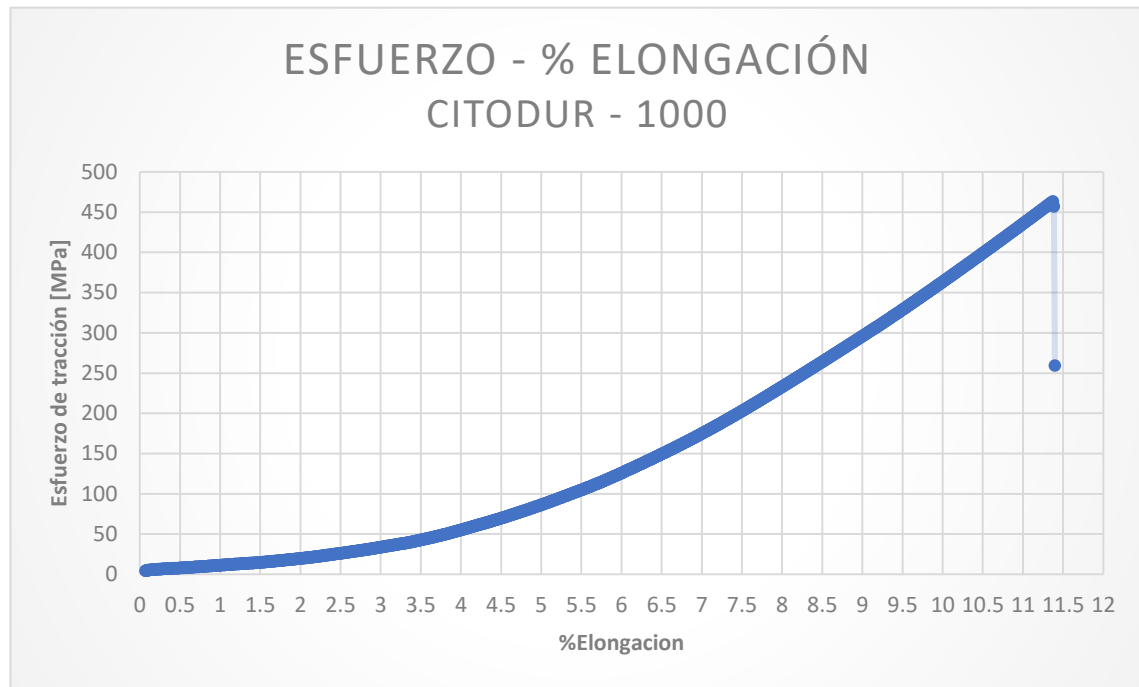
Gráfica 4-6 - Curva de esfuerzo - % elongación P1 - EXADUR - 43 [1]

La deformación de esta probeta es considerada uniforme hasta la carga máxima de 351.66 Mpa, esta probeta no cuenta con deformación plástica y por ende no cuenta con resistencia a la tracción en esta etapa. Se puede observar también que el esfuerzo pasa de la etapa cedencia a la ruptura directamente. El esfuerzo de la ruptura para esta probeta fue de 202.28 Mpa



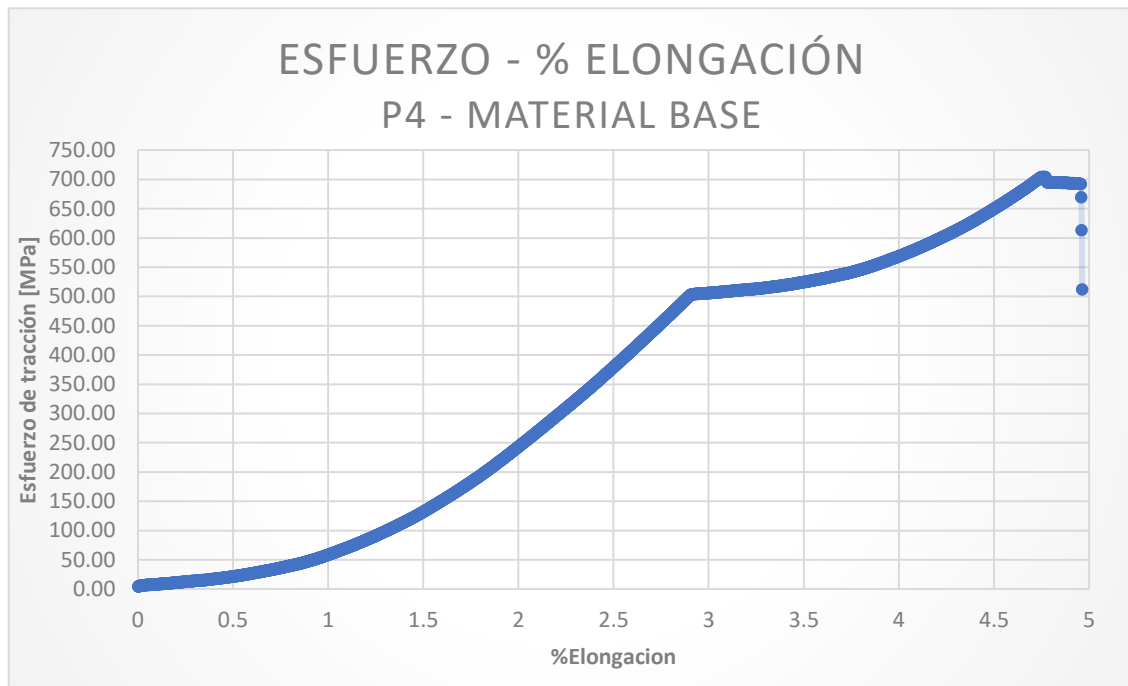
Gráfica 4-7 - Curva de esfuerzo - % elongación P2 – CITOMANGAN [1]

La deformación de esta probeta es considerada uniforme hasta la carga máxima de 424.00 Mpa, esta probeta no cuenta con fluencia, pero cuenta con alargamiento homogéneo hasta el esfuerzo 228.39 Mpa, el esfuerzo donde se produce la ruptura para esta probeta fue de 144.20 Mpa



Gráfica 4-8 - Curva de esfuerzo - % elongación P3 – CITODUR – 1000 [1]

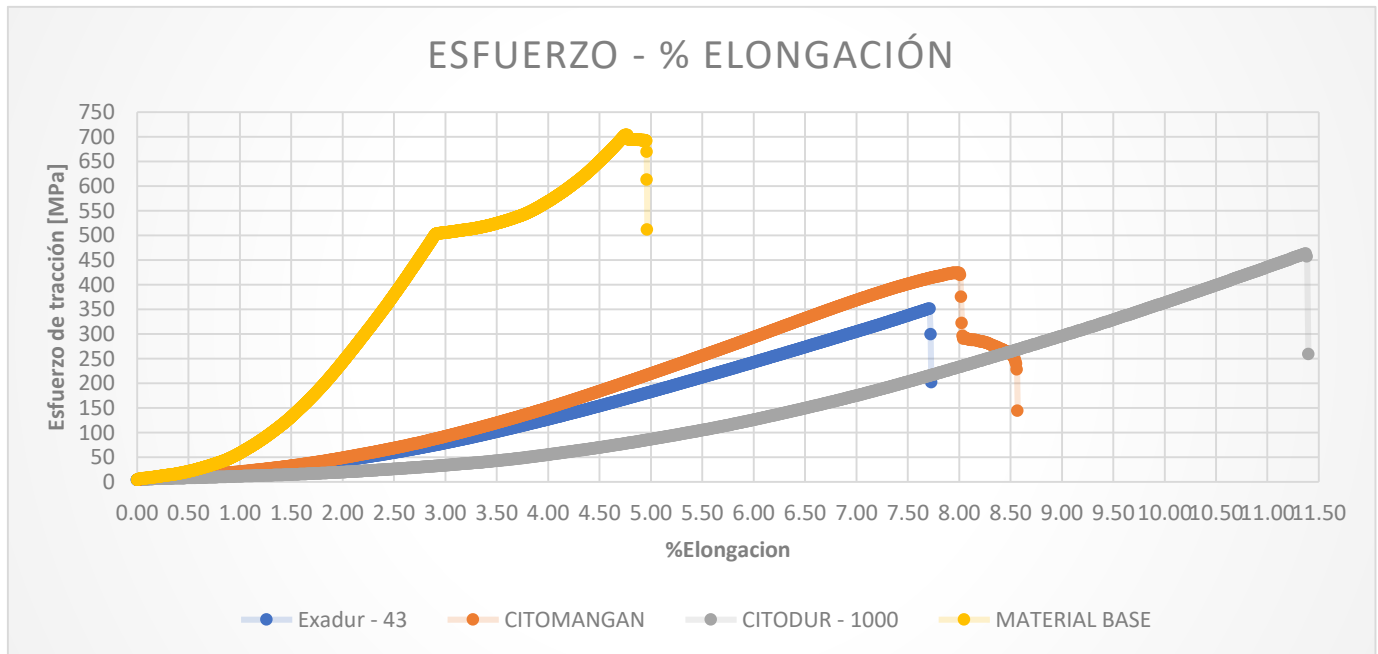
La deformación de esta probeta es considerada uniforme hasta la carga máxima de 463.36 Mpa, esta probeta no cuenta con deformación plástica y por ende no cuenta con resistencia a la tracción en esta etapa. Se puede observar también que el esfuerzo pasa de la etapa cedencia a la ruptura directamente. El esfuerzo de la ruptura para esta probeta fue de 259.2567 Mpa



Gráfica 4-9 - Curva de esfuerzo - % elongación P4 – MATERIAL BASE [1]

La deformación de esta probeta es considerada uniforme hasta la carga máxima de 502.42 Mpa, esta probeta cuenta con zona de fluencia hasta el esfuerzo 703.56 Mpa, también cuenta con alargamiento homogéneo hasta el esfuerzo 613.08 Mpa, el esfuerzo donde se produce la ruptura para esta probeta fue de 511.8165 Mpa.

Se elaboró la Gráfica 4-10, que representa las curvas esfuerzo vs % elongación de los materiales ensayados.



Gráfica 4-10 - Curva de esfuerzo - % elongación P1-P2-P3-P4 [1]

Se puede observar en la Gráfica 4-10 que la probeta P4 Material Base presenta el mayor esfuerzo a la tracción con 703.56 Mpa, seguido de P3 C-1000 con 463.36 Mpa, seguido de la probeta P2 – Citomangan con 424.00 Mpa y por último se tiene a la probeta P1 – EXADUR 43 con 351.66 Mpa. Se observa también que la probeta que mas sufrió de Elongación fue la probeta P3 C – 1000 con un % 11.40 y la que menos sufrió de elongación fue la probeta P4 – Material Base con % 4.96 de elongación.

En la siguiente Tabla 4-7 se muestra los datos iniciales de las probetas ensayadas a tracción.

Tabla 4-7 - Datos iniciales probetas de tracción [1]

Probeta		Diámetro Inicial (mm)	Longitud Inicial (mm)	Área (mm <sup>2</sup> ) Inicial
1	<b>Exadur 43</b>	8.89	36.7	62.07
2	<b>Citomangan</b>	8.86	38.42	61.65
3	<b>C 1000</b>	8.69	37.76	59.31
4	<b>Material Base</b>	7.95	61.64	49.64

Culminado los ensayos de tracción, se midió las probetas y se obtuvo los siguientes datos de la siguiente Tabla 4-8.

Tabla 4-8 - Datos finales probetas de tracción [1]

Probeta		Diámetro Final (mm)	Longitud Final (mm)
1	<b>Exadur 43</b>	8.71	39.54
2	<b>Citomangan</b>	8.62	41.71
3	<b>C 1000</b>	8.47	42.1
4	<b>Material Base</b>	7.85	64.7

Con los datos de la Tabla 4-8, se obtiene la Porcentaje de alargamiento o Deformación porcentual total y el % Reducción área (estricción) en la siguiente Tabla 4-9.

Tabla 4-9 - Datos finales probetas de tracción [1]

Probeta		Elongación	Estricción
		%	%
1	<b>Exadur 43</b>	7.73	2.02
2	<b>Citomangan</b>	8.57	2.71
3	<b>C 1000</b>	11.4	2.53
4	<b>Material Base</b>	4.96	1.26



Los Resultados de la Fuerza Máxima y Resistencia a la tracción del ensayo a la tracción se muestra en la siguiente Tabla 4-10.

Tabla 4-10 - Resultados Fuerza Máxima y Resistencia a la tracción [1]

Probeta		Fuerza Máxima N	Resistencia a la Tracción MPA
1	Exadur 43	21827.94	351.67
2	Citomangan	26140.48	424.01
3	C 1000	27481.82	463.36
4	Material Base	34923.6	703.55

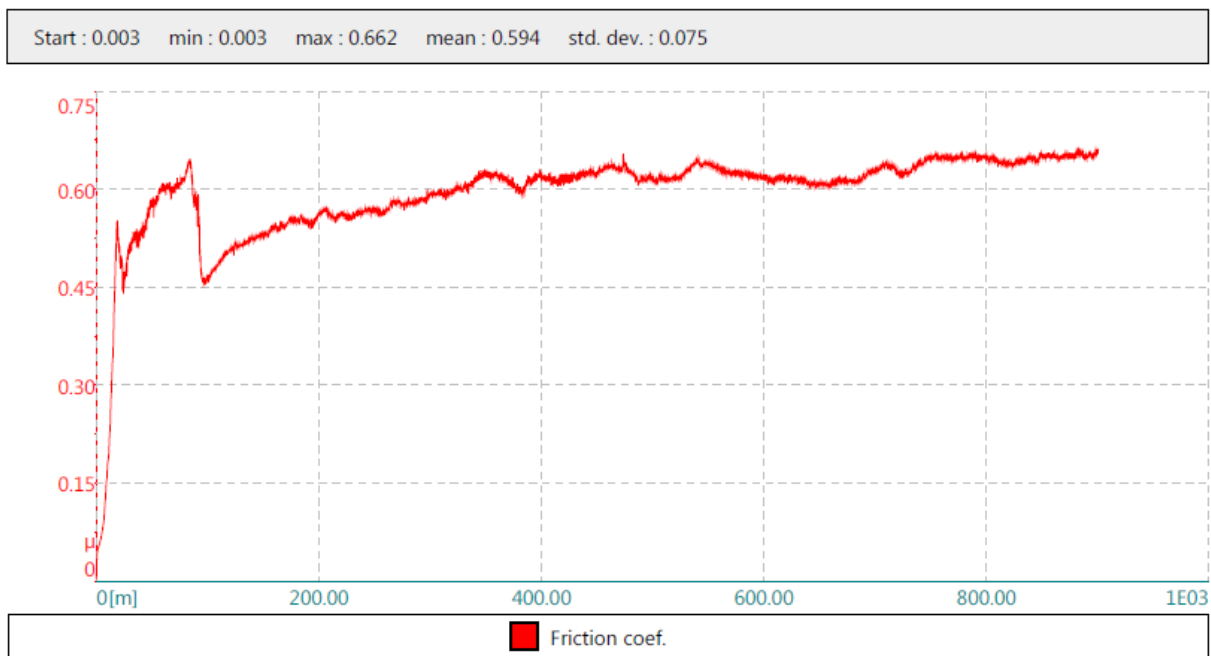
Con los resultados de la Fuerza Máxima, Resistencia a la tracción, el % de Elongación y el % Reducción área. Se obtuvo el Módulo de Young E y Coeficiente de Poisson  $\nu$  para cada Probeta en la siguiente Tabla 4-11.

Tabla 4-11 - Resultados Modulo de Young y Coeficiente de Poisson [1]

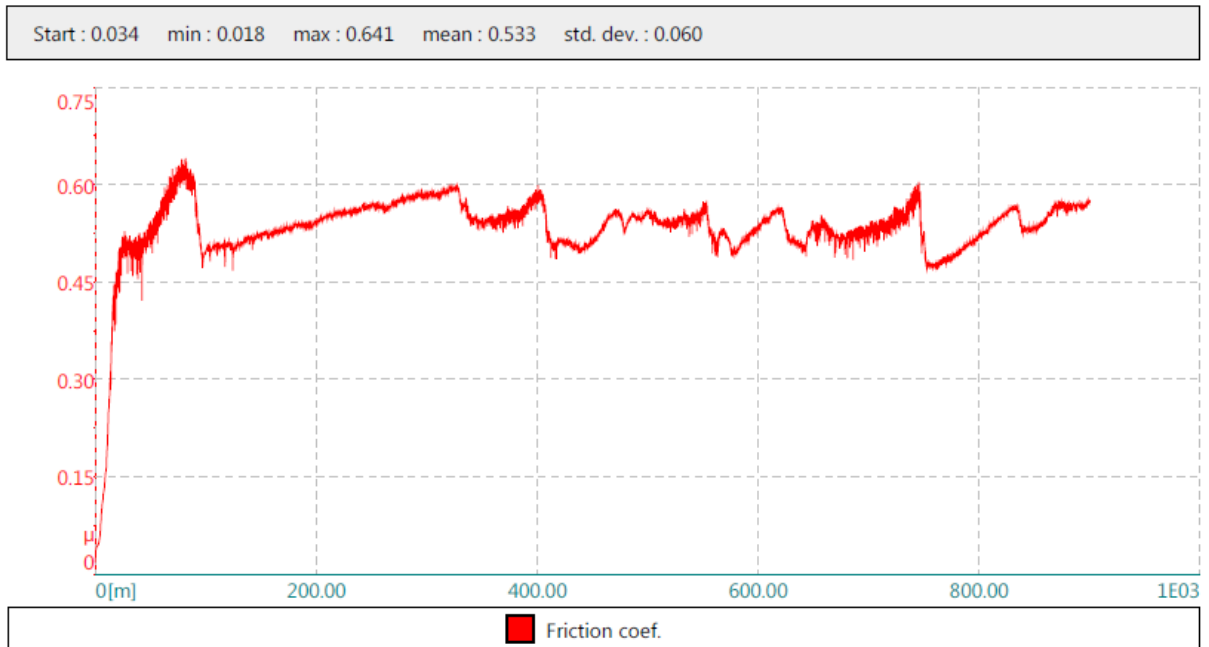
Probeta		Módulo de Young E	Coeficiente de Poisson $\nu$
1	Exadur 43	4549.683	0.262
2	Citomangan	4947.858	0.316
3	C 1000	4064.816	0.222
4	Material Base	14172.51	0.253

#### 4.5. Ensayo de desgaste

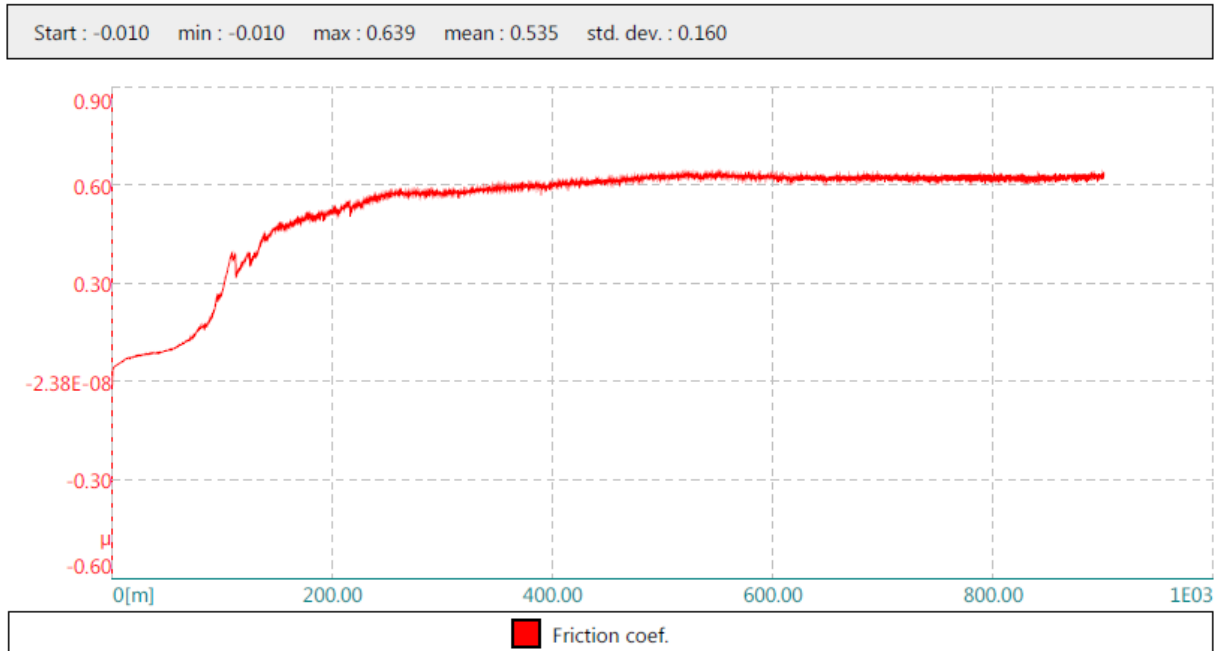
Los ensayos de resistencia al desgaste se han realizado mediante el método Pin on disk, bajo la norma “Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus”, determinándose el coeficiente de desgaste a partir de la pérdida de masa experimentada por la muestra. También, se obtuvo el coeficiente de fricción desarrollado a lo largo de los ensayos que se muestra en la Gráfica 4-11 a la Gráfica 4-14.



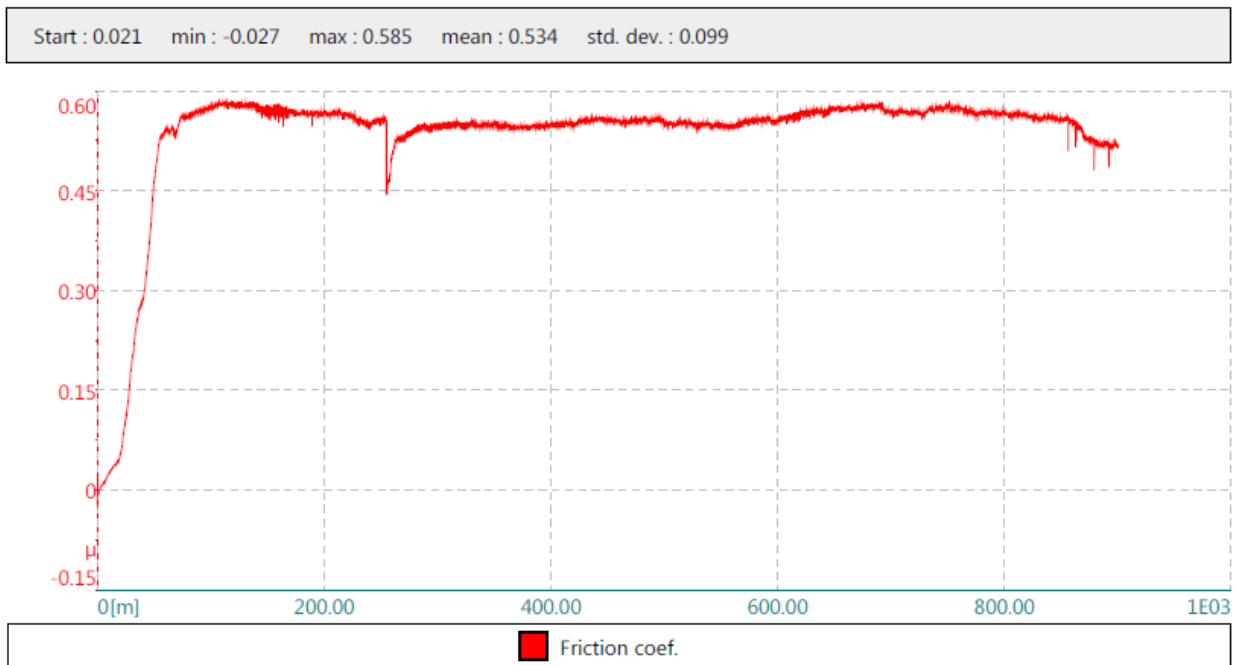
Gráfica 4-11 - Coeficiente de fricción en función a la distancia recorrida – Material Base [1]



Gráfica 4-12 - Coeficiente de fricción en función a la distancia recorrida – Citomangan [1]



Gráfica 4-13 - Coeficiente de fricción en función a la distancia recorrida – Exadur – 43 [1]



Gráfica 4-14 - Coeficiente de fricción en función a la distancia recorrida – Citodur 1000 [1]

La Gráfica 4-11 representa el coeficiente de fricción realizado en el ensayo del Material Base sin recubrimiento. Puede observarse cómo el valor del coeficiente de fricción tiene un comportamiento ascendente hasta la distancia 120 m aproximadamente, en donde también llega al punto más alto de coeficiente de fricción, a partir de la distancia 150 m permanece constante a lo largo del ensayo. El valor medio que nos da el equipo fue de  $\mu = 0.594$

La Gráfica 4-12 representa el coeficiente de fricción realizado en el ensayo del recubrimiento con Recargue Citomangan. Puede observarse cómo el valor del coeficiente de fricción fluctúa entre los valores 0.60 y 0.45 durante todo el ensayo. El valor medio que nos da el equipo fue de  $\mu = 0.533$

La Gráfica 4-13 representa el coeficiente de fricción realizado en el ensayo del recubrimiento con Recargue Exadur – 43. Puede observarse cómo el valor del coeficiente de fricción tiene un comportamiento ascendente hasta la distancia 220 m aproximadamente, a partir de esa distancia permanece constante a lo largo del ensayo. El valor medio que nos da el equipo fue de  $\mu = 0.535$

La Gráfica 4-14 representa el coeficiente de fricción realizado en el ensayo del recubrimiento con Recargue Citodur - 1000. Puede observarse cómo el valor del coeficiente de fricción tiene un comportamiento ascendente hasta la distancia 80 m aproximadamente, a partir de esa distancia permanece constante a lo largo del ensayo. El valor medio que nos da el equipo fue de  $\mu = 0.534$

#### 4.5.1. Resultados de ensayo de desgaste

En la siguiente tabla se muestra los resultados de los pesajes iniciales de las muestras, así también de las billas de wolframio de tungsteno (Tablas 4-12, 4-13) respectivamente.

Tabla 4-12 - Resultados de pesaje inicial y final de probetas de desgaste [1]

Probeta	Masa inicial (g)	Masa Final (g)
Material Base	22.5312	22.5304
Citomangan (A)	42.1089	42.1082
Exadur - 43 (B)	40.8777	40.8773
Citodur 1000 (C)	39.9690	39.9685

Tabla 4-13 - Resultados de pesaje inicial y final de billas de WC [1]

Identador (Wc)	Masa inicial (g)	Masa Final (g)
Billa 1 (BASE)	1.6891	1.6887
Billa 2 (A)	1.6883	1.6882
Billa 3 (B)	1.6876	1.6875
Billa 4 (C)	1.6880	1.6879

Teniendo las masas, se procede a calcular el coeficiente de desgaste utilizando la siguiente ecuación 4-1.

$$k = \frac{W}{FN \cdot S} \quad \text{Ec 4-1}$$

Donde:

k = El coeficiente de desgaste

W = Volumen desgastado.

FN = Es la fuerza normal

S = Es la distancia lineal Total

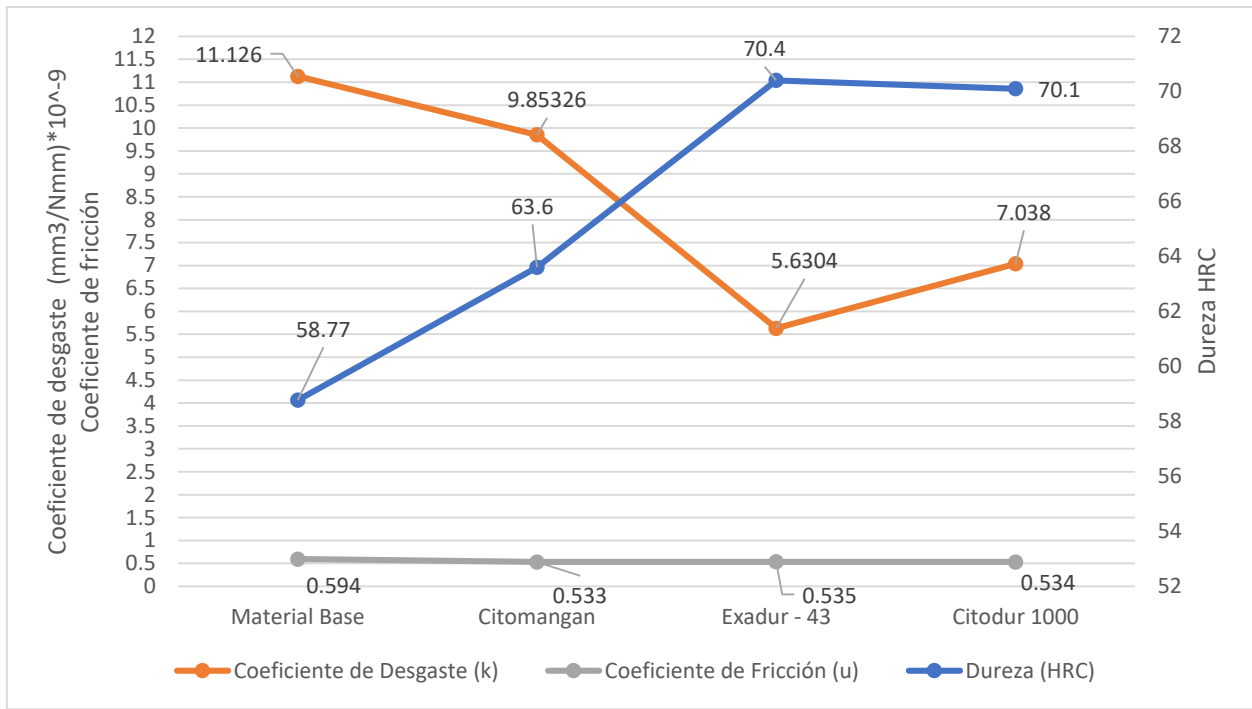
Los resultados de coeficiente de desgaste a partir de la pérdida de peso se muestran en la siguiente Tabla 4-14:

Tabla 4-14 - Resultados de coeficiente de desgaste [1]

Probeta	Masa inicial	Masa Final	Diff Masa	volumen loss, mm <sup>3</sup> por Masa	k mm <sup>3</sup> /N*mm
Material Base	22.5312	22.5304	0.0008	0.1019108	1.12609E-08
Citomangan	42.1089	42.1082	0.0007	0.089172	9.85326E-09
Exadur 43	40.8777	40.8773	0.0004	0.0509554	5.63043E-09
Citodur 1000	39.969	39.9685	0.0005	0.0636943	7.03804E-09

En la siguiente Gráfica 4-15 se muestran los resultados obtenidos de los ensayos de desgaste de todas las probetas, en función del coeficiente de desgaste calculado, junto con el resultado del valor medio del coeficiente de fricción y la dureza Rockwell de cada una

de las probetas ensayados. Los datos representados gráficamente son los valores medios obtenidos en cada ensayo.



Gráfica 4-15 - Resultados de ensayos de desgaste [1]

Se puede observar en la gráfica que la probeta con menos desgaste fue el que tuvo recargue de soldadura con  $5.63 \cdot 10^{-9}$ , cabe resalta que esta probeta posee la mayor dureza de todas, con 70.4 HRC en promedio. La probeta con más desgaste con recargue fue la de Citomangan con  $9.85 \cdot 10^{-9}$ , esta probeta posee la menor dureza de las probetas con recargue con 63.6 HRC. La probeta sin recargue obtuvo un desgaste de  $11.26 \cdot 10^{-9}$ , esta probeta obtuvo la menor dureza de todas las probetas con 58.77 HRC.

También se puede observar que no hay mucha variación en el coeficiente de fricción entre todas las probetas, siendo el valor más alto 0.594 que corresponde a la probeta de Material Base, y el menor 0.533 que corresponde a la probeta con recargue de Citomangan.

#### 4.5.2. Perfil de Huella de Wear Track

Se tiene las siguientes Figuras 4-6 al 4-9, donde se puede observar las modelizaciones de profundidad de la pista de desgaste de las probetas de desgaste ensayadas.

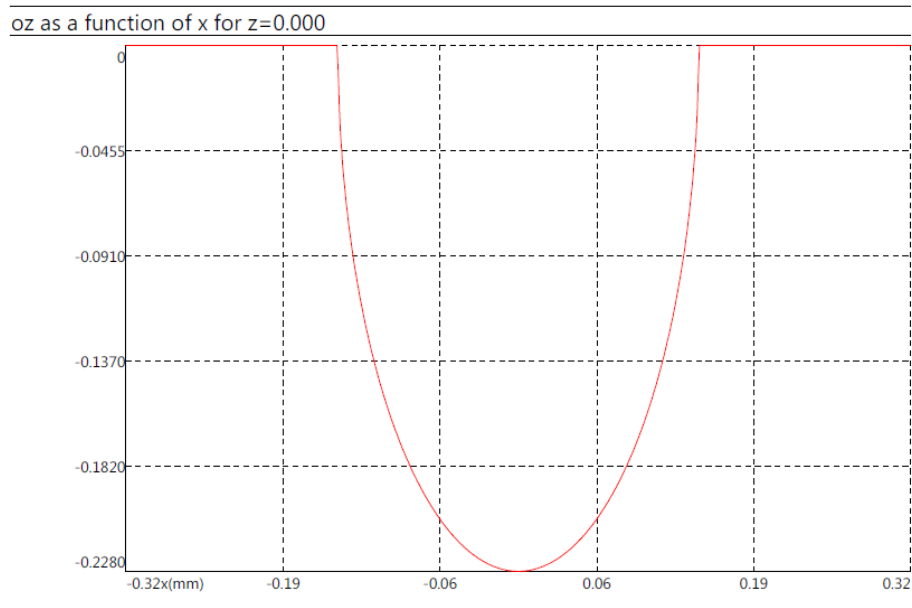


Figura 4-6 - Modelización de pista de desgaste – Material Base [1]

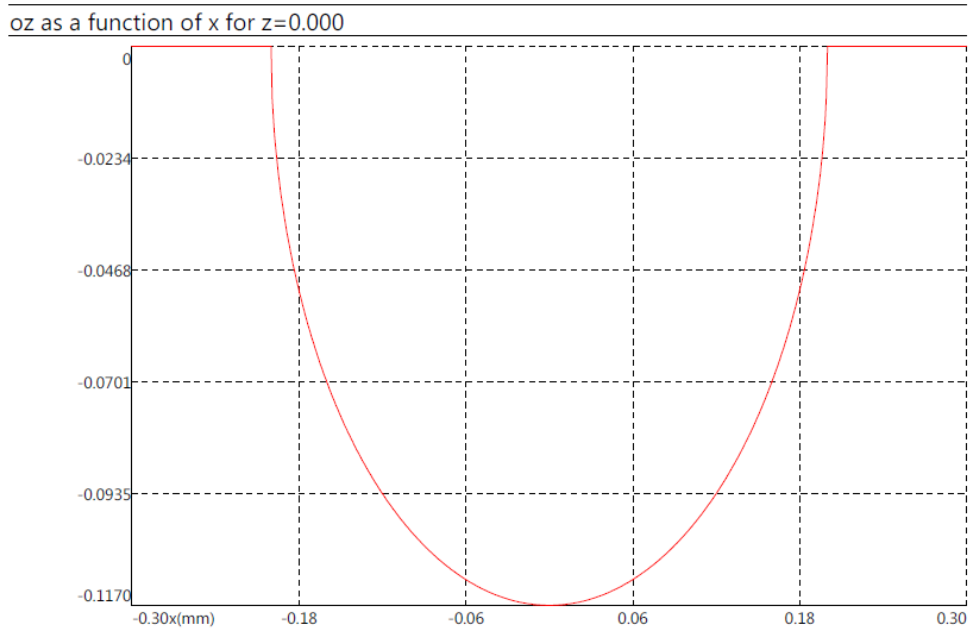


Figura 4-7 - Modelización de pista de desgaste – Citomangan [1]



oz as a function of x for z=0.000

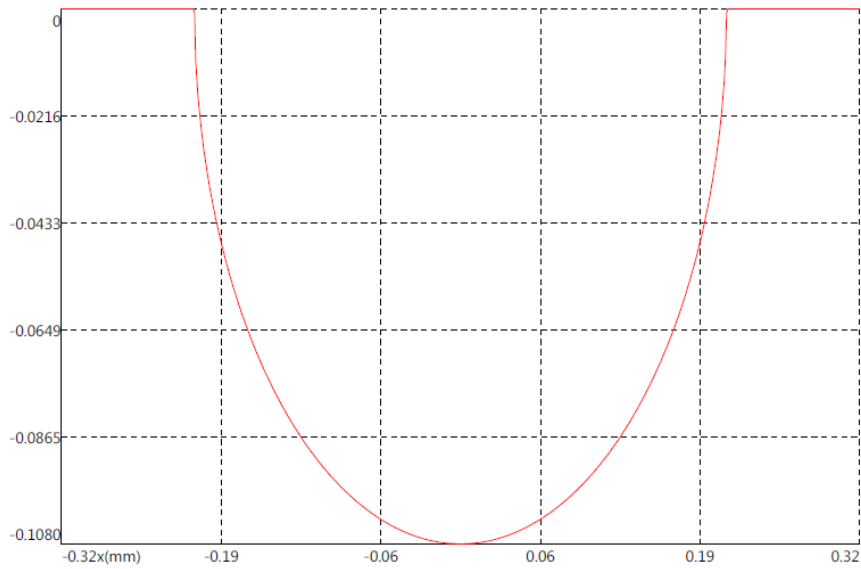


Figura 4-8 - Modelización de pista de desgaste – Exadur – 43 [1]

oz as a function of x for z=0.000

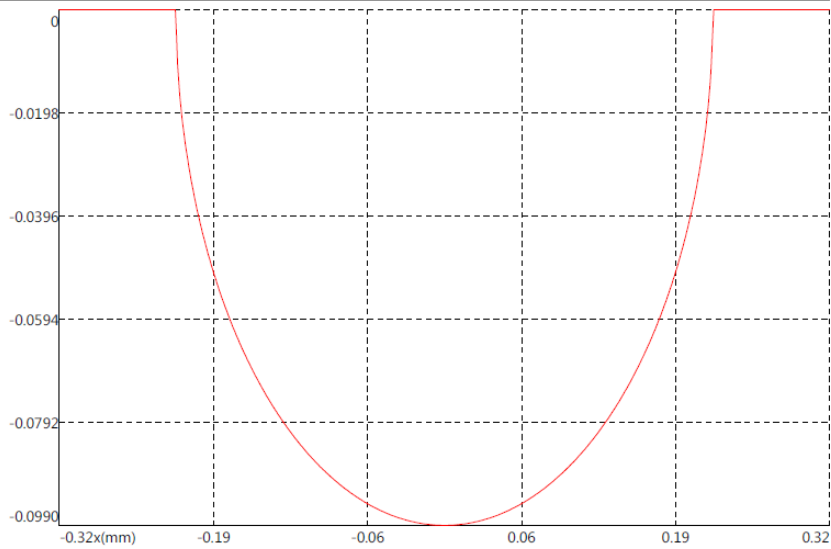


Figura 4-9 - Modelización de pista de desgaste – Citodur – 1000 [1]

#### 4.5.3. Medidas de Wear Track y Billa de WC

En las siguientes Figuras 4-10 al 4-17, se puede observar la longitud de la pista de desgaste de las probetas de desgaste y las billas de WC.

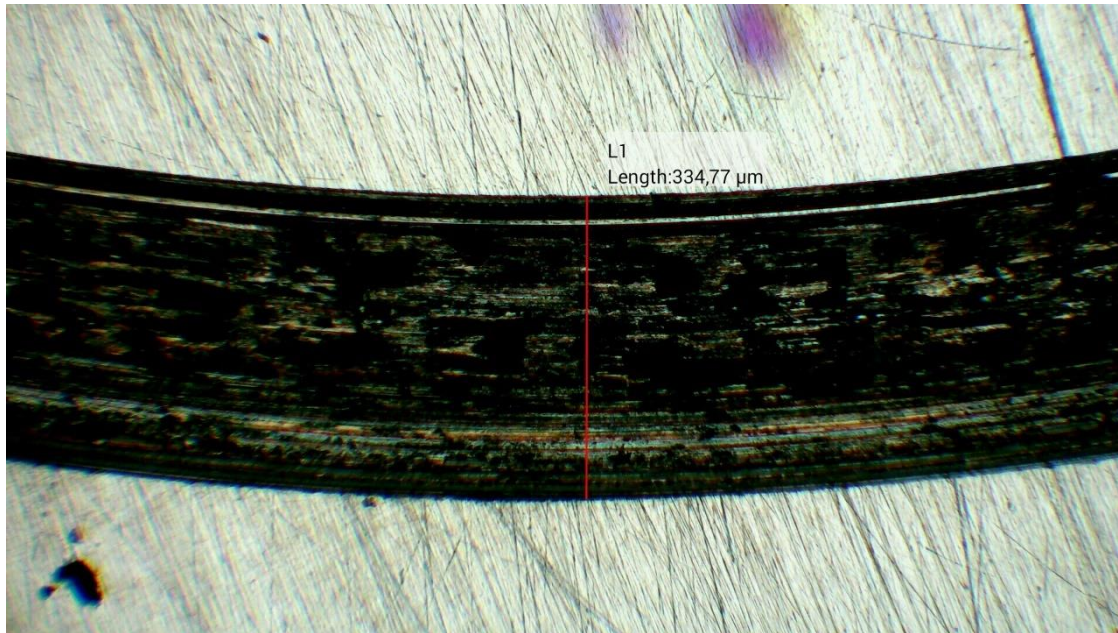


Figura 4-10 - Medida de pista de desgaste – Material Base [1]



Figura 4-11 - Medida de desgaste Billa de WC con Material Base [1]

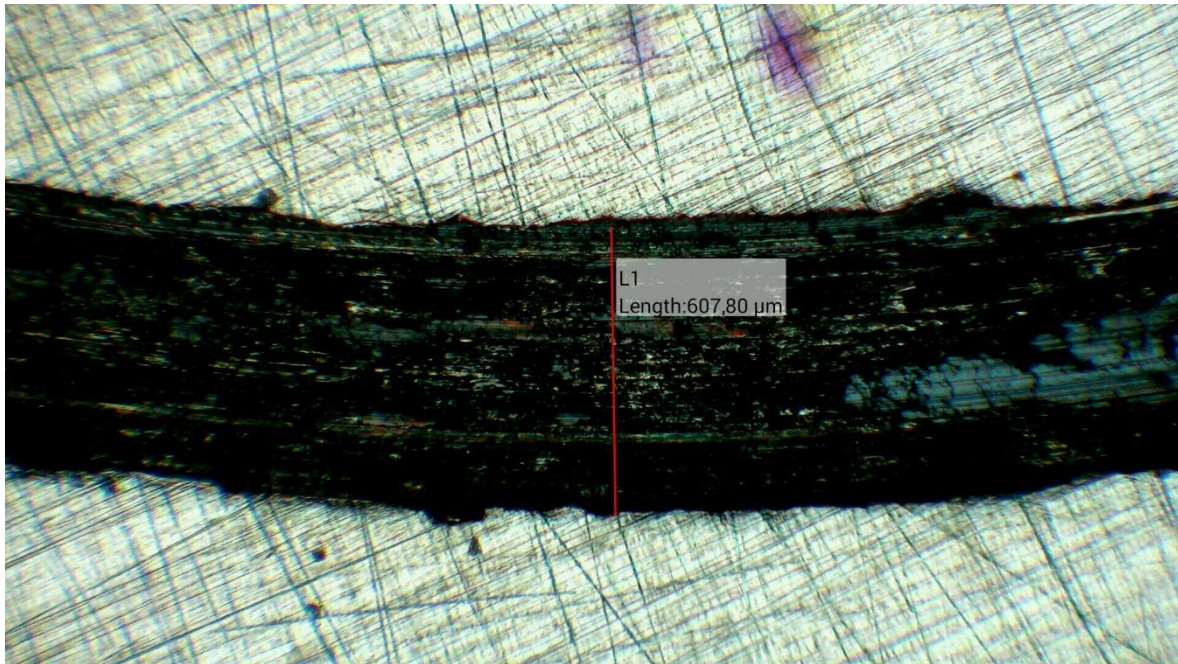


Figura 4-12 - Medida de pista de desgaste – Citomangan [1]

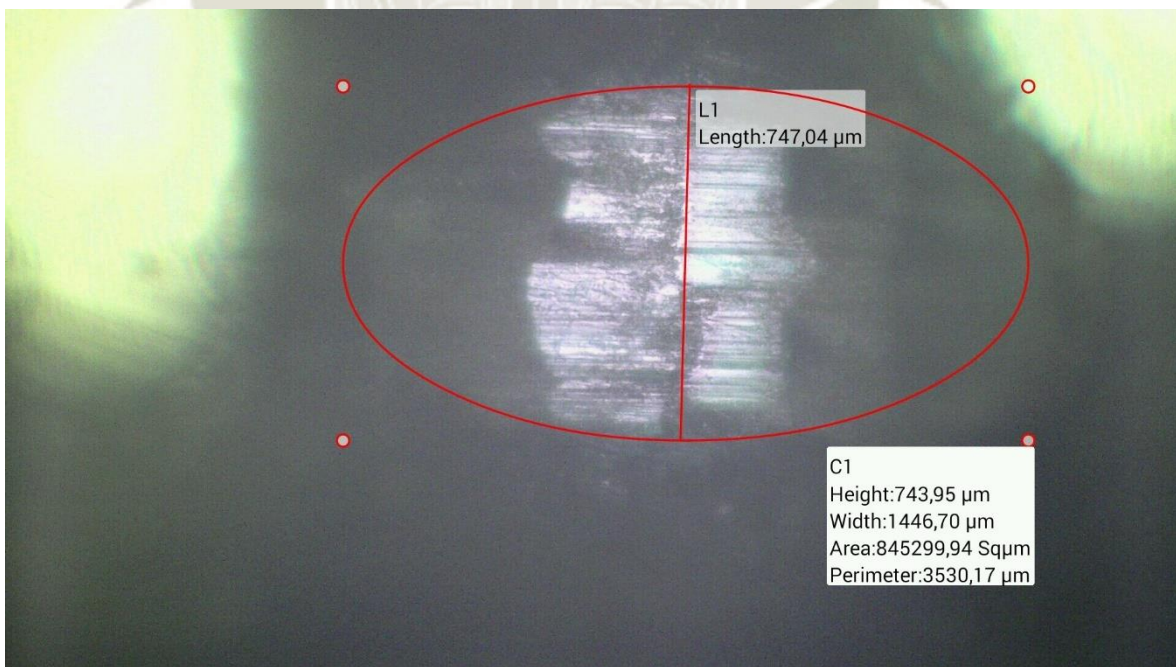


Figura 4-13 - Medida de desgaste Billa de WC con Citomangan [1]

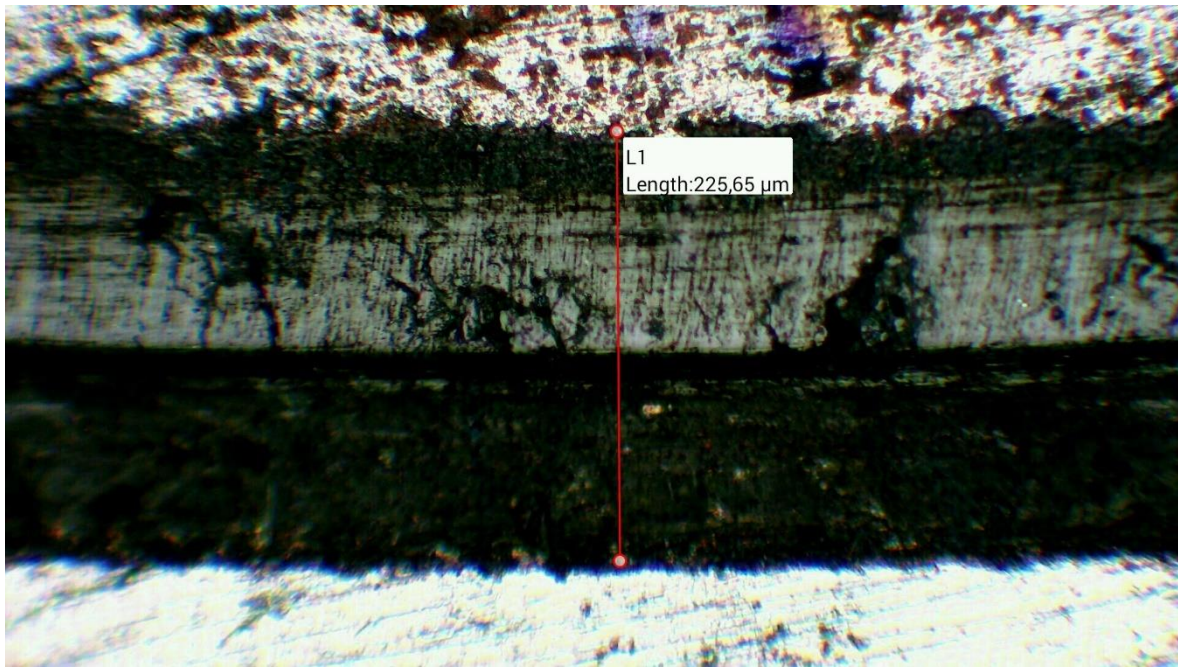


Figura 4-14 - Medida de pista de desgaste – Exadur – 43 [1]



Figura 4-15 - Medida de desgaste Billa de WC con Exadur – 43 [1]

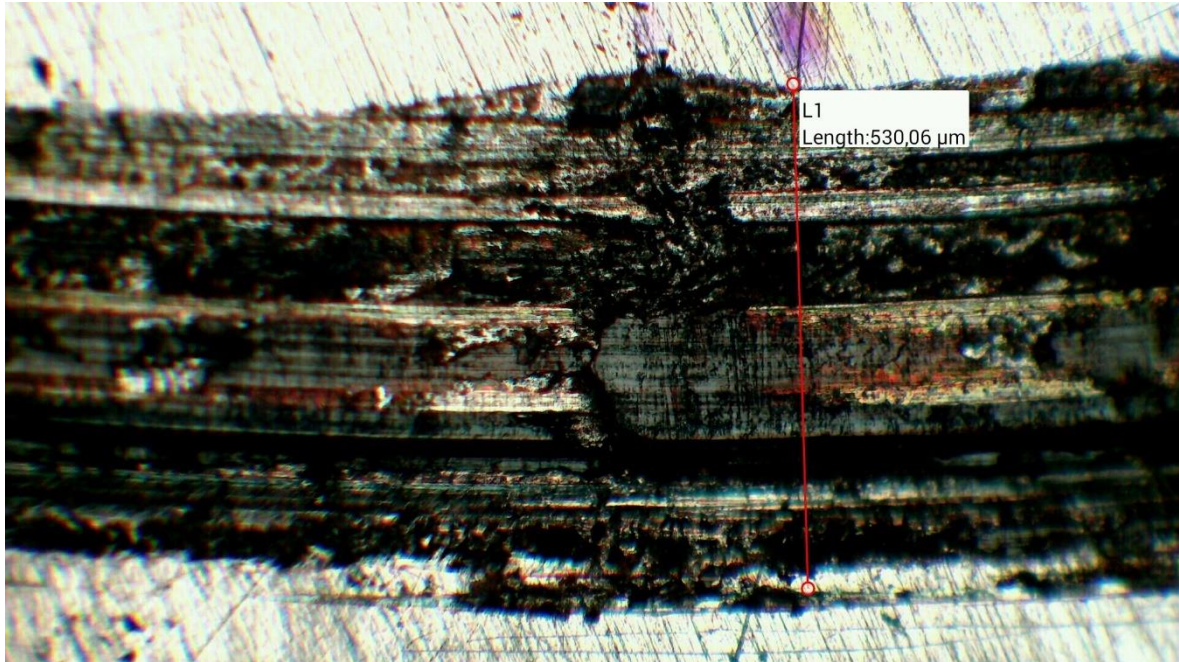


Figura 4-16 - Medida de pista de desgaste – Citodur – 1000 [1]



Figura 4-17 - Medida de desgaste Billa de WC con Citodur – 1000 [1]

De las Figuras 4-10 al 4-17, se puede observar que el recubrimiento que más desgaste obtuvo es del recargue de Citomangan, con una longitud de Wear Track 607.80 micras, y la que menos desgaste obtuvo es del recargue Exadur – 43 con 225.66 micras.

Del resultado de las modelizaciones de profundidad, las medidas de longitud de Wear Track y las billas de WC, el software InstrumX nos da como resultado los siguientes coeficientes de desgaste que se visualiza en las siguientes Figuras 4-18 al 4-21.

## Base

### Standard parameters

#### Instrument

- Standard tribometer
- Serial number: 1000059319
- Tribometer / Version 7.3.17
- Date of measurement: 8/1/2019 1:43:48 PM

#### Static partner

- Coating: -
- Substrate: WC
- Dimension: 6.00 [mm]
- Geometry: Ball

#### Sample

- Coating: -
- Substrate: Base 2
- Cleaning: -
- Supplier: -

#### Environment

- Temperature: 20.50 [°C]
- Atmosphere: Air
- Humidity: 10.00 [%]

#### Sequence

- Sequence count: 1
- Single-way mode
- Radius: 8.00 [mm]
- Lin. Speed: 25.00 [cm/s]
- Acquisition rate: 5.0 [Hz]
- Cycles sampled: 1/1
- Pause: 0 [s]
- Homing at begin: Yes
- Normal load: 10.00 [N]
- Unload at end: No
- Stop condit.: 905.00 [m]  
Or  $\mu > 0.80$
- Effective Stop: Meters

Sample	Static partner	Calculations
Worn track section: 76997.1 [ $\mu\text{m}^2$ ]	Worn cap diameter: 897.4 [ $\mu\text{m}$ ]	Sample Wear Rate: 0.0004277 [ $\text{mm}^3/\text{N/m}$ ]
Young's Modulus: 14.2 [GPa]	Young's Modulus: 600.0 [GPa]	Partner Wear Rate: 1.182E-006 [ $\text{mm}^3/\text{N/m}$ ]
Poisson ratio: 0.250	Poisson ratio: 0.300	Max Herzian Stress: 0.3607 [GPa]

Start : 0.003    min : 0.003    max : 0.662    mean : 0.594    std. dev. : 0.075

Figura 4-18 - Resultado coeficiente de desgaste Material Base [1]

### Muestra A - Citomangan

#### Standard parameters

##### Instrument

- Standard tribometer
- Serial number: 1000059319
- Tribometer / Version 7.3.17
- Date of measurement: 7/31/2019 4:34:40 PM

##### Static partner

- Coating: -
- Substrate: WC
- Dimension: 6.00 [mm]
- Geometry: Ball

##### Sample

- Coating: -
- Substrate: Muestra A
- Cleaning: -
- Supplier: -

##### Environment

- Temperature: 21.20 [°C]
- Atmosphere: Air
- Humidity: 10.00 [%]

##### Sequence

- Sequence count: 1
- Single-way mode
- Radius: 8.01 [mm]
- Lin. Speed: 25.00 [cm/s]
- Acquisition rate: 5.0 [Hz]
- Cycles sampled: 1/1
- Pause: 0 [s]
- Homing at begin: Yes
- Normal load: 10.00 [N]
- Unload at end: No
- Stop condit.: 905.00 [m]  
Or  $\mu > 0.80$
- Effective Stop: Meters

Sample	Static partner	Calculations
Worn track section: 72936.0 [ $\mu\text{m}^2$ ] Young's Modulus: 5.0 [GPa] Poisson ratio: 0.320	Worn cap diameter: 747.0 [ $\mu\text{m}$ ] Young's Modulus: 600.0 [GPa] Poisson ratio: 0.300	Sample Wear Rate: 0.0004056 [ $\text{mm}^3/\text{N}/\text{m}$ ] Partner Wear Rate: 5.661E-007 [ $\text{mm}^3/\text{N}/\text{m}$ ] Max Herzian Stress: 0.186 [GPa]

Start : 0.034 min : 0.018 max : 0.641 mean : 0.533 std. dev. : 0.060

Figura 4-19 - Resultado coeficiente de desgaste Citomangan [1]

### Muestra B - Exadur - 43

#### Standard parameters

##### Instrument

- Standard tribometer
- Serial number: 1000059319
- Tribometer / Version 7.3.17
- Date of measurement: 8/1/2019 3:13:30 PM

##### Static partner

- Coating: -
- Substrate: WC
- Dimension: 6.00 [mm]
- Geometry: Ball

##### Sample

- Coating: -
- Substrate: Muestra B2
- Cleaning: -
- Supplier: -

##### Environment

- Temperature: 20.50 [°C]
- Atmosphere: Air
- Humidity: 10.00 [%]

##### Sequence

- Sequence count: 1
- Single-way mode
- Radius: 8.01 [mm]
- Lin. Speed: 25.00 [cm/s]
- Acquisition rate: 5.0 [Hz]
- Cycles sampled: 1/1
- Pause: 0 [s]
- Homing at begin: Yes
- Normal load: 10.00 [N]
- Unload at end: No
- Stop condit.: 905.00 [m]  
Or  $\mu > 0.80$
- Effective Stop: Meters

Sample	Static partner	Calculations
Worn track section: 24821.5 [ $\mu\text{m}^2$ ] Young's Modulus: 4.6 [GPa] Poisson ratio: 0.260	Worn cap diameter: 634.3 [ $\mu\text{m}$ ] Young's Modulus: 600.0 [GPa] Poisson ratio: 0.300	Sample Wear Rate: 0.000138 [ $\text{mm}^3/\text{N}/\text{m}$ ] Partner Wear Rate: 2.937E-007 [ $\text{mm}^3/\text{N}/\text{m}$ ] Max Herzian Stress: 0.1715 [GPa]

Figura 4-20 - Resultado coeficiente de desgaste Exadur - 43 [1]

## Muestra C - Citodur - 1000

### Standard parameters

#### Instrument

- Standard tribometer
- Serial number: 1000059319
- Tribometer / Version 7.3.17
- Date of measurement: 8/1/2019 12:33:36 PM

#### Static partner

- Coating: -
- Substrate: WC
- Dimension: 6.00 [mm]
- Geometry: Ball

#### Sample

- Coating: -
- Substrate: Muestra C
- Cleaning: -
- Supplier: -

#### Environment

- Temperature: 20.50 [°C]
- Atmosphere: Air
- Humidity: 10.00 [%]

#### Sequence

- Sequence count: 1
- Single-way mode
- Radius: 8.00 [mm]
- Lin. Speed: 25.00 [cm/s]
- Acquisition rate: 5.0 [Hz]
- Cycles sampled: 1/1
- Pause: 0 [s]
- Homing at begin: Yes
- Normal load: 10.00 [N]
- Unload at end: No
- Stop condit.: 905.00 [m]  
Or  $\mu > 0.80$
- Effective Stop: Meters

Sample	Static partner	Calculations
Worn track section: 53006.0 [ $\mu\text{m}^2$ ] Young's Modulus: 4.1 [GPa] Poisson ratio: 0.220	Worn cap diameter: 976.3 [ $\mu\text{m}$ ] Young's Modulus: 600.0 [GPa] Poisson ratio: 0.300	Sample Wear Rate: 0.0002944 [ $\text{mm}^3/\text{N}/\text{m}$ ] Partner Wear Rate: 1.657E-006 [ $\text{mm}^3/\text{N}/\text{m}$ ] Max Herzian Stress: 0.1569 [GPa]

Figura 4-21 - Resultado coeficiente de desgaste Citodur – 1000 [1]

En la siguiente Tabla 4-15 se puede visualizar los resultados de coeficiente de desgaste.

Tabla 4-15 - Resultados de coeficiente de desgaste InstrumX – Anton Paar Tribometro [1]

MATERIAL	k $\text{mm}^3/\text{N}*\text{m}$	k $\text{mm}^3/\text{N}*\text{mm}$
Base	0.0004277	4.28E-07
Citomangan (A)	0.0004056	4.06E-07
Exadur 43 - (B)	0.000138	1.38E-07
C-1000 - (C)	0.0002944	2.94E-07

En donde se puede observar que la probeta con más desgaste es el material base con  $4.28*10^{-7}$  y la probeta con menos desgaste es la de recargue Exadur – 43 con  $1.38*10^{-7}$



#### 4.6. Análisis de Desgaste mediante Software EDEM

4.6.1. Los resultados de Desgaste se pueden ver en las siguientes Figuras 4-22 al 4-29.

##### 4.6.1.1. Material Base – 32MnCrMo6-4-3

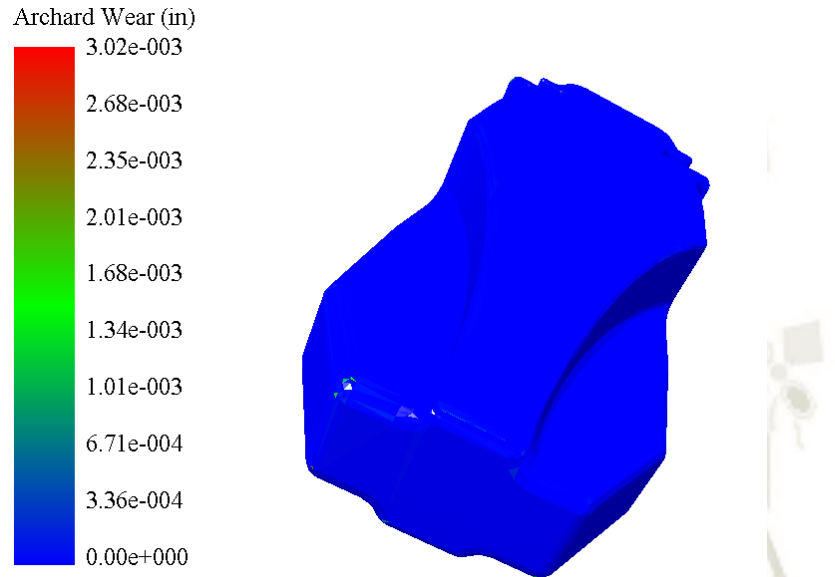


Figura 4-22 - Simulación de desgaste EDEM – Material Base 32MnCrMo6-4-3 [1]

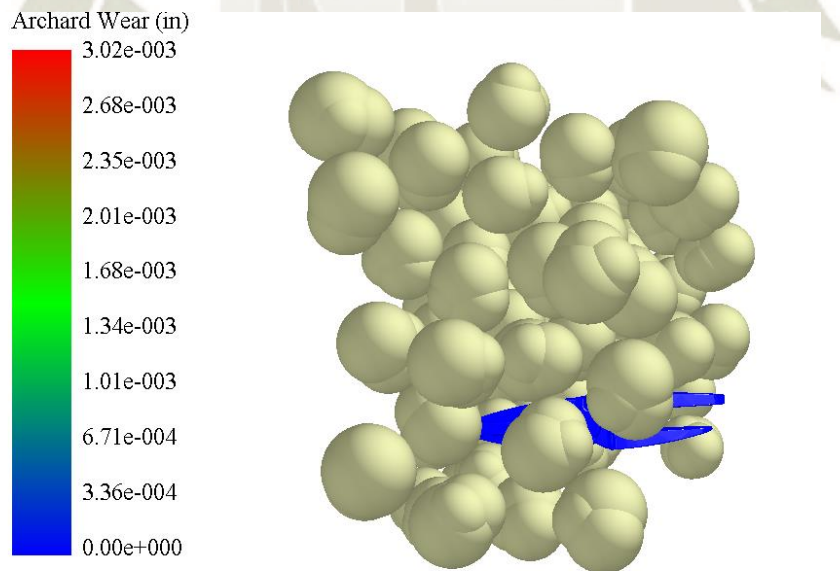


Figura 4-23 - Simulación de desgaste EDEM – Material Base 32MnCrMo6-4-3 [1]

En donde se puede observar que el mayor desgaste es de coloración verde, entonces se da como resultado de desgaste  $1.68 \cdot 10^{-3}$  in en 60 segundos.

#### 4.6.1.2. Material Base – Citomangan

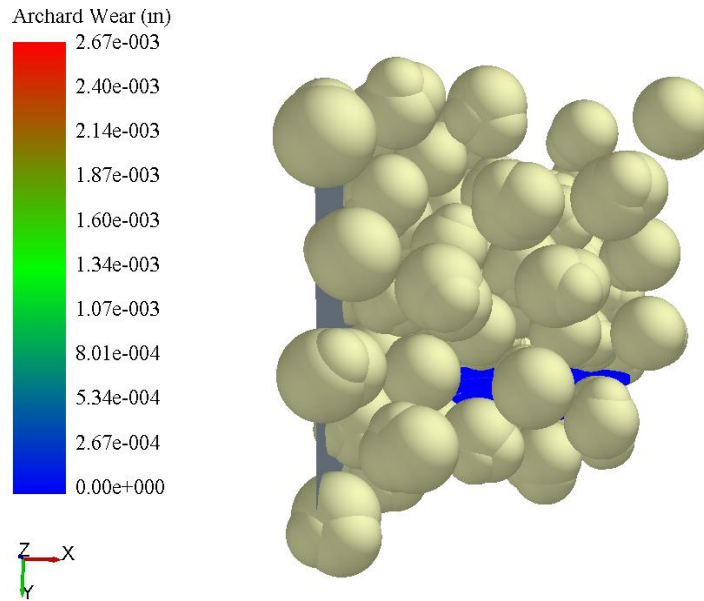


Figura 4-24 - Simulación de desgaste EDEM – Material Citomangan [1]

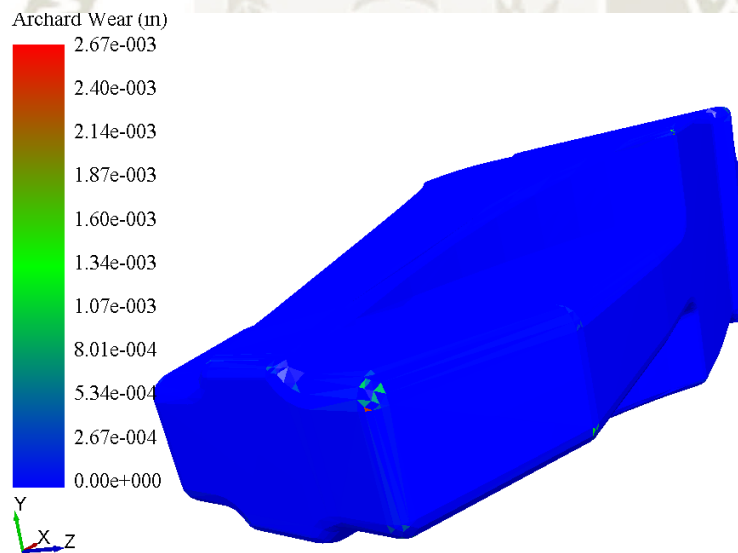


Figura 4-25 - Simulación de desgaste EDEM – Material Citomangan [1]

En donde se puede observar que el mayor desgaste es de coloración verde, entonces se da como resultado de desgaste  $1.60 \cdot 10^{-3}$  in en 60 segundos.

#### 4.6.1.3. Material Base – Exadur 43

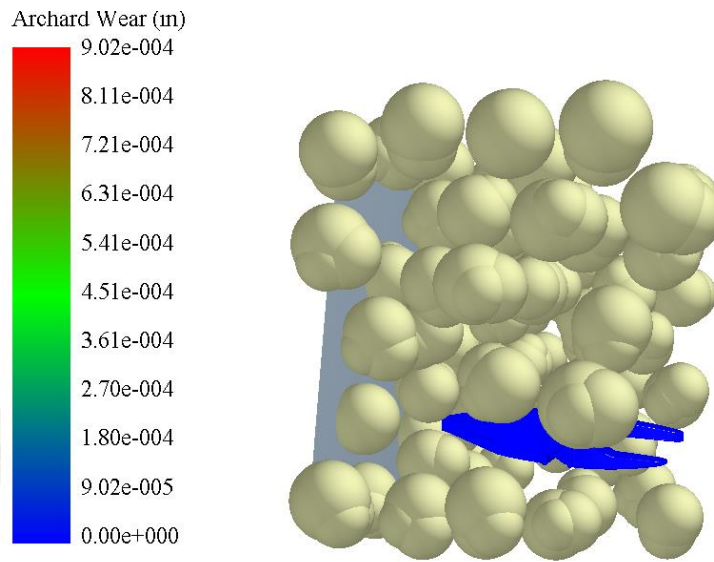


Figura 4-26 - Simulación de desgaste EDEM – Material Exadur – 43 [1]

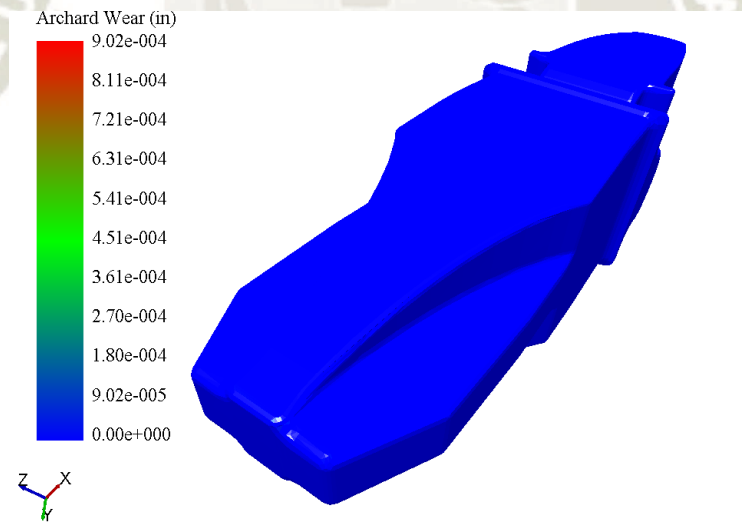


Figura 4-27 - Simulación de desgaste EDEM – Material Exadur – 43 [1]

En donde se puede observar que el mayor desgaste es de coloración verde, entonces se da como resultado de desgaste  $5.43 \cdot 10^{-4}$  in en 60 segundos.

4.6.1.4. Material Base – Citodur – 1000

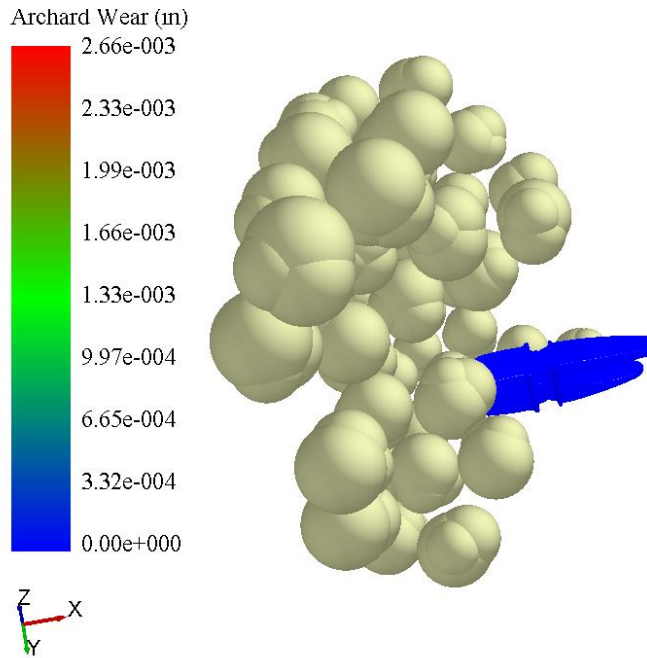


Figura 4-28 - Simulación de desgaste EDEM – Material Citodur – 1000 [1]



Figura 4-29 - Simulación de desgaste EDEM – Material Citodur – 1000 [1]

En donde se puede observar que el mayor desgaste es de coloración verde, entonces se da como resultado de desgaste  $1.17 \cdot 10^{-3}$  in en 60 segundos.

En la siguiente Tabla 4-16, se puede observar el resumen de los resultados de desgaste mediante el Software EDEM.

Tabla 4-16 - Resultado de desgaste EDEM [1]

Material	k por masas / Maquina		Resultado de Desgaste Mediante EDEM
	k por masas mm <sup>3</sup> /N*mm	k por Maquina mm <sup>3</sup> /N*mm	Wear Rate In /60 Segundos
Base 32MnCrMo6-4-3	1.13E-08	4.28E-07	1.68E-03
Citomangan (A)	9.85E-09	4.06E-07	1.60E-03
Exadur 43 (B)	5.63E-09	1.38E-07	5.43E-04
C-1000	7.04E-09	2.94E-07	1.16E-03

#### 4.6.2. Estimación de vida útil

En las siguientes Figuras 4-30 y 4-31 se puede observar una unidad de uña de Acero 32MnCrMo6-4-3, en donde se mide la longitud inicial y final, esto para poder obtener la medida de vida útil de esta.



Figura 4-30 - Longitud inicial de una uña de acero 32MnCrMo6-4-3 [1]



Figura 4-31 - Longitud final de una uña de acero 32MnCrMo6-4-3 [1]

Teniendo los resultados de ensayo de desgaste mediante la norma ASTM G-99 y el Software se deduce la cantidad de días que duraría la uñas mediante las siguientes formulas:  
Según las mediciones, se tiene la vida útil con la siguiente ecuación 4-2:

$$16.5 \text{ in (largo)} - 6.5 \text{ (corto)} = 10 \text{ in} \quad \text{Ec 4-2}$$

Pero por precaución y no dañar los adaptadores se cambia cuando esta tiene un desgaste de 8 in.

#### 4.6.2.1. Material Base 32MnCrMo6-4-3

$$\frac{1.68 \cdot 10^{-3}}{1 \text{ min}} * \frac{60 \text{ min}}{1 \text{ h}} * \frac{24 \text{ h}}{1 \text{ día}} = 2.4247 \frac{\text{in}}{\text{día}} \quad \text{Ec 4-3}$$

Teniendo un desgaste máximo de 8 in, entonces la uña durara:

$$\frac{2.4247 \frac{\text{in}}{\text{día}}}{8 \text{ in}} = 3.2923 \text{ días} \quad \text{Ec 4-4}$$

#### 4.6.2.2. Material Base – Citomangan

$$\frac{1.60 \cdot 10^{-3}}{1 \text{ min}} * \frac{60 \text{ min}}{1 \text{ h}} * \frac{24 \text{ h}}{1 \text{ día}} = 2.2994 \frac{\text{in}}{\text{día}} \quad \text{Ec 4-5}$$

Teniendo un desgaste máximo de 8 in, entonces la uña durara:

$$\frac{2.2994 \frac{\text{in}}{\text{dia}}}{8 \text{ in}} = 3.4790 \text{ dias} \quad \text{Ec 4-6}$$

4.6.2.3. Material Base - Exadur – 43

$$\frac{5.43 \cdot 10^{-4}}{1 \text{ min}} * \frac{60 \text{ min}}{1 \text{ h}} * \frac{24 \text{ h}}{1 \text{ dia}} = 0.7823 \frac{\text{in}}{\text{dia}} \quad \text{Ec 4-7}$$

Teniendo un desgaste máximo de 8 in, entonces la uña durara:

$$\frac{0.7823 \frac{\text{in}}{\text{dia}}}{8 \text{ in}} = 10.2254 \text{ dias} \quad \text{Ec 4-8}$$

4.6.2.4. Material Base – Citodur – 1000

$$\frac{1.16 \cdot 10^{-3}}{1 \text{ min}} * \frac{60 \text{ min}}{1 \text{ h}} * \frac{24 \text{ h}}{1 \text{ dia}} = 1.6690 \frac{\text{in}}{\text{dia}} \quad \text{Ec 4-9}$$

Teniendo un desgaste máximo de 8 in, entonces la uña durara:

$$\frac{1.6690 \frac{\text{in}}{\text{dia}}}{8 \text{ in}} = 4.7931 \text{ dias} \quad \text{Ec 4-10}$$

Se recopiló la frecuencia de cambio de las uñas de Acero 32MnCrMo6-4-3 sin recubrimiento en las OTS. Se pudo observar en la siguiente Tabla 4-17:

Tabla 4-17 - Frecuencia de cambio de Uñas de Acero 32MnCrMo6-4-3 en Barrick Lagunas Norte [1]

	DESCRIPCION DE EDD	FECHA INICIO	HOROMETRO INICIO	FECHA DE FIN	HOROMETRO DE FIN	DURACION EN HORAS
1	JUEGO DE UÑAS ALTERNATIVOS	11/05/2017	4249	21/05/2017	4340	91
2	JUEGO DE UÑAS ALTERNATIVOS	21/05/2017	4340	28/05/2017	4417	77
3	JUEGO DE UÑAS ALTERNATIVOS	28/05/2017	4417	17/06/2017	4494	77
4	JUEGO DE UÑAS ALTERNATIVOS	17/06/2017	4494	27/06/2017	4568	74
5	JUEGO DE UÑAS ALTERNATIVOS	27/06/2017	4568	30/06/2017	4623	55
6	JUEGO DE UÑAS ALTERNATIVOS	30/06/2017	4623	28/07/2017	4723	100
7	JUEGO DE UÑAS ALTERNATIVOS	28/07/2017	4723	30/07/2017	4752	29
8	JUEGO DE UÑAS ALTERNATIVOS	30/07/2017	4752	07/08/2017	4842	90
9	JUEGO DE UÑAS ALTERNATIVOS	07/08/2017	4842	16/08/2017	4925	83
10	JUEGO DE UÑAS ALTERNATIVOS	16/08/2017	4925	22/08/2017	5025	100
11	JUEGO DE UÑAS ALTERNATIVOS	22/08/2017	5025	27/08/2017	5115	90
12	JUEGO DE UÑAS ALTERNATIVOS	27/08/2017	5115	03/09/2017	5202	87
13	JUEGO DE UÑAS ALTERNATIVOS	03/09/2017	5202	08/09/2017	5281	79
14	JUEGO DE UÑAS ALTERNATIVOS	08/09/2017	5281	16/09/2017	5361	80
15	JUEGO DE UÑAS ALTERNATIVOS	16/09/2017	5361	20/09/2017	5440	79
16	JUEGO DE UÑAS ALTERNATIVOS	20/09/2017	5440	27/09/2017	5512	72
17	JUEGO DE UÑAS ALTERNATIVOS	27/09/2017	5512	04/10/2017	5632	120
18	JUEGO DE UÑAS ALTERNATIVOS	04/10/2017	5632	15/10/2017	5771	139
19	JUEGO DE UÑAS ALTERNATIVOS	15/10/2017	5771	18/10/2017	5823	52
20	JUEGO DE UÑAS ALTERNATIVOS	18/10/2017	5823	21/10/2017	5877	54
21	JUEGO DE UÑAS ALTERNATIVOS	21/10/2017	5877	05/11/2017	5985	108
22	JUEGO DE UÑAS ALTERNATIVOS	05/11/2017	5985	10/11/2017	6069	84
23	JUEGO DE UÑAS ALTERNATIVOS	10/11/2017	6069	14/11/2017	6136	67
24	JUEGO DE UÑAS ALTERNATIVOS	14/11/2017	6136	17/11/2017	6180	44
25	JUEGO DE UÑAS ALTERNATIVOS	17/11/2017	6180	22/11/2017	6262	82
26	JUEGO DE UÑAS ALTERNATIVOS	22/11/2017	6262	25/11/2017	6311	49
27	JUEGO DE UÑAS ALTERNATIVOS	25/11/2017	6311	30/11/2017	6401	90
28	JUEGO DE UÑAS ALTERNATIVOS	30/11/2017	6401	05/12/2017	6495	94
29	JUEGO DE UÑAS ALTERNATIVOS	05/12/2017	6495	08/12/2017	6538	43
30	JUEGO DE UÑAS ALTERNATIVOS	08/12/2017	6538	10/12/2017	6561	23
31	JUEGO DE UÑAS ALTERNATIVOS	10/12/2017	6561	13/12/2017	6611	50



De las Ots se tiene los siguientes resultados que se muestra en la siguiente Tabla 4-18:

Tabla 4-18 - Frecuencia de cambio de uñas de acero 32MnCrMo6-4-3 [1]

* COSTO DE JUEGO DE EDD				\$ 500.00
RATIO PROM. (HRS/EDD)	RATIO PROM. TRAB (HRS/DIA)	FRECUENCIA DE CAMBIO (DIA/EDD)	RATIO PROM. MENSUAL ( EDD/MES)	COSTO MES
76.19354839	22	3.463	9	\$ 1,731.67

En donde la frecuencia de cambio para el Contexto Operacional es 3.463 días para uñas de acero 32MnCrMo6-4-3 sin recubrimiento, similar al resultado que salió mediante el Software EDEM que dio como resultado 3.2923 días para el mismo material.

Tabla 4-19 – Resultado de duración de material [1]

Material	Duración (Días)
Base 32MnCrMo6-4-3 (OT)	3.46
Base 32MnCrMo6-4-3	3.29
Citomangan (A)	3.48
Exadur 43 (B)	10.23
C-1000	4.79

Se concluye de la tabla 4-19, que las soldaduras de recubrimiento más efectivas al desgaste son:

- Exadur – 43 con una duración de 10.2254 días
- Citodur – 1000 con una duración de 4.7931 días

Ahora se realiza el análisis de costos en el Capítulo 5 – Evaluación Económica, para ver si es viable la aplicación de estos recubrimientos en el contexto Operacional (Mina Barrick Lagunas Norte).



# CAPÍTULO V

## 5. EVALUACIÓN ECÓNOMICA

### 5.1. Análisis de costo

El presente capítulo está referido al costo para el revestimiento de 1 juego de uñas de acero 32MnCrMo6-4-3 (K-130) de una excavadora Cat 336 D2 L. Adicional se analizará el impacto económico por la hora de parada de la excavadora así también las horas de parada de los equipos dependientes de esta, como son los Camiones Articulados A40-F al no tener stock adecuado de estos elementos de desgaste (uñas de acero 32MnCrMo6-4-3).

#### 5.1.1. Costo de juego uñas de Acero 32MnCrMo6-4-3

El costo por uña según el proveedor RG TRACTO PARTS S.A.C. por unidad es de \$ 91.00 dólares, este cucharón tiene como configuración 5 uñas. Entonces por 20 unidades se tendrá un costo total de \$ 1820.00 dólares. Para un total de 04 cambios. En este caso se analizará en base a un cambio que será de \$ 455.00 dólares.

#### 5.1.2. Costo de Soldadura

Se plantea utilizar 03 tipos de soldadura que son Citomangan, Exadur-43 y Citodur 1000.

El costo por kilo se describe en la siguiente Tabla 5-1 según el proveedor Sedisa S.A.

Tabla 5-1 - Costos de electrodos de Recubrimiento [1]

Precios cotizados a Octubre de 2019					
Item	Cant (kg)	Descripción	P UNIT	S/. P. Total	\$ P. Total Precio Sin IGV
1	5	Exadur 43 1/8 3.25mm	73.5258	367.629	114.88
2	5	Citomangan 3/16 5 mm	34.8808	174.404	54.50
3	5	Citodur 1000 5/32 4 mm	95.8514	479.257	149.77
			P. Total	1021.29	319.15

Pero se necesitan un aproximado de 2kg de revestimiento por uña, entonces se tendrá el precio por 10 kg en la siguiente Tabla 5-2 para un juego de Uñas 32MnCrMo6-4-3.

Tabla 5-2 - Costos de electrodos de Recubrimiento [1]

Precios cotizados a Octubre de 2019					
Item	Cant (kg)	Descripción	P UNIT	S/. P. Total	\$ P. Total Precio Sin IGV
1	10	Exadur 43 1/8 3.25mm	73.5258	735.258	229.77
2	10	Citomangan 3/16 5 mm	34.8808	348.808	109.00
3	10	Citodur 1000 5/32 4 mm	95.8514	958.514	299.54
			P. Total	2042.58	638.31

### 5.1.3. Costo de Hora-Hombre

Para el recubrimiento de las uñas 32MnCrMo6-4-3 se necesitarán 2.4 H-H por uña, para un juego completo se necesitará 12 H-H.

Se puede observar el costo laboral de un soldador en la siguiente Tabla 5-3.

Tabla 5-3 – Costo laboral Soldador [1]

Item	Cantidad	Descripción	\$ Base	\$ Anual
1	12	Remuneración Básica	1500	18000.00
2	2	Gratificación	1500	3000.00
3	1	Vacaciones	1500	1500.00
4	2	CTS	1500	3000.00
5	2	Bonificación	500	1000.00
6	12	Seguro Social	100	1200.00
7	12	SCTR	25	300.00
			Total \$	28000.00

Entonces el costo laboral de un soldador es 78 \$/día

### 5.1.4. Costo de Moto soldadora

El costo de la moto soldadora mensual es de \$ 1200.00 por mes.

$$\$ \frac{1200}{1 \text{ mes}} * \frac{1 \text{ mes}}{30 \text{ días}} = 40 \frac{\$}{\text{día}}$$

**Ec 5-1**

De la ecuación 5-1, nos da como resultado 40 \$/día, por Revestimiento.

Se tiene que la moto soldadora consume promedio 15 gal/día, entonces se tiene el costo del combustible en la siguiente ecuación 5-2

$$\$ \frac{6}{1 \text{ galon}} * \frac{15 \text{ galones}}{1 \text{ dia}} = 90 \frac{\$}{\text{dia}}$$

Ec 5-2

Se hace un Resumen general de Costos por recubrimiento por soldadura de 1 juego de uñas.

32MnCrMo6-4-3 en la siguiente Tabla 5-4.

Tabla 5-4 - Costos de general de recubrimiento [1]

Precios cotizados a Octubre de 2019						
Soldadura			H-H Soldador	Moto Soldadora	Combustible	Total
Item	Descripción	\$ P. Total	\$ P. Total	\$ P. Total	\$ P. Total	\$ P. Total Sin IGv
1	Exadur 43 1/8 3.25mm 5kg	229.77	78	40	90	438
2	Citomangan 3/16 5 mm 5kg	109.00	78	40	90	317
3	Citodur 1000 5/32 4 mm 5 kg	299.54	78	40	90	508

Costo por juego de uñas 32MnCrMo6-4-3 (Tabla 5-5).

Tabla 5-5 - Costo de juego de uña de acero 32MnCrMo6-4-3 [1]

Precios cotizados a Octubre de 2019				
Item	Descripción	Cant	\$ P UNIT	\$ P. Total Sin IGv
1	PUNTA 32MnCrMo6-4-3	5	91.00	455.00

Determinación de juego uñas 32MnCrMo6-4-3 según la estimación de vida útil obtenida en el capítulo 4, que se observa en la siguiente Tabla 5-6

Tabla 5-6 - Costo de estimación de vida útil [1]

MATERIAL	Duración/Dia	Duración/Mes
Base 32MnCrMo6-4-3	3.29	9
Citomangan	3.48	9
Exadur 43	10.23	3
C-1000	4.79	6

En la siguiente Tabla 5-7 se determina los costos totales por juego de uña en 1 mes y 1 año, de acuerdo con la vida útil y los costos por adquisición de uñas y recubrimiento de uñas.

Tabla 5-7 - Costo total por juego de uñas de acero 32MnCrMo6-4-3 [1]

Precios cotizados a Octubre de 2019							
MATERIAL	Duración/ Dia	Duración /Mes	Costo de Recubrim iento \$	Costo x Juego \$	Costo x Juego \$ + Recubrimiento \$	Costo x Mes Total \$	Costo x Anual Total \$ Sin IGv
Base 32MnCrMo6-4-3	3.29	9	0	455	455	4095	49140
Citomangan	3.48	9	317	455	772	6948	83376
Exadur - 43	10.23	3	438	455	893	2679	32148
C-1000	4.79	6	508	455	963	5778	69336

Se puede Observar que el costo Anual del juego con recubrimiento de Soldadura Exadur – 43 es \$ 16992.0 más bajo que el juego sin recubrimiento, en porcentaje se deduce que es un % 34.58 menos costoso.

Este análisis es para solo 01 excavadora, el proyecto cuenta con 04 excavadoras con la misma configuración de cucharón. Entonces se podría ahorrar un promedio de \$ 67968.0 dólares por el recubrimiento de estas uñas con Soldadura Exadur – 43.

No sale a cuenta recubrir las uñas 32MnCrMo6-4-3 con los demás Soldaduras. Si se aplica estos recubrimientos, nos podríamos asegurar un stock adecuado de Gets (Elementos de desgaste en Almacén).

## 5.2. Impacto económico por parada

Al parar una excavadora por falta de Elementos de desgaste, este acarrea a dos articulados más, el impacto económico por falta (Gets) en Almacén en la siguiente Tabla 5-8:

Tabla 5-8 - Costo hora x maquina [1]

Precios cotizados a Octubre de 2019				
1	ALQUILERES DE EQUIPOS PARA EL SERVICIO MOVIMIENTO DE TIERRAS			
1.1	Tarifa horaria por equipo	H	DIA	AÑO
1.1.2	Alquiler de Excavadora hidráulico (01 und) 336 D2 L	\$130.00	\$3,120.00	\$37,440.00
1.1.3	Alquiler de Camiones articulados de 24 m3 (02 und)	\$140.00	\$6,720.00	\$80,640.00
Total \$			\$9,840.00	\$118,080.00

En el proyecto se observó que cada mes para una excavadora por falta de Gets (Uñas de Acero 32MnCrMo6-4-3), entonces se puede deducir que se pierde un total de \$ 118.080.00 dólares anuales.

Los ahorros anuales por evitar equipos parados y aumento de vida útil de los GETS se observan en la siguiente Tabla 5-9.

Tabla 5-9 - Costos equipos parados y vida útil de uñas de acero 32MnCrMo6-4-3 [1]

Precios cotizados a Octubre de 2019		
Item	Impacto Económico	\$ Total
1	Costo por parada de 01 Excavadora 336D2 L y 02 Articulados A-40F	\$118,080.00
2	Costo ahorro por Recubrimiento de Uñas 32MnCrMo6-4-3	\$67,968.00
		\$186,048.00

Se puede observar que se puede obtener un ahorro de \$186048.0 dólares si se tiene una correcta estrategia de Mantenimiento (Recubrimiento de uñas 32MnCrMo6-4-3, stock adecuado en Almacén) anualmente.

## CONCLUSIONES

1. Se analizó y evaluó el desgaste en revestimientos duros aplicados por procesos de soldadura en uñas de acero 32MnCrMo 6-4-3 de una excavadora hidráulica Cat 336D2 L.
2. Se analizó el desgaste en revestimientos duros aplicados por procesos de soldadura mediante elementos discretos (MED). En donde se concluye que la uña de acero sin recubrimiento es la más afectada al desgaste, con un promedio de  $1.68 \times 10^{-3}$  in por minuto. Se concluye que la uña con recubrimiento Exadur – 43 posee un menor desgaste con  $5.43 \times 10^{-4}$  in por minuto.
3. Se evaluó el desgaste en revestimientos duros aplicados por procesos de soldadura bajo la norma ASTM G-99, en donde se demostró que la probeta con menos desgaste fue Exadur – 43, con un coeficiente de fricción 0.563 y un coeficiente de desgaste de  $5.6304 \times 10^{-9}$ , seguido de la probeta con recargue Citodur – 1000, con un coeficiente de fricción de 0.534 y un coeficiente de desgaste de  $7.0380 \times 10^{-9}$ , seguido de la probeta con recargue Citomangan, con un coeficiente de fricción de 0.533 y un coeficiente de desgaste de  $9.8532 \times 10^{-9}$ . Teniendo como la probeta con más desgaste sin recubrimiento con un coeficiente de fricción de 0.594 y un coeficiente de desgaste de  $1.1260 \times 10^{-8}$ .
4. Se evaluó las pérdidas Volumétricas existentes bajo la norma ASTM G-99. En donde se observa que la probeta sin revestimiento tiene una pérdida volumétrica de  $0.1019 \text{ mm}^3$ , seguido de la probeta recubierta con Citomangan con  $0.0892 \text{ mm}^3$ , seguido de la probeta recubierta con Citodur - 1000 con  $0.0636 \text{ mm}^3$ . Teniendo como la probeta con menos pérdidas Volumétricas la recubierta con Exadur – 43 con una pérdida de  $0.0509 \text{ mm}^3$ .
5. Se observa que la estructura más resistente al desgaste es la Austenítica, con carburos de Cromo y Niobio, esta estructura corresponde al recubrimiento con soldadura Exadur – 43.



6. Se realizó el análisis de dureza en cada uno de los procesos de recubrimientos. En donde se observó que la probeta con más dureza obtenida fue el recargue de Exadur – 43, este obtuvo como promedio 70.4 HRC. Esto también puede deberse al alto contenido de % Cromo (20.3) y % Niobio (4.3).
7. Se determinó el tipo de electrodo más adecuado que garantice sus buenas propiedades contra el desgaste es el recubrimiento Exadur – 43, ya que posee un coeficiente de desgaste más bajo, tiene la mayor dureza y posee el menor desgaste por minuto que los demás recubrimientos.
8. Se determinó la influencia de las características del mineral explotado en la mina y de las condiciones de operación de los equipos en el desgaste presentado, al ser un contexto Operacional duro. Se determinó que afecto en los resultados al desgaste mediante la simulación MED (Elementos Discretos).
9. Se Analizó el costo-beneficio del recargue duro aplicado a las uñas de las excavadoras. En donde puede concluir que es factible el recubrimiento de las uñas con soldadura Exadur – 43, pudiendo ahorrar anualmente \$186,048.00 mil dólares anualmente aumentando el ciclo de vida útil de esta por excavadora y evitando roturas de Stock de Almacén.

## RECOMENDACIONES

1. Se debe simular también los esfuerzos que interactúan el material acero con el mineral, ya que el software EDEM permite exportar los valores de presiones y fuerzas en rangos determinados de tiempo. Esto para poder tener un mejor análisis de costo beneficio de recargue de los materiales a estudiar.
2. Se debe realizar el estudio de desgaste de electrodos de recargue de otras marcas de similar composición química, esto para poder tener un mejor análisis de rendimiento y costo beneficio.
3. Las superficies de desgaste y las virutas deberán ser analizados por MEB y espectroscopia de energías de rayos X dispersados (EDX).
4. Se debe realizar el costo beneficio por disponibilidad operacional de equipos y cantidad de mineral procesado en planta.

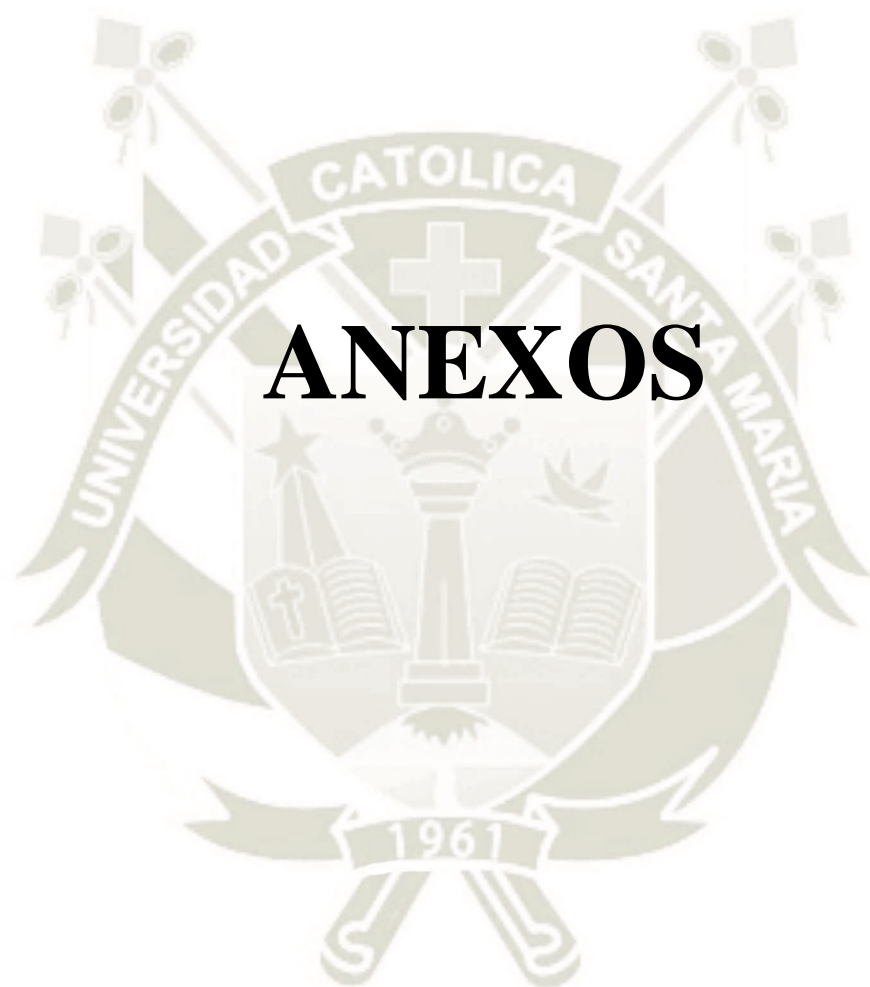
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# ANEXOS

A large, faint watermark of the Universidad Católica de Santa María logo is centered in the background. It features a shield with a cross, a book, and a lamp, with the university's name and the year 1961 visible.

# **ANEXO 1**

# **PROPIEDADES**

# **ACERO**

# **32MnCrMo6-4-3**



The world's most comprehensive materials database

## Saarstahl - 32MnCrMo6-4-3

Standard / Country      PROPRIETARY  
 Subgroup                Saerstahl AG

---

### Physical Properties

[Official](#)   [Other Sources](#)   [Similar Materials](#)   [Typical](#)

#### Density, $\rho$ [Kg/dm<sup>3</sup>]

Value	Comment
7.85	Typical property value for mild carbon low-alloyed steels. This value is not provided by standard, it is indicative and cannot be used for design purposes.

#### Modulus of elasticity (GPa)

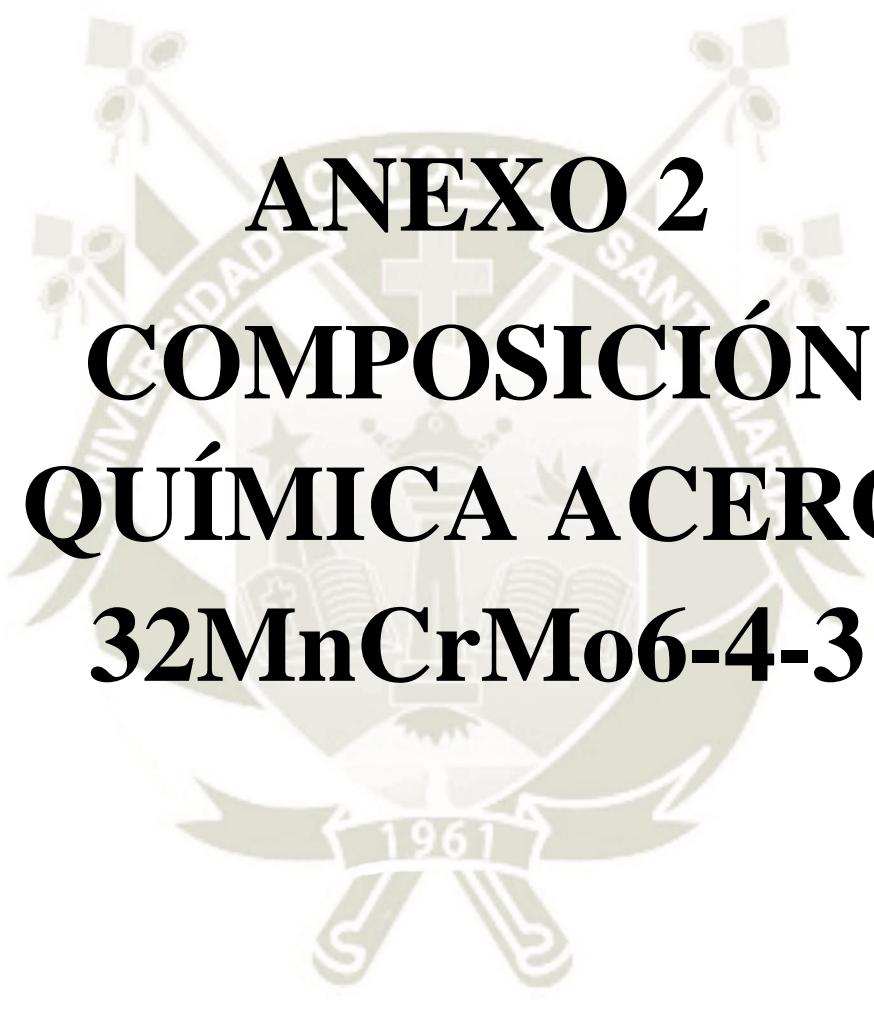
Value	Comment
200-207	Typical property value for mild carbon low-alloyed steels. This value is not provided by standard, it is indicative and cannot be used for design purposes.

#### Poisson's coefficient, $\nu$

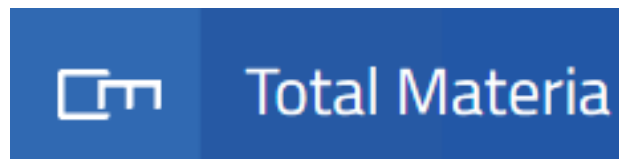
Value	Comment
0.27-0.30	Typical property value for mild carbon low-alloyed steels. This value is not provided by standard, it is indicative and cannot be used for design purposes.

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**ANEXO 2**  
**COMPOSICIÓN**  
**QUÍMICA ACERO**  
**32MnCrMo6-4-3**



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## Saarstahl - 32MnCrMo6-4-3

Standard / Country      **PROPRIETARY**  
 Subgroup                **Saarstahl AG**

### Chemical Composition

#### Chemical Composition (%)

Criteria	Min.	Max.	Approx	CAS Number
<a href="#">C</a>	0.2800	0.3600	-	<a href="#">7440-44-0</a>
<a href="#">Mn</a>	1.4000	1.8000	-	<a href="#">7439-96-5</a>
<a href="#">P</a>	-	0.0250	-	<a href="#">7723-14-0</a>
<a href="#">S</a>	-	0.0400	-	<a href="#">7704-34-9</a>
<a href="#">Si</a>	-	0.5000	-	<a href="#">7440-21-3</a>
<a href="#">Cr</a>	0.8000	1.2000	-	<a href="#">7440-47-3</a>
<a href="#">Mo</a>	0.2500	0.4000	-	<a href="#">7439-98-7</a>

#### Carbon Equivalent

Ceq 1 = 0.85

PCM = 0.48

#### Formulas

Ceq 1 = C + Mn/6 + Cr/5 + Mo/5 + V/5 + Cu/15 + Ni/15

PCM = C + Si/30 + (Mn + Cu + Cr)/20 + Ni/60 + Mo/15 + V/10 + 5\*B

Comment: Middle carbon steel

Precautions for the steel C>0.25% and thicknesses of welded materials t>12 mm

- preheating treatment required
- apply constant cooling rate e.g. limitation max and min welding interpass temperature
- apply both base coated electrodes and powder materials
- apply shielding gas protect zone of welding without presence of moisture
- low content of diffusions line, etc.

The value of C eq is by its nature approximative. Please review these results with welding specialists, especially if there is significant difference among results obtained by different formulas and/or with values recommended by standards.





**ANEXO 3**  
**NORMA AWS**  
**A5.13/A5.13M:2010**



**AWS A5.13/A5.13M:2010**  
An American National Standard

# Specification for Surfacing Electrodes for Shielded Metal Arc Welding



**American Welding Society**



**AWS A5.13/A5.13M:2010**  
**An American National Standard**

**Approved by the**  
**American National Standards Institute**  
**March 24, 2010**

# **Specification for Surfacing Electrodes for Shielded Metal Arc Welding**

**5<sup>th</sup> Edition**

**Supersedes AWS A5.13:2000**

Prepared by the  
American Welding Society (AWS) A5 Committee on Filler Metals and Allied Materials

Under the Direction of the  
AWS Technical Activities Committee

Approved by the  
AWS Board of Directors

## **Abstract**

This specification prescribes the requirements for classification of surfacing electrodes for shielded metal arc welding. Classification is based upon the chemical composition of the deposited weld metal except for tungsten carbide electrodes where classification is based on the mesh range, quantity, and composition of the tungsten carbide granules. A guide is appended to the specification as a source of information as to the characteristics and applications of the classified electrodes.



**American Welding Society**

550 N.W. LeJeune Road, Miami, FL 33126

AWS A5.13/A5.13M:2010

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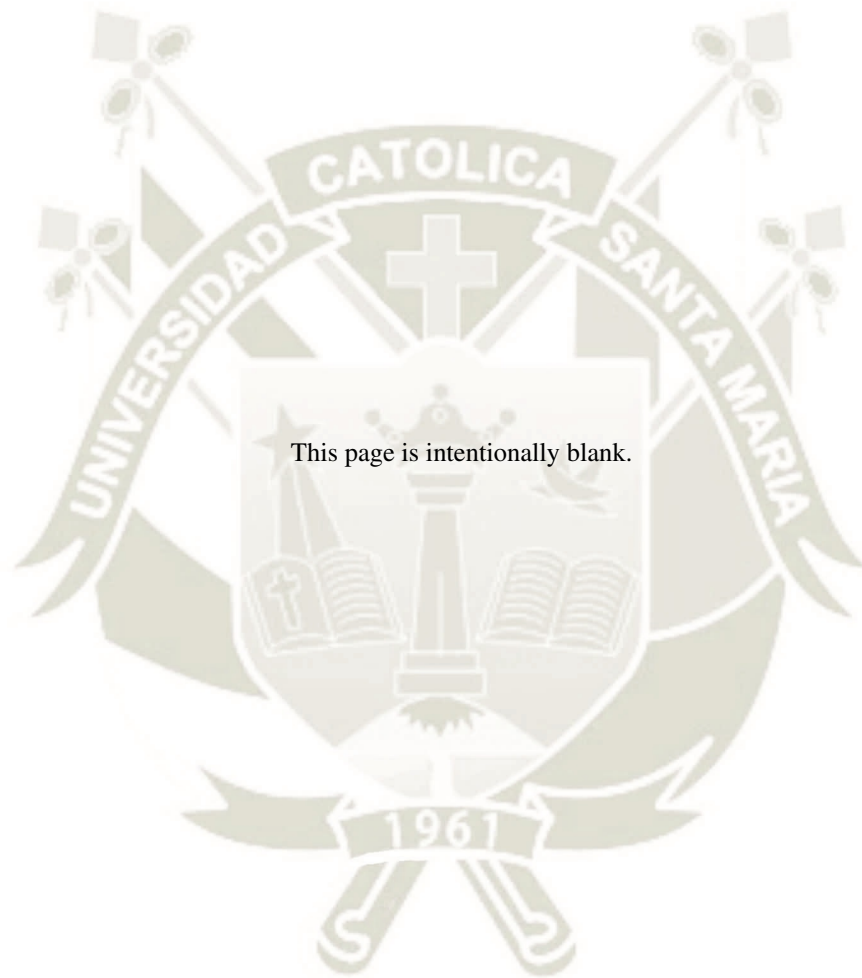
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AWS A5.13/A5.13M:2010



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AWS A5.13/A5.13M:2010

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## Foreword

This foreword is not part of AWS A5.13/A5.13M:2010, *Specification for Surfacing Electrodes for Shielded Metal Arc Welding*, but is included for informational purposes only.

The first AWS specification for surfacing filler metals was published in 1956 as a joint ASTM/AWS specification. It was the first of what would later become a two-set series, A5.13 and A5.21.

The composite electrodes and rods classifications were removed from the 1970 revision of A5.13 and placed into a new specification, A5.21. A5.13–70 specification contained requirements for both covered and bare electrodes or rods employing solid core only. This distinction was maintained for the 1980 revision of A5.13.

The revisions of both A5.13:2000 and A5.21:2001 incorporated a totally different scope. The method of manufacture of the core of the electrode or rod was no longer a factor in determining placement of a classification. Instead, the covered electrode products were classified under AWS A5.13:2000 and the bare electrode products under AWS A5.21:2001.

*This document is the first of the A5.13 specifications which makes use of both U.S. Customary Units and the International System of Units (SI). The measurements are not exact equivalents; therefore each system must be used independently of the other, without combining values in any way. In selecting rational metric units, ANSI/AWS A1.1, Metric Practice Guide for the Welding Industry, and ISO 544 Welding consumables – Technical delivery conditions for welding filler materials – Type of product, dimensions, tolerances and marking, are used where suitable. Tables and figures make use of both the U.S. Customary and SI Units, which, with the application of the specified tolerances, provides for interchangeability of products in both the U.S. Customary and SI Units.*

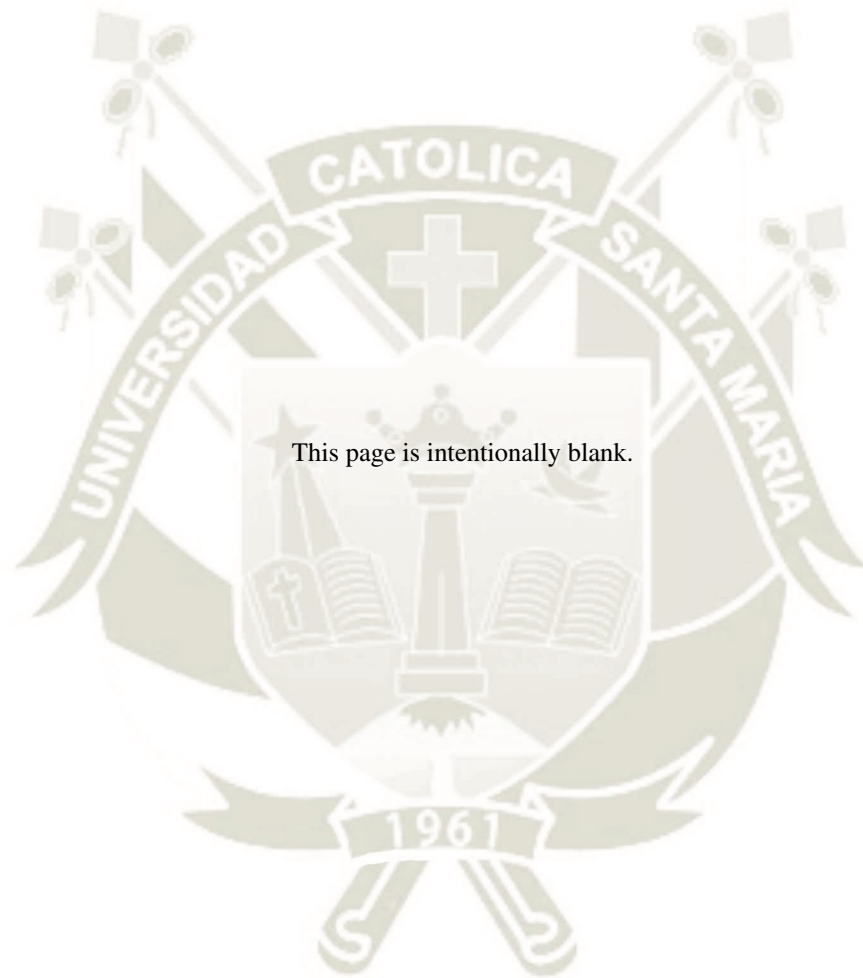
*Rounding-off Procedure has been revised in this edition. Detailed general safety information in Clause A9 has been replaced by Safety and Health Fact Sheets. Such substantive changes are shown in Italic font in this specification.*

The historical evolution of the specification is:

ASTM A 399-56T AWS A5.13-56T	<i>Tentative Specification for Surfacing Welding Rods and Electrodes</i>
AWS A5.13-70 ANSI W3.13-73	<i>Specification for Surfacing Welding Rods and Electrodes</i>
ANSI/AWS A5.13-80 AWS A5.13:2000	<i>Specification for Solid Surfacing Welding Rods and Electrodes</i> <i>Specification for Surfacing Electrodes for Shielded Metal Arc Welding</i>

Comments and suggestions for the improvement of this standard are welcome. They should be sent to the Secretary, AWS A5 Committee on Filler Metals and Allied Materials, American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

AWS A5.13/A5.13M:2010



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# Specification for Surfacing Electrodes for Shielded Metal Arc Welding

## 1. Scope

**1.1** This specification prescribes requirements for the classification of surfacing electrodes for shielded metal arc welding. Solid bare electrodes and rods for surfacing are classified in AWS A5.21:2001, *Specification for Bare Electrodes and Rods for Surfacing* (see Clause A8 in Annex A).

**1.2** Safety and health issues and concerns are beyond the scope of this standard and, therefore, are not fully addressed herein. Some safety and health information can be found in Clauses A5 and A9 in Annex A. Safety and health information is available from other sources, including, but not limited to ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*, and applicable federal and state regulations.

**1.3** This specification makes use of both U.S. Customary Units and the International System of Units (SI). The measurements are not exact equivalents; therefore, each system must be used independently of the other without combining in any way when referring to material properties. The specification with the designation A5.13 uses the U.S. Customary Units. The specification A5.13M uses the SI Units. The latter are shown within brackets [ ] or in appropriate columns in tables and figures. Standard dimensions based on either system may be used for sizing of filler metal or packaging or both under A5.13 or A5.13M specifications.

## 2. Referenced Documents

The following documents are referenced within this publication. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply.

### 2.1 AWS standards<sup>1</sup>

- (1) AWS A5.01M/A5.01(ISO 14344), *Procurement Guidelines for Consumables – Welding and Allied Processes – Flux and Gas Shielded Electrical Welding Processes*
- (2) AWS A3.0, *Standard Welding Terms and Definitions*
- (3) AWS F3.2, *Ventilation Guide for Weld Fume*

### 2.2 ANSI standard<sup>2</sup>

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*

### 2.3 ASTM standards<sup>3</sup>

- (1) ASTM A 36/A 36M, *Standard Specification for Carbon Structural Steels*
- (2) ASTM A 285/A 285M, *Standard Specification for Pressure Vessel Plates, Carbon Steel, Low-and Intermediate-Tensile Strength*

<sup>1</sup> AWS Standards are published by the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

<sup>2</sup> ANSI Z49.1 is published by the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

<sup>3</sup> ASTM Standards are published by the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.



(3) ASTM B 214, *Standard Test Method for Sieve Analysis of Metal Powders*

(4) ASTM E 29, *Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications*

#### 2.4 ISO standards<sup>4</sup>

(1) ISO 80 000-1, *Quantities and units – Part 1: General*

(2) ISO 544, *Welding Consumables – Technical delivery conditions for welding filler materials – Type of product, dimensions, tolerances, and marking*

### 3. Classification

3.1 Except for tungsten carbide electrodes, the surfacing electrodes covered by this A5.13/A5.13M specification are classified according to the chemical composition of the undiluted weld metal, as specified in Tables 1, 2, and 3.

3.2 Tungsten carbide surfacing electrodes are classified on the basis of size and chemical composition of the tungsten carbide granules (see Tables 4 and 5).

3.3 Electrodes classified under one classification shall not be classified under any other classification in this specification.

### 4. Acceptance

Acceptance<sup>5</sup> of the electrodes shall be in accordance with the provisions of AWS A5.01M/A5.01 (ISO 14344).

### 5. Certification

By affixing the AWS specification and classification designations to the package, or the classification to the product, the manufacturer certifies that the product meets the requirements of this specification.<sup>6</sup>

### 6. Rounding-Off Procedure

*For purposes of determining compliance with the requirements of this standard, the actual test values obtained shall be subjected to the rounding-off rules of ASTM E 29 or ISO 80000-1, Annex B, Rule A (the results are the same). If the measured values are obtained by equipment calibrated in units other than those of the specified limit, the measured values shall be converted to the units of the specified limit before rounding off. If an average value is to be compared to the specified limit, rounding off shall be done only after calculating the average. An observed or calculated value shall be rounded to the nearest 1 000 psi for yield strength for U.S. Customary Unit standard to the nearest 10 MPa for yield strength for SI unit standard and to the nearest unit in the last right-hand place of figures used in expressing the limiting values for other quantities. The rounded-off results shall fulfil the requirements for the classification under test.*

### 7. Summary of Tests

7.1 Except for tungsten carbide electrodes, chemical composition of undiluted weld metal is the only test required for classification of a product under this specification (see Tables 1, 2, and 3).

<sup>4</sup> ISO standards are published by the *International Organization for Standardization*, 1, rue de Varembé, Case postale 56, CH-1211 Geneva 20, Switzerland.

<sup>5</sup> See Clause A3, Acceptance (in Annex A), for further information concerning acceptance, testing of material shipped, and AWS A5.01M/A5.01.

<sup>6</sup> See Clause A4, Certification (in Annex A), for further information concerning certification and the testing called for to meet this requirement.

**Table 1**  
**Iron Base Surfacing Electrodes—Chemical Composition Requirements<sup>a</sup>**

		Deposit Composition, weight percent <sup>b,c,d</sup>											Other Elements, Total	
AWS Classification	Annex A Reference	UNS Number <sup>e</sup>	C	Mn	Si	Cr	Ni	Mo	V	W	Ti	Nb(Cb)	Fe	
EFFe1	A7.1.1	W74001	0.04–0.20	0.5–2.0	1.0	0.5–3.5	—	1.5	—	—	—	—	Rem	1.0
EFFe2	A7.1.1	W74002	0.10–0.30	0.5–2.0	1.0	1.8–3.8	1.0	1.0	0.35	—	—	—	Rem	1.0
EFFe3	A7.1.2	W74003	0.50–0.80	0.5–1.5	1.0	4.0–8.0	—	1.0	—	—	—	—	Rem	1.0
EFFe4	A7.1.3	W74004	1.0–2.0	0.5–2.0	1.0	3.0–5.0	—	—	—	—	—	—	Rem	1.0
EFFe5	A7.1.4	W75110	0.30–0.80	1.5–2.5	0.90	1.5–3.0	—	—	—	—	—	—	Rem	1.0
EFFe6	A7.1.5	W77510	0.6–1.0	0.4–1.0	1.0	3.0–5.0	—	7.0–9.5	0.5–1.5	0.5–1.5	—	—	Rem	1.0
EFFe7	A7.1.6	W77610	1.5–3.0	0.5–2.0	1.5	4.0–8.0	—	1.0	—	—	—	—	Rem	1.0
EFFeMn-A	A7.1.7	W79110	0.5–1.0	12–16	1.3	—	2.5–5.0	—	—	—	—	—	Rem	1.0
EFFeMn-B	A7.1.7	W79310	0.5–1.0	12–16	1.3	—	—	0.5–1.5	—	—	—	—	Rem	1.0
EFFeMn-C	A7.1.7	W79210	0.5–1.0	12–16	1.3	2.5–5.0	2.5–5.0	—	—	—	—	—	Rem	1.0
EFFeMn-D	A7.1.7	W79410	0.5–1.0	15–20	1.3	4.5–7.5	—	—	0.4–1.2	—	—	—	Rem	1.0
EFFeMn-E	A7.1.7	W79510	0.5–1.0	15–20	1.3	3.0–6.0	1.0	—	—	—	—	—	Rem	1.0
EFFeMn-F	A7.1.7	W79610	0.8–1.2	17–21	1.3	3.0–6.0	1.0	—	—	—	—	—	Rem	1.0
EFFeMnCr	A7.1.8	W79710	0.25–0.75	12–18	1.3	13–17	0.5–2.0	2.0	1.0	—	—	—	Rem	1.0
EFFeCr-A1A	A7.1.9	W74011	3.5–4.5	4.0–6.0	0.5–2.0	20–25	—	0.5	—	—	—	—	Rem	1.0
EFFeCr-A2	A7.1.10	W74012	2.5–3.5	0.5–1.5	0.5–1.5	7.5–9.0	—	—	—	—	1.2–1.8	—	Rem	1.0
EFFeCr-A3	A7.1.11	W74013	2.5–4.5	0.5–2.0	1.0–2.5	14–20	—	1.5	—	—	—	—	Rem	1.0
EFFeCr-A4	A7.1.9	W74014	3.5–4.5	1.5–3.5	1.5	23–29	—	1.0–3.0	—	—	—	—	Rem	1.0
EFFeCr-A5	A7.1.12	W74015	1.5–2.5	0.5–1.5	2.0	24–32	4.0	4.0	—	—	—	—	Rem	1.0
EFFeCr-A6	A7.1.13	W74016	2.5–3.5	0.5–1.5	1.0–2.5	24–30	—	0.5–2.0	—	—	—	—	Rem	1.0
EFFeCr-A7	A7.1.13	W74017	3.5–5.0	0.5–1.5	0.5–2.5	23–30	—	2.0–4.5	—	—	—	—	Rem	1.0
EFFeCr-A8	A7.1.14	W74018	2.5–4.5	0.5–1.5	1.5	30–40	—	2.0	—	—	—	—	Rem	1.0
EFFeCr-E1	A7.1.15	W74211	5.0–6.5	2.0–3.0	0.8–1.5	12–16	—	—	—	—	4.0–7.0	—	Rem	1.0
EFFeCr-E2	A7.1.15	W74212	4.0–6.0	0.5–1.5	1.5	14–20	—	5.0–7.0	1.5	—	—	—	Rem	1.0
EFFeCr-E3	A7.1.15	W74213	5.0–7.0	0.5–2.0	0.5–2.0	18–28	—	5.0–7.0	—	3.0–5.0	—	—	Rem	1.0
EFFeCr-E4	A7.1.15	W74214	4.0–6.0	0.5–1.5	1.0	20–30	—	5.0–7.0	0.5–1.5	2.0	—	4.0–7.0	Rem	1.0

<sup>a</sup> Solid bare electrodes and rods previously classified in AWS A5.13–80 are now either discontinued or reclassified in AWS A5.21:2001, *Specification for Bare Electrodes and Rods for Surfacing* (see A8 in Annex A).

<sup>b</sup> Single values are maximum. Rem = Remainder.

<sup>c</sup> Electrodes and rods shall be analyzed for the specific elements for which values are shown in this table. If the presence of other elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total does not exceed the limit specified for “Other Elements, Total” in the last column of the table.

<sup>d</sup> Sulfur and phosphorus contents each shall not exceed 0.035%.

<sup>e</sup> SAE HS-1086/ASTM DS-56, *Metals & Alloys in the Unified Numbering System*.

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**Table 2**  
**Nickel and Cobalt Base Surfacing Electrodes—Chemical Composition Requirements**

AWS Classification	Annex A Reference	UNS Number <sup>d</sup>	Deposit Composition, weight percent <sup>a, b, c</sup>											Other Elements, Total
			C	Mn	Si	Cr	Ni	Mo	Fe	W	Co	B	V	
ECrCr-A	A7.2.1	W73006	0.7–1.4	2.0	2.0	25–32	3.0	1.0	5.0	3.0–6.0	Rem	—	—	1.0
ECrCr-B	A7.2.2	W73012	1.0–1.7	2.0	2.0	25–32	3.0	1.0	5.0	7.0–9.5	Rem	—	—	1.0
ECrCr-C	A7.2.3	W73001	1.7–3.0	2.0	2.0	25–33	3.0	1.0	5.0	11–14	Rem	—	—	1.0
ECrCr-E	A7.2.4	W73021	0.15–0.40	1.5	2.0	24–29	2.0–4.0	4.5–6.5	5.0	0.50	Rem	—	—	1.0
ENiCr-C	A7.3.1	W89606	0.5–1.0	—	3.5–5.5	12–18	Rem	—	3.5–5.5	—	1.0	2.5–4.5	—	1.0
ENiCrMo-5A	A7.3.2	W80002	0.12	1.0	1.0	14–18	Rem <sup>e</sup>	14–18	4.0–7.0	3.0–5.0	—	—	0.40	1.0
ENiCrFeCo	A7.3.3	W83002	2.2–3.0	1.0	0.6–1.5	25–30	10–33	7.0–10.0	20–25	2.0–4.0	10–15	—	—	1.0

<sup>a</sup> Single values are maximum percentages. Rem = Remainder.

<sup>b</sup> The weld metal shall be analyzed for the specific elements for which values are shown in this table. If the presence of other elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total does not exceed the limit specified for “Other Elements, Total” in the last column of the table.

<sup>c</sup> Sulfur and phosphorus contents each shall not exceed 0.03%.

<sup>d</sup> SAE HS-1086/ASTM DS-56, *Metals & Alloys in the Unified Numbering System*.

<sup>e</sup> Includes incidental cobalt.

**Table 3**  
**Copper Base Surfacing Electrodes—Chemical Composition Requirements**

Deposit Composition, weight percent<sup>a,b</sup>

AWS Classification	Annex A Reference	UNS Number <sup>c</sup>	Cu	Mn	P	Si	Fe	Al	Zn	Ni <sup>d</sup>	Pb	Sn	Ti	Other Elements, Total
ECuAl-A2 <sup>f</sup>	A7.4.1.1	W60617	Rem	§	—	1.5	0.5–5.0	8.5–11.0	§	§	0.02	§	—	0.50
ECuAl-B <sup>f</sup>	A7.4.1.2	W60619	Rem	§	—	1.5	2.5–5.0	11–12	§	§	0.02	§	—	0.50
ECuAl-C	A7.4.1.2	W60625	Rem	—	—	1.0	3.0–5.0	12–13	0.02	—	0.02	—	—	0.50
ECuAl-D	A7.4.1.3	W61625	Rem	—	—	1.0	3.0–5.0	13–14	0.02	—	0.02	—	—	0.50
ECuAl-E	A7.4.1.3	W62625	Rem	—	—	1.0	3.0–5.0	14–15	0.02	—	0.02	—	—	0.50
ECuSi <sup>f</sup>	A7.4.1.4	W60656	Rem	1.5	§	2.4–4.0	0.50	0.01	§	§	0.02	1.5	—	0.50
ECuSn-A <sup>f</sup>	A7.4.1.5	W60518	Rem	§	0.05–0.35	§	0.25	0.01	§	§	0.02	4.0–6.0	—	0.50
ECuSn-C <sup>f</sup>	A7.4.1.5	W60521	Rem	§	0.05–0.35	§	0.25	0.01	§	§	0.02	7.0–9.0	—	0.50
ECuNi <sup>e,f</sup>	A7.4.1.6	W60715	Rem	1.0–2.5	0.02	0.50	0.40–0.75	—	§	29–33	0.02	§	0.50	0.50
ECuNiAl <sup>f</sup>	A7.4.1.7	W60632	Rem	0.5–3.5	—	1.5	3.0–6.0	8.5–9.5	§	4.0–6.0	0.02	§	—	0.50
ECuMnNiAl <sup>f</sup>	A7.4.1.8	W60633	Rem	11–14	—	1.5	2.0–4.0	7.0–8.5	§	1.5–3.0	0.02	§	—	0.50

<sup>a</sup> Single values shown are maximum percentages. Rem = Remainder.

<sup>b</sup> The weld metal shall be analyzed for the specific elements for which values, or a “g,” are shown in this table. If the presence of other elements is indicated in the course of this work, the amount of those elements shall be determined to ensure that their total does not exceed the limit specified for “Other Elements, Total” in the last column of the table.

<sup>c</sup> SAE HS-1086/ASTM DS-56, *Metals & Alloys in the Unified Numbering System*.

<sup>d</sup> Includes cobalt.

<sup>e</sup> Sulfur is restricted to 0.015% maximum.

<sup>f</sup> This AWS classification is intended to correspond to the same classification that appears in AWS A5.6, *Specification for Copper and Copper-Alloy Covered Electrodes*. Because of revision dates the composition ranges may not be identical.

<sup>g</sup> These elements must be included in “Other Elements, Total.”

7.2 Tests required for tungsten carbide electrodes include:

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7.2.1 Determination of the amount and mesh size distribution of the tungsten carbide granules (see Table 4). Sieve analysis shall be in accordance with ASTM B 214.

7.2.2 Determination of the chemical composition of the tungsten carbide granules (see Table 5).

## 8. Retest

If the results of any test fail to meet the requirement, that test shall be repeated twice. The results of both retests shall meet the requirement. Material, specimens, or samples for retest may be taken from the original test assembly or sample, or from one or two new test assemblies or samples. For chemical analysis, retest need be only for those specific elements that failed to meet the test requirement. If the results of one or both retests fail to meet the requirement, the material under test shall be considered as not meeting the requirements of this specification for that classification.

In the event that, during preparation or after completion of any test, it is clearly determined that prescribed or proper procedures were not followed in preparing the weld test assembly or test specimen(s) or in conducting the test, the test shall be considered invalid, without regard to whether the test was actually completed or whether test results met, or failed to meet, the requirement. That test shall be repeated, following proper prescribed procedures. In this case, the requirement for doubling the number of test specimens does not apply.

**Table 4**  
**Mesh Size and Quantity of Tungsten Carbide (WC) Granules in the Core of Tungsten Carbide Electrodes**

AWS Classification <sup>a, b</sup>	U.S. Standard Mesh Size of Tungsten Carbide Granules <sup>c</sup>	SI Mesh Size mm	Quantity of Tungsten Carbide (WC1 + WC2) Granules, weight percent
EWCX-12/30	thru 12–on 30	thru 1.70–on 0.60	60
EWCX-20/30	thru 20–on 30	thru 0.85–on 0.60	60
EWCX-30/40	thru 30–on 40	thru 0.60–on 0.43	60
EWCX-40	thru 40	thru 0.43	60
EWCX-40/120	thru 40–on 120	thru 0.43–on 0.13	60

<sup>a</sup> “X” designates the type of tungsten carbide granules; X = 1 for WC1 granules, X = 2 for WC2 granules, X = 3 for a blend of WC1 and WC2 granules.

<sup>b</sup> These AWS classifications have been transferred to AWS A5.21:2001 without a change in classification for solid bare electrodes and rods and with the prefix “ERC” for electrode/rod made from metal or flux cored stock.

<sup>c</sup> The mesh size of the tungsten carbide granules may vary from that specified above, provided that no more than 5% of the granules are retained on the “thru” sieve, and that no more than 20% passes the “on” sieve.

**Table 5**  
**Chemical Composition of Tungsten Carbide (WC) Granules**

Element	Composition, weight percent <sup>a</sup>		
	WC1	WC2	WC3
C	3.6–4.2	6.0–6.2	
Si	0.3	0.3	
Ni	0.3	0.3	As agreed
Mo	0.6	0.6	between
Co	0.3	0.3	purchaser
W	94.0 min.	91.5 min.	and supplier
Fe	1.0	0.5	
Th	0.01	0.01	

<sup>a</sup> Single values are maximum, unless noted otherwise.

## 9. Weld Test Assembly

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**9.1** A sample for chemical analysis is the only test assembly required. The sample may be prepared by any method producing undiluted weld metal. In case of dispute, the weld pad described in 9.2 shall be the referee method.

**9.2** The dimensions of the completed pad shall be as shown in Figure 1 for each size of electrode. Testing of this assembly shall be as specified in Clause 10, Chemical Analysis.

**9.2.1** Welding shall be done in the flat position using welding conditions specified by the manufacturer.

**9.2.2** Postweld heat treatment may be used to facilitate subsequent sampling.

**9.3** The base metal shall conform to one of the following specifications or its equivalent:

**9.3.1** ASTM A 285/A 285M Grade A (UNS K01700).

**9.3.2** ASTM A 36/A 36M (UNS K02600).

## 10. Chemical Analysis

### 10.1 For All Except Covered Tungsten Carbide Electrodes

**10.1.1** Shielded metal arc welding surfacing electrodes shall be analyzed in the form of undiluted weld metal. The sample shall come from a weld metal pad.

**10.1.2** The top surface of the pad, as described in Clause 9 and shown in Figure 1, shall be removed and discarded, and a sample for analysis shall be obtained from the underlying metal by any appropriate mechanical means. The sample shall be free of slag.

For electrodes 3/32 in [2.5 mm] in diameter and smaller, the sample shall be taken at least 1/2 in [13 mm] from the nearest surface of the base metal.

For electrodes 1/8–3/16 in [3.2–5.0 mm] in diameter, the sample shall be taken at least 5/8 in [16 mm] from the nearest surface of the base metal.

For electrodes larger than 3/16 in [5.0 mm] in diameter, the sample shall be taken at least 3/4 in [19 mm] from the nearest surface of the base metal.

**10.1.3** The sample may be removed from an undiluted weld metal pad by any convenient method.

**10.1.4** The sample shall be analyzed by accepted analytical methods as agreed upon between the purchaser and supplier. The referee method shall be the appropriate ASTM method for the element being determined.

**10.1.5** The results of the analysis shall meet the requirements of Tables 1, 2, or 3 for the classification of electrode under test.

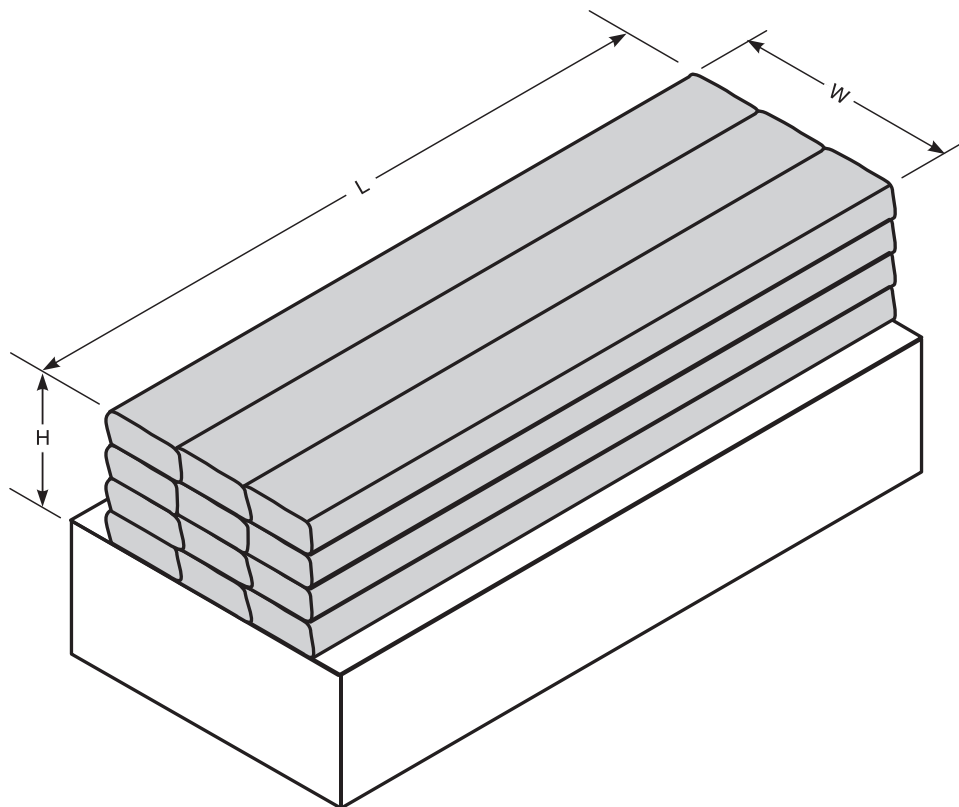
### 10.2 For Tungsten Carbide Electrodes

**10.2.1** Chemical composition of tungsten carbide granules shall conform to the requirements of Table 5. Chemical analysis may be made by any suitable method as agreed upon between the purchaser and supplier.

**10.2.2** Tungsten carbide granules for chemical analysis shall be free of any surface contaminant.

**10.2.3** The percentage by weight of the tungsten carbide, as specified in Table 4, can be determined by the following steps:

- (1) Record the weight of the tungsten carbide welding electrode after removing any covering present.
- (2) Remove the tungsten carbide from the tube and clean it by washing with water and treating with 1-1 hydrochloric acid, as required, to remove any flux, powdered iron, graphite, etc. Heating of the acid may be required. A hot or cold 1-1 hydrochloric acid will not appreciably attack cast tungsten carbide in less than an hour. When handling any acids appropriate safety precautions should be followed.



Electrode Size		Weld Pad Size, minimum	
in	mm	in	mm
5/64 (0.078)	2.0	L = 1-1/2	38
3/32 (0.094)	2.4	W = 1/2	13
(0.097)	2.5	H = 1/2	13
1/8 (0.125)	3.2	L = 2	50
5/32 (0.156)	4.0	W = 1/2	13
3/16 (0.187)	4.8	H = 5/8	16
(0.197)	5.0		
7/32 (0.219)		L = 2-1/2	64
(0.236)	6.0	W = 1/2	13
1/4 (0.250)	6.4	H = 3/4	19
5/16 (0.312)	8.0		

Source: AWS A5.13:2000, Figure 1.

**Figure 1—Pad for Chemical Analysis of Undiluted Weld Metal**

- (3) Dry tungsten carbide for a minimum period of two hours by holding in an oven at 250°F ± 25°F [120°C ± 15°C].
- (4) Weigh the cleaned and dried tungsten carbide granules. Calculate the percentage of tungsten carbide from the initial weight of the tube using the following formula:

$$\text{Tungsten carbide \%} = \frac{\text{Weight of clean and dry tungsten carbide granules}}{\text{Weight of electrode after removal of covering}} \times 100$$

## 11. Method of Manufacture

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The electrodes classified according to this specification may be manufactured by any method that will produce material that meets the requirements of this specification. For tungsten carbide electrodes, any carbon steel sheath material (typically C1008) that will not alter the matrix significantly may be used.

## 12. Standard Sizes and Lengths

12.1 Standard sizes (diameter of core wire) and lengths of electrodes and applicable tolerances shall be as shown in Tables 6, 7, and 8.

**Table 6**  
**Standard Sizes and Lengths of Covered Electrodes Using Solid Drawn Core Wire<sup>a</sup>**

Electrode Sizes, Diameter of Solid Drawn Core Wire <sup>b</sup>		Standard Lengths		
in	mm	in	mm	
5/64	(0.078)	2.0	9 ± 1/4	230 ± 10
3/32	(0.094)	2.4 } 2.5 }	9 ± 1/4	230 ± 10
	(0.097)		12 ± 1/4	300 ± 10
1/8	(0.125)	3.2 } 4.0 }	14 ± 1/4	350 ± 10
	(0.156)		14 ± 1/4	350 ± 10
3/16	(0.187)	4.8 <sup>c</sup> } 5.0 }	14 ± 1/4	350 ± 10
	(0.197)		18 ± 1/4	450 ± 10
1/4	(0.236)	6.0 } 6.4 <sup>c</sup> }	14 ± 1/4	350 ± 10
	(0.250)		18 ± 1/4	450 ± 10
5/16	(0.312)	8.0	14 ± 1/4	350 ± 10
			18 ± 1/4	450 ± 10

<sup>a</sup> Other electrode diameters and lengths may be supplied as agreed between the manufacturer and purchaser.

<sup>b</sup> Tolerance on the diameter shall be ± 0.002 in [± 0.05 mm]

<sup>c</sup> These metric sizes are not shown in ISO 544.

**Table 7**  
**Standard Sizes and Lengths for Covered Cast and Composite Tubular Electrodes<sup>a</sup>**

Electrode Sizes, Nominal Diameter of Core Wire <sup>b</sup>		Standard Lengths			
		For Cast Electrodes		For Composite Tubular Electrodes	
in	mm	in	mm	in	mm
1/8 (0.125)	3.2				
5/32 (0.156)	4.0				
3/16 (0.187)	4.8 <sup>c</sup>	9 to 14 ± 3/8	230 to 350 ± 10	9 to 14 ± 3/8	230 to 350 ± 10
	(0.197)				
(0.236)	6.0			14 ± 3/8	350 ± 10
(0.236)	6.0			18 ± 3/8	450 ± 10
1/4 (0.250)	6.4 <sup>c</sup>	12 to 14 ± 3/8	300 to 350 ± 10	14 ± 3/8	350 ± 10
1/4 (0.250)	6.4 <sup>c</sup>			18 ± 3/8	450 ± 10
5/16 (0.312)	8.0	12 to 14 ± 3/8	300 to 350 ± 10	14 ± 3/8	350 ± 10
5/16 (0.312)	8.0			18 ± 3/8	450 ± 10

<sup>a</sup> Other diameter and lengths of electrodes may be supplied as agreed between the manufacturer and the purchaser.

<sup>b</sup> Diameter tolerance shall be ± 0.02 in [± 0.5 mm] from the nominal diameter.

<sup>c</sup> These metric sizes are not shown in ISO 544.



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**Table 8**  
**Standard Sizes and Lengths for Covered**  
**Tungsten Carbide (WC) Electrodes**

Electrode Sizes, Diameter of Solid Drawn Core Wire <sup>a</sup>		Standard Lengths	
in	mm	in	mm
3/32	(0.094)	9 ± 3/8	225 ± 10
	(0.098)	14 ± 3/8	350 ± 10
1/8	(0.125)	9 ± 3/8	225 ± 10
		14 ± 3/8	350 ± 10
5/32	(0.156)	9 ± 3/8	225 ± 10
		14 ± 3/8	350 ± 10
3/16	(0.187)	9 ± 3/8	225 ± 10
	(0.097)	14 ± 3/8	350 ± 10
1/4	(0.236)	14 ± 3/8	350 ± 10
	(0.250)	18 ± 3/8	450 ± 10
5/16	(0.312)	14 ± 3/8	350 ± 10
		18 ± 3/8	450 ± 10

<sup>a</sup> Diameter tolerance shall be ± 0.04 in [±1.0 mm] from the nominal diameter.

<sup>b</sup> These metric sizes are not shown in ISO 544.

### 13. Core Wire and Covering

Core wire and covering shall be free of defects that would interfere with uniform deposition of the electrode.

### 14. Exposed Core

**14.1** The grip end of each electrode shall be bare (free of covering) for a distance of not less than 1/2 in [13 mm], nor more than 1-1/2 in [38 mm], to provide for electrical contact with the electrode holder.

**14.2** The arc end of each electrode shall be sufficiently bare and the covering sufficiently tapered to permit easy striking of the arc. The length of the bare portion, measured from the end of the core wire to the location where the full cross-section of the covering is obtained, shall not exceed 1/8 in [3 mm] or the diameter of the core wire, whichever is less. Electrodes with chipped coverings near the arc end, baring the core wire slightly more than the prescribed distance, may be accepted provided no chip uncovers more than 50% of the circumference of the core.

**14.3** Electrodes with electrically conductive coverings or strike tips may be exempt from the requirements of 14.2 providing they are capable of easy arc starting without stripping.

### 15. Electrode Identification

**15.1** All electrodes, except dip-covered electrodes, shall be identified as follows:

**15.1.1** At least one imprint of the electrode classification shall be applied to the electrode covering starting within 2-1/2 in [65 mm] of the grip end of the electrode.

**15.1.2** The numbers and letters of the imprint shall be of bold block type of a size large enough to be legible.

**15.1.3** The ink used for imprinting shall provide sufficient contrast with the electrode covering so that, in normal use, the numbers and letters are legible both before and after welding.

15.1.4 The prefix letter E in the electrode classification may be omitted from the imprint.

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15.2 Identification of dip-covered electrodes shall be as agreed upon between the purchaser and supplier. Imprinting is not mandatory.

## 16. Packaging

16.1 Electrodes shall be suitably packaged to protect them against damage during shipment and storage under normal conditions.

16.2 Standard package weights shall be as agreed between purchaser and supplier.

## 17. Marking of Packages

17.1 The following product information (as a minimum) shall be legibly marked on the outside of each unit package:

- (1) AWS specification and classification designations (year of issue may be excluded)
- (2) Supplier's name and trade designation
- (3) Size and net weight
- (4) Lot, control, or heat number

17.2 The appropriate precautionary information<sup>7</sup> as given in ANSI Z49.1,<sup>8</sup> latest edition (as a minimum) or its equivalent, shall be prominently displayed in legible print on all packages of electrodes, including individual unit packages enclosed within a larger package.

<sup>7</sup> Typical examples of "warning labels" are shown in figures in ANSI Z49.1 for some common or specific consumables used with certain processes.

<sup>8</sup> ANSI Z49.1 is published by the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

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# Annex A (Informative)

## Guide to AWS Specification for Surfacing Electrodes for Shielded Metal Arc Welding

This annex is not part of AWS A5.13/A5.13M:2010, *Specification for Surfacing Electrodes for Shielded Metal Arc Welding*, but is included for informational purposes only.

### A1. Introduction

This guide has been prepared as an aid to prospective users of the electrodes covered by the specification in determining the classification of filler metal best suited for a particular application, with due consideration to the particular requirements for that application.

### A2. Classification System

**A2.1** The system for identifying the electrode classifications in this specification follows the standard pattern used in other AWS filler metal specifications. The letter E at the beginning of each classification designation stands for electrode. The letters immediately after the E are the chemical symbols for the principal elements in the classification. Thus, CoCr is a cobalt–chromium alloy, CuAl is a copper–aluminum alloy, etc. Where more than one classification is included in a basic group, the individual classifications in the group are identified by the letters A, B, C, etc., as in ECuSn-A. Further subdivision is done by using a 1, 2, etc., after the last letter, as the 2 in ECuAl-A2. An additional letter or number has been added to some designations if the composition requirements in this specification differ somewhat from those of the earlier versions for electrodes of the same basic classification.

**A2.2** From an application point of view, many classifications in this specification have a corresponding classification in AWS A5.21 *Specification for Bare Electrodes and Rods for Surfacing* (see Table A.1).

**A2.3** An international system for designating welding filler metals is under development by the International Institute of Welding (IIW) for possible adoption as an ISO specification. The latest proposal for designating welding filler metals appears in AWS IFS:2002, *International Index of Welding Filler Metal Classifications*<sup>9</sup>. Table A.1 shows the proposed ISO designations applicable to filler metal classifications included in this specification.

#### A2.4 Request for Filler Metal Classification

(1) When a surfacing electrode or rod cannot be classified as given in this specification, the manufacturer may request that a classification be established for that welding electrode. The manufacturer may do this by following the procedure given here.

(2) A request to establish a new electrode or rod classification must be in writing, and it needs to provide sufficient detail to permit the AWS A5 Committee on Filler Metals and Allied Materials or the subcommittee to determine whether the new classification or the modification of an existing classification is more appropriate, and whether either is necessary to satisfy the need. The request needs to state the variables and their limits, for such a classification or modification. The

<sup>9</sup> This publication is published by the American Welding Society, 550 N.W. LeJeune Rd, Miami, FL 33126, in an electronic format (CDROM).

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**Table A.1**  
**Comparison of Classifications**

A5.13/A5.13M Classifications	A5.21 Classifications	Proposed ISO Designations <sup>a</sup>
EFe1	ERFe-1	EF7314
EFe2	ERFe-2	EF7418
EFe3	ERFe-3	EF7430
EFe4		EF7460
EFe5	ERFe-5	EF7413
EFe6	ERFe-6	EF7680
EFe7		EF7834
EFeMn-A		EF7909
EFeMn-B		EF7907
EFeMn-C	ERFeMn-C	EF7921
EFeMn-D		EF7932
EFeMn-E		EF7940
EFeMn-F	ERFeMn-F	EF7941
EFeMnCr	ERFeMnCr	EF7970
EFeCr-A1A	ERFeCr-A1A	EF8616
EFeCr-A2		EF8612
EFeCr-A3	ERFeCr-A3A	EF8613
EFeCr-A4	ERFeCr-A4	EF8624
EFeCr-A5	ERFeCr-A5	EF8530
EFeCr-A6		EF8621
EFeCr-A7		EF8618
EFeCr-A8		EF8629
EFeCr-E1		EF8720
EFeCr-E2		EF8812
EFeCr-E3		EF8810
EFeCr-E4		EF8724
ECoCr-A	ERCoCr-A	ECo 3006
ECoCr-B	ERCoCr-B	ECo 3012
ECoCr-C	ERCoCr-C	ECo 3113
ECoCr-E	ERCoCr-E	ECo 3021
ENiCr-C	ERNiCr-C	ENi 9946
ENiCrMo-5A	ERNiCrMo-5A	ENi 9906
ENiCrFeCo	ERNiCrFeCo	ENi 9961
ECuAl-A2	ERCuAl-A2	ECu 6180
ECuAl-B		ECu 6220
ECuAl-C	ERCuAl-C	ECu 6280
ECuAl-D	ERCuAl-D	ECu 6281
ECuAl-E	ERCuAl-E	ECu 6282
ECuSi	ERCuSi-A	ECu 6560
ECuSn-A	ERCuSn-A	ECu 5180
ECuSn-C		ECu 5210
ECuNi		ECu 7158
ECuNiAl		ECu 6328
ECuMnNiAl		ECu 6338

<sup>a</sup> IFS: 2002, Tables 13A and 13B

request should contain some indication of the time by which completion of the new classification or modification is needed. In particular, the request needs to include:

(a) All classification requirements as given for existing classifications, such as chemical composition ranges and usability test requirements.

(b) Any testing conditions for conducting the tests used to demonstrate that the product meets the classification requirements. (It would be sufficient, for example, to state that welding conditions are the same as for other classifications.)

(c) Information on Descriptions and intended Use, which parallels that for existing classifications, for that section of the Annex.

(d) A request for a new classification without the above information will be considered incomplete. The Secretary will return the request to the requestor for further information.

(3) The request should be sent to the Secretary of the AWS A5 Committee on Filler Metals and Allied Materials at AWS Headquarters. Upon receipt of the request, the Secretary will:

- (a) Assign an identifying number to the request. This number will include the date the request was received.
- (b) Confirm receipt of the request and give the identification number to the person who made the request.
- (c) Send a copy of the request to the Chair of the AWS A5 Committee on Filler Metals and Allied Materials, and the Chair of the particular Subcommittee involved.
- (d) File the original request.
- (e) Add the request to the log of outstanding requests.

(4) All necessary action on each request will be completed as soon as possible. If more than 12 months lapse, the Secretary shall inform the requestor of the status of the request, with copies to the Chairs of the Committee and of the Subcommittee. Requests still outstanding after 18 months shall be considered not to have been answered in a “timely manner” and the Secretary shall report these to the Chair of the AWS A5 Committee on Filler Metals and Allied Materials, for action.

(5) The Secretary shall include a copy of the log of all requests pending and those completed during the preceding year with the agenda for each AWS A5 Committee on Filler Metals and Allied Materials meeting. Any other publication of requests that have been completed will be at the option of the American Welding Society, as deemed appropriate.

### A3. Acceptance

Acceptance of all welding materials classified under this specification is in accordance with AWS A5.01M/A5.01 (ISO 14344) as the specification states. Any testing a purchaser requires of the supplier, for material shipped in accordance with this specification, shall be clearly stated in the purchase order, according to the provisions of AWS A5.01M/A5.01 (ISO 14344). In the absence of any such statement in the purchase order, the supplier may ship the material with whatever testing he normally conducts on material of that classification, as specified in Schedule 1 or F, Table 1, of the AWS A5.01M/A5.01 (ISO 14344). Testing in accordance with any other schedule in that table must be specifically required by the purchase order. In such cases, acceptance of the material shipped will be in accordance with those requirements.

### A4. Certification

The act of placing the AWS specification and classification designations on the packaging enclosing the product, or the classification on the product itself, constitutes the supplier’s (manufacturer’s) certification that the product meets all of the requirements of the specification.

The only testing requirement implicit in this certification is that the manufacturer has actually conducted the tests required by the specification on material that is representative of that being shipped and that the material met the requirements of the specification. Representative material, in this case, is any production run of that classification using the same formulation. “Certification” is not to be construed to mean that tests of any kind were necessarily conducted on samples of the specific material shipped. Tests on such material may or may not have been made. The basis for the certification required by the specification is the classification test of “representative material” cited above, and the “Manufacturer’s Quality Assurance System” in AWS A5.01M/A5.01 (ISO 14344).

### A5. Ventilation During Welding

**A5.1** Five major factors govern the quantity of fume in the atmosphere to which welders and welding operators are exposed during welding:

- (1) Dimensions of the space in which welding is done (with special regard to the height of the ceiling)
- (2) Number of welders and welding operators working in that space

- (3) Rate of evolution of fume, gases, or dust, according to the materials and processes used
- (4) The proximity of the welders or welding operators to the fumes as they issue from the welding zone, and to the gases and dusts in the space in which they are working
- (5) The ventilation provided to the space in which the welding is done

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**A5.2** American National Standard ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes* (published by the American Welding Society), discusses the ventilation that is required during welding and should be referred to for details. Attention is particularly drawn to the section of that document on Health Protection and Ventilation. See also AWS F3.2, *Ventilation Guide for Weld Fume* for more detailed descriptions of ventilation options.

## A6. Welding Considerations

**A6.1 Role of Hydrogen in Surfacing.** Hydrogen can be detrimental to surfacing deposits. The effect varies widely from one alloy type to another. Hydrogen can be detrimental to weld ductility and also result in hydrogen-assisted cracking in the weld metal or HAZ. In general, hydrogen's detrimental effect is the most pronounced for martensitic types, with austenitic types being the least affected. Other factors influencing hydrogen's effect include carbon and alloy contents plus in-service welding variables.

In welding there are many sources for hydrogen contamination. Coating moisture is one of the most important ones. Most electrodes are manufactured and packaged to control moisture. When received, consideration must be given to proper storage to prevent moisture pick-up. During use, improper regard to welding procedure and environmental variables can result in spalling or "hydrogen-induced" (underbead) cracking.

**A6.2** Low equipment cost, great versatility, and general convenience make manual shielded metal arc welding very popular. The welding machine, which is essentially a power conversion device, is usually the main item of equipment needed. It may be a motor-generator, transformer, transformer-rectifier combination, or fuel-operated engine combined with a generator. The arc power may be either direct or alternating current. The filler metal is in the form of covered electrodes. (Bare electrode arc welding is a rarity today, though it is feasible with austenitic manganese steel electrodes.) Welding can be done in almost any location and is practicable for a variety of work, ranging from very small to quite large. For some applications, it is the only feasible method; and, for many others (especially where continuous methods do not offer significant benefits), it is the economical choice.

The operation is under the observation and control of the welder, who can easily cover irregular areas and often correct for adverse conditions. It is also helpful if the welder exercises judgment in other matters, such as holding the arc power down to minimize cracking; keeping a short arc and avoiding excessive puddling to minimize the loss of expensive alloying elements in the filler metal; minimizing dilution with base metal; and restricting hydrogen pickup. This process is used extensively for hardfacing, buttering, buildup, and cladding.

Surfacing of carbon and low-alloy steels, high-alloy steels, and many nonferrous metals may be done with the shielded metal arc process. Base metal thicknesses may range from 1/4 in [6 mm] to 18 in [450 mm]. The surfacing metals employed include low- and high-alloy steels, the stainless steels, nickel-base alloys, cobalt-base alloys, and copper-base alloys.

The welding conditions for surfacing are not fundamentally different from those used in welding a joint. The arc and weld pool are shielded by the slag or the gases, or both, produced by the electrode. The type of covering on the electrode has considerable effect on the characteristics of the weld metal. Surfacing can be done on work ranging in size from very small to quite large.

Table A.2 shows how the various shielded metal arc process variables affect the three most important surfacing characteristics: dilution, deposition rate, and deposit thickness.

The table indicates only general trends and does not cover questions of weldability or weld soundness. These factors may make it unwise to change only the indicated variable; this in turn may mean that the desired change in dilution, deposition rate, or deposit thickness may not be achieved. For example, a given welding procedure with a small electrode diameter may produce high dilution. The table indicates that a change to a large size electrode will decrease dilution. This is true, however, only if the amperage, travel speed, position, etc., also remain constant. In many cases, a larger amperage

**Table A.2**  
**Effect of Shielded Metal Arc Variables on the Three Most Important Characteristics of Surfacing**

/A5.13M:2010

Variable	Change of Variable <sup>a</sup>	Influence of Change on		
		Dilution	Deposition Rate	Deposit Thickness
Polarity	AC	Intermediate	Intermediate	Intermediate
	DCEP	High	Low	Thin
	DCEN	Low	High	Thick
Amperage	High	High	High	Thick
	Low	Low	Low	Thin
Technique	Stringer	High	No effect	Thick
	Weave	Low	No effect	Thin
Bead spacing	Narrow	Low	No effect	Thick
	Wide	High	No effect	Thin
Electrode diameter	Small	High	High	Thick
	Large	Low	Low	Thin
Arc length	Long	Low	No effect	Thin
	Short	High	No effect	Thick
Travel speed	Fast	High	No effect	Thin
	Slow	Low	No effect	Thick

<sup>a</sup> This table assumes that only one variable at a time is changed. However, for acceptable surfacing conditions, a change in one variable may require a change in one or more other variables.

value must be used with the larger electrode size to obtain acceptable weld quality. In this case, the dilution may remain constant or even increase with the change to the larger electrode size.

The process usually achieves a deposition rate from 1–4 lb [0.5–2 kg] per hour at dilution levels from 30%–50%.

## A7. Description and Intended Use of Surfacing Electrodes

### A7.1 Iron-Base Electrodes

#### A7.1.1 EFe1 and EFe2 Electrodes

**A7.1.1.1 Characteristics.** Deposits made with these electrodes are a machinery grade steel suitable for application on carbon and alloy steels. With care, they can be applied crack-free. Deposits are machinable with carbide-tipped tools. Deposit hardness generally is in the range of 25–50 HRC with EFe2 electrodes providing weld metal with the higher hardness. These deposits contain sufficient alloy to attain full hardness without the need of heat treatment. Abrasion resistance is comparable to heat-treated steels of equal hardness.

**A7.1.1.2 Applications.** These electrodes are used to restore worn machinery parts to their original dimensions. Deposit surfaces are suitable for metal-to-metal rolling and sliding contact, such as occurs on large, low-speed gear teeth, shafts, etc. High compressive strength makes these materials suitable as a base for more abrasion-resistant materials.

#### A7.1.2 EFe3 Electrodes

**A7.1.2.1 Characteristics.** Weld metal deposited by these electrodes is an air-hardening tool steel type with high room temperature hardness (55–60 HRC). Deposits can be applied crack-free with careful procedures. The deposits cannot be machined and generally are ground when finishing is required.

**A7.1.2.2 Applications.** EFe3 electrodes are used to overlay surfaces and edges requiring high hardness and crack-free deposits, such as the edges of tools and dies. Deposits are compatible with many tool steels. Although generally used



for metal-to-metal applications, EFe3 weld metal performs well in earth abrasion applications where high impact is encountered.

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### A7.1.3 EFe4 Electrodes

**A7.1.3.1 Characteristics.** These electrodes will have a graphitic (black) coating and are suitable for application on cast iron. Although the deposited metal is relatively brittle, crack-free deposits can be made with controlled procedures. Deposits can be machined providing they are slow cooled from an annealing temperature.

**A7.1.3.2 Applications.** EFe4 weld metal is used to rebuild worn cast iron machinery parts subject to metal-to-metal rolling or sliding contact. Although EFe4 weld deposits are compatible with carbon and low-alloy steel, EFe2 electrodes generally are preferred for such applications.

### A7.1.4 EFe5 Electrodes

**A7.1.4.1 Characteristics.** EFe5 electrodes deposit a cold work type of tool steel. Hardness as-deposited should be in the range of 50–55 HRC. Weld metal deposited by EFe5 electrodes is air-hardening and machinable only after annealing.

**A7.1.4.2 Applications.** Typical applications include those requiring high compressive strength with moderate abrasion and metal-to-metal wear, such as machine components, shafts, and brake drums.

### A7.1.5 EFe6 Electrodes

**A7.1.5.1 Characteristics.** Weld metal deposited by EFe6 electrodes is a high-speed tool steel with a hardness in range of 60 HRC or higher. The deposit maintains a high degree of hardness to 1100°F [600°C]. Weld metal deposited by EFe6 electrodes is air-hardening and is machinable only after annealing.

**A7.1.5.2 Applications.** Weld deposits may be used for metal-to-metal wear applications at temperatures up to 1100°F [600°C]. Typical applications combine high temperature service with severe abrasion and metal-to-metal wear and include shear blades, trimming dies, and punching dies.

### A7.1.6 EFe7 Electrodes

**A7.1.6.1 Characteristics.** EFe7 series electrodes are essentially a higher carbon modification of EFe3 electrodes. Abrasion resistance of the weld deposit is improved with some sacrifice in resistance to impact. Deposits air harden, and a two-layer deposit can be expected to have a hardness of 60 HRC or higher. Stress-relief cracks (checks) typically occur through the overlay. Deposits cannot be machined.

**A7.1.6.2 Applications.** EFe7 electrodes are used for overlaying surfaces that require good low-stress abrasion resistance. Applications include cement chutes, fan blades, bulldozer blades, and other parts and equipment used for earthmoving or construction. Carbon and alloy steels, tool steels, and stainless steels are compatible base metals.

### A7.1.7 EFeMn Series Electrodes (EFeMn-A through EFeMn-F)

**A7.1.7.1 Characteristics.** Deposits made with EFeMn series electrodes nominally contain 14% manganese, although they may vary from 12% to 21%. This is an amount sufficient to yield austenitic weld deposits. Austenite is a nonmagnetic, tough form of steel. To preserve the toughness, excessive heat must be avoided during welding. Stringer beads and a block sequence are recommended. The additions of other elements, such as 4% nickel, are made to give more stability to the austenite; chromium, molybdenum, and vanadium are also added singly or in combination of 0.5%–8% to increase the yield strength. Abrasion resistance is only a little better than that of low-carbon steel unless there has been sufficient impact to cause work hardening. As-deposited surfaces generally are no harder than HRC 20, but can work harden to HRC 55. Since deposits are difficult to machine, grinding is preferred for finishing.

**A7.1.7.2 Applications.** These electrodes are used for the rebuilding, repair, and joining of Hadfield austenitic manganese steel. Ability to absorb high impact makes such deposits ideal for the rebuilding of worn rock crushing equipment and parts subject to impact loading, such as railroad frogs.

### A7.1.8 EFeMnCr Electrodes

**A7.1.8.1 Characteristics.** Weld metal deposited by EFeMnCr electrodes have characteristics similar to austenitic manganese deposits. The high chromium content imparts stainless steel qualities. These deposits cannot be flame cut. Although care must be taken in application to avoid heat build-up, deposits are more stable than FeMn series electrodes.

**A7.1.8.2 Applications.** Like EFeMn type electrodes, EFeMnCr electrodes are used for rebuilding, repair, and joining of equipment made of Hadfield austenitic manganese steel. EFeMnCr electrodes offer the added advantage of being usable for joining austenitic manganese steel both to itself and to carbon steel. EFeMnCr weld metals often are used as a base for surfacing with EFeCr types for parts subject to both wear and impact.

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#### **A7.1.9 EFeCr-A1A and EFeCr-A4 Electrodes**

**A7.1.9.1 Characteristics.** Weld metal deposited by these electrodes will contain massive chromium carbides in an austenitic matrix providing excellent wear resistance and toughness. Surface checks are typical and give some degree of stress relief. Deposits cannot be machined and must be ground when finishing is required. To ensure the desired deposit composition, two layers are recommended. Additional layers invite spalling and must be applied with caution. Electrodes are suitable for welding on carbon, alloy, and austenitic steels as well as cast irons. The weld metal deposited by EFeCr-A1A electrodes generally provides greater resistance to impact but slightly less abrasion resistance than weld metal deposited by EFeCr-A4 electrodes.

**A7.1.9.2 Applications.** Deposits frequently are used to surface parts and equipment involved in sliding and crushing of rock, ore, etc., such as bucket lips and teeth, impact hammers, and conveyors. Very low coefficients of friction develop as a result of scouring by earth products.

#### **A7.1.10 EFeCr-A2 Electrodes**

**A7.1.10.1 Characteristics.** The weld metal deposit contains titanium carbide in an austenitic matrix. It is machinable only by grinding. Build-up should be limited to three layers to minimize relief check cracking.

**A7.1.10.2 Applications.** This weld metal group may be applied to both carbon steel and austenitic manganese base metal. Deposits frequently are used to hardface mining, construction, earth moving, and quarrying equipment subject to abrasion and moderate impact.

#### **A7.1.11 EFeCr-A3 Electrodes**

**A7.1.11.1 Characteristics.** Filler metal deposited by EFeCr-A3 electrodes is similar to a deposit made using EFeCr-A1A electrodes except, due to the lower manganese content, a martensitic matrix is present, rendering the deposit somewhat brittle. These deposits are not machinable but may be finished by grinding where necessary.

**A7.1.11.2 Applications.** This weld metal is a general purpose hardfacing alloy for earth abrasion applications and is suitable for low stress scratching abrasion with low impact.

#### **A7.1.12 EFeCr-A5 Electrodes**

**A7.1.12.1 Characteristics.** The weld deposit contains chromium carbide in an austenitic matrix. The nonmagnetic weld metal has fair machinability. Build-up should be restricted to three layers to minimize stress-relief checking.

**A7.1.12.2 Applications.** Surfaced components frequently are used for applications involving frictional metal-to-metal wear or earth scouring under low stress abrasion.

#### **A7.1.13 EFeCr-A6 and EFeCr-A7 Electrodes**

**A7.1.13.1 Characteristics.** These are a higher carbon version of EFeCr-A5 electrodes. The deposit contains hexagonal chromium carbides in an austenitic matrix and has a hardness of 50–60 HRC. Deposits develop stress-relief checks. The addition of molybdenum increases wear resistance to high stress abrasion. The weld metal may be applied on carbon, alloy, or austenitic manganese steel base metal.

**A7.1.13.2 Applications.** Weld metal is frequently used for applications involving low stress abrasive wear combined with moderate impact.

#### **A7.1.14 EFeCr-A8 Electrodes**

**A7.1.14.1 Characteristics.** EFeCr-A8 is a higher chromium version of EFeCr-A3. The deposit contains hexagonal chromium carbides in an austenitic matrix and has a hardness of 50–60 HRC. The increased chromium content tends to decrease the toughness while increasing the abrasion resistance. Maximum relief checking can be expected. The weld metal may be applied to carbon, alloy, or austenitic manganese base metals.

**A7.1.14.2 Applications.** Weld metal is frequently used for applications involving low stress abrasion combined with minimum impact.

### A7.1.15 EFeCr-EX Series Electrodes

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**A7.1.15.1 Characteristics.** This family of electrodes deposits weld metal containing finely dispersed chromium carbides plus one or more metallic carbides (vanadium, niobium [columbium], tungsten, or titanium). The resultant deposits are not machinable, and maintain their hot hardness and abrasion resistance to 1200 °F [650 °C]. Deposits stress-relief check readily.

**A7.1.15.2 Applications.** Equipment subjected to severe high stress abrasion combined with moderate impact may be surfaced with one of the specific grades. Selection of the specific grade will be dependent on local service conditions and the specific application.

### A7.2 Cobalt-Base Surfacing Electrodes

#### A7.2.1 ECoCr-A Electrodes

**A7.2.1.1 Characteristics.** Weld metal deposited by ECoCr-A electrodes is characterized by a hypoeutectic structure consisting of a network of about 13% eutectic chromium carbides distributed in a cobalt-chromium-tungsten solid solution matrix. The result is a material with a combination of overall resistance to low stress abrasive wear coupled with the necessary toughness to resist some degree of impact. Cobalt alloys also are inherently good for resisting metal-to-metal wear, particularly in high load situations that are prone to galling. The high alloy content of the matrix also affords excellent resistance to corrosion, oxidation, and elevated temperature retention of hot hardness up to a maximum of 1200 °F [650 °C]. These alloys are not subject to allotropic transformation and therefore do not lose their properties if the base metal subsequently is heat treated.

**A7.2.1.2 Applications.** The alloy is recommended for cases where wear is accompanied by elevated temperatures and where corrosion is involved, or both. Typical applications include automotive and fluid flow valves, chain saw guides, hot punches, shear blades, extruder screws, etc.

#### A7.2.2 ECoCr-B Electrodes

**A7.2.2.1 Characteristics.** Weld metal deposited by ECoCr-B electrodes is similar in composition to ECoCr-A deposits except for a slightly higher carbide content (approximately 16%). The alloy also has a slightly higher hardness coupled with better abrasive and metal-to-metal wear resistance. Impact and corrosion resistance are lowered slightly. Deposits can be machined with carbide tools.

**A7.2.2.2 Applications.** ECoCr-B electrodes are used interchangeably with ECoCr-A. Choice will depend on the specific application.

#### A7.2.3 ECoCr-C Electrodes

**A7.2.3.1 Characteristics.** This alloy's deposits have a higher carbide content (19%) than those made using either ECoCr-A or ECoCr-B electrodes. In fact, the composition is such that primary hypereutectic carbides are found in the microstructure. This characteristic gives the alloy higher wear resistance, accompanied by reductions in the impact and corrosion resistance. The higher hardness also means a greater tendency to stress crack during cooling. The cracking tendency may be minimized by closely monitoring preheating, interpass temperature, and postheating techniques.

While the cobalt–chromium deposits soften somewhat at elevated temperatures, they normally are considered immune to tempering.

**A7.2.3.2 Applications.** Weld metal deposited by ECoCr-C electrodes is used to build up mixer rotors and items that encounter severe abrasion and low impact.

#### A7.2.4 ECoCr-E Electrodes

**A7.2.4.1 Characteristics.** Welds made using ECoCr-E electrodes have very good strength and ductility at temperatures up to 1600 °F [870 °C]. Deposits are resistant to thermal shock, and oxidizing and reducing atmospheres. Early applications of these types of alloys were found in jet engine components such as turbine blades and vanes.

The deposit is a solid-solution-strengthened alloy with a relatively low weight-percent carbide phase in the microstructure. Hence, the alloy is very tough and will work harden. Deposits possess excellent self-mated galling resistance and also are very resistant to cavitation erosion.

**A7.2.4.2 Applications.** Welds made using ECoCr-E electrodes are used where resistance to thermal shock is important. Typical applications, similar to those of ECoCr-A deposits, include guide rolls, hot extrusion and forging dies, hot shear blades, tong bits, and valve trim.

**A7.2.5** Typical hardness values for multilayer welds made using the cobalt-base electrodes are:

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ECoCr-A	23–47 HRC
ECoCr-B	34–47 HRC
ECoCr-C	43–58 HRC
ECoCr-E	20–32 HRC

Hardness values for single layer deposits will be lower because of dilution from the base metal.

### **A7.3 Nickel-Base Surfacing Electrodes**

#### **A7.3.1 ENiCr-C Electrodes**

**A7.3.1.1 Characteristics.** Undiluted weld metal of this composition exhibits a structure consisting of chromium carbides and chromium borides in a nickel-rich matrix. The nickel base and high chromium content give these deposits good heat and corrosion resistance. Care should be taken when cooling hardfacing deposits because of a tendency to stress crack. This alloy possesses excellent resistance to low stress abrasion.

**A7.3.1.2 Applications.** ENiCr-C weld metal flows very easily, has very high abrasion resistance, and normally takes on a high polish. Typical applications include cultivator sweeps, plow shares, extrusion screws, pump sleeves, pistons, and impellers, capstan rings, glass mold faces, centrifuge filters, sucker pump rods, etc. The deposits have high corrosion resistance and normally require grinding for finishing. Single layer deposits typically have a hardness of 35–45 HRC. Multilayer deposits typically have a hardness of 49–56 HRC.

#### **A7.3.2 ENiCrMo-5A Electrodes**

**A7.3.2.1 Characteristics.** Undiluted weld metal deposited by ENiCrMo-5A electrodes is a solid-solution-strengthened alloy with relatively low weight-percent carbide phase produced through secondary hardening. The resultant deposit is tough and work hardenable.

Deposits have the ability to retain hardness up to 1400°F [760°C]. Deposits are machinable with high-speed tool bits and have excellent resistance to high-temperature wear and impact.

**A7.3.2.2 Applications.** These electrodes are used to rebuild and repair hot extrusion dies, hot forging dies, sizing punches, hot shear blades, guide rolls, tong bits, blast furnace bells, etc.

#### **A7.3.3 ENiCrFeCo Electrodes**

**A7.3.3.1 Characteristics.** Weld metal deposited by these electrodes contain a fairly large volume fraction of hypereutectic chromium carbides distributed throughout the microstructure. The alloy offers many of the same high-performance characteristics of deposits made using ECoCr-C or ENiCr-C electrodes in terms of abrasive wear resistance. The reduced nickel or cobalt content, or both, lowers corrosion properties and galling resistance. The high volume fraction of carbides makes this alloy sensitive to cracking during cooling.

**A7.3.3.2 Applications.** Welds made using ENiCrFeCo electrodes are preferred where high abrasion (low impact) is a major factor. Typical applications are feed screws, slurry pumps, and mixer components.

### **A7.4 Copper-Base Alloy Electrodes**

**A7.4.1 Introduction.** The copper-base alloy electrodes classified by this specification are used to deposit overlays and inlays for bearing, corrosion-resistant, or wear-resistant surfaces.

**A7.4.1.1** ECuAl-A2 electrodes are used for surfacing bearing surfaces, requiring the hardness in the ranges of 130–150 HB, as well as corrosion-resistant surfaces.

**A7.4.1.2** ECuAl-B and ECuAl-C electrodes are used primarily for surfacing bearing surfaces requiring hardness in the range of 140–220 HB. These alloys are not recommended for applications that require resistance to corrosion.

**A7.4.1.3** ECuAl-D and ECuAl-E electrodes are used to surface bearing and wear-resistant surfaces requiring hardness in the range of 230–320 HB, such as gears, cams, sheaves, wear plates, dies, etc. These alloys are also used to surface dies that form or draw titanium, low-carbon and stainless steels. These alloys are not recommended for applications that require resistance to corrosion.

**A7.4.1.4** The ECuSi electrodes are used primarily for surfacing corrosion-resistant surfaces. Copper–silicon deposits generally are not recommended for bearing service.

**A7.4.1.5** Copper–tin (ECuSn-A and -C) electrodes are used primarily to surface bearing surfaces where the lower hardness of these alloys is required, for surfacing corrosion-resistant surfaces, and, occasionally, for applications requiring wear resistance.

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**A7.4.1.6** Copper–nickel (ECuNi) electrodes are used for rebuilding 70/30, 80/20, and 90/10% copper–nickel alloy or the clad side of copper–nickel clad steel. Preheating generally is not necessary.

**A7.4.1.7** Copper-nickel-aluminum electrodes (ECuNiAl) are used to rebuild nickel-aluminum-bronze castings or wrought components. Typical applications are those requiring a high resistance to corrosion, erosion, or cavitation in salt or brackish water.

**A7.4.1.8** Copper-manganese-nickel-aluminum (ECuMnNiAl) electrodes are used to rebuild or surface cast manganese-nickel-aluminum bronze castings or wrought material. Typical applications include those requiring excellent resistance to corrosion, erosion, and cavitation.

#### A7.4.2 Applications

**A7.4.2.1 Hardness Ranges.** See Table A.3 for typical hardness ranges.

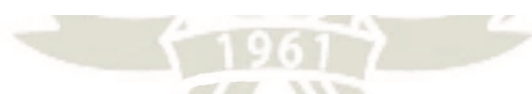
**A7.4.2.2 Hot Hardness.** The copper-base alloy filler metals are not recommended for use at elevated temperatures. Mechanical properties, especially hardness, will tend to decrease consistently as the temperature increases above 400° F [200° C].

**A7.4.2.3 Impact.** In general, as the aluminum content increases, impact resistance decreases rapidly. The impact resistance of deposits made by using ECuAl-A2 electrodes will be the highest of the copper-base alloy classifications. Deposits made using ECuSi electrodes have good impact properties. Deposits made using ECuSn electrodes have low impact values.

**A7.4.2.4 Oxidation Resistance.** Weld metal deposited by any of the ECuAl family of electrodes forms a protective oxide coating upon exposure to the atmosphere. Oxidation resistance of the copper–silicon deposit is fair, while that of copper–tin deposits is comparable to the oxidation resistance of pure copper.

**A7.4.2.5 Corrosion Resistance.** Several copper base alloy filler metals are used rather extensively to surface areas subject to corrosion from reducing type acids, mild alkalis, and salt water. They should not be used in the presence of oxidizing acids, such as HNO<sub>3</sub>, or when sulfur compounds are present. Filler metals producing deposits of higher hardness may be used to surface areas subject to corrosive action as well as erosion from liquid flow for such applications as condenser heads and turbine runners.

**A7.4.2.6 Abrasion.** None of the copper-base alloy deposits is recommended for use where severe abrasion is encountered in service.



**Table A.3**  
**Approximate Weld Deposit Hardness (SMAW)**

AWS Classification	Brinell Hardness <sup>a</sup>	
	3000 kg Load	500 kg Load
ECuAl-A2	130–150	—
ECuAl-B	140–180	—
ECuAl-C	180–220	—
ECuAl-D	230–270	—
ECuAl-E	280–320	—
ECuSi	—	80–100
ECuSn-A	—	70–85
ECuSn-C	—	85–100
ECuNi	—	60–80
ECuNiAl	160–200	—
ECuMnNiAl	160–200	—

<sup>a</sup> As-welded condition.

**A7.4.2.7 Metal-to-Metal Wear.** Copper–aluminum deposits with hardnesses of 130 to approximately 320 HB are used to overlay surfaces subjected to excessive wear from metal-to-metal contact. For example, ECuAl-E electrodes are used to surface dies, and to draw and form stainless and carbon steels and aluminum.

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All of the copper-base alloy filler metals classified by this specification are used to deposit overlays and inlays for bearing surfaces, with the exception of the CuSi filler metals. Silicon bronzes are considered poor bearing alloys. Copper-base alloy filler metals selected for a bearing surface should produce a deposit of 50–75 HB under that of the mating part. Equipment should be designed so that the bearing will wear in preference to the mating part.

**A7.4.2.8 Mechanical Properties in Compression.** Deposits of the ECuAl filler metals have high elastic limits and ultimate strengths in compression ranging between 25 000–65 000 psi [170–450 MPa] and 120 000–171 000 psi [825–1180 MPa], respectively. The elastic limit of ECuSi deposits is around 22 000 psi [150 MPa] with an ultimate strength in compression of 60 000 psi [415 MPa]. The ECuSn deposits will have an elastic limit of 11 000 psi [75 MPa] and an ultimate strength of 32 000 psi [220 MPa].

**A7.4.2.9 Machinability.** All of these copper-base alloy deposits are machinable.

**A7.4.2.10 Heat Treatment.** Ordinarily, no heat treatment is needed in surfacing with copper-base alloy filler metals.

**A7.4.2.11 Welding Characteristics.** To minimize dilution from the base metal when surfacing with copper-base electrodes, the first layer should be deposited using as low an amperage as practical. Excessive base metal dilution can result in reduced machinability and service performance. The manufacturer should be consulted for specific welding parameters.

**A7.4.2.12 Preheat.** Generally, a preheat is not necessary unless the part is exceptionally large; in this case, a 200 °F [100 °C] preheat may be desirable to facilitate the smooth flow of the weld metal. At no time should the preheat temperature be above 400 °F [200 °C] when applying the first layer. On subsequent layers, an interpass temperature of approximately 200 °F–600 °F [100 °C–300 °C] will simplify deposition of the weld metal.

## A7.5 Tungsten Carbide Electrodes

**A7.5.1 Characteristics.** Tungsten carbide covered electrodes contain 60% by weight tungsten carbide granules. The WC1 carbide is a mixture of WC and W<sub>2</sub>C. The WC2 carbide is macrocrystalline WC. Hardness of the matrix of the deposit can be varied from 30 HRC to 60 HRC depending on welding technique. Hardness of individual carbide particles typically is about 2400 HV20. The abrasion resistance of tungsten carbide deposits is outstanding.

**A7.5.2 Applications.** Tungsten carbide deposits are applied on surfaces subjected to sliding abrasion combined with limited impact. Such applications are encountered in earth drilling, digging, and farming. Specific tools that may require this type of surfacing overlay include oil drill bits and tool joints, earth handling augers, excavator teeth, farm fertilizer applicator knives, and cultivator shares.

## A8. Discontinued Classifications

Some classifications have been discontinued from one revision of this specification to another. This results either from changes in commercial practice or changes in the classification system used in the specification. The classifications that have been discontinued are listed in Table A.4, along with the year in which they were last included in the specification.

## A9. General Safety Considerations

**A9.1 Safety and health issues and concerns** are beyond the scope of this standard and, therefore, are not fully addressed herein. Some safety and health information can be found in Clause A5 and below. Safety and health information is available from other sources, including but not limited to ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*, and applicable federal and state regulations.

**A9.2 Safety and Health Fact Sheets.** The Safety and Health Fact Sheets listed below are published by the American Welding Society (AWS). They may be downloaded and printed directly from the AWS website at <http://www.aws.org>. The Safety and health Fact Sheets are revised and additional sheets added periodically.

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**Table A.4**  
**Discontinued Electrode and Rod Classifications<sup>a</sup>**

AWS Classification	Last A5.13 (ASTM A 399) Publication Date	AWS Classification	Last A5.13 (ASTM A 399) Publication Date
RFeCr-A2	1956	ERCuAl-A3 <sup>c</sup>	1980
EFeCr-A2	1956	RCuAl-C <sup>b</sup>	1980
ECuZn-E	1956	RCuAl-D <sup>b</sup>	1980
RCuAl-B	1970	RCuAl-E <sup>b</sup>	1980
RCuSn-E	1970	ERCuSn-A	1980
ECuSn-E	1970	RCuSn-D <sup>b</sup>	1980
RFe5-A	1980	RNiCr-A <sup>b</sup>	1980
RFe5-B	1980	RNiCr-B <sup>b</sup>	1980
RFeCr-A1	1980	RNiCr-C <sup>b</sup>	1980
RCoCr-A <sup>b</sup>	1980	EFe5-A	1980
RCoCr-B <sup>b</sup>	1980	EFe5-B	1980
RCoCr-C <sup>b</sup>	1980	EFe5-C	1980
RCuZn-E	1980	EFeCr-Al	1980
ERCuSi-A <sup>c</sup>	1980	ENiCr-A	1980
ERCuAl-A2 <sup>c</sup>	1980	ENiCr-B	1980

<sup>a</sup> See A8, Discontinued Classifications (in Annex A), for information on discontinued classifications.

<sup>b</sup> These AWS classifications have been transferred to AWS A5.21:2001 with the revised prefix of “ER” for electrode/rod made from solid stock or prefix of “ERC” for electrode/rod made from metal or flux cored composite stock.

<sup>c</sup> These AWS classifications have been transferred to AWS A5.21:2001 without a change in the classification designation for solid bare electrodes and rods or with the prefix “ERC” for electrode/rod made from metal or flux cored stock.

### A9.3 AWS Safety and Health Fact Sheet Index (SHF)<sup>10</sup>

#### No. Title

- 1 *Fumes and Gases*
- 2 *Radiation*
- 3 *Noise*
- 4 *Chromium and Nickel in Welding Fume*
- 5 *Electrical Hazards*
- 6 *Fire and Explosion Prevention*
- 7 *Burn Protection*
- 8 *Mechanical Hazards*
- 9 *Tripping and Falling*
- 10 *Falling Objects*
- 11 *Confined Spaces*
- 12 *Contact Lens Wear*
- 13 *Ergonomics in the Welding Environment*
- 14 *Graphic Symbols for Precautionary Labels*
- 15 *Style Guidelines for Safety and Health Documents*
- 16 *Pacemakers and Welding*
- 17 *Electric and Magnetic Fields (EMF)*
- 18 *Lockout/Tagout*
- 19 *Laser Welding and Cutting Safety*
- 20 *Thermal Spraying Safety*
- 21 *Resistance Spot Welding*
- 22 *Cadmium Exposure from Welding & Allied Processes*
- 23 *California Proposition 65*

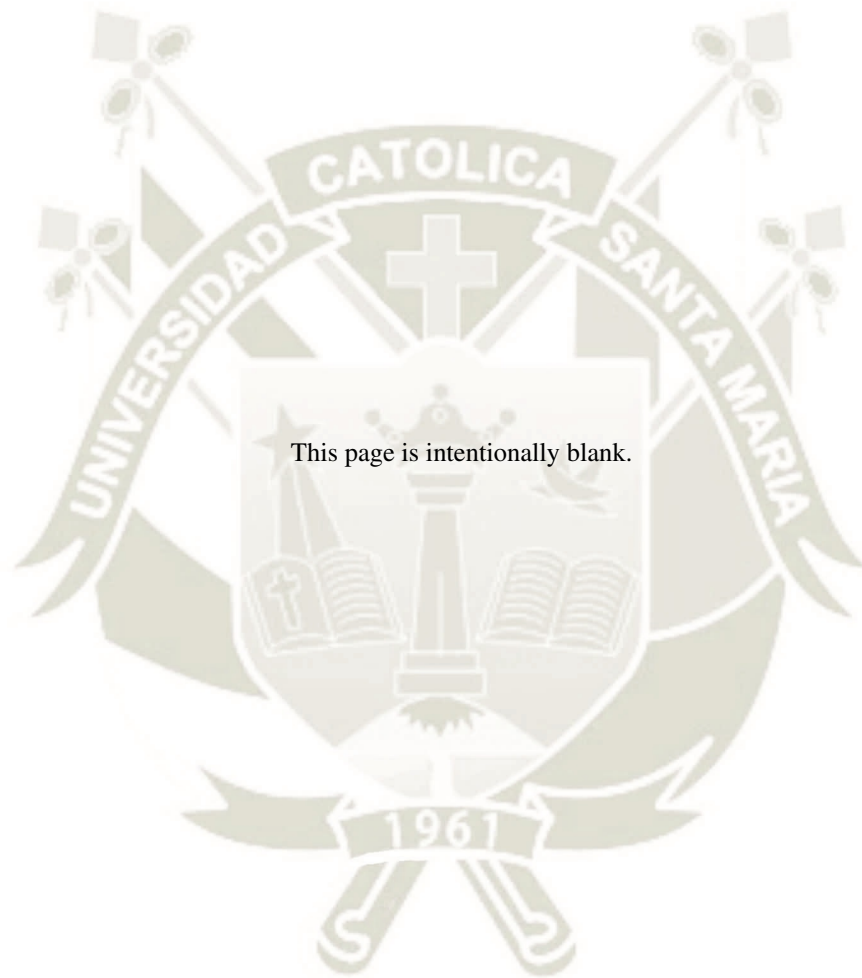
<sup>10</sup> AWS standards are published by the American Welding Society, 550 N.W. LeJeune Rd, Miami, FL 33126.

- 24 *Fluxes for Arc Welding and Brazing: Safe Handling and Use*
- 25 *Metal Fume Fever*
- 26 *Arc Welding Distance*
- 27 *Thoriated Tungsten Electrodes*
- 28 *Oxyfuel Safety: Check Valves and Flashback Arrestors*
- 29 *Grounding of Portable and Vehicle Mounted Welding Generators*
- 30 *Cylinders: Safe Storage, Handling, and Use*
- 31 *Eye and Face Protection for Welding and Cutting Operations*
- 33 *Personal Protective Equipment (PPE) for Welding & Cutting*
- 34 *Coated Steels: Welding and Cutting Safety Concerns*
- 36 *Ventilation for Welding & Cutting*
- 37 *Selecting Gloves for Welding & Cutting*

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## Annex B (Informative)

# Guidelines for the Preparation of Technical Inquiries

This annex is not part of AWS A5.13/A5.13M:2010, *Specification for Surfacing Electrodes for Shielded Metal Arc Welding*, but is included for informational purposes only.

### B1. Introduction

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all interpretations are made by the committee that is responsible for the standard. Official communication concerning an interpretation is directed through the AWS staff member who works with that committee. The policy requires that all requests for an interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the complexity of the work and the procedures that must be followed, some interpretations may require considerable time.

### B2. Procedure

All inquiries shall be directed to:

Managing Director  
Technical Services Division  
American Welding Society  
550 N.W. LeJeune Road  
Miami, FL 33126

All inquiries shall contain the name, address, and affiliation of the inquirer, and they shall provide enough information for the committee to understand the point of concern in the inquiry. When the point is not clearly defined, the inquiry will be returned for clarification. For efficient handling, all inquiries should be typewritten and in the format specified below.

**B2.1 Scope.** Each inquiry shall address one single provision of the standard unless the point of the inquiry involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the inquiry along with the edition of the standard that contains the provision(s) the inquirer is addressing.

**B2.2 Purpose of the Inquiry.** The purpose of the inquiry shall be stated in this portion of the inquiry. The purpose can be to obtain an interpretation of a standard's requirement or to request the revision of a particular provision in the standard.

**B2.3 Content of the Inquiry.** The inquiry should be concise, yet complete, to enable the committee to understand the point of the inquiry. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annex) that bear on the inquiry shall be cited. If the point of the inquiry is to obtain a revision of the standard, the inquiry shall provide technical justification for that revision.

**B2.4 Proposed Reply.** The inquirer should, as a proposed reply, state an interpretation of the provision that is the point of the inquiry or provide the wording for a proposed revision, if this is what the inquirer seeks.

### B3. Interpretation of Provisions of the Standard

Interpretations of provisions of the standard are made by the relevant AWS technical committee. The secretary of the committee refers all inquiries to the chair of the particular subcommittee that has jurisdiction over the portion of the

standard addressed by the inquiry. The subcommittee reviews the inquiry and the proposed reply to determine what the response to the inquiry should be. Following the subcommittee's development of the response, the inquiry and the response are presented to the entire committee for review and approval. Upon approval by the committee, the interpretation is an official interpretation of the Society, and the secretary transmits the response to the inquirer and to the *Welding Journal* for publication.

AWS A5.13/A5.13M:2010

#### **B4. Publication of Interpretations**

All official interpretations will appear in the *Welding Journal* and will be posted on the AWS web site.

#### **B5. Telephone Inquiries**

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The *AWS Board Policy Manual* requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.

#### **B6. AWS Technical Committees**

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees or to consideration of revisions to existing provisions on the basis of new data or technology. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.



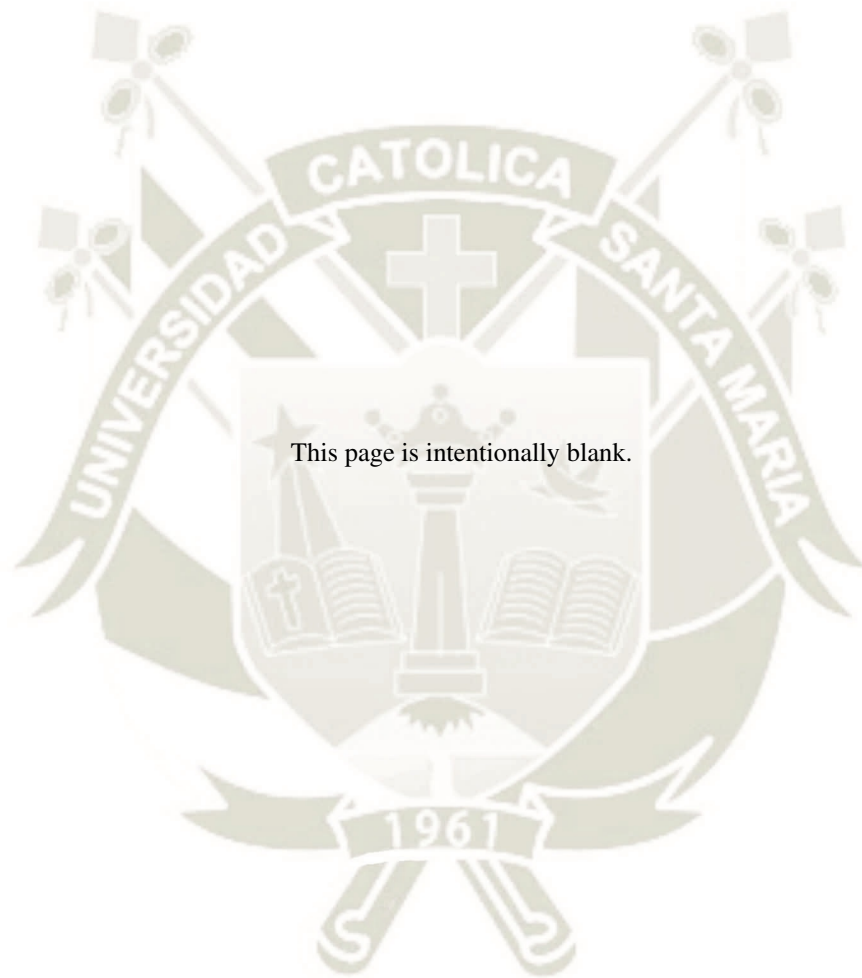
**AWS Filler Metal Specifications by Material and Welding Process**

AWS A5.13/A5.13M:2010

	OFW	SMAW	GTAW GMAW PAW	FCAW	SAW	ESW	EGW	Brazing
Carbon steel	A5.2	A5.1	A5.18	A5.20	A5.17	A5.25	A5.26	A5.8, A5.31
Low-alloy steel	A5.2	A5.5	A5.28	A5.29	A5.23	A5.25	A5.26	A5.8, A5.31
Stainless steel		A5.4	A5.9, A5.22	A5.22	A5.9	A5.9	A5.9	A5.8, A5.31
Cast iron	A5.15	A5.15	A5.15	A5.15				A5.8, A5.31
Nickel alloys		A5.11	A5.14	A5.34	A5.14	A5.14		A5.8, A5.31
Aluminum alloys		A5.3	A5.10					A5.8, A5.31
Copper alloys		A5.6	A5.7					A5.8, A5.31
Titanium alloys			A5.16					A5.8, A5.31
Zirconium alloys			A5.24					A5.8, A5.31
Magnesium alloys			A5.19					A5.8, A5.31
Tungsten electrodes			A5.12					
Brazing alloys and fluxes								A5.8, A5.31
Surfacing alloys	A5.21	A5.13	A5.21	A5.21	A5.21			
Consumable inserts			A5.30					
Shielding gases			A5.32	A5.32			A5.32	



AWS A5.13/A5.13M:2010



**AWS Filler Metal Specifications and Related Documents**

AS.13M:2010

<b>Designation</b>	<b>Title</b>
FMC	<i>Filler Metal Comparison Charts</i>
IFS	<i>International Index of Welding Filler Metal Classifications</i>
UGFM	<i>User's Guide to Filler Metals</i>
A4.2M (ISO 8249)	<i>Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Ferritic-Austenitic Stainless Steel Weld Metal</i>
A4.3	<i>Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding</i>
A4.4M	<i>Standard Procedures for Determination of Moisture Content of Welding Fluxes and Welding Electrode Flux Coverings</i>
A5.01M/A5.01 (ISO 14344)	<i>Procurement guidelines for consumables – Welding and allied processes – Flux and Gas Shielded Electrical Welding Processes</i>
A5.02/A5.02M	<i>Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes</i>
A5.1/A5.1M	<i>Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding</i>
A5.2/A5.2M	<i>Specification for Carbon and Low Alloy Steel Rods for Oxyfuel Gas Welding</i>
A5.3/A5.3M	<i>Specification for Aluminum-Alloy Electrodes for Shielded Metal Arc Welding</i>
A5.4/A5.4M	<i>Specification for Stainless Steel Welding Electrodes for Shielded Metal Arc Welding</i>
A5.5/A5.5M	<i>Specification for Low Alloy Steel Electrodes for Shielded Metal Arc Welding</i>
A5.6/A5.6M	<i>Specification for Covered Copper and Copper-Alloy Arc Welding Electrodes</i>
A5.7/A5.7M	<i>Specification for Copper and Copper Alloy Bare Welding Rods and Electrodes</i>
A5.8/A5.8M	<i>Specification for Filler Metals for Brazing and Braze Welding</i>
A5.9/A5.9M	<i>Specification for Bare Stainless Steel Welding Electrodes and Rods</i>
A5.10/A5.10M	<i>Specification for Bare Aluminum and Aluminum-Alloy Welding Electrodes and Rods</i>
A5.11/A5.11M	<i>Specification for Nickel and Nickel-Alloy Welding Electrodes for Shielded Metal Arc Welding</i>
A5.12/A5.12M	<i>Specification for Tungsten and Tungsten-Alloy Electrodes for Arc Welding and Cutting</i>
A5.13/A5.13M	<i>Specification for Surfacing Electrodes for Shielded Metal Arc Welding</i>
A5.14/A5.14M	<i>Specification for Nickel and Nickel-Alloy Bare Welding Electrodes and Rods</i>
A5.15	<i>Specification for Welding Electrodes and Rods for Cast Iron</i>
A5.16/A5.16M	<i>Specification for Titanium and Titanium Alloy Welding Electrodes and Rods</i>
A5.17/A5.17M	<i>Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding</i>
A5.18/A5.18M	<i>Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding</i>
A5.19	<i>Specification for Magnesium Alloy Welding Electrodes and Rods</i>
A5.20/A5.20M	<i>Specification for Carbon Steel Electrodes for Flux Cored Arc Welding</i>
A5.21	<i>Specification for Bare Electrodes and Rods for Surfacing</i>
A5.22/A5.22M	<i>Specification for Stainless Steel Flux Cored and Metal Cored Welding Electrodes and Rods</i>
A5.23/A5.23M	<i>Specification for Low-Alloy Steel Electrodes and Fluxes for Submerged Arc Welding</i>
A5.24/A5.24M	<i>Specification for Zirconium and Zirconium Alloy Welding Electrodes and Rods</i>
A5.25/A5.25M	<i>Specification for Carbon and Low-Alloy Steel Electrodes and Fluxes for Electroslag Welding</i>

<b>Designation</b>	<b>Title</b>	A5.13M:2010
A5.26/A5.26M	<i>Specification for Carbon and Low-Alloy Steel Electrodes for Electrode Gas Welding</i>	
A5.28/A5.28M	<i>Specification for Low-Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding</i>	
A5.29/A5.29M	<i>Specification for Low-Alloy Steel Electrodes for Flux Cored Arc Welding</i>	
A5.30/A5.30M	<i>Specification for Consumable Inserts</i>	
A5.31	<i>Specification for Fluxes for Brazing and Braze Welding</i>	
A5.32/A5.32M	<i>Specification for Welding Shielding Gases</i>	
A5.34/A5.34M	<i>Specification for Nickel-Alloy Electrodes for Flux Cored Arc Welding</i>	







# **ANEXO 4**

# **PROPIEDADES**

# **CITODUR – 1000**

Electrodo para recargue de gran resistencia a la corrosión oxidación y abrasión severa. El material depositado es una fundición blanca con alto contenido de cromo (36%), por lo que, se recomienda aplicar 2 pases para que el relleno no se desprenda. En la mayoría de los casos, para obtener las características deseadas, es recomendable usar una cama cojín apropiada en función a las características del material base o los desgastes presentes. Gracias a su alto contenido de carburos de cromo, el depósito conserva la resistencia a la abrasión severa aún a temperaturas elevadas (hasta 1000°C). Los cordones que deposita son perfectamente lisos, libres de poros, sin salpicaduras ni inclusiones de escoria. El material de aporte es no maquinable, pero puede ser forjado y templado.

Clasificación	
AWS A5.13 / ASME SFA-5.13	EFeCr-A8
DIN 8555	E10 - UM 60 CGRZ


#### Análisis Químico de Metal Depositado (valores típicos) [%]

C	Mn	Si	P	S	Mo	Ni	Cr	Cu	Otros
4,00	1,10	0,60	máx. 0,020	máx. 0,020	-	-	36,00	-	-

#### Propiedades Mecánicas del Metal Depositado

Tratamiento Térmico	Resistencia a la Tracción [MPa (psi)]	Límite de Fluencia [MPa (psi)]	Elongación en 2" [%]	Energía Absorbida ISO-V [°C (°F)] [J (Ft-Lbf)]	Dureza
Sin tratamiento	-	-	-	-	58 - 62 HRC

Conservación del Producto
<ul style="list-style-type: none"> <li>Mantener en un lugar seco y evitar humedad.</li> <li>No requiere almacenamiento bajo horno.</li> <li>Resecado de 300°C a 350°C por 2 horas.</li> </ul>

Posiciones de Soldadura
P, H. 

#### Parámetros de Soldeo Recomendados

Para corriente alterna(AC) o continua (DC): Electrodo al polo positivo DCEP							
Diámetro	[mm]	1,60	2,50	3,25	4,00	5,00	6,30
	[pulgadas]	1/16	3/32	1/8	5/32	3/16	1/4
Amperaje mínimo		-	-	120	150	180	-
Amperaje máximo		-	-	140	160	230	-

#### Aplicaciones

- Para recuperar y recubrir piezas que están expuestas a desgaste por abrasión severa y bajo impacto.
- Usado en la industria minera, siderúrgica, construcción, ladrillera, cementera, agrícola y todas aquellos sectores donde los materiales están expuestos a desgaste abrasivo severo.
- Ideal para la recuperación y protección de dientes, cucharas, baldes y cubos de draga, sinfines de transporte, paletas de mezcladoras, uñas de palas, bombas de arena, aletas de ventiladores, etc.
- Para ollas, moldes y bordes de cucharas de fundición, que sufren desgaste por abrasión o erosión de escorias o metal líquido a temperaturas elevadas.



# **ANEXO 5**

# **PROPIEDADES**

# **CITOMANGAN**

Electrodo que deposita un acero al manganeso con 12,0 – 14,0% Mn. Presenta excelente comportamiento frente a abrasión e impacto severo. El material depositado posee una estructura austenítica de gran tenacidad, que le permite absorber los golpes durante el trabajo. Por las características del CITOMANGAN, requiere estar expuesto a impacto severo para que la superficie se autoendurezca y llegue a una dureza final de 55 HRC. Usar una técnica de soldadura que garantice el mínimo aporte de calor y cuidar que la pieza no sobrepase los 250°C (riesgo de cristalización). Es susceptible al fisuramiento en caliente, riesgo que se incrementa por las elevadas contracciones que presenta este material. Cuando se trata de rellenos considerables, es necesario el empleo de cordones alternados, alivio de tensiones mecánico y de ser necesario soldar en tinas de agua para extraer el calor aportado.

Clasificación	
AWS : A5.13	EFe Mn-B
DIN 8555	E 7 - UM - 200 KP


### Análisis Químico de Metal Depositado (valores típicos) [%]

C	Mn	Si	P	S	Mo	Ni	Cr	Cu	Otros
1,00	12,00 14,00	0,50	máx. 0,020	máx. 0,020	-	-	-	-	-

### Propiedades Mecánicas del Metal Depositado

Tratamiento Térmico	Resistencia a la Tracción [MPa (psi)]	Límite de Fluencia [MPa (psi)]	Elongación en 2" [%]	Energía Absorbida ISO-V [°C (°F)] [J (Ft-Lbf)]	Dureza
Sin tratamiento Auto endurecido	-	-	-	-	19 - 28 HRC 50 - 60 HRC

Conservación del Producto
<ul style="list-style-type: none"> <li>Mantener en un lugar seco y evitar humedad.</li> <li>No requiere almacenamiento bajo horno.</li> <li>Resecado de 300°C a 350°C por 2 horas.</li> </ul>

Posiciones de Soldadura
<p>P, H.</p> 

### Parámetros de Soldeo Recomendados

Para corriente alterna(AC) o continua (DC): Electrodo al polo positivo DCEP							
Diámetro	[mm]	1,60	2,50	3,25	4,00	5,00	6,30
	[pulgadas]	1/16	3/32	1/8	5/32	3/16	1/4
Amperaje mínimo		-	-	110	140	170	-
Amperaje máximo		-	-	135	175	220	-

### Aplicaciones

- Para recubrimiento de aceros que van a estar expuestos a desgaste abrasivo combinado con impacto severo.
- Utilizado con frecuencia en equipos de minería, movimiento de tierra, construcción y ferrocarril.
- Para unir y rellenar piezas de acero al manganeso (13%)
- Las aplicaciones principales son: Relleno de dientes de excavadoras, mandíbulas de trituradoras, forros de molino, cilindros de trapiche, rieles, cruces y desvíos de vías férreas, baldes de draga, zapatas para orugas, etc.

Observaciones: El éxito de la aplicación dependerá de la técnica de soldadura seguida, para lo cual, comuníquese con SOLDEXA para que le brindemos asesoramiento técnico.



# **ANEXO 6**

# **PROPIEDADES**

# **EXADUR – 43**

Electrodo de máxima resistencia a la abrasión e impacto. El material depositado es aleado al C, Cr, Nb, los carburos están distribuidos en una matriz austenítica que incrementa su resistencia al impacto. El EXADUR 43 es un electrodo de bajo hidrógeno, cuyo depósito es un recubrimiento protector de excelentes características, de fácil aplicación en posición plana e inclinada ascendente. También es aplicable en posición horizontal. Posee muy poca escoria y es de fácil remoción. Se recomienda aplicar sólo 2 capas. Las fisuras transversales son de alivio de tensiones. Electrodo de alto rendimiento y gran velocidad de deposición.

### Análisis Químico de Metal Depositado (valores típicos) [%]

C	Mn	Si	P	S	Mo	Ni	Cr	Cu	Otros
3,40	1,10	0,60	máx 0,020	máx 0,020	-	-	22,00	-	8,0%Nb

### Propiedades Mecánicas del Metal Depositado

Tratamiento Térmico	Resistencia a la Tracción [MPa (psi)]	Límite de Fluencia [MPa (psi)]	Elongación en 2" [%]	Energía Absorbida ISO-V [°C(°F)] [J (Ft-Lbf)]	Dureza
Sin tratamiento	-	-	-	-	60 HRC- 62 HRC

#### Conservación del Producto

- Mantener en un lugar seco y evitar humedad.
- No requiere almacenamiento bajo horno.
- Resecado de 300°C a 350°C por 2 horas.

#### Posiciones de Soldadura

P, FH.



### Parámetros de Soldeo Recomendados

Para corriente alterna(AC) o continua (DC): Electrodo al polo positivo DCEP

Diámetro	[mm]	1,60	2,50	3,25	4,00	5,00	6,30
	[pulgadas]	1/16	3/32	1/8	5/32	3/16	1/4
Amperaje mínimo	-	-	-	90	120	160	-
Amperaje máximo	-	-	-	130	180	220	-

### Aplicaciones

- Recubrimiento protector extra duro para ser empleado en partes sometidas a abrasión extremadamente severa, con impactos moderados, hasta temperaturas que no excedan los 450°C.
- Para recuperar tornillos de extrusión para la fabricación de ladrillos refractarios, ladrillos comunes y cemento.
- Para reconstruir palas de mezcladoras.
- Para tornillos transportadores, paletas, ventiladores, etc.
- Para reconstruir conos de trituradoras y chancadoras.
- En general empleado en la industria minera, agro-industrial, siderúrgica, cementera, ladrillera, etc.



# **ANEXO 7**

# **CASOS DE ESTUDIO**

# **EDEM – FEA**



# Optimizing for Handling Bulk Materials





# Contents

- Challenges of designing bulk material handling equipment 3
- The importance of including the impact of materials 5
- Traditional approaches for calculating material loads 7
- Simulating bulk material behavior with the Discrete Element Method 8
- Introducing realistic material loads in Finite Element Analysis and Multi-body Dynamics 9
- Case study: Austin Engineering Optimize Custom Truck Body Performance 11
- Case study: Dragline Bucket Design at VR Steel 13

# Challenges of Designing Bulk Material Handling Equipment

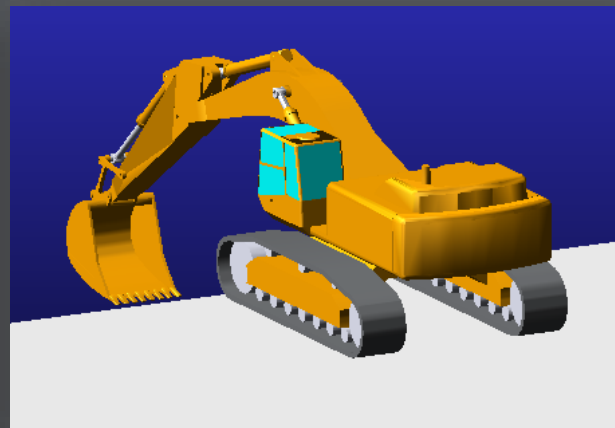
When designing heavy equipment in the construction, off-highway or mining industries such as truck bodies, diggers, grab buckets and excavators, engineers are faced with many challenges. Machines need to be reliable and efficient, being able to perform well under extreme conditions, there is constant pressure to increase payload capacity but at the same time equipment needs to be lightweight and use fuel efficiently to keep costs down.



To address those challenges, the use of CAE tools such as Finite element analysis (FEA) and Multi-body dynamics (MBD) are well established in the engineering toolkit for the design of structures and mechanical equipment. The benefits of simulation driven product development are numerous and include shorter design cycles, reduced product development time and costs, product innovation and the need for fewer physical prototypes resulting in significant cost reduction.

But there is one thing missing in such analysis:

**the material itself that the machine is supposed to handle!**



*Can you spot the difference?*

for Handling Bulk Materials

Publicación autorizada con fines académicos e investigativos

En su investigación no olvide referenciar esta tesis



# The importance of including the impact of materials

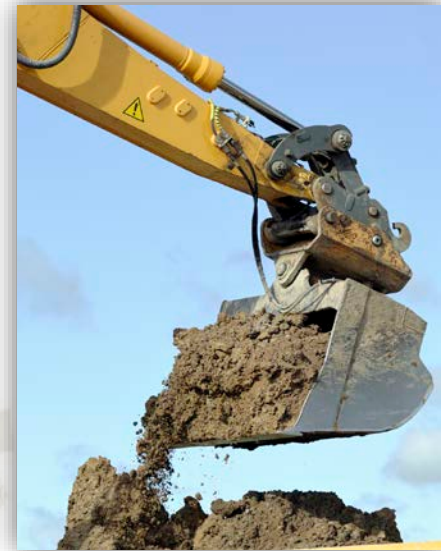
Let's think about a bucket moving a material like sand. It can be free-flowing one day but after a heavy rain shower it becomes highly cohesive and very difficult to handle.

When in operation, nearly every aspect of equipment performance – stresses on load arms, hydraulic forces, traction of tyres, delivery of power, etc. – is dependent to some degree on the bulk material being handled.

Real bulk materials such as rocks, coal, iron ores, gravel, soil and grains are complex in their behaviors. They can vary widely in shape and size. This variability means it is very difficult for engineers to predict how they will behave with their equipment.

Engineers could be dealing with heavy duty, large quarry rocks that are generating high force impacts; or perhaps a fine but highly abrasive material such as sand; or even cohesive clay-like materials that can be difficult to handle and stick to the equipment.

***Bulk materials exist in different form – free-flowing, sticky, cohesive, dry, large lumps, sandy...***





Predicting how a specific material might affect a piece of equipment is challenging due to the complexity of bulk materials. Assumptions may be dangerous and lead to expensive mistakes.

[left] Mine conveyor transfer failure - \$10M/day loss in production.

Understanding how a design will perform in a particular material environment is critical to ensuring an optimal design that combines strength and durability, with performance efficiency.

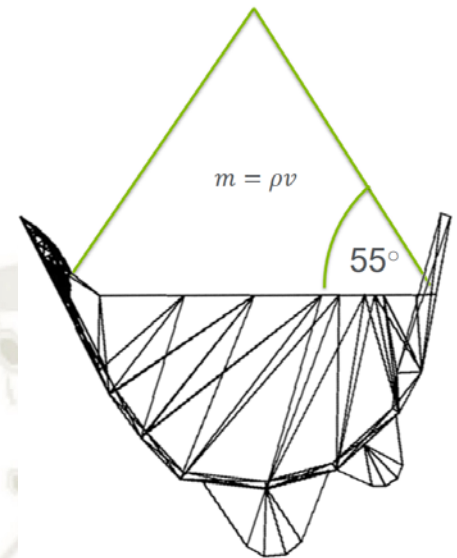
It is important to analyze the forces on machinery to minimize failure but also minimize weight, and to understand how the equipment interacts with materials to maximize the amount of material being moved while preventing handling errors. In order to determine this, engineers will often create estimates of the forces and loads acting on equipment, or they might build a physical prototype but such approaches simplify the complex behaviors of real bulk materials and have limitations.



It is important that to have an understanding of the forces acting on equipment to **minimize the chances of damage or failure.**

## Traditional approaches for calculating material loads

Traditional approaches to get representative load data in Finite Element Analysis or Multi-body Dynamics simulations include hand calculations to approximate the load, reliance on prior experience, or assumption of the anticipated material behavior. However, these methods cannot guarantee accuracy and small errors in calculations can lead to large errors in stress analysis results and fatigue life prediction. In addition, predicting material behavior is difficult and by relying on hand calculations and assumption, an engineer may only be able to assess a small set of conditions – such as the estimated maximum load at one point during operation. This method cannot guarantee the optimum design and performance and may lead to inclusion of excessive safety margins and a risk of over-engineering.



Another approach to get loads is physical testing where experimental data is integrated into the simulation to produce more accurate and realistic loads to represent the complex ground material. However, creating an experimental run is a costly and time-consuming process and typically restricted to a small number of available materials and motions. Obviously, it is also necessary to actually build the design that the engineer wants to test. Due to the high cost, such prototyping is often reserved for late stage design assessment, rather than as a regular design iteration check.

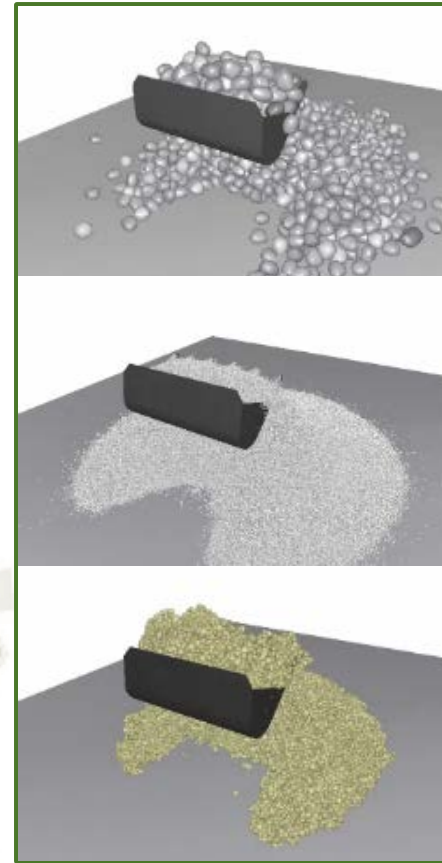
In order to iterate to the best possible design, an engineer needs to be able to define with confidence the material loads acting on their equipment and understand how these loads impact on the performance of the equipment.

# Simulating bulk material behavior with the Discrete Element Method

The Discrete Element Method (DEM) is a particle-scale numerical method for modeling the bulk behavior of granular materials and geomaterials such as iron ores, rocks, pellets, tablets, grains, soils, gravel and more.

Using a software powered by DEM technology means engineers can recreate the behavior of real materials of any size and shape in a virtual environment and get crucial insight into how such materials will interact with equipment during a range of operation and process conditions.

By adding DEM in the design process, engineers can perform virtual testing of buckets, excavators, bulldozers, truck bodies and any other piece of equipment with an accurate representation of the bulk material they are intended to handle.



*DEM Simulation of large boulders/ rocks, fine and cohesive materials*



for Handling Bulk Materials

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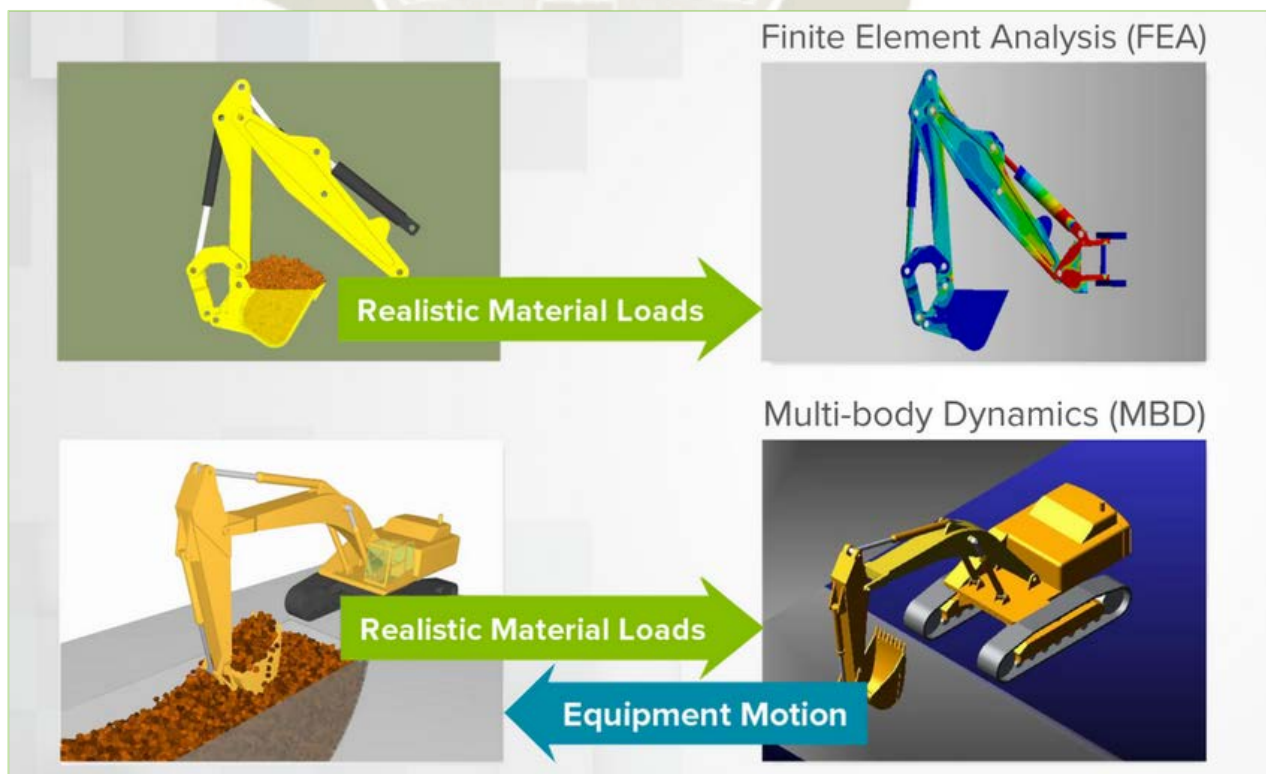
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# Introducing realistic material loads in Finite Element Analysis (FEA) and Multi-body Dynamics (MBD)

When combined with other CAE tools such as FEA and MBD, Discrete Element Method (DEM) simulation can provide key insight into equipment designs. It allows engineers to reduce the reliance on hand calculation and assumption when designing heavy equipment and addresses the challenges of how their equipment will perform when dealing with bulk materials.

## Why include the insight of DEM?

- Get an accurate representation of loads and forces acting on equipment – this means more accuracy, no more hand calculations, approximations or assumptions
- Examine how various movements and conditions as well as different types of materials will affect the overall design
- Reduce the need for physical prototyping – hence reducing costs significantly!
- Increase confidence that a design will perform as planned in real conditions
- Gain greater insight into equipment performance



for Handling Bulk Materials

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## CASE STUDY

# Austin Engineering Optimizes Custom Truck Body Performance

Austin Engineering is a leading designer and manufacturer of customized dump truck bodies, buckets and ancillary products used in the mining industry.

Finite Element Analysis (FEA) and Discrete Element Method (DEM) simulation are used by Austin Engineering to model and virtually test the design of their truck bodies to improve durability and performance.



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## CHALLENGE

Austin Engineering designs and manufactures truck bodies for use in off-highway environments.

Each site where their equipment is deployed is different, and Austin Engineering has to customize their designs for each client to cope with the local environmental challenges and meet productivity requirements.

Optimized durability and performance efficiency is a key part of all their custom truck body designs. Physical prototyping at this scale is expensive, and so each custom design needs to be tested virtually to guarantee performance at each site.

## SOLUTION

Austin Engineering uses DEM with FEA to evaluate each of their truck body designs.

The DEM software simulates realistic material behavior and provides engineers with accurate pressure distributions of material acting on their equipment.

These loads are then used as inputs into structural and fatigue analysis.

Austin Engineering is able to perform extensive 'what-if' analysis of operational scenarios such as alternative tray loadings and cornering conditions.

## RESULTS

Using DEM with FEA enables Austin Engineering to improve the durability and performance of each truck body design.

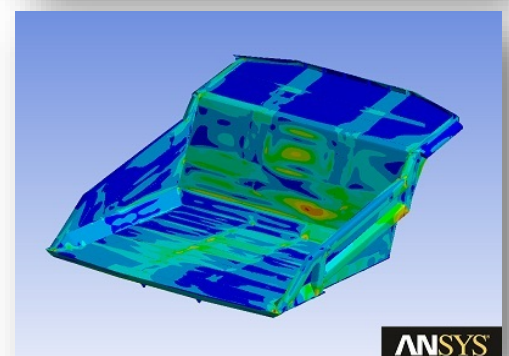
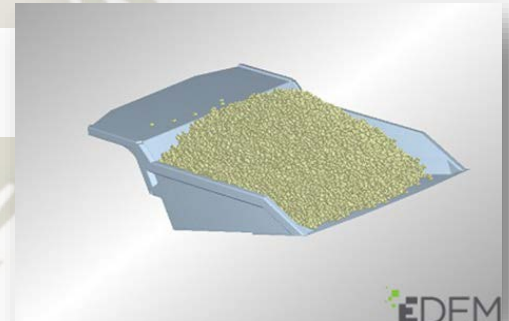
The realistic material loads from the DEM tool significantly improve accuracy compared to traditional approaches and mean truck body designs are strong, efficient and will perform in a range of operational conditions.

Combining DEM with FEA allows Austin Engineering to show their clients how a design will perform on-site, and ensure that their needs are met before it is sent for fabrication.

“

*EDEM and ANSYS software let us simulate any on-site condition and demonstrate to our clients that each solution will meet their specific needs. The EDEM [integration with] ANSYS Workbench provides an easy-to-use and streamlined interface for performing realistic analysis of our equipment designs. With this capability we can optimize the design and performance of each Austin Engineering truck body.*

Lyndon Greeshaw  
Mechanical Engineer  
Austin Engineering

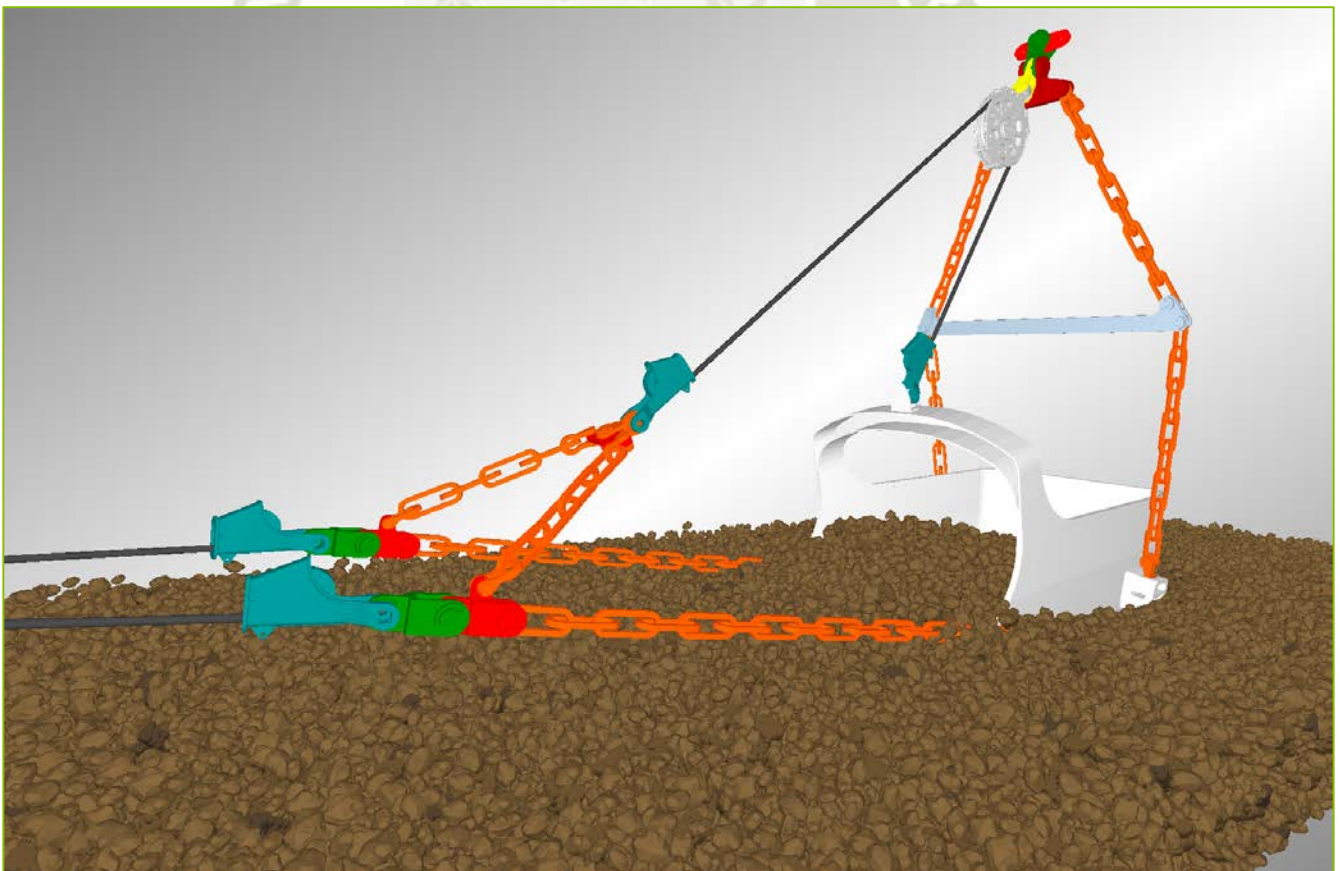


## CASE STUDY

### Dragline Bucket Design at VR Steel

VR Steel (Pty) Ltd designs, builds, and repairs fabricated mining equipment attachments.

VR Steel uses Multi-body Dynamics (MBD) and Discrete Element Method (DEM) software to field-test new design options, custom designs for specific users, build fewer physical prototypes, shorten the design cycle and increase customers' productivity.



## CHALLENGE

Optimization of dragline bucket performance and productivity—for a wide range of media and mining conditions around the globe.

VR Steel needed to develop a new optimized bucket design—balancing efficiency, capacity, durability, and projected operating & maintenance (O&M) costs.

VR Steel wanted to streamline the design process. Their customers needed design solutions assured to:

- Fill easily and empty completely
- Operate at maximum capacity
- Boost wear protection
- Reduce operating costs
- Improve overall efficiency

## SOLUTION

VR Steel used a Discrete Element Method tool coupled with multibody dynamics simulation software, to simulate both the bulk soil dynamics and the dynamics of the bucket and lifting gear.

This cutting edge, integrated particle-machine dynamics solution successfully modelled the transient particle-structure interaction—simulating the complete digging cycle of a dragline bucket.

This virtual performance testing predicted the prototype bucket:

- Mode and rate of fill
- Transient loading of bucket & gear
- Wear patterns and rates

## RESULTS

The ability to accurately simulate the performance of prototype bucket designs and wear packages resulted in:

Engineering Solutions:

- Increase in fill level
- Shorter filling cycle
- Reduction in bucket mass
- Lower operating costs provided an overall productivity gain of 2%

Benefits to VR Steel:

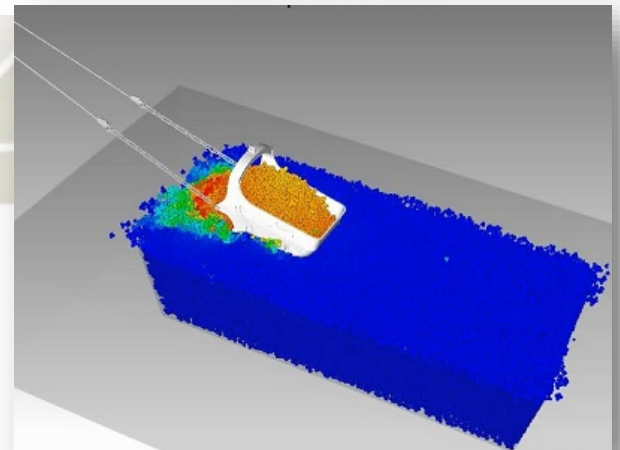
- Improved bucket design delivering:
- Only one physical prototype
- Repetitive virtual testing under the same operating conditions
- Faster convergence to the best design

“

*When a 45 ton bucket digs through soil during its filling cycle, numerous loads are applied to the structure at various locations over time, which can eventually lead to wear and strain on equipment.*

*The combined capabilities of EDEM and MSC Adams gave us the insight to be able to minimize the level of wear and strain on equipment whilst in the design stage - before going into full production. We therefore increased the productivity for the customer while minimizing peak strains in their equipment. What more could the customer and OEM want?*

**Bertus Haasbroek**  
Chief Design Engineer  
**VR Steel**

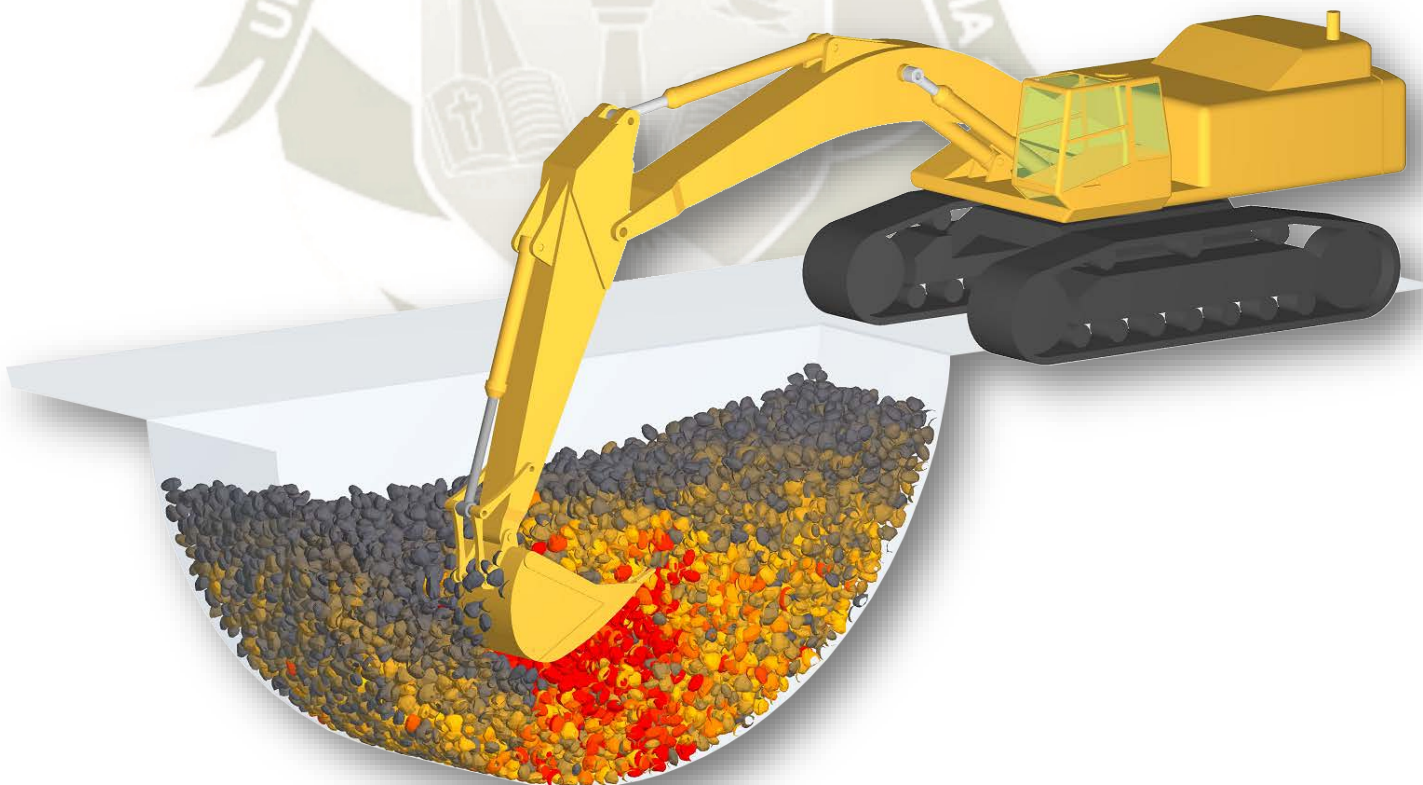


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Discover EDEM for CAE –  
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for Handling Bulk Materials

Publicación autorizada con fines académicos e investigativos

En su investigación no olvide referenciar esta tesis



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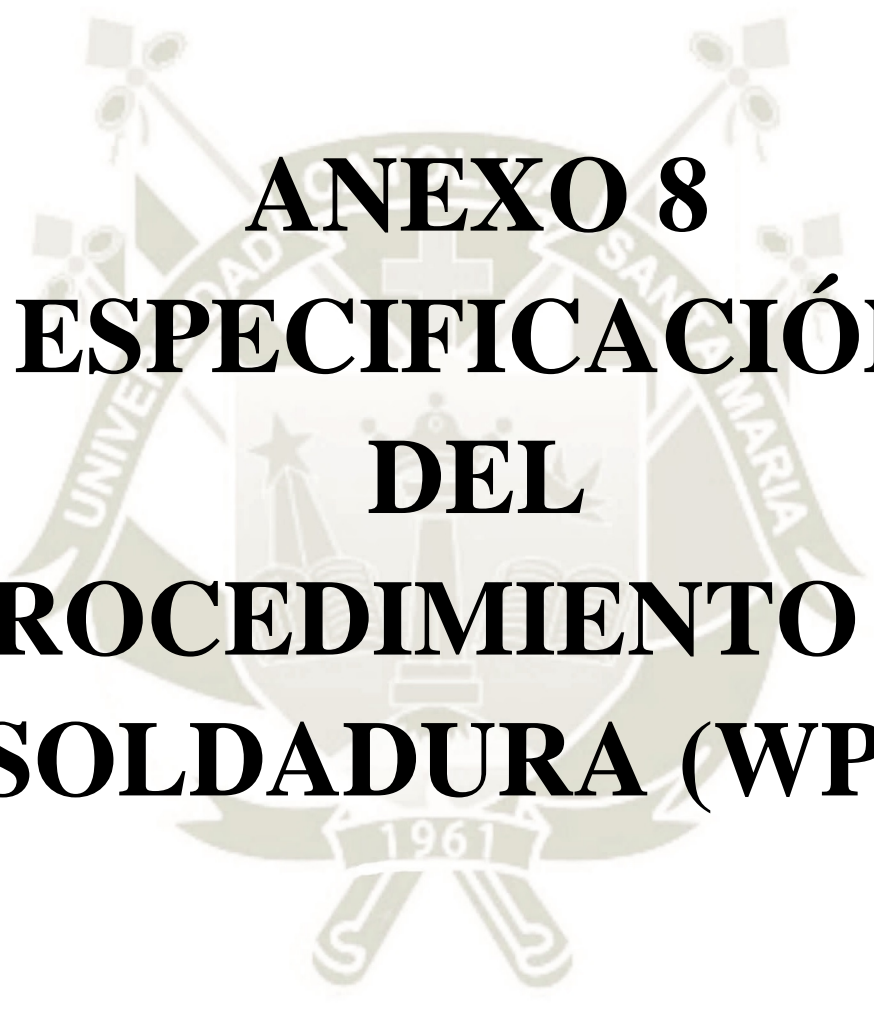
EDEM is the market-leading Discrete Element Method (DEM) software for bulk material simulation.

EDEM is used for 'virtual testing' of equipment that handles or processes bulk materials in the manufacturing of mining, construction, off-highway and agricultural machinery, as well as in the mining and process industries.

Blue-chip companies around the world use EDEM to optimize equipment design, increase productivity, reduce costs of operations, shorten product development cycles and drive product innovation.

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**ANEXO 8  
ESPECIFICACIÓN  
DEL  
PROCEDIMIENTO DE  
SOLDADURA (WPS)**





AWSD1.1/01.1M-2008

**WELDING PROCEDURE SPECIFICATION (WPS) Yes**   
**PREQUALIFIED \_\_\_\_\_ QUALIFIED BY TESTING \_\_\_\_\_**  
**or PROCEDURE QUALIFICATION RECORDS (PQR) Yes**

Company Name \_\_\_\_\_  
 Welding Process(es) \_\_\_\_\_  
 Supporting PQR No.(s) \_\_\_\_\_

Identification # \_\_\_\_\_  
 Revision \_\_\_\_\_ Date \_\_\_\_\_ By \_\_\_\_\_  
 Authorized by \_\_\_\_\_ Date \_\_\_\_\_  
 Type—Manual  Semiautomatic   
 Machine  Automatic

**JOINT DESIGN USED**

Type:  
 Single  Double Weld   
 Backing: Yes  No   
 Backing Material: \_\_\_\_\_

Root Opening \_\_\_\_\_ Root Face Dimension \_\_\_\_\_  
 Groove Angle: \_\_\_\_\_ Radius (J-U) \_\_\_\_\_  
 Back Gouging: Yes  No  Method \_\_\_\_\_

**BASE METALS**

Material Spec. \_\_\_\_\_  
 Type or Grade \_\_\_\_\_  
 Thickness: Groove \_\_\_\_\_ Fillet \_\_\_\_\_  
 Diameter (Pipe) \_\_\_\_\_

**FILLER METALS**

AWS Specification \_\_\_\_\_  
 AWS Classification \_\_\_\_\_

**SHIELDING**

Flux \_\_\_\_\_ Gas \_\_\_\_\_  
 Composition \_\_\_\_\_  
 Electrode-Flux (Class) \_\_\_\_\_ Flow Rate \_\_\_\_\_  
 Gas Cup Size \_\_\_\_\_

**PREHEAT**

Preheat Temp., Min. \_\_\_\_\_  
 Interpass Temp., Min. \_\_\_\_\_ Max. \_\_\_\_\_

**POSITION**

Position of Groove: \_\_\_\_\_ Fillet: \_\_\_\_\_  
 Vertical Progression: Up  Down

**ELECTRICAL CHARACTERISTICS**

Transfer Mode (GMAW) Short-Circuiting   
 Globular  Spray   
 Current: AC  DCEP  DCEN  Pulsed   
 Power Source: CC  CV   
 Other \_\_\_\_\_  
 Tungsten Electrode (GTAW)  
 Size: \_\_\_\_\_  
 Type: \_\_\_\_\_

**TECHNIQUE**

Stringer or Weave Bead: \_\_\_\_\_  
 Multi-pass or Single  
 Pass (per side) \_\_\_\_\_ Number of  
 Electrodes \_\_\_\_\_  
 Electrode Spacing Longitudinal \_\_\_\_\_  
 Lateral \_\_\_\_\_  
 Angle \_\_\_\_\_  
 Contact Tube to Work Distance \_\_\_\_\_  
 Peening \_\_\_\_\_  
 Interpass Cleaning: \_\_\_\_\_

**POSTWELD HEAT TREATMENT**

Temp. \_\_\_\_\_  
 Time \_\_\_\_\_

**WELDING PROCEDURE**

Pass or Weld Layer(s)	Process	Filler Metals		Current		Volts	Travel Speed	Joint Details
		Class	Diam.	Type & Polarity	Amps or Wire Feed Speed			

Procedure Qualification Record (PQR) # \_\_\_\_\_  
Test Results

TENSILE TEST

Specimen No.	Width	Thickness	Area	Ultimate Tensile Load, lb	Ultimate Unit Stress, psi	Character of Failure and Location

GUIDED BEND TEST

Specimen No.	Type of Bend	Result	Remarks

VISUAL INSPECTION

Appearance \_\_\_\_\_  
Undercut \_\_\_\_\_  
Piping porosity \_\_\_\_\_  
Convexity \_\_\_\_\_  
Test date \_\_\_\_\_  
Witnessed by \_\_\_\_\_

Radiographic-ultrasonic examination  
RT report no.: \_\_\_\_\_ Result \_\_\_\_\_  
UT report no.: \_\_\_\_\_ Result \_\_\_\_\_

FILLET WELD TEST RESULTS

Minimum size multiple pass    Maximum size single pass  
Macroetch    Macroetch  
1. \_\_\_\_\_ 3. \_\_\_\_\_ 1. \_\_\_\_\_ 3. \_\_\_\_\_  
2. \_\_\_\_\_ 2. \_\_\_\_\_

Other Tests

All-weld-metal tension test  
Tensile strength, psi \_\_\_\_\_  
Yield point/strength, psi \_\_\_\_\_  
Elongation in 2 in, % \_\_\_\_\_  
Laboratory test no. \_\_\_\_\_

Welder's name \_\_\_\_\_

Clock no. \_\_\_\_\_ Stamp no. \_\_\_\_\_

Tests conducted by \_\_\_\_\_

Laboratory \_\_\_\_\_

Test number \_\_\_\_\_

Per \_\_\_\_\_

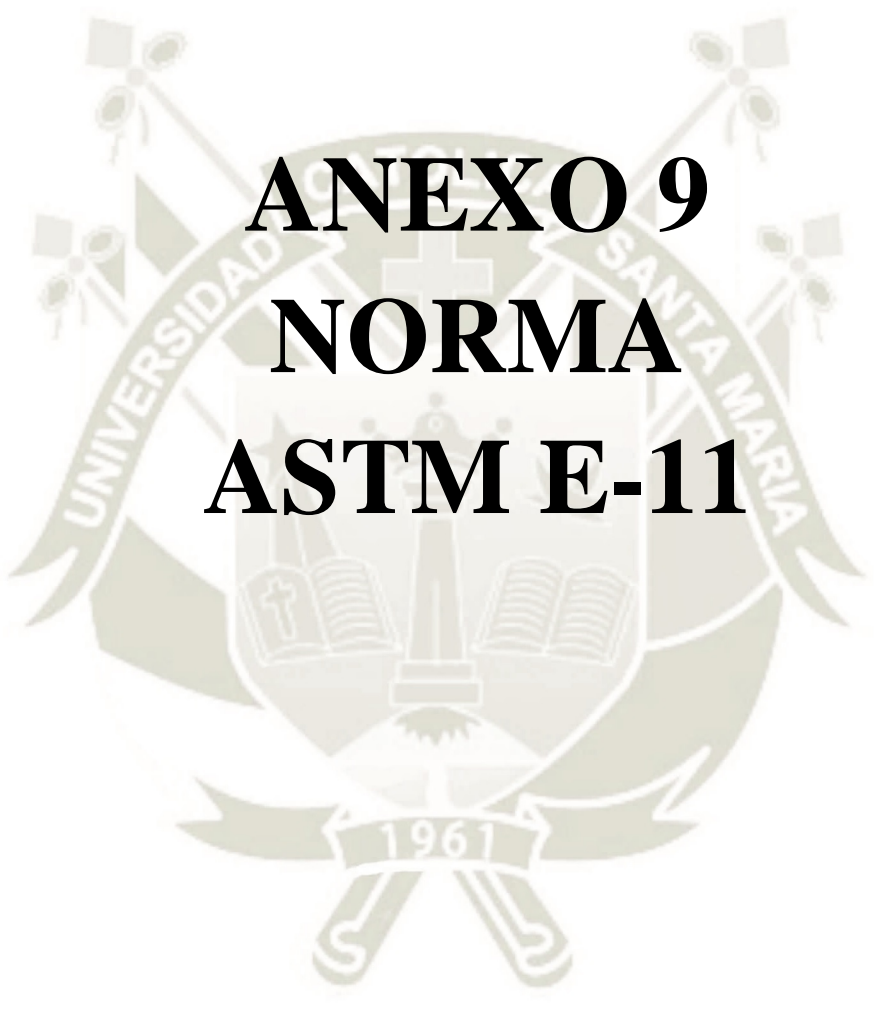
We, the undersigned, certify that the statements in this record are correct and that the test welds were prepared, welded, and tested in conformance with the requirements of Clause 4 of AWS D1.1/D1.1M, (\_\_\_\_\_) *Structural Welding Code—Steel*.  
(year)

Signed \_\_\_\_\_  
Manufacturer or Contractor

By \_\_\_\_\_

Title \_\_\_\_\_

Date \_\_\_\_\_



# **ANEXO 9 NORMA ASTM E-11**



# Standard Guide for Preparation of Metallographic Specimens<sup>1</sup>

This standard is issued under the fixed designation E3; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reappraisal. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reappraisal.

*This standard has been approved for use by agencies of the Department of Defense.*

## 1. Scope

1.1 The primary objective of metallographic examinations is to reveal the constituents and structure of metals and their alloys by means of a light optical or scanning electron microscope. In special cases, the objective of the examination may require the development of less detail than in other cases but, under nearly all conditions, the proper selection and preparation of the specimen is of major importance. Because of the diversity in available equipment and the wide variety of problems encountered, the following text presents for the guidance of the metallographer only those practices which experience has shown are generally satisfactory; it cannot and does not describe the variations in technique required to solve individual specimen preparation problems.

NOTE 1—For a more extensive description of various metallographic techniques, refer to Samuels, L. E., *Metallographic Polishing by Mechanical Methods*, American Society for Metals (ASM) Metals Park, OH, 3rd Ed., 1982; Petzow, G., *Metallographic Etching, ASM, 1978*; and VanderVoort, G., *Metallography: Principles and Practice*, McGraw Hill, NY, 2nd Ed., 1999.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

## 2. Referenced Documents

### 2.1 ASTM Standards:

- A90/A90M Test Method for Weight [Mass] of Coating on Iron and Steel Articles with Zinc or Zinc-Alloy Coatings<sup>2</sup>
- E7 Terminology Relating to Metallography
- E45 Test Methods for Determining the Inclusion Content of Steel

<sup>1</sup> This guide is under the jurisdiction of ASTM Committee E04 on Metallography and is the direct responsibility of Subcommittee E04.01 on Specimen Preparation. Current edition approved May 1, 2011. Published June 2011. Originally approved in 1921. Last previous edition approved in 2007 as E3–01(2007)<sup>ε1</sup>. DOI: 10.1520/E0003-11.

<sup>2</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

- E768 Guide for Preparing and Evaluating Specimens for Automatic Inclusion Assessment of Steel
- E1077 Test Methods for Estimating the Depth of Decarburization of Steel Specimens
- E1122 Practice for Obtaining JK Inclusion Ratings Using Automatic Image Analysis (Withdrawn 2006)<sup>3</sup>
- E1245 Practice for Determining the Inclusion or Second-Phase Constituent Content of Metals by Automatic Image Analysis
- E1268 Practice for Assessing the Degree of Banding or Orientation of Microstructures
- E1558 Guide for Electrolytic Polishing of Metallographic Specimens
- E1920 Guide for Metallographic Preparation of Thermal Sprayed Coatings

## 3. Terminology

### 3.1 Definitions:

3.1.1 For definitions used in this practice, refer to Terminology E7.

### 3.2 Definitions of Terms Specific to This Standard:

3.2.1 *castable mount*—a metallographic mount generally made from a two component castable plastic. One component is the resin and the other hardener. Both components can be liquid or one liquid and a powder. Castable mounts generally do not require heat and pressure to cure.

3.2.2 *compression mount*—a metallographic mount made using plastic that requires both heat and pressure for curing.

3.2.3 *planar grinding*—is the first grinding step in a preparation procedure used to bring all specimens into the same plane of polish. It is unique to semi or fully automatic preparation equipment that utilize specimen holders.

3.2.4 *rigid grinding disc*—a non-fabric support surface, such as a composite of metal/ceramic or metal/polymer charged with an abrasive (usually 6 to 15 $\mu$ m diamond particles), and used as the fine grinding operation in a metallographic preparation procedure.

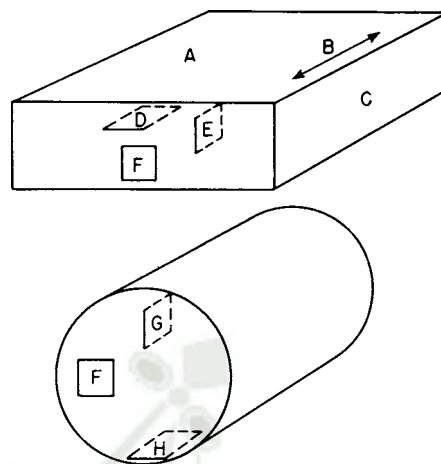
<sup>3</sup> The last approved version of this historical standard is referenced on [www.astm.org](http://www.astm.org).

#### 4. Significance and Use

4.1 Microstructures have a strong influence on the properties and successful application of metals and alloys. Determination and control of microstructure requires the use of metallographic examination.

4.2 Many specifications contain a requirement regarding microstructure; hence, a major use for metallographic examination is inspection to ensure that the requirement is met. Other major uses for metallographic examination are in failure analysis, and in research and development.

4.3 Proper choice of specimen location and orientation will minimize the number of specimens required and simplify their interpretation. It is easy to take too few specimens for study, but it is seldom that too many are studied.



#### 5. Selection of Metallographic Specimens

5.1 The selection of test specimens for metallographic examination is extremely important because, if their interpretation is to be of value, the specimens must be representative of the material that is being studied. The intent or purpose of the metallographic examination will usually dictate the location of the specimens to be studied. With respect to purpose of study, metallographic examination may be divided into three classifications:

5.1.1 *General Studies or Routine Work*—Specimens should be chosen from locations most likely to reveal the maximum variations within the material under study. For example, specimens could be taken from a casting in the zones wherein maximum segregation might be expected to occur as well as specimens from sections where segregation could be at a minimum. In the examination of strip or wire, test specimens could be taken from each end of the coils.

5.1.2 *Study of Failures*—Test specimens should be taken as closely as possible to the fracture or to the initiation of the failure. Before taking the metallographic specimens, study of the fracture surface should be complete, or, at the very least, the fracture surface should be documented. In many cases, specimens should be taken from a sound area for a comparison of structures and properties.

5.1.3 *Research Studies*—The nature of the study will dictate specimen location, orientation, etc. Sampling will usually be more extensive than in routine examinations.

5.2 Having established the location of the metallographic samples to be studied, the type of section to be examined must be decided.

5.2.1 For a casting, a section cut perpendicular to the surface will show the variations in structure from the outside to the interior of the casting.

5.2.2 In hot-worked or cold-worked metals, both transverse and longitudinal sections should be studied. Special investigations may require specimens with surfaces prepared parallel to the original surface of the product.

5.2.3 In the case of wire and small rounds, a longitudinal section through the center of the specimen proves advantageous when studied in conjunction with the transverse section.

Symbol in Diagram	Suggested Designation
A	Rolled surface
B	Direction of rolling
C	Rolled edge
D	Planar section
E	Longitudinal section perpendicular to rolled surface
F	Transverse section
G	Radial longitudinal section
H	Tangential longitudinal section

FIG. 1 Method of Designating Location of Area Shown in Photomicrograph.

5.3 Transverse sections or cross sections taken perpendicular to the main axis of the material are often used for revealing the following information:

- 5.3.1 Variations in structure from center to surface,
- 5.3.2 Distribution of nonmetallic impurities across the section,
- 5.3.3 Decarburization at the surface of a ferrous material (see Test Method E1077),
- 5.3.4 Depth of surface imperfections,
- 5.3.5 Depth of corrosion,
- 5.3.6 Thickness of protective coatings, and
- 5.3.7 Structure of protective coating. See Guide E1920.

5.4 Longitudinal sections taken parallel to the main axis of the material are often used for revealing the following information:

- 5.4.1 Inclusion content of steel (see Practices E45, E768, E1122, and E1245),
- 5.4.2 Degree of plastic deformation, as shown by grain distortion,
- 5.4.3 Presence or absence of banding in the structure (see Practice E1268), and
- 5.4.4 The microstructure attained with any heat treatment.

5.5 The locations of surfaces examined should always be given in reporting results and in any illustrative micrographs. A suitable method of indicating surface locations is shown in Fig. 1.

#### 6. Size of Metallographic Specimens

6.1 For convenience, specimens to be polished for metallographic examination are generally not more than about 12 to 25

**TABLE 1 Cutoff Blade Selection**

Hardness HV	Materials	Abrasive	Bond	Bond Hardness
up to 300	non-ferrous (Al, Cu)	SiC	P or R	hard
up to 400	non-ferrous (Ti)	SiC	P or R	med.
up to 400	soft ferrous	Al <sub>2</sub> O <sub>3</sub>	P or R	hard
up to 500	medium soft ferrous	Al <sub>2</sub> O <sub>3</sub>	P or R	med.
up to 600	medium hard ferrous	Al <sub>2</sub> O <sub>3</sub>	P or R	hard
up to 700	hard ferrous	Al <sub>2</sub> O <sub>3</sub>	P or R&R	medium
up to 800	very hard ferrous	Al <sub>2</sub> O <sub>3</sub>	P or R&R	soft
> 800	extremely hard ferrous	CBN	P or M	hard
	more brittle ceramics	diamond	P or M	very hard
	tougher ceramics	diamond	M	ext. hard

P—phenolic  
R—rubber  
R&R—resin and rubber  
M—metal

mm (0.5 to 1.0 in.) square, or approximately 12 to 25 mm in diameter if the material is cylindrical. The height of the specimen should be no greater than necessary for convenient handling during polishing.

6.1.1 Larger specimens are generally more difficult to prepare.

6.1.2 Specimens that are, fragile, oddly shaped or too small to be handled readily during polishing should be mounted to ensure a surface satisfactory for microscopical study. There are, based on technique used, three fundamental methods of mounting specimens (see Section 9).

## 7. Cutting of Metallographic Specimens

7.1 In cutting the metallographic specimen from the main body of the material, care must be exercised to minimize altering the structure of the metal. Three common types of sectioning are as follows:

7.1.1 Sawing, whether by hand or machine with lubrication, is easy, fast, and relatively cool. It can be used on all materials with hardnesses below approximately 350 HV. It does produce a rough surface containing extensive plastic flow that must be removed in subsequent preparation.

7.1.2 An abrasive cut-off blade will produce a smooth surface often ready for fine grinding. This method of sectioning is normally faster than sawing. The choice of cut-off blade, lubricant, cooling conditions, and the grade and hardness of metal being cut will influence the quality of the cut. A poor choice of cutting conditions can easily damage the specimen, producing an alteration of the microstructure. Generally, soft materials are cut with a hard bond blade and hard materials with a soft bond blade. Aluminum oxide abrasive blades are preferred for ferrous metals and silicon carbide blades are preferred for nonferrous alloys. Abrasive cut-off blades are essential for sectioning metals with hardness above about 350 HV. Extremely hard metallic materials and ceramics may be more effectively cut using diamond-impregnated cutting blades. Manufacturer's instructions should be followed as to the choice of blade. **Table 1** lists the suggested cutoff blades for materials with various Vickers (HV) hardness values.

7.1.3 A shear is a type of cutting tool with which a material in the form of wire, sheet, plate or rod is cut between two opposing blades.

7.2 Other methods of sectioning are permitted provided they do not alter the microstructure at the plane of polishing. All cutting operations produce some depth of damage, which will have to be removed in subsequent preparation steps.

## 8. Cleanliness

8.1 Cleanliness (see **Appendix X1**) during specimen preparation is essential. All greases, oils, coolants and residue from cutoff blades on the specimen should be removed by some suitable organic solvent. Failure to clean thoroughly can prevent cold mounting resins from adhering to the specimen surface. Ultrasonic cleaning may be effective in removing the last traces of residues on a specimen surface.

8.2 Any coating metal that will interfere with the subsequent etching of the base metal should be removed before polishing, if possible. If etching is required, when studying the underlying steel in a galvanized specimen, the zinc coating should be removed before mounting to prevent galvanic effects during etching. The coating can be removed by dissolving in cold nitric acid (HNO<sub>3</sub>, sp gr 1.42), in dilute sulfuric acid (H<sub>2</sub>SO<sub>4</sub>) or in dilute hydrochloric acid (HCl). The HNO<sub>3</sub> method requires care to prevent overheating, since large samples will generate considerable heat. By placing the cleaning container in cold water during the stripping of the zinc, attack on the underlying steel will be minimized. More information may be found in Test Method **A90/A90M**.

NOTE 2—Picral etchant produces little or no galvanic etching effects when used on galvanized steel.

NOTE 3—The addition of an inhibitor during the stripping of Zn from galvanized coatings will minimize the attack of the steel substrate. NEP (poethylene polyamine) or SbCl<sub>3</sub> are two useful inhibitors.

8.3 Oxidized or corroded surfaces may be cleaned as described in **Appendix X1**.

## 9. Mounting of Specimens

9.1 There are many instances where it will be advantageous to mount the specimen prior to grinding and polishing. Mounting of the specimen is usually performed on small, fragile, or oddly shaped specimens, fractures, or in instances where the specimen edges are to be examined.

9.2 Specimens may be either mechanically mounted, mounted in plastic, or a combination of the two.

### 9.3 Mechanical Mounting:

9.3.1 Strip and sheet specimens may be mounted by binding or clamping several specimens into a pack held together by two end pieces and two bolts.

9.3.2 The specimens should be tightly bound together to prevent absorption and subsequent exudation of polishing materials or etchants.

9.3.3 The use of filler sheets of a softer material alternated with the specimen may be used in order to minimize the seepage of polishing materials and etchants. Use of filler material is especially advantageous if the specimens have a high degree of surface irregularities.

9.3.4 Filler material *must* be chosen so as not to react electrolytically with the specimen during etching. Thin pieces of plastic, lead, or copper are typical materials that are used.

**TABLE 2 Characteristics of Hot-Compression Mounting Compounds**

Type of Compound	Characteristics
Acrylic	thermoplastic, cure time 10-15 min, optically clear, moderate shrinkage, low abrasion resistance, degraded by hot etchants
Diallyl phthalate <sup>A</sup>	thermosetting, cure time 5-10 min, opaque, minimal shrinkage, good resistance to etchants, moderate abrasion resistance
Epoxy <sup>A</sup>	thermosetting, cure time 5-10 min, opaque, very low shrinkage, good resistance to etchants, high abrasion resistance
Phenolic <sup>A</sup> (Bakelite)	thermosetting, cure time 5-10 min, opaque, moderate shrinkage, degraded by hot etchants, moderate abrasion resistance

<sup>A</sup> These compounds may be filled with wood flour, glass fiber or mineral particulate.

Copper is especially good for steel specimens since the usual etchants for steels will not attack the copper.

9.3.5 Alternatively, the specimens may be coated with a layer of epoxy resin before being placed in the clamp in order to minimize the absorption of polishing materials or etchants.

9.3.6 The clamp material should be similar in composition to the specimen to avoid galvanic effects that would inhibit etching. The specimen will not etch if the clamp material is more readily attacked by the etchant.

9.3.7 The clamp should preferably be of similar hardness as the specimens to minimize the rounding of the edges of the specimens during grinding and polishing.

9.3.8 Exercise care in clamping the specimen. Excessive clamping pressure may damage soft specimen.

#### 9.4 Plastic Mounting:

9.4.1 Specimens may be embedded in plastic to protect them from damage and to provide a uniform format for both manual and automatic preparation. This is the most common method for mounting metallographic specimens. Mounting plastics may be divided into two classes—compression and castable.

9.4.2 The choice of a mounting compound will influence the extent of edge rounding observed during the grinding and polishing operations. There are several methods available that minimize rounding. The specimen may be surrounded by hard shot, small rivets, rings, etc., of approximately the same hardness or, when using a castable resin, a slurry of resin and alumina may be poured around the specimen. The specimen may also be plated before mounting (see Section 10). Many mounting procedures result in sharp edges on the mount corners. The corners should be beveled to remove any plastic mounting flash.

9.4.3 *Compression Mounting*—There are four types of compression mounting plastics used predominantly in the metallographic laboratory (see Table 2). These plastics require the use of a mounting press providing heat (140-180°C) and force (27-30 MPa). Thermosetting plastics can be ejected hot but the best results are obtained when the cured mount is cooled under pressure. Thermoplastic compounds do not harden until cooled and therefore should not be ejected while hot. Regardless of the resin used, the best results are obtained when (1) the specimen is clean and dry, and (2) the cured mount is cooled under full pressure to below 40°C before ejection from the press. This will ensure minimal shrinkage gap formation.

9.4.4 *Castable Plastics*—Castable mounts are usually prepared at room temperature. Some may require an external heat source or applied pressure in order to cure. These resins consist

of two or more components which must be mixed just prior to use. There are four kinds of castable plastics in common use (see Table 3).

9.4.5 The molds for castable plastics are often simple cups that hold the resin until it cures. They may be reusable or not; the choice is a matter of convenience and cost. Handling castable resins requires care. They all can cause dermatitis. Manufacturers' recommendations for mixing and curing must be followed to obtain best results.

#### 9.5 Mounting Porous Specimen:

9.5.1 Porous or intricate specimens may be vacuum impregnated in order to fill voids, prevent contamination and seepage, and prevent loss of friable or loose components. Impregnation is accomplished by placing the specimen in a mold in a vacuum chamber and then introducing the resin into the mold after the chamber has been evacuated. The introduction of the resin into the mold can be accomplished either by having a funnel or stopcock fitted to the vacuum chamber or by having a basin of the resin present inside the chamber. A low-viscosity resin will produce the best results. The pressure in the chamber must remain above the critical vapor pressure of the hardener to avoid boiling away the hardener. After the pressure has equilibrated, the resin is introduced into the mold and the vacuum is released and air admitted to the chamber. Atmospheric pressure will force the resin into fine pores, cracks, and holes.

9.5.2 If a low-viscosity resin is used, the funnel and stopcock may be eliminated. The specimen and resin are placed in the mold prior to evacuation. The air in the specimen will bubble out through the resin. Exercise care to ensure the hardening agent is not evaporated during evacuation. Dipping the specimen in the resin prior to placing it in the mold may help in filling voids.

9.5.3 Vacuum impregnation is an effective method for ensuring optimal results for porous metallographic mounts. It is imperative that the specimens be completely dry prior to impregnation.

9.5.4 A more rapid technique but less effective method is to lacquer the specimens with one of the formulations used by the canning industry to line food containers. The formulations are highly penetrating and the cure is a short time at low temperatures. After lacquering, the specimens are mounted in the usual fashion.

## 10. Plating of Specimens

10.1 Specimens such as fractures or those where it is necessary to examine the edges, are often plated to obtain good

**TABLE 3 Characteristics of Castable Mounting Compounds**

Type of Compound	Characteristics
Acrylic	Cure time 8-15 min, moderate shrinkage, peak curing temperature can reach 90-120°C during polymerization, low abrasion resistance, opaque to transparent
Polyester-acrylic (quartz-filled)	Cure time 8-15 min, very low shrinkage, peak curing temperature can reach 90-120°C during polymerization, high abrasion resistance, opaque
Polyester	Cure time 30-60 min, high shrinkage, peak curing temperature can reach 90- 120 C during polymerization, moderate abrasion resistance, transparent
Epoxy	Cure time ½-20 h, very low shrinkage, good adhesion, low heat generation during polymerization, moderate abrasion resistance, low viscosity (good for vacuum impregnation), transparent

edge retention. Plating can be done electrolytically or with electroless solutions. These specimens are invariably mounted prior to the grinding and polishing procedures. Electroless plating solutions can be purchased commercially.

10.2 Thoroughly clean the specimen surface prior to plating to ensure good adhesion of the plating. Avoid industrial cleaning treatments that are too harsh and may cause damage to the specimen surface. Milder cleaning treatments that involve detergents, solvents, mild alkaline, or acidic solutions are recommended.

10.3 Chromium, copper, iron, nickel, gold, silver, and zinc may be electrolytically deposited although copper and nickel are predominantly used in metallographic laboratories.

10.3.1 Ferrous metals are commonly plated electrolytically with nickel or copper. A flash coat in a copper or electroless nickel bath can be first applied for specimens that are difficult to electroplate.

10.3.2 Nonferrous metals may be plated with silver and the precious metals may be plated with nickel, gold, or silver.

10.4 The plating material should not react galvanically with the base metal of the specimen during plating, polishing, or etching.

10.5 Electroless plating is preferred to electrolytic plating for specimens with rough, porous, or irregular surfaces, because the electroless solution provides better surface coverage and penetration.

10.6 Active metals such as zinc and aluminum are difficult to plate. Sometimes a flash cyanide copper plate can be deposited, which then can be followed by normal plating from a sulfate bath. Evaporated coatings of copper, gold, or chromium may also be used as starter coatings.

10.7 It is recommended that the plating thickness be at least 5µm.

## 11. Grinding and Polishing

### General Information

11.1 Many metals and alloys can be prepared using a similar sequence of grinding and polishing. Hard alloys may require greater pressure than soft alloys. The major differences will be in the final polishing. Some metals and alloys will require specific combinations of abrasive and support material, but a surprising number can be handled by the same procedure. Supplies and instructions for grinding, lapping, and polishing are readily obtainable from laboratory supply houses.

11.2 *Grinding*—Grinding can be done in a number of ways, ranging from rubbing the specimen on a stationary piece of abrasive paper to the use of automatic devices. The choice of method depends on the number and type of specimens to be done, financial considerations and requirements such as flatness and uniformity.

11.2.1 Abrasive grit size designations in this practice are expressed in the ANSI (American National Standards Institute) or CAMI (Coated Abrasives Manufacturers Institute) system units with the corresponding FEPA (European Federation of Abrasive Producers) numbers in parentheses. **Table 4** provides a correlation between these two systems and the approximate median particle diameter for a given size in micrometres.

11.2.2 Grinding should start with the finest paper, platen or stone capable of flattening the specimen and removing the effects of prior operations, such as sectioning. The subsequent steps should remove the effects of previous ones in a short time. Grinding consists of two stages— planar (rough) and fine.

11.2.3 Planar or rough grinding [240 grit (P220) and coarser] may be performed on belts, rotating wheels or stones. In some methods, diamond abrasives are used on rigid platens. Planar grinding may be used to accomplish the following:

11.2.3.1 Flatten an irregular or damaged cut surface,

11.2.3.2 Remove sectioning damage, scale and other surface conditions prior to mounting,

11.2.3.3 Remove substantial amounts of specimen material to reach a desired plane for polishing,

11.2.3.4 Level the mount surface.

11.2.4 In fine grinding, damage to the specimen incurred from the planar or rough grinding step must be removed. The specimen is either ground on successively finer abrasive papers (using water to wash away grinding debris and to act as a coolant) or on a rigid disc or cloth charged with a suitable abrasive.

11.2.5 After all grinding is done, the specimen must be cleaned thoroughly. Ultrasonic cleaning in a water/soap solution containing a corrosion inhibitor may prove beneficial.

11.3 *Polishing*—Polishing is usually distinguished from grinding by the use of loose abrasive ( $\leq 6\mu\text{m}$ ) embedded in an appropriately lubricated supporting surface. The choice of abrasive, lubricant, and polishing surface support is often specific to the metal and the object of the investigation. Polishing can be divided into rough and fine (final) stages.

11.3.1 Rough polishing is often sufficient for routine evaluations like microindentation hardness and grain size.



**TABLE 4 European/USA Grit Grade Comparison Guide**

Grit Number	FEPA		ANSI/CAMI	
	Size (µm)		Grit Number	Size (µm)
P120	125.0		120	116.0
P150	100.0		180	78.0
P220	68.0		220	66.0
P240	58.5		...	...
P280	52.2		240	51.8
P320	46.2		...	...
P360	40.5		280	42.3
P400	35.0		320	34.3
P500	30.2		...	...
P600	25.8		360	27.3
P800	21.8		400	22.1
P1000	18.3		500	18.2
P1200	15.3		600	14.5
P1500	12.6		800	11.5
P2000	10.3		1000	9.5
P2500	8.4		1500	8.0
P4000 <sup>A</sup>	5.0		...	...

<sup>A</sup> Not found in the FEPA grading system.

ANSI—American National Standards Institute  
 CAMI—Coated Abrasives Manufacturers Institute  
 FEPA—European Federation of Abrasive Producers

11.3.2 When fine polishing is required, it may be performed with diamond or an oxide slurry step or both. The choice of final polishing abrasive type and size is dictated by the hardness of the specimen. For instance, a 1µm diamond final polish is often sufficient for many grades of steel, however, softer steels and non-ferrous materials often require an additional polishing step with an oxide slurry or suspension of SiO<sub>2</sub> or Al<sub>2</sub>O<sub>3</sub>. Final polishing cloths are generally softer and higher in nap than rough polishing cloths. Therefore, polishing time and force must be kept to a minimum to avoid artifacts such as edge rounding and relief.

11.3.3 Careful cleaning of the specimen between stages is mandatory to prevent contamination by coarser abrasive. Ultrasonic cleaning may be effective.

11.3.4 The polishing operations may be conducted by manual or by automated methods (preferred).

### Manual (Hand-held) Methods

11.4 When grinding manually, the specimen should be moved back and forth across the paper to allow for even wear. Between grinding steps, the specimen should be rotated 45-90°. At the end of grinding on each paper, the surface of the specimen and its mount, if any, should be flat with one set of unidirectional grinding scratches.

11.5 Manual polishing methods consist of holding the specimen by hand against an abrasive-charged rotating wheel and moving the specimen in a circular path around the wheel against the direction of rotation of the wheel. The specimen should be held firmly in contact with the wheel.

11.6 The amount of force applied along with the rate of movement of the specimen during grinding and polishing is a matter of personal preference and experience. In the preparation of difficult materials such as thermally sprayed coatings or composites, the operating parameters must be strictly controlled.

11.7 A traditional manual preparation sequence consists of a series of grinding and polishing steps and may be similar to those listed in [Table 5](#).

### Automated Methods

11.8 Many styles of automated specimen preparation machinery are available. Most units can perform grinding and polishing steps. Many use holders capable of accommodating multiple specimens. Major advantages of automated grinding and polishing procedures are the consistent quality of specimen preparation and the substantial decrease in time. Therefore, automated techniques are recommended over manual techniques.

11.9 Most of the devices for automated grinding and polishing move the specimen around a rotating wheel covered with abrasive so that the specimen follows an epicycloid path. In some devices, the specimen rotates on its own axis as well. The resulting scratch pattern now consists of randomly oriented arcs. Deciding when the previous scratches have been removed is more difficult than with directional (manual) grinding. The specimen surface should show uniform scratches before proceeding to the next step. Cleaning between stages is required to prevent carryover of abrasives and contamination of subsequent preparation surfaces.

11.10 [Table 5](#) illustrates a traditional automated preparation method. This method uses conventional SiC papers for grinding and is suitable for all but the hardest of materials. [Tables 6 and 7](#) are preparation methods that utilize rigid grinding discs or cloths for fine grinding. The method in [Table 6](#) has been shown to be effective for the preparation of materials harder than HRC45. The method in [Table 7](#) may be used for the preparation of materials softer than HRC45. These procedures may produce excellent results outside of the recommended hardness ranges.

## 12. Special Procedures

12.1 Occasionally, the metallographer is faced with the preparation of unfamiliar specimens or with special situations. Anticipation of every possible situation is, of course, impossible but some guidance can be offered.

12.1.1 When used properly, electrolytic polishing can produce near deformation-free surfaces but works best on solid solution alloys. Once the operating parameters are set, specimens can be prepared quickly. See Guide [E1558](#).

12.1.2 Vibratory polishing produces excellent results on many materials. Although slow, a number of specimens can be prepared simultaneously. It is especially advantageous for soft materials.

12.2 *Porous Specimens*—Specimens with continuous or open pores can be vacuum-impregnated (see [9.5](#)) with epoxy. Specimens with closed pores are mounted by a suitable method, ground through the fine grinding stage, cleaned, and dried thoroughly. The surface is then wiped with epoxy mounting compound, usually the same material used to mount the specimen, to seal the pores. After hardening, the last fine-grinding stage is repeated to remove the excess material, and specimen preparation is continued as usual. The choice of

**TABLE 5 Preparation Method 1 (General Use)**

Surface	Lubricant	Abrasive Type/Size ANSI (FEPA)	Time sec.	Force <sup>A</sup> N(lbf)	Platen RPM <sup>B</sup>	Rotation
Planar Grinding paper/stone	water	120–320 (P120–400) grit SiC/Al <sub>2</sub> O <sub>3</sub>	15–45	20–30 (5–8)	200–300 <sup>C</sup>	CO <sup>D</sup>
Fine Grinding paper	water	240 (P220) grit SiC	15–45	20–30 (5–8)	200–300	CO
paper	water	320 (P500) grit SiC	15–45	20–30 (5–8)	200–300	CO
paper	water	600 (P1200) grit SiC	15–45	20–30 (5–8)	200–300	CO
Rough Polishing low/no nap cloth	compatible lubricant	6µm diamond	120–300	20–30 (5–8)	100–150	CO
Final Polishing med./high nap cloth	compatible lubricant	1µm diamond	60–120	10–20 (3–5)	100–150	CO
synthetic suede <sup>E</sup>	water	0.04µm colloidal silica or 0.05µm alumina	30–60	10–20 (3–5)	100–150	CONTRA <sup>F</sup>

<sup>A</sup> Force per 30 mm (1¼ in.) diameter mount.

<sup>B</sup> Power heads generally rotate between 25 and 150 rpm.

<sup>C</sup> High-speed stone grinders generally rotate at greater than 1000 rpm.

<sup>D</sup> Complimentary rotation, surface and specimen rotate in same direction.

<sup>E</sup> Optional step.

<sup>F</sup> Contra rotation, surface and specimen rotate in opposite directions.

**TABLE 6 Preparation Method 2 for Harder Materials ≥ HRC 45 (450 HV)**

Surface	Lubricant	Abrasive Type/Size ANSI (FEPA)	Time sec.	Force <sup>A</sup> N(lbf)	Platen RPM <sup>B</sup>	Rotation
Planar Grinding paper/stone	water	120–320 (P120–400) grit SiC/Al <sub>2</sub> O <sub>3</sub>	15–45	20–30 (5–8)	200–300 <sup>C</sup>	CO <sup>D</sup>
Fine Grinding rigid disc	compatible lubricant	6–15µm diamond	180–300	20–30 (5–8)	100–150	CO
Rough Polishing low/no nap cloth	compatible lubricant	3–6µm diamond	120–300	20–30 (5–8)	100–150	CO
Final Polishing med./high nap cloth	compatible lubricant	1µm diamond	60–120	10–20 (3–5)	100–150	CO
synthetic suede <sup>E</sup>	water	0.04µm colloidal silica or 0.05µm alumina	30–60	10–20 (3–5)	100–150	CONTRA <sup>F</sup>

<sup>A</sup> Force per 30 mm (1¼ in.) diameter mount.

<sup>B</sup> Power heads generally rotate between 25 and 150 rpm.

<sup>C</sup> High-speed stone grinders generally rotate at greater than 1000 rpm.

<sup>D</sup> Complimentary rotation, surface and specimen rotate in same direction.

<sup>E</sup> Optional step.

<sup>F</sup> Contra rotation, surface and specimen rotate in opposite directions.

**TABLE 7 Preparation Method 3 for Softer Materials ≤ HRC 45 (450 HV)**

Surface	Lubricant	Abrasive Type/Size ANSI (FEPA)	Time sec.	Force <sup>A</sup> N(lbf)	Platen RPM <sup>B</sup>	Rotation
Planar Grinding paper/stone	water	120–320 (P120–400) grit SiC/Al <sub>2</sub> O <sub>3</sub>	15–45	20–30 (5–8)	200–300 <sup>C</sup>	CO <sup>D</sup>
Fine Grinding heavy nylon cloth	compatible lubricant	6–15µm diamond	180–300	20–30 (5–8)	100–150	CO
Rough Polishing low/no nap cloth	compatible lubricant	3–6µm diamond	120–300	20–30 (5–8)	100–150	CO
Final Polishing med./high nap cloth	compatible lubricant	1µm diamond	60–120	10–20 (3–5)	100–150	CO
synthetic suede <sup>E</sup>	water	0.04µm colloidal silica or 0.05µm alumina	30–60	10–20 (3–5)	100–150	CONTRA <sup>F</sup>

<sup>A</sup> Force per 30 mm (1¼ in.) diameter mount.

<sup>B</sup> Power heads generally rotate between 25 and 150 rpm.

<sup>C</sup> High-speed stone grinders generally rotate at greater than 1000 rpm.

<sup>D</sup> Complimentary rotation, surface and specimen rotate in same direction.

<sup>E</sup> Optional step.

<sup>F</sup> Contra rotation, surface and specimen rotate in opposite directions.

epoxy for impregnation depends on the nature of the specimen. It should be inert toward the specimen.

12.3 *Composite Materials*—Composite materials, particularly hard fibers in a soft matrix or wires in a soft insulation,

can be particularly difficult to prepare. The best approach is to first seal or impregnate pores or holes. Then grind carefully, using copious lubrication. The grinding surface must be kept flat and firm. In the polishing stages, the substrate should have no nap and should be fairly hard. Diamond abrasive is recommended. Both will minimize rounding of the hard components. Sometimes, a compromise will have to be made between accepting a few artifacts such as scratches or rounded edges.

#### 12.4 Coated Materials:

12.4.1 Coated metals, such as galvanized steel, electroplated metal, enamel ware, and so forth, can be considered a variety of composite materials. They present problems of their own, such as flaking, chipping, and rounding. For example, some coatings are so thin as to be unresolvable on simple cross sections (tinplate). Other problems are the presence of a soft coating on a harder substrate (galvanized steel) or a hard brittle coating on a soft substrate (porcelain enamel on aluminum).

12.4.1.1 The problem of thin coatings can be handled by using a taper mount. In this method, the specimen is mounted so that the plane of polish is at a small angle to the plane of the surface. For example, a tapered plug is inserted in the mounting press with the taper up. A blank tapered mount is prepared. Masking tape is wrapped around the circumference of the mount to make a well on the tapered end. A small amount of epoxy mounting compound is mixed. The specimen, cut to fit inside the well, is wetted with the epoxy and laid on the face of the tapered mount, coated side up. Using a probe, the specimen is pressed down firmly onto the tapered face. The balance of the epoxy compound is added and allowed to harden. The mounted specimen is ground and polished on the epoxy face in the conventional manner exercising care that the plane of

polish is perpendicular to the cylindrical axis of the mount. This is easily done with most automatic grinding machines.

12.4.1.2 The problem of soft coatings can be solved by the use of a suitable backup. A piece of spring steel is useful to hold the backup in place, or the backup may be cemented to the specimen. The cement can act as an insulation to minimize galvanic effects. Caution: some cements will dissolve in epoxy mounting compounds. A particularly suitable backup is another piece of the same material, with the coating sandwiched in. Another solution is to add another coating, for example, electroplate. However, this may introduce undesirable galvanic effects during etching. Galvanic problems may arise also from the interaction of the coating and its substrate. The mounting procedure used must result in excellent adhesion to the coated surface to minimize edge rounding. If edge rounding persists, the polishing time and applied force may have to be decreased.

12.4.1.3 Hard coatings on softer substrates can be mounted with a backup piece or a hard-filled mounting compound. Diamond abrasives on a napless cloth will minimize surface relief during polishing.

12.5 Fragile specimens should be mounted in one of the castable mounting formulations. Vacuum impregnation will ensure filling of holes and cavities (see 9.5). Thin walls can be reinforced by electroless nickel plating, which will alleviate the rounding problem.

12.6 Likewise, friable specimens can be bound together by impregnation with plastic or by electroless nickel plating, or both. Further guidance can be found in texts on preparation of mineralogical specimens.

### 13. Keywords

13.1 alloys; grinding; metallography; metals; mounting; polishing; sectioning; specimen preparation (metallographic)

## APPENDIXES

### (Nonmandatory Information)

#### X1. CLEANING SPECIMENS

X1.1 Metallographers frequently need to clean specimens. In some instances, the adherent debris, oxidation, or corrosion product must be collected for analysis, for example, by X-ray diffraction. In other cases, the adherent matter is of no interest, it merely needs to be removed. If the underlying surface is of no interest, the surface can be shot blasted, wire brushed, or ground. However, if the underlying surface is important, for example, a fracture surface, then the cleaning operation must do as little damage as possible. These different aims of the cleaning operation must be kept in mind before formulating the cleaning program.

X1.2 When the adherent material is to be analyzed, a variety of procedures may be applied depending upon whether or not the underlying surface can or cannot be damaged.

X1.2.1 In the case of debris or corrosion product on the surface of a part, a stylus, scalpel, or other sharp object can be

used to scrape off or pry off enough material for analysis. This will do some damage to the surface, but it will be localized.

X1.2.2 As an alternative, use cellulose acetate replicating tape to remove surface debris by the extraction replica approach. A number of approaches have been developed and are described in STP 547<sup>4</sup> as well as in many textbooks on electron microscopy. Generally, thick (0.127 mm or 0.005 in.) tape is employed. One surface is moistened with acetone and then pressed against the debris-coated surface. After it dries, strip off the tape in the same way as you would remove adhesive tape. The debris will adhere to the tape.

X1.3 When the surface is to be examined, but the adherent debris will not be analyzed, several approaches can be used.

<sup>4</sup> "Manual Electron Metallography Techniques," 1973. Available from ASTM Headquarters. Request STP 547.

**TABLE X1.1 Cleaning Solutions for Use When Standard Methods Are Inadequate**

6N HCl plus 2 g/L Hexamethylene tetramine <sup>A</sup>	Immerse specimen in solution for 1 to 15 min. Good for steels. Cleaning action can be enhanced by light brushing or by brief (5 s) periods in an ultrasonic cleaner.
3 mL HCl 4 mL 2-Butyne-1, 4 diol inhibitor 50 mL water <sup>B</sup>	Use a fresh solution at room temperature. Use in an ultrasonic cleaner for about 30 s.
49 mL water 49 mL HCl 2 mL Rodine-50 inhibitor <sup>C</sup>	Wash specimen in alcohol for 2 min in an ultrasonic cleaner before and after a 2-min ultrasonic cleaning period with the inhibited acid bath.
6 g sodium cyanide 6 g sodium sulphite 100 mL distilled water <sup>DEF</sup>	Electrolytic rust removal solution. Use under a hood with care. Use 100-mA/cm <sup>2</sup> current density for up to 15 min.
10 g ammonium citrate 100 mL distilled water <sup>G</sup>	Use solution heated to 30°C (86°F).
70 mL orthophosphoric acid 32 g chromic acid 130 mL water <sup>H</sup>	Recommended for removing oxides from aluminum alloy fractures (some sources claim that only organic solvents should be used).
8 oz endox 214 powder 1000 mL cold water (add small amount of Photo-Flo) <sup>I,J</sup>	Use electrolytically at 250-mA/cm <sup>2</sup> current density for 1 min with a Pt cathode to remove oxidation products. Wash in an ultrasonic cleaner with the solution for 1 min. Repeat this cycle several times if necessary. Use under a hood.

<sup>A</sup> deLeiris, H., et al, "Techniques for Removing Rust from Fractures of Steel Parts that are to be Examined by Electron Microfractography," *Mem. Sci. Rev. Met.*, Vol 63, No. 5, May 1966, pp. 463–472.

<sup>B</sup> Dahlberg, E. P., "Techniques for Cleaning Service Failures in Preparation for Scanning Electron Microscope and Microprobe Analysis," *Scanning Electron Microscopy*, 1974, Part IV, pp. 911–918.

<sup>C</sup> Brooks, C. E., and Lundin, C. D., "Rust Removal from Steel Fractures—Effect on Fractographic Evaluation," *Microstructural Science*, Vol 3A, Elsevier, NY, 1975, pp. 21–33.

<sup>D</sup> deLeiris, H., et al, "Techniques for Removing Rust from Fractures of Steel Parts That Are to be Estimated by Electron Microfractography," *Mem. Sci. Rev. Met.*, Vol 63, No. 5, May 1966, pp. 463–472.

<sup>E</sup> Russ, J. C., and Miller, G. A., "Effect of Oxidation on the Electron Fractographic Interpretation of Fractures in Steel," *JISI*, December 1969, pp. 1635–1638.

<sup>F</sup> Pickwick, K. M., and Smith, E., "The Effect of Surface Contamination in SEM Fractographic Investigations," *Micron*, Vol 3, No. 2, 1972, pp. 224–237.

<sup>G</sup> Interrante, C. G., and Hicho, G. E., "Removal of Iron-Sulfide Deposits from Fracture Surfaces," *ASTM STP 610*, 1976, pp. 349–365.

<sup>H</sup> Beachem, C. D., *The Interpretation of Electron Microscope Fractographs*, NRL Report 6360, U.S. Government Printing Office, Jan. 21, 1966.

<sup>I</sup> Yuzawich, P. M., and Hughes, C. W., "An Improved Technique for Removal of Oxide Scale from Fractured Surfaces of Ferrous Materials," *Prakt. Met.*, Vol 15, April 1978, pp. 184–195.

<sup>J</sup> Goubau, B., and Werner, H., "Microfractographic Investigation of Fracture Surfaces Coated With Magnetite," *Prakt. Met.*, Vol 17, No. 5, May 1980, pp. 209–219.

Always try the simplest, safest methods first. For example, use a blast of compressed air to remove any loosely adherent material. A soft camel-hair brush or a soft toothbrush may also be useful for removing loosely adherent matter.

X1.3.1 If the techniques in X1.3 do not suffice, try aqueous solutions, organic solvents, or alcohol with an ultrasonic cleaner. Aqueous solutions (8 g of Alconox per litre of warm water) containing Alconox<sup>5</sup>, a detergent, have been found (1, 2) to be effective. Follow the Alconox bath with rinsing under running water, then dry. Organic solvents, such as acetone, ethyl methyl ketone, toluene, xylene, or alcohol (ethanol is preferable to methanol because of potential health problems with the latter) are also very effective. Before choosing one of these solutions, be sure that it will not adversely affect the material being cleaned. Avoid use of chlorinated organic solvents (such as trichlorethylene or carbon tetrachloride) due to their carcinogenic nature. Repeated replication, as described in X1.2.2, is an effective method for cleaning fractures (3, 4).

X1.3.2 When the procedures in X1.3 and X1.3.1 are unsuccessful, more drastic methods are required. Electrolytic cleaning solutions (Table X1.1), have been found to be quite useful. An inert material (stainless steel, graphite, or platinum, for example) is used as an anode, while the specimen is the cathode in the electrolytic cell. Some of these solutions can generate dangerous fumes, hence they should be used under a hood with care. Endox 214<sup>6</sup> has been found (1) to be useful for cleaning heavily rusted steel fractures.

X1.3.3 Cathodic cleaning solutions or acid-inhibited baths have also been employed to clean fractures (3, 5). However, as the degree of corrosion or oxidation increases, fracture features will be destroyed to a greater extent and cleaning, while it can remove the surface deposits, cannot restore damaged fracture features.

X1.3.4 A number of proprietary rust removal solutions have been developed. These are premixed and used directly out of the container. Two such products are described in Refs 6 and 7.

<sup>5</sup> The sole source of supply of Alconox known to the committee at this time is Alconox, Inc., New York, NY 10003. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,<sup>1</sup> which you may attend.

<sup>6</sup> The sole source of supply of Endox 214 known to the committee at this time is Enthone, Inc., West Haven, CT 06516. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,<sup>1</sup> which you may attend.

X1.3.5 Cleaning can also be accomplished by argon-ion bombardment (6) or by use of a glow-discharge method (7, 8). These methods require specialized equipment.

## X2. PRESERVING PREPARED SPECIMENS

X2.1 After specimens have been polished and possibly etched, there is usually a need to preserve that surface for others to examine, either to confirm an observation, to view problems reported, or in litigations, for the opposing experts to view the same details. If the detail to be examined may be at the origin of a failure, or may be small, it may be lost if the specimen is re-prepared. This is not a problem usually when the general microstructural conditions are to be examined.

X2.2 For short term preservation, the prepared specimen can be placed in a vacuum dessicator. Specimens that have inherent corrosion resistance can be observed without difficulty after some time in a dessicator, depending upon how frequently it is opened and room humidity. Storage in a dessicator for a long time may not be practical if a great many specimens must be stored.

X2.3 For longer term preservation, there are several options. First, one can coat the surface with a clear lacquer and then place the specimen within a closed polymeric container or wrap it up carefully with tissue and place it in a protective box or drawer. The microstructure can be seen through the lacquer, or the lacquer can be removed with the appropriate solvent. Another solution is to place a protective “cap plug” polymeric closure tightly over the polished or etched surface, or both, and then store the specimen in an appropriately marked box or drawer. A somewhat less satisfactory long-term solution is to tape a large piece of cotton over the polished and/or etched face and then place that specimen in an appropriate box or drawer.

## X3. APPLIED LOAD CONVERSIONS

X3.1 Automated preparation machines commonly display force in either pound-force (lbf) or newtons (N). The ability to convert from one unit to the other may be necessary when trying to interpret a documented procedure.

X3.1.1 To convert from pound-force to newton multiply the pound-force value by 4.5.

X3.1.2 To convert from newton to pound-force multiply the newton value by 0.225.

X3.2 When multiple specimens of equal contact area are held in a holder, the applied force must be divided by the number of specimens in the holder to determine the load per specimen.

X3.2.1 Some automated machines apply force individually to each specimen. In this case it is necessary to divide the force by the contact area to determine the load per specimen.

X3.3 Caution should be taken when using automated machines that display pressure in pound-force per square inch (psi). Typically, the machine is displaying the air pressure within the loading cylinder and not the actual pressure applied to either the specimen holder or individual specimen.

X3.4 When converting from a force to a pressure, the surface area of the specimen(s) must be determined. The value of force is then divided by the contact area to determine the required pressure.

## X4. PROCEDURE IMPROVEMENT

X4.1 To improve the preparation of a particular material, try one of the preparation methods described in Table 5, Table 6, or Table 7. Following are general guidelines that may help improve results.

X4.2 If a material is being prepared for the first time, the surface should be microscopically examined after every step.

X4.3 Before proceeding to the next step, be sure that all deformation and artifacts from the previous step, such as scratches, pull-outs or embedded grains, are completely removed. It is difficult to identify when an artifact was introduced if the specimen is not examined prior to the final step.

You must know when the artifact was introduced in order to improve the method.

X4.4 Keep the preparation times as short as possible. Excessive preparation wastes consumables and may introduce artifacts such as relief and edge rounding.

X4.5 New consumables such as polishing cloths or diamond grinding products may need to be “broken in” for a short period prior to use.

X4.6 The following section lists common preparation artifacts and prevention measures.

X4.7 *Scratches*—Scratches are grooves in the surface of the specimen produced by the points of abrasive particles.

X4.7.1 Make sure that after planar grinding the surface of all of the specimens in the holder exhibit the same uniform scratch pattern over the entire specimen. Repeat the planar grinding step if necessary.

X4.7.2 Clean the specimens and holder carefully after each step to avoid contamination.

X4.7.3 If there are still scratches left over from the previous step after finishing the current step, increase the preparation time by 25 to 50 %. If this does not work then you should consider altering the method by inserting an intermediate step.

X4.8 *Deformation*—Deformation can be classified by two types, elastic and plastic. Elastic deformation disappears when the applied load is removed. Plastic deformation, often called cold work, can be induced during sectioning, mounting, grinding, lapping or polishing. Residual plastic deformation can first be seen after etching. Only deformation that was introduced during metallographic preparation can be eliminated with procedure modification. Deformation from manufacturing operations such as bending, drawing and stretching are not considered because they cannot be removed by altering the preparation method.

X4.8.1 If the deformation is visible in brightfield in the unetched condition, please see X4.7.3 Scratches, for tips on how to improve the preparation.

X4.8.2 If after etching, the deformation is restricted to single or a few grains then it is minimal and may be removed by repeating the previous step.

X4.8.3 If after etching, the deformation is well defined covering several grains or even the whole specimen, then it may have been recently introduced. Check and clean the polishing cloth for possible contamination. Replace the cloth if results do not improve (see X4.14). Repeat the previous step.

X4.8.4 If after etching, the deformation is in the form of long, blunt lines covering several grains (with possible interruptions) then it may have been introduced from an earlier stage. Repeat the procedure starting from the fine grinding stage.

X4.9 *Smearing*—Smearing is the flow of material at the surface of the specimen. It is the result of material being “pushed” across the surface instead of being cut.

X4.9.1 Check the amount of lubricant. Smearing most often occurs when lubrication levels are too low. Increase or change the lubricant to eliminate smearing.

X4.9.2 Check the applied load. Excessive loads can result in smearing. Reduce the load to eliminate smearing.

X4.9.3 Check the abrasive size. Abrasives grains that are too small may not be effective in material removal. Increase the abrasive grain size.

X4.10 *Edge Rounding*—Edge rounding results when the edge of the specimen abrades at a greater rate than the body of the specimen.

X4.10.1 Mount the specimen. Unmounted specimens always exhibit greater edge rounding than mounted specimens.

X4.10.2 Use the correct mounting compound. There should be minimal shrinkage of the mounting compound away from the specimen. Try to match the abrasion resistance of the mounting compound closely to that of the specimen. See Section 9.

X4.10.3 If the edge rounding first occurred during grinding, consider changing the grinding substrate to a less resilient form. Also consider changing the abrasive type. Diamond abrasive is often more effective than SiC at cutting hard materials.

X4.10.4 Reduce polishing times as much as possible. Long polishing procedures often result in excessive edge rounding.

X4.10.5 Reduce applied load. Normally lower loads result in less edge rounding.

X4.10.6 Change the polishing lubricant. Oil or water/oil type lubricants may help preserve edges.

X4.10.7 Change the polishing cloth. Less resilient cloths produce better edges.

X4.10.8 If the preceding steps are ineffective then consider plating the specimen. See Section 10.

X4.11 *Relief*—Relief results when material from different phases is removed at different rates due to varying hardness or wear rate of individual phases.

X4.11.1 Relief normally first occurs during polishing. However, if there are extreme differences in the hardness between phases it may occur during grinding. If this is the case then an alternative grinding method should be considered. See Tables 5 and 6.

X4.11.2 Polishing time should be kept to a minimum.

X4.11.3 Polishing cloths that have less resiliency produce less relief (see Edge Rounding in X4.10).

X4.11.4 The polishing abrasive should be at least 2.5 times harder (on the Vickers scale) than the hardest phase being polished.

X4.12 *Pull-outs*—Pullouts are the cavities left in the surface after grains or particles are torn out during preparation.

X4.12.1 Avoid high loads during grinding and polishing.

X4.12.2 Do not use coarse abrasives for Planar or Fine grinding steps.

X4.12.3 Do not make large abrasive size jumps between preparation steps. Insert an intermediate step if necessary.

X4.12.4 Napless polishing cloths produce less pull-out than napped cloths.

X4.12.5 Every step has to remove the damage from the previous step, and has to introduce as little damage as possible.

X4.12.6 Check the specimen after every step in order to find out when the pull-out occurs.

X4.13 *Gaps*—Gaps are the voids between the mounting compound and the specimen. Gaps can result in a variety of preparation artifacts such as edge rounding, contamination and staining.

X4.13.1 Clean and dry the specimen thoroughly prior to mounting.

X4.13.2 Select a mounting compound with low shrinkage (see Section 9).

X4.13.3 For hot compression mounting, cool the specimen under pressure.

X4.13.4 For castable mounting compounds, avoid high curing temperatures. It may be necessary to cool the specimen during the curing.

X4.13.5 Specimen height should be kept as low as practical to minimize gaps when using hot compression mounting.

X4.14 *Contamination*—Contamination is material from a source other than the specimen itself which is deposited on the specimen surface during grinding or polishing.

X4.14.1 Thoroughly clean the specimen between preparation steps (see 11.2.5, 11.3.3).

X4.14.2 Store grinding and polishing discs in a clean, dust-free environment.

X4.14.3 Change grinding or polishing substrate/abrasive if necessary.

X4.15 *Embedded Abrasive*—Embedded abrasive results when loose grinding, lapping, or polishing abrasive sticks into the surface of the specimen.

X4.15.1 Embedded abrasive is most common with soft non-ferrous materials.

X4.15.2 Change to a more resilient grinding substrate.

X4.15.3 Use a block of paraffin or candle to “pick up” loose SiC particles on fine grit papers. This is done by lightly passing the paraffin block across the paper.

X4.15.4 Change to a more resilient polishing substrate when using diamond abrasives that are less than 3 $\mu$ m in diameter.

X4.15.5 Change to an oil or water/oil-based polishing lubricant.

X4.16 *Lapping Tracks*—Lapping tracks are indentations on the specimen surface made by abrasive particles moving freely (rolling) on a hard surface. Lapping tracks can be produced during both grinding and polishing.

X4.16.1 Change to a more resilient grinding or polishing substrate.

X4.16.2 Increase the applied load in 10 % increments until the lapping tracks disappear.

X4.16.3 Employ optimal dynamics.

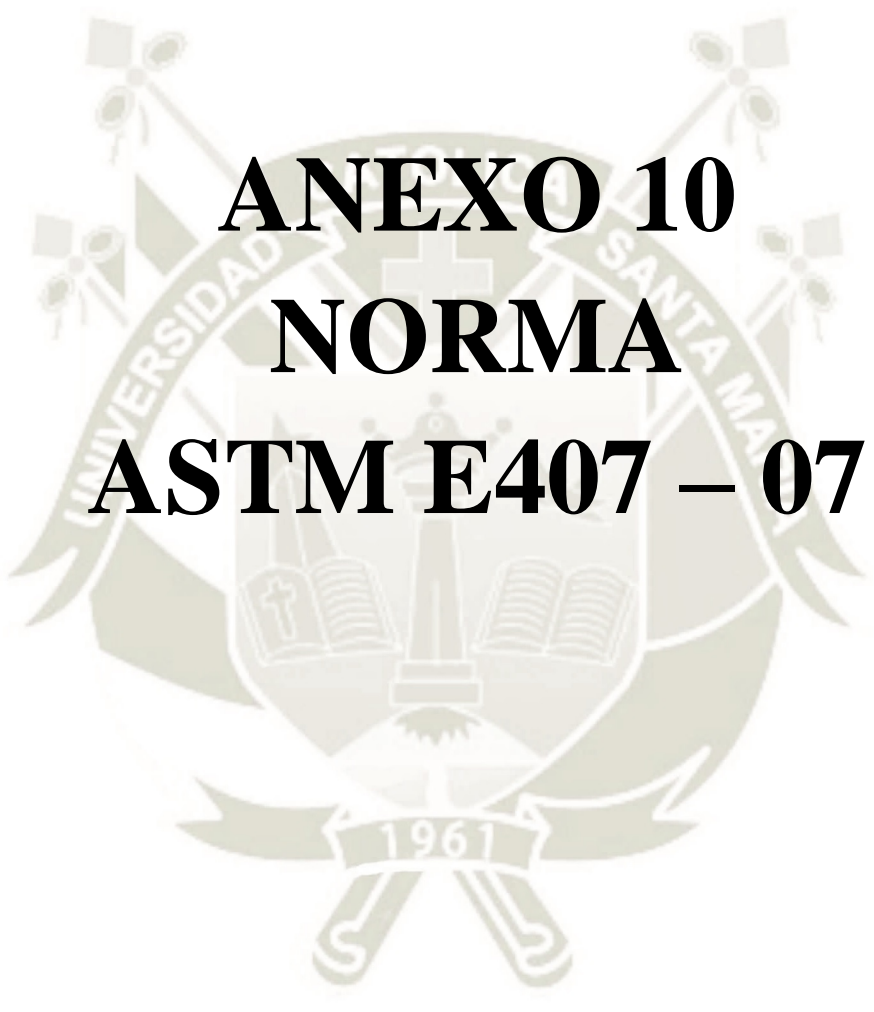
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**ANEXO 10**  
**NORMA**  
**ASTM E407 – 07**





# Standard Practice for Microetching Metals and Alloys<sup>1</sup>

This standard is issued under the fixed designation E407; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

*This standard has been approved for use by agencies of the U.S. Department of Defense.*

<sup>ε1</sup> NOTE—Originally approved date was editorially corrected to 1970 in footnote 1 in January 2016.

## 1. Scope

1.1 This practice covers chemical solutions and procedures to be used in etching metals and alloys for microscopic examination. Safety precautions and miscellaneous information are also included.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific cautionary statements, see 6.1 and Table 2.

## 2. Referenced Documents

2.1 *ASTM Standards:*<sup>2</sup>

D1193 Specification for Reagent Water

E7 Terminology Relating to Metallography

E2014 Guide on Metallographic Laboratory Safety

## 3. Terminology

3.1 *Definitions:*

3.1.1 For definition of terms used in this standard, see Terminology E7.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *tint etch*—an immersion etchant that produces color contrast, often selective to a particular constituent in the microstructure, due to a thin oxide, sulfide, molybdate, chromate or elemental selenium film on the polished surface that reveals the structure due to variations in light interference effects as a function of the film thickness (also called a "stain etch").

<sup>1</sup> This practice is under the jurisdiction of ASTM Committee E04 on Metallography and is the direct responsibility of Subcommittee E04.01 on Specimen Preparation.

Current edition approved June 1, 2015. Published September 2015. Originally approved in 1970. Last previous edition approved in 2007 as E407–07<sup>ε1</sup>. DOI: 10.1520/E0407-07R15E01.

<sup>2</sup> For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.2.2 *vapor-deposition interference layer method*— a technique for producing enhanced contrast between microstructural constituents, usually in color, by thin films formed by vacuum deposition of a dielectric compound (such as ZnTe, ZnSe, TiO<sub>2</sub>, ZnS or ZnO) with a known index of refraction, generally due to light interference effects (also known as the "Pepperhoff method").

## 4. Summary of Practice

4.1 Table 1 is an alphabetical listing of the metals (including rare earths) and their alloys for which etching information is available. For each metal and alloy, one or more etchant numbers and their corresponding use is indicated. Alloys are listed as a group or series when one or more etchants are common to the group or series. Specific alloys are listed only when necessary. When more than one etchant number is given for a particular use, they are usually given in order of preference. The numbers of electrolytic etchants are *italicized* to differentiate them from nonelectrolytic etchants.

4.2 Table 2 is a numerical listing of all the etchants referenced in Table 1 and includes the composition and general procedure to be followed for each etchant.

4.3 To use the tables, look up the metal or alloy of interest in Table 1 and note the etchant numbers corresponding to the results desired. The etchant composition and procedure is then located in Table 2 corresponding to the etchant number.

4.4 If the common name of an etchant is known (Marble's, Vilella's, etc.), and it is desired to know the composition, Table 3 contains an alphabetical listing of etchant names, each coded with a number corresponding to the etchant composition given in Table 2.

## 5. Significance and Use

5.1 This practice lists recommended methods and solutions for the etching of specimens for metallographic examination. Solutions are listed to highlight phases present in most major alloy systems.

## 6. Safety Precautions

6.1 Before using or mixing any chemicals, all product labels and pertinent Material Safety Data Sheets (MSDS) should be

read and understood concerning all of the hazards and safety precautions to be observed. Users should be aware of the type of hazards involved in the use of all chemicals used, including those hazards that are immediate, long-term, visible, invisible, and with or without odors. See Guide E2014 on Metallographic Laboratory Safety for additional information on; Chemical Safety, Electrolytic Polishing/Etching and Laboratory Ventilation/Fume Hoods.

6.1.1 Consult the product labels and MSDSs for recommendations concerning proper protective clothing.

6.1.2 All chemicals are potentially dangerous. All persons using any etchants should be thoroughly familiar with all of the chemicals involved and the proper procedure for handling, mixing, and disposing of each chemical, as well as any combinations of those chemicals. This includes being familiar with the federal, state, and local regulations governing the handling, storage, and disposal of these chemical etchants.

6.2 Some basic suggestions for the handling and disposing of etchants and their ingredients are as follows:

6.2.1 When pouring, mixing, or etching, always use the proper protective equipment, (glasses, gloves, apron, etc.) and it is strongly recommended to always work under a certified and tested fume hood. This is imperative with etchants that give off noxious odors or toxic vapors that may accumulate or become explosive. In particular, note that solutions containing perchloric acid must be used in an exclusive hood equipped with a wash down feature to avoid accumulation of explosive perchlorates. See Guide E2014 on Metallographic Laboratory Safety for additional information on safety precautions for electrolytes containing perchloric acid.

6.2.2 No single type of glove will protect against all possible hazards. Therefore, a glove must be carefully selected and used to ensure that it will provide the needed protection for the specific etchant being used. In some instances it may be necessary to wear more than one pair of gloves to provide proper protection. Information describing the appropriate glove may be obtained by consulting the MSDS for the chemical being used. If that does not provide enough detailed information, contact the chemical manufacturer directly. Additionally, one can contact the glove manufacturer or, if available, consult the manufacturers glove chart. If the chemical is not listed or if chemical mixtures are being used, contact the glove manufacturer for a recommendation.

6.2.3 Use proper devices (glass or plastic) for weighing, mixing, containing, and storage of solutions. A number of etchants generate fumes or vapors and should only be stored in properly vented containers. Storage of fuming etchants in sealed or non-vented containers may create an explosion hazard.

6.2.4 When mixing etchants, always add reagents to the solvent unless specific instructions indicate otherwise.

6.2.5 When etching, always avoid direct physical contact with the etchant and specimen; use devices such as tongs to hold the specimen (and tufts of cotton, if used).

6.2.6 Methanol is a cumulative poison hazard. Where ethanol or methanol, or both are listed as alternates, ethanol is the preferred solvent. Methanol should be used in a properly designed chemical fume hood.

6.2.7 When working with HF always be sure to wear the appropriate gloves, eye protection and apron. Buying HF at the lowest useable concentration will significantly reduce risk. Additionally, it is recommended that a calcium gluconate cream or other appropriate HF neutralizing agent be available for use if direct skin contact of the etchant occurs.

6.2.8 The EPA states that human studies have clearly established that inhaled chromium (VI) is a human carcinogen, resulting in an increased risk of lung cancer. Animal studies have shown chromium (VI) to cause lung tumors via inhalation exposure. Therefore, when working with Cr(VI) compounds such as  $K_2Cr_2O_7$  and  $CrO_3$  always use a certified and tested fume hood. Additional information can be obtained at the EPA website<sup>3</sup>.

6.2.9 For safety in transportation, picric acid is distributed by the manufacturer wet with greater than 30% water. Care must be taken to keep it moist because dry picric acid is shock sensitive and highly explosive especially when it is combined with metals such as copper, lead, zinc, and iron. It will also react with alkaline materials including plaster and concrete to form explosive compounds. It should be purchased in small quantities suitable for use in six to twelve months and checked periodically for lack of hydration. Distilled water may be added to maintain hydration. It must only be stored in plastic or glass bottles with nonmetallic lids. If dried particles are noted on or near the lid, submerge the bottle in water to re-hydrate them before opening. It is recommended that any bottle of picric acid that appears dry or is of unknown vintage not be opened and that proper emergency personnel be notified.

6.2.10 Wipe up or flush any and all spills, no matter how minute in nature.

6.2.11 Properly dispose of all solutions that are not identified by composition and concentration.

6.2.12 Store, handle and dispose of chemicals according to the manufacturer's recommendations. Observe printed cautions on reagent bottles.

6.2.13 Information pertaining to the toxicity, hazards, and working precautions of the chemicals, solvents, acids, bases, etc. being used (such as material safety data sheets, MSDS) should be available for rapid consultation. A selection of useful books on this subject is given in Refs. (1-11)<sup>4</sup>.

6.2.14 Facilities which routinely use chemical etchants should have an employee safety training program to insure the employees have the knowledge to properly handle chemical etchants.

6.2.15 When working with etchants always know where the nearest safety shower, eye-wash station, and emergency telephone are located.

## 7. Miscellaneous Information

7.1 If you know the trade name of an alloy and need to know the composition to facilitate the use of Table 1, refer to a compilation such as Ref (12).

7.2 Reagent grade chemicals shall be used for all etchants. Unless otherwise indicated, it is intended that all reagents

<sup>3</sup> <http://www.epa.gov/ttn/atw/hlthef/chromium.html>

<sup>4</sup> The boldface numbers in parentheses refer to the list of references at the end of this standard.

conform to specifications of the Committee on Analytical Reagents of the American Chemical Society where such specifications are available. Other grades, such as United States Pharmacopeia (USP), may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without detrimental effect.

7.2.1 Unless otherwise indicated, references to water shall be understood to mean reagent water as defined by Type IV of specification **D1193**. Experience has shown that the quality of tap water varies significantly and can adversely affect some etchants.

7.3 Methanol is usually available only as absolute methanol. When using this alcohol it is imperative that approximately 5 volume % of water is added whenever an etchant composition calls for 95 % methanol. Some of these etchants will not work at all if water is not present.

7.4 For conversion of small liquid measurements, there are approximately 20 drops/mL.

7.5 Etching should be carried out on a freshly polished specimen.

7.6 Gentle agitation of the specimen or solution during immersion etching will result in a more uniform etch.

7.7 The etching times given are only suggested starting ranges and not absolute limits.

7.8 In electrolytic etching, d-c current is implied unless indicated otherwise.

7.9 A good economical source of d-c current for small scale electrolytic etching is the standard 6-V lantern battery.

7.10 In electrolytic etching, the specimen is the anode unless indicated otherwise.

7.11 Do not overlook the possibility of multiple etching with more than one solution in order to fully develop the structure of the specimen.

7.12 Microscope objectives can be ruined by exposure to hydrofluoric acid fumes from etchant residue inadvertently left on the specimen. This problem is very common when the specimen or mounting media contain porosity and when the mounting material (such as Bakelite) does not bond tightly to the specimen resulting in seepage along the edges of the specimen. In all cases, extreme care should be taken to remove all traces of the etchant by thorough washing and complete drying of the specimen before placing it on the microscope stage.

7.13 Tint etchants (**13, 14-16**) are always used by immersion, never by swabbing, as this would inhibit film formation. An extremely high quality polish is required as tint etchants will reveal remaining polishing damage even if it is not visible with bright field illumination. After polishing, the surface must be carefully cleaned. Use a polyethylene beaker to contain the etchant if it contains fluorine ions (for example, etchants containing ammonium bifluoride,  $\text{NH}_4\text{FHF}$ ). The specimen is placed in the solution using tongs, polished face up. Gently agitate the solution while observing the polished surface. After coloration begins, allow the solution to settle and remain motionless. Remove the specimen from the etchant when the surface is colored violet, rinse and dry. A light pre-etch with a general-purpose chemical etchant may lead to sharper delineation of the structure after tint etching.

7.14 Specimens should be carefully cleaned before use of a vapor-deposition interference film (“Pepperhoff”) method (**13, 14-17**). A light pre-etch, or a slight amount of polishing relief, may lead to sharper delineation of the constituents after vapor deposition. The deposition is conducted inside a vacuum evaporator of the type used to prepare replicas for electron microscopy. One or several small lumps of a suitable dielectric compound with the desired index of refraction is heated under a vacuum until it evaporates. A vacuum level of 1.3 to 0.013 Pa ( $10^{-3}$  to  $10^{-5}$  mm Hg) is adequate and the polished surface should be about 10–15 cm beneath the device that holds the dielectric compound. Slowly evaporate the lumps and observe the surface of the specimen. It may be helpful to place the specimen on a small piece of white paper. As the film thickness increases, the surface (and the paper) will become colored with the color sequence changing in the order yellow, green, red, purple, violet, blue, silvery blue. Stop the evaporation when the color is purple to violet, although in some cases, thinner films with green or red colors have produced good results.

7.15 Metals Handbook (**18**) provides additional advice on etching solutions and techniques for various alloys.

## 8. Precision and Bias

8.1 It is not possible to specify the precision or bias of this practice since quantitative measurements are not made.

## 9. Keywords

9.1 etch; etchant; interference method; metallography; metals; microetch; microscope; microstructure; Pepperhoff method; tint etch

**TABLE 1 Etchants for Metals**

NOTE 1—It is strongly recommended to always mix and use etchants under a certified and tested fume hood.

NOTE 2—Electrolytic etchants are *italicized*.

Metal	Etchants	Uses
<i>Aluminum Base:</i>		
Pure Al	1a, 2, 3 4, 5 1b	general structure grain structure under polarized light grain boundaries and slip lines
1000 series	1a, 3, 2 4, 5 6, 7	general structure grain structure under polarized light phase identifications
2000 series	3, 2, 1a 8a, 6, 7	general structure phase identifications
3000 series	3, 1a 4, 5 8a, 6, 7	general structure grain structure under polarized light phase identifications
4000 series	3, 1a	general structure
5000 series	3, 1a, 2, 6, 8a 4, 5	general structure grain structure under polarized light
6000 series	3, 1a, 2, 6, 8a, 222 4, 5 1a, 2, 7, 6, 8a	general structure grain structure under polarized light phase identifications
7000 series	3, 1a, 2 4, 5 3b, 6	general structure grain structure under polarized light phase identifications
<i>Beryllium Base:</i>		
Pure Be Be alloys	9, 10 11	general structure via polarized light general structure
<i>Chromium Base:</i>	12, 13c	general structure
<i>Cobalt Base:</i>		
Pure Co Hard-facing and tool metals High-temperature alloys	14, 15, 16, 17 18, 19, 20 20, 18, 16, 21, 22b, 24, 25 19	general structure general structure general structure phase identification
<i>Columbium Base (see niobium base)</i>		
<i>Copper Base:</i>		
Pure Cu	26, 27, 28, 29, 30, 31d, 32, 33, 34b, 35, 36, 37, 38, 39, 40, 41, 42, 8b, 210, 215 43, 28	general structure chemical polish and etch
Cu-Al (aluminum bronze)	44, 31d, 34b, 35, 36, 37, 38, 39, 40, 45, 215	general structure
Cu-Be	46, 41, 45	general structure
Cu-Cr	41	general structure
Cu-Mn	41	general structure
Cu-Ni	34, 47, 48, 40, 49, 50	general structure
Cu-Si	41	general structure
Cu-Sn (tin bronze)	51, 52	general structure
Admiralty metal Gilding metal Cartridge brass Free-cutting brass Nickel silver	8b    31d, 32, 33, 41, 42, 49	general structure    general structure
Cu alloys	26, 27, 28, 29, 30, 44, 41, 31d, 32, 33, 34b, 35, 36, 37, 38, 39, 210, 215 53, 43, 28, 49 42, 49, 210 54	general structure  chemical polish and etch darkens beta in alpha-beta brass etching of cold worked brass
<i>Dysprosium Base:</i>	55, 56	general structure

**TABLE 1** *Continued*

Metal	Etchants	Uses
<i>Erbium Base:</i>	55, 56	general structure
<i>Gadolinium Base:</i>	55, 56, 57	general structure
<i>Germanium Base:</i>	58, 59, 60	general structure
<i>Gold Base:</i>		
Pure Au	61, 62	general structure
	63	chemical polish and etch
Au alloys	64b, 62	general structure
	63	chemical polish and etch
>90 % noble metals	61	general structure
<90 % noble metals	65	general structure
<i>Hafnium base:</i>	66, 67, 68, 69, 70	general structure
	71	grain structure under polarized light
	72	chemical polish and etch
<i>Holmium Base:</i>	55, 56	general structure
<i>Iridium Base:</i>	73c	general structure
<i>Iron Base:</i>		
Pure Fe	74a	grain boundaries
	75	substructure
	210	colors ferrite grains
Fe + C	76, 74a, 77, 78, 79	general structure
and	74a, 77, 31a, 223	ferrite grain boundaries
Fe + <1C + <4 % additions	80, 81, 82	prior austenitic grain boundaries in martensitic and bainitic steels
	78, 222a	untempered martensite
	31b, 78	carbides and phosphides (matrix darkened, carbides and phosphides remain bright)
	83	cementite attacked rapidly, susenite less, ferrite and iron phosphide least
	84	overheating and burning
	85	stains carbides
	86	chemical polish-etch
	210, 211	colors ferrite
	213, 214	colors carbides
	216	colors lath martensite in low-carbon high-alloy grades for dual phase steels; reveals pearlite, darkens martensite and outlines austenite
	222b	
Fe + 4–12 Cr	80, 87, 88, 89, 90, 91, 79, 210	general structure
	86	chemical polish-etch
Fe + 12–30 Cr + <6 Ni (400 Series)	80, 87, 88, 89, 34, 40, 92, 93, 94, 95, 91, 226	general structure
	96, 97, 98	signs phase
	31c	carbides
	86	chemical polish-etch
	219	grain boundary etch
	220	darkens delta ferrite
Fe + 12–20 Cr + 4–10 Ni + <7 % other elements (controlled transformation, precipitation hardening, stainless maraging alloys)	80, 31c, 89, 99, 100, 91	general structure
	31c	carbides
	86	chemical polish-etch
	220	darkens delta ferrite
Fe + 15–30 Cr + 6–40 Ni + <5 % other elements (300 Series)	13b, 89, 87, 88, 83a, 80, 94, 95, 91, 101, 212, 221, 226	general structure
	13a, 102, 31c, 48c, 213	carbides and sensitization
	48, 96, 97, 98	stains sigma phase
and	103, 104, 98	delineates sigma phase and welds of dissimilar metals
Fe + 16–25 Cr + 3–6 Ni + 5–10 Mn (200 series)	103, 104	chemical polish-etch
	86	grain boundary etch (no twins)
	219	darkens delta ferrite
	220	
High temperature	89, 25, 105, 106, 97, 212, 221	general structure
	107, 108, 213	$\gamma'$ precipitate
	86	chemical polish-etch
Nonstainless maraging steels	109, 89, 99, 100, 221	general structure
	83b	grain boundaries
	86	chemical polish-etch

TABLE 1 Continued

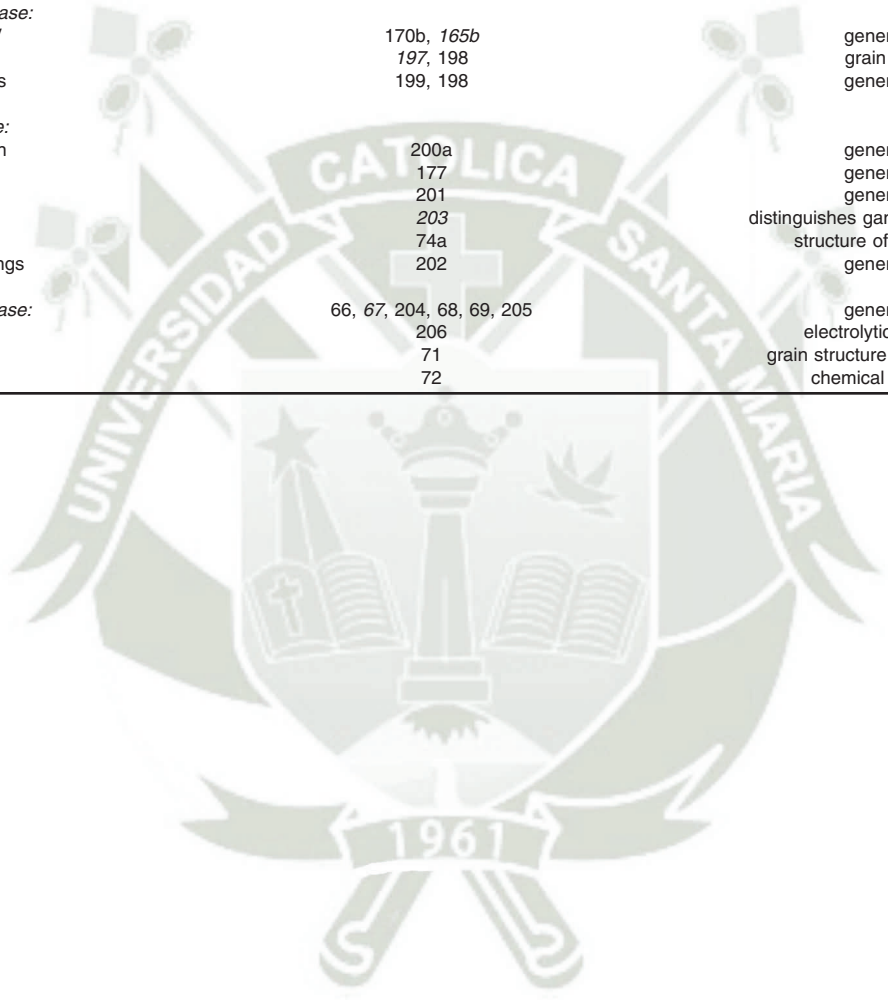
Metal	Etchants	Uses
Tool steels	74a, 80, 14	general structure
	110	grain boundaries in tempered tool steel
	210, 211	colors ferrite, lower alloy grades
	214, 214	colors cementite
	224, 225	carbides attacked and colored
Superalloys	86, 87, 94, 221, 226	general etch
	111	general structure
	111	γ' depletion
<i>Lead Base:</i>		
Pure Pb	57, 112	general structure
	113	for alternate polishing and etching
Pb + <2 Sb	114, 115, 57, 74b	general structure
Pb + >2 Sb	113	for alternate polishing and etching
	114, 57, 74b	general structure
Pb + Ca	113	for alternate polishing and etching
	112	general structure
Pb alloys	113	for alternate polishing and etching
	116, 117b	general structure
Babbitt	74b	general structure
<i>Magnesium Base:</i>		
Pure Mg	118, 119, 74a, 120, 121, 122	general structure
	123	stain-free polish-etch
Mg-Mn	119, 74a, 124, 122	general structure
Mg-Al, Mg-Al-Zn (Al + Zn <5 %)	118, 119, 74a, 125, 124, 123, 122	general structure
	120, 125, 126, 127	phase identification
	124, 126, 127	grain structure
Mg-Al, Mg-Al-Zn (Al + Zn >5 %)	118, 119, 74a, 125, 124, 121, 122	general structure
	120, 125, 126, 127	phase identification
	124, 126, 127	general structure
Mg-Zn-Zr and	118, 119, 74a, 1d, 128, 124, 126,	general structure
	127, 121, 122	phase identification
Mg-Zn-Th-Zr	120, 121	general structure
Mg-Th-Zr and	118, 119, 74a, 1d, 124, 127, 121, 122	phase identification
	120, 121	general structure
Mg-Rare Earth-Zr	120, 121	phase identification
<i>Molybdenum Base:</i>		
As cast	98c, 129, 130, 131	general structure
	132a	chemical polish prior to etching
<i>Nickel Base:</i>		
Pure Ni and high Ni alloys	133, 134, 47, 135, 136, 25, 108, 31c	general structure
	137	grain boundary sulfidation
Ni-Ag	38, 138, 50, 139	general structure
Ni-Al	50, 140, 141, 142, 89, 143	general structure
Ni-Cr	144, 50, 83, 134, 145, 98, 146, 147, 13a	general structure
Ni-Cu	38, 138, 50, 133, 140, 25, 134, 47,	general structure
	48b, 94, 108, 34	general structure
Ni-Fe	50, 140, 141, 83, 134, 148, 40, 107, 149	general structure
	74e, 25, 150	orientation pitting
Ni-Mn	74e	general structure
Ni-Mo	143	general structure
Ni-Ti	143, 151, 50, 133	general structure
Ni-Zn	152	general structure
Superalloys	94, 105, 138, 153, 12, 87, 89, 212, 226	general structure
	25, 94	grain size
	107, 111, 13a	reveals microstructural inhomogeneity
	133	grain boundary sulfidation
	154	fine precipitation structure
	19b, 155, 156	differential matrix and nonmetallic staining
	22a	for passive alloys (for example, UNS Alloy N06625)
	157	specific for UNS Alloy N10004
	107	submicroscopic structure in aged super-alloys particularly for electron microscopy. Stains the matrix when γ' precipitates are present
	154	γ' banding
	18	pre-etch activation for passive specimens
213	colors carbide and γ'	

**TABLE 1** *Continued*

Metal	Etchants	Uses
<i>Niobium (Columbium) Base:</i>	129, 66, 158, 159, 160, 161, 162, 163 164, 129, 160	general structure grain boundaries
<i>Osmium Base:</i>	165a 165a	general structure etch-polishing for viewing grains with polarized light
<i>Palladium Base:</i>		
Pure Pd	61, 166, 62, 165a	general structure
Pd alloys	166, 64a, 62, 165a	general structure
>90 % noble metals	61	general structure
<90 % noble metals	65	general structure
<i>Platinum Base:</i>		
Pure Pt	64a, 73a 167	general structure electrolytic polish and etch
Pt Alloys	64b, 73a 167	general structure electrolytic polish and etch
>90 % noble metals	61	general structure
<90 % noble metals	65	general structure
Pt-10 % Rh	168	general structure
<i>Plutonium Base:</i>	169	general structure
<i>Rhenium Base:</i>	13b, 98c, 132b, 170a	general structure
<i>Rhodium Base:</i>	171	general structure
<i>Ruthenium Base:</i>	73b 73b	general structure etch-polishing for viewing grains with polarized light
<i>Silver Base:</i>		
Pure Ag	172, 173, 62	general structure
Ag alloys	65, 61, 174, 175, 62	general structure
Ag-Cu alloys	130	general structure
Ag-Pd alloys	173	general structure
Ag solders	173, 176	general structure
<i>Tantalum Base:</i>		
Pure Ta	177	general structure
Ta alloys	159, 66, 178, 163, 161, 179 164 158	general structure grain boundaries and inclusions grain boundaries—retains carbide precipitate
<i>Thorium Base:</i>		
Pure Th	185	general structure
Th alloys	185	general structure
<i>Tin Base:</i>		
Pure Sn	74d, 180, 151 181	general structure grain boundaries
Sn-Cd	74d	general structure
Sn-Fe	74d, 177a	general structure
Sn-Pb	182, 183, 74b 116	general structure darkens Pb in Sn-Pb eutectic
Sn coatings (on steel)	183	general structure
Babbitts	184	general structure
Sn-Sb-Cu	74b	general structure
<i>Titanium Base:</i>		
Pure Ti	186, 187, 67, 68, 69, 217 188 72	general structure removes stain chemical polish and etch
Ti-5 Al-2,5 Sn	189	reveals hydrides
Ti-6 Al-6 V-2 Sn	190	Stains alpha and transformed beta, retained beta re mains white
Ti-Al-Zr	191	general structure
Ti-8Mn	192	general structure
Ti-13 V-11 Cr-3 Al (aged)	192	general structure
Ti-Si	193	general structure
Ti alloys	186, 187, 192, 194, 158, 132b, 1c, 67, 68, 69, 3a, 218 11, 1c 72, 192, 178 170a 188	general structure reveals alpha case chemical polish and etch outlines and darkens hydrides in some alloys removes stain
<i>Tungsten Base:</i>		

TABLE 1 Continued

Metal	Etchants	Uses
Pure W	98c, 131	general structure
As cast	132a	chemical polish prior to etching
W-Th	209	general structure
<i>Uranium Base:</i>		
Pure U	67, 69, 195, 196	general structure
U + Zr	68	general structure
U beryllides	170a	general structure
U alloys	67, 69, 195, 96	general structure
	207	carbides
<i>Vanadium Base:</i>		
Pure V	170b, 165b	general structure
V alloys	197, 198	grain boundaries
	199, 198	general structure
<i>Zinc Base:</i>		
Pure Zn	200a	general structure
Zn-Co	177	general structure
Zn-Cu	201	general structure
	203	distinguishes gamma ( $\gamma$ ) and epsilon ( $\epsilon$ )
Zn-Fe	74a	structure of galvanized sheet
Die castings	202	general structure
<i>Zirconium Base:</i>		
	66, 67, 204, 68, 69, 205	general structure
	206	electrolytic polish and etch
	71	grain structure under polarized light
	72	chemical polish and etch





**TABLE 2 Numerical List of Etchants**

NOTE 1—It is strongly recommended to always mix and use etchants under a certified and test fume hood.

Etchant	Composition	Procedure
1	1 mL HF 200 mL water	(a) Swab with cotton for 15 s. (b) Alternately immerse and polish several minutes. (c) Immerse 3–5 s. (d) Immerse 10–120 s.
2	3 mL HF 100 mL water	(a) Swab 10 s to reveal general structure. (b) Immerse 15 min, wash 10 min in water to form film with hatching which varies with grain orientation.
3	2 mL HF 3 mL HCl 5 mL HNO <sub>3</sub> 190 mL water	(a) Immerse 10–20 s Wash in stream of warm water. Reveals general structure. (b) Dilute with 4 parts water-colors constituents—mix fresh.
4	24 mL H <sub>3</sub> PO <sub>4</sub> 50 mL Carbitol (diethylene glycol monoethyl ether) 4 g boric acid 2 g oxalic acid 10 mL HF 32 mL water	Electrolytic: Use carbon cathode raising d-c voltage from 0–30 V in 30 s. Total etching time 3 min with agitation. Wash and cool. Repeat if necessary.
5	5 g HBF <sub>4</sub> 200 mL water	Electrolytic: Use Al, Pb, or stainless steel cathode. Anodize 1–3 min, 20–45 V d-c. At 30 V, etch for 1 min.
6	25 mL HNO <sub>3</sub> 75 mL water	Immerse 40 s at 70°C (160°F). Rinse in cold water.
7	10–20 mL H <sub>2</sub> SO <sub>4</sub> 80 mL water	Immerse 30 s at 70°C (160°F). Rinse in cold water.
8	10 mL H <sub>3</sub> PO <sub>4</sub> 90 mL water	(a) Immerse 1–3 min at 50°C (120°F). (b) Electrolytic at 1–8 V for 5–10 s.
9	3–4 g sulfamic acid 5 drops HF 100 mL water	Use just prior to the last polishing operation. It is not intended as a final etchant. The specimen is examined as polished under polarized light.
10	10 mL HF 90 mL methanol (90 %)	Immerse 10–30 s.
11	2 mL HF 100 mL water	Immerse or swab few seconds to a minute.
12	20 mL HNO <sub>3</sub> 60 mL HCl	Use a certified and tested hood. Do not store. Immerse or swab 5–60 s.
13	10 g oxalic acid 100 mL water	Electrolytic at 6 V: (a) 10–15 s. (b) 1 min. (c) 2–3 s. Use stainless steel cathode and platinum or Nichrome connection to specimen.
14	10 mL HNO <sub>3</sub> 90 mL methanol (95 %)	Immerse few seconds to a minute.
15	15 mL HNO <sub>3</sub> 15 mL acetic acid 60 mL HCl 15 mL water	Use a certified and tested hood. Age before use. Immerse 5–30 s. May be used electrolytically.
16	5–10 mL HCl 100 mL water	Electrolytic at 3 V for 2–10 s.
17	5 mL HCl 10 g FeCl <sub>3</sub> 100 mL water	Electrolytic at 6 V for few seconds.
18	2–10 g CrO <sub>3</sub> 100 mL water	Use a certified and tested hood. Electrolytic at 3 V for 2–10 s.

**TABLE 2** *Continued*

Etchant	Composition	Procedure
19	A 8 g NaOH 100 mL water B Saturated aqueous solution of $\text{KMnO}_4$	Immerse in freshly mixed Solutions A + B (1:1) for 5–10 s. If surface activation is necessary, first use Etch #18, then rinse in water. While still wet, immerse in Solutions A + B (1:1). Mixture of solutions A + B has 15-min useful life. Note: $\text{KMnO}_4$ is an aggressive staining agent.
20	5 mL $\text{H}_2\text{O}_2$ (30 %) 100 mL HCl	Use a certified and tested hood. <i>Mix fresh</i> . Immerse polished face up for few seconds.
21	1 g $\text{CrO}_3$ 140 mL HCl	Use a certified and tested hood. To mix, add the HCl to $\text{CrO}_3$ . Electrolytic at 3 V for 2–10 s.
22	100 mL HCl 0.5 mL $\text{H}_2\text{O}_2$ (30 %)	Use a certified and tested hood. Do not store. (a) Immerse or swab $\frac{1}{2}$ –3 min. Add $\text{H}_2\text{O}_2$ dropwise to maintain action. (b) Electrolytic, 4 V, 3–5 s.
23	5 mL HCl 95 mL ethanol (95 %) or methanol (95 %)	Electrolytic at 6 V for 10–20 s.
24	5 mL $\text{HNO}_3$ 200 mL HCl 65 g $\text{FeCl}_3$	Use a certified and tested hood. Immerse few seconds.
25	10 g $\text{CuSO}_4$ 50 mL HCl 50 mL water	Immerse or swab 5–60 s. Made more active by adding few drops of $\text{H}_2\text{SO}_4$ just before use.
26	5 g $\text{FeCl}_3$ 10 mL HCl 50 mL glycerol 30 mL water	Swab 16–60 s. Activity may be decreased by substituting glycerol for water.
27	1 g KOH 20 mL $\text{H}_2\text{O}_2$ (3 %) 50 mL $\text{NH}_4\text{OH}$ 30 mL water	Dissolve KOH in water, then slowly add $\text{NH}_4\text{OH}$ to solution. Add 3 % $\text{H}_2\text{O}_2$ last. Use fresh—immerse few seconds to a minute.
28	1 g $\text{FeNO}_3$ 100 mL water	Swab or immerse few seconds to a minute.
29	1 g $\text{K}_2\text{Cr}_2\text{O}_7$ 4 mL $\text{H}_2\text{SO}_4$ 50 mL water	Use a certified and tested hood. Add 2 drops of HCl just before using. Swab few seconds to a minute.
30	25 mL $\text{NH}_4\text{OH}$ 25 mL water 50 mL $\text{H}_2\text{O}_2$ (3 %)	Mix $\text{NH}_4\text{OH}$ and water before adding $\text{H}_2\text{O}_2$ . Must be used fresh. Swab 5–45 s.
31	10 g ammonium persulfate 100 mL water	(a) Swab or immerse to 5 s. (b) Immerse to 2 min to darken matrix to reveal carbides and phosphides. (c) Electrolytic at 6 V for few seconds to a minute. (d) Immerse 3–60 s. Can be heated to increase activity.
32	60 g $\text{CrO}_3$ 100 mL water	Use a certified and tested hood. Saturated solution. Immerse or swab 5–30 s.
33	10 g $\text{CrO}_3$ 2–4 drops HCl 100 mL water	Use a certified and tested hood. Add HCl just before use. Immerse 3–30 s. Phases can be colored by Nos. 35, 36, 37.
34	5 g $\text{FeCl}_3$ 50 mL HCl 100 mL water	(a) Immerse or swab few seconds to few minutes. Small additions of $\text{HNO}_3$ activate solution and minimize pitting. (b) Immerse or swab few seconds at a time. Repeat as necessary.
35	20 g $\text{FeCl}_3$ 5 mL HCl 1 g $\text{CrO}_3$ 100 mL water	Use a certified and tested hood. Immerse or swab few seconds at a time until desired results are obtained.
36	25 g $\text{FeCl}_3$ 25 mL HCl 100 mL water	Immerse or swab few seconds at a time until desired results are obtained.

**TABLE 2** *Continued*

Etchant	Composition	Procedure
37	1 g FeCl <sub>3</sub> 10 mL HCl 100 mL water	Immerse or swab few seconds at a time until desired results are obtained
38	8 g FeCl <sub>3</sub> 25 mL HCl 100 mL water	Swab 5–30 s.
39	5 g FeCl <sub>3</sub> 10 mL HCl 1 g CuCl <sub>2</sub> 0.1 g SnCl <sub>2</sub> 100 mL water	Immerse or swab few seconds at a time until desired results are obtained.
40	5 g FeCl <sub>3</sub> 16 mL HCl 60 mL ethanol (95 %) or methanol (95 %)	Immerse or swab few seconds to few minutes.
41	2 g K <sub>2</sub> Cr <sub>2</sub> O <sub>7</sub> 8 mL H <sub>2</sub> SO <sub>4</sub> 4 drops HCl 100 mL water	Use a certified and tested hood. Add the HCl just before using. Immerse 3–60 s.
42	10 g cupric ammonium chloride 100 mL water NH <sub>4</sub> OH	Add NH <sub>4</sub> OH to solution until neutral or slightly alkaline. Immerse 5–60 s.
43	20 mL NH <sub>4</sub> OH 1 g ammonium persulfate 60 mL water	Immerse 5–30 s.
44	50 mL NH <sub>4</sub> OH 20–50 mL H <sub>2</sub> O <sub>2</sub> (3 %) 0–50 mL water	Use fresh. Peroxide content varies directly with copper content of alloy to be etched. Immerse or swab to 1 min. Film on etched aluminum bronze removed by No. 82.
45	1 g CrO <sub>3</sub> 100 mL water	Use a certified and tested hood. Electrolytic at 6 V for 3–6 s. Use aluminum cathode.
46	15 mL NH <sub>4</sub> OH 15 mL H <sub>2</sub> O <sub>2</sub> (3 %) 15 mL water 4 pellets NaOH	When mixing, add NaOH pellets last. For best results use before pellets have dissolved.
47	5 g NaCN or KCN 5 g (NH <sub>4</sub> ) <sub>2</sub> S <sub>2</sub> O <sub>2</sub> 100 mL water	Use a certified and tested hood—Can give off extremely poisonous hydrogen cyanide. Precaution—Also poisonous by ingestion as well as skin contact.
48	10 g NaCN 100 mL water	Use a certified and tested hood—Can give off extremely poisonous hydrogen cyanide. Precaution—Also poisonous by ingestion as well as skin contact. Electrolytic at 6 V: (a) 5 s for sigma. (b) 30 s for ferrite and general structure. (c) to 5 min for carbides.
49	3 g FeSO <sub>4</sub> 0.4 g NaOH 10 mL H <sub>2</sub> SO <sub>4</sub> 190 mL water	Electrolytic at 8–10 V (0.1 A) for 5–15 s.
50	5 mL acetic acid 10 mL HNO <sub>3</sub> 85 mL water	Use a certified and tested hood. Do not store. Electrolytic at 1.5 V for 20 to 60 s. Use platinum wires.
51	2 g FeCl <sub>3</sub> 5 mL HCl 30 mL water 60 mL ethanol or methanol	Immerse few minutes.
52	1 g sodium dichromate 1 g NaCl 4 mL H <sub>2</sub> SO <sub>4</sub> 250 mL water	Swab few seconds.
53	1–5 mL NH <sub>4</sub> OH 100 mL water	Immerse 5–60 s.

**TABLE 2** *Continued*

Etchant	Composition	Procedure
54	1 g ammonium acetate 3 g sodium thiosulfate 7 mL NH <sub>4</sub> OH 1300 mL water	Electrolytic at 0.3 A/cm <sup>2</sup> for 5–30 s.
55	1 mL H <sub>2</sub> SO <sub>4</sub> 15 mL HNO <sub>3</sub> 10 mL acetic acid 5 mL H <sub>3</sub> PO <sub>4</sub> 20 mL lactic acid	Use a certified and tested hood. Swab gently 10–15 s. Rinse with methanol and blow dry. Helps to chemically polish. If final etch is too mild, follow with No. 98. Do not store.
56	30 mL HNO <sub>3</sub> 10 mL H <sub>3</sub> PO <sub>4</sub> 20 mL acetic acid 10 mL lactic acid	Use a certified and tested hood. Swab gently 5–15 s. Rinse with ethanol or methanol and blow dry. Do not store.
57	75 mL acetic acid 25 mL H <sub>2</sub> O <sub>2</sub> (30 %)	Use a certified and tested hood. Immerse 6–15 s. Do not store.
58	25 mL HF 25 mL HNO <sub>3</sub> 5 mL water	Swab 3–20 s.
59	2 g AgNO <sub>3</sub> 40 mL water 40 mL HF 20 mL HNO <sub>3</sub>	Mix AgNO <sub>3</sub> and water, then add HF and HNO <sub>3</sub> . Swab ½ –2 min.
60	25 mL HNO <sub>3</sub> 15 mL acetic acid 15 mL HF 5–7 drops bromine	Use a certified and tested hood. Do not store. Let stand ½ h before using. Swab 3–20 s.
61	60 mL HCl 40 mL HNO <sub>3</sub>	Use a certified and tested hood. Immerse few seconds to a minute.
62	1–5 g CrO <sub>3</sub> 100 mL HCl	Use a certified and tested hood. Vary composition of reagent and aging of reagent after mixing to suit alloy. Swab or immerse few seconds to a minute.
63	0.1 g CrO <sub>3</sub> 10 mL HNO <sub>3</sub> 100 mL HCl	Use a certified and tested hood. Swab few seconds to a minute.
64	5 mL HNO <sub>3</sub> 25 mL HCl 30 mL water	(a) Immerse 1–5 min. (b) Use hot. Will form chloride film on gold alloys if much silver is present. Ammonia will remove film.
65	A 10 g ammonium persulfate 100 mL water B 10 g KCN 100 mL water	Use a certified and tested hood—Can give off extremely poisonous hydrogen cyanide. Precaution—Also poisonous by ingestion as well as skin contact. Mix 1 + 1 mixture of Solutions A and B just before use. (A mixture of 5 drops of each will cover the surface of a 1 in. dia. mount.) Immerse ½ – 2 min.
66	30 mL HF 15 mL HNO <sub>3</sub> 30 mL HCl	Use a certified and tested hood. Swab 3–10 s or immerse to 2 min.
67	10 mL perchloric acid 10 mL 2-butoxyethanol 70 mL ethanol (95 %) 10 mL water	Use in wash down/perchloric rated fume hood. Precaution—Keep cool when mixing and use. Electrolytic at 30–65 V for 10–60 s.
68	3 mL perchloric acid 35 mL 2-butoxyethanol 60 mL methanol (absolute)	Use in wash down/perchloric rated fume hood. Precaution—Keep cool when mixing and use. Electrolytic at 60–150 V for 5–30 s.
69	5 mL perchloric acid 80 mL acetic acid	Use in wash down/perchloric rated fume hood. Precaution—Keep cool when mixing and use. Electrolytic at 20–60 V for 1–5 min. Do not store.
70	5 mL HF 2 mL AgNO <sub>3</sub> (5 %) 200 mL water	Swab for 5–60 s.
71	5 mL HF 95 mL water	Add 5–10 drops of this solution on the final polishing wheel which has been charged with the polishing solution. The specimen is polished on this wheel until the surface turns black. Distilled water is then slowly added to the wheel and polishing continued until the surface is bright. At this time the specimen should be ready for examination via polarized light. Note—Use inert substance between cloth and wheel to prevent attack of the wheel. Wear appropriate gloves.

**TABLE 2** *Continued*

Etchant	Composition	Procedure
72	10 mL HF 45 mL HNO <sub>3</sub> 45 mL water	Swab for 5–20 s.
73	20 mL HCl 25 g NaCl 65 mL water	Electrolytic etch—use carbon cathode and platinum wire connection to specimen. (a) 6 V ac for 1 min. (b) 5 V–20 V ac for 1–2 min. (c) 20 V ac for 1–2 min. For etch-polishing, use shorter times. After etching, water rinse, alcohol rinse, and dry.
74	1–5 mL HNO <sub>3</sub> 100 mL ethanol (95 %) or methanol (95 %)	Etching rate is increased, sensitivity decreased with increased percentage of HNO <sub>3</sub> . (a) Immerse few seconds to a minute. (b) Immerse 5–40 s in 5 % HNO <sub>3</sub> solution. To remove stain, immerse 25 s in 10 % HCl-methanol solution. (c) For Inconels and Nimonic, use 5 mL HNO <sub>3</sub> solution—electrolytic at 5–10 V for 5–20 s. (d) Swab or immerse several minutes. (e) Swab 5–60 s. HNO <sub>3</sub> may be increased to 30 mL in methanol only depending on alloy. (Ethanol is unstable with over 5 % HNO <sub>3</sub> .) Do not store.
75	5 g picric acid 8 g CuCl <sub>2</sub> 20 mL HCl 200 mL ethanol (95 %) or methanol (95 %)	Immerse 1–2 s at a time and immediately rinse with methanol. Repeat as often as necessary. (Long immersion times will result in copper deposition on surface.)
76	4 g picric acid 100 mL ethanol (95 %) or methanol (95 %)	Composition given will saturate with picric acid. Immerse few seconds to a minute or more. Adding a wetting agent such as zepherin chloride will increase response.
77	10 g picric acid 5 drops HCl 100 mL ethanol (95 %) or methanol (95 %)	Composition given will saturate the solution with picric acid. Immerse few seconds to a minute or more.
78	10 g potassium metabisulfite 100 mL water	Immerse 1–15 s. Better results are sometimes obtained by first etching lightly with No. 76 or 74.
79	40 mL HCl 5 g CuCl <sub>2</sub> 30 mL water 25 mL ethanol (95 %) or methanol (95 %)	Swab few seconds to a minute.
80	5 mL HCl 1 g picric acid 100 mL ethanol (95 %) or methanol (95 %)	Immerse or swab few seconds to 15 min. Reaction may be accelerated by adding a few drops of 3 % H <sub>2</sub> O <sub>2</sub> . Optional (for prior austenite grain boundaries)—temper specimen at 600–900°F prior to preparation.
81	2 g picric acid 1 g sodium tridecylbenzene sulfonate. 100 mL water	Composition given will saturate the solution with picric acid. (a) Immerse few seconds to a minute. (b) Immerse to 15 min with occasional swabbing for heavy grain boundary attack.
82	5 g FeCl <sub>3</sub> 5 drops HCl 100 mL water	Immerse 5–10 s.
83	10 g CrO <sub>3</sub> 100 mL water	Use a certified and tested hood—(a) Electrolytic at 6 V for 5–60 s. Attacks carbides. (b) Electrolytic at 6 V for 3–5 s.
84	10 mL H <sub>2</sub> SO <sub>4</sub> 10 mL HNO <sub>3</sub> 80 mL water	Use a certified and tested hood. Precaution—Add H <sub>2</sub> SO <sub>4</sub> slowly to water and cool, then add HNO <sub>3</sub> . Immerse 30 s. Swab in running water. Repeat three times and repolish lightly.
85	2 g picric acid 25 g NaOH 100 mL water	Use a certified and tested hood. Immerse in boiling solution for 5 min. Precaution—Do not boil dry—anhydrous picric acid is unstable and highly explosive. Alternative: Electrolytic at 6 V for 40 s (room temperature). Use stainless steel cathode.
86	3 g oxalic acid 4 mL H <sub>2</sub> O <sub>2</sub> (30 %) 100 mL water	Use a certified and tested hood. Solution should be freshly prepared. Immerse 15–25 min when specimens or parts cannot be given usual metallographic polish. Multiple etching may be required.
87	10 mL HNO <sub>3</sub> 20–50 mL HCl 30 mL glycerol	Use a certified and tested hood—Can give off nitrogen dioxide gas. Precaution—Mix HCl and glycerol thoroughly before adding HNO <sub>3</sub> . Do not store. Properly discard before solution attains a dark orange color. Immerse or swab few seconds to few minutes. Higher percentage of HCl minimizes pitting. A hot water rinse just prior to etching may be used to activate the reaction. Sometimes a few passes on the final polishing wheel is also necessary to remove a passive surface.
88	10 mL HNO <sub>3</sub> 20 mL HCl 30 mL water	Use a certified and tested hood—Can give off nitrogen dioxide gas. Precaution—Properly discard before solution attains a dark orange color. Immerse few seconds to a minute. Much stronger reaction than No. 87.

**TABLE 2** *Continued*

Etchant	Composition	Procedure
89	10 mL HNO <sub>3</sub> 10 mL acetic acid 15 mL HCl 2–5 drops glycerol	Use a certified and tested hood. Do not store. Immerse or swab few seconds to few minutes.
90	10 mL HNO <sub>3</sub> 20 mL HF 20–40 mL glycerol	Use a certified and tested hood—Immerse 2–10 s. Do not store. Properly discard after use. Solution decomposes on standing.
91	5 mL HNO <sub>3</sub> 5 mL HCl 1 g picric acid 200 mL ethanol (95 %) or methanol (95 %)	This etchant is equivalent to a 1 + 1 mixture of No. 80 and No. 74 (5 % HNO <sub>3</sub> ). Swab for 30 s or longer.
92	10 mL HCl 100 mL ethanol (95 %) or methanol (95 %)	Immerse 5–30 min or electrolytic at 6 V for 3–5 s.
93	concentrated HNO <sub>3</sub>	Use a certified and tested hood. Electrolytic at 0.2 A/cm <sup>2</sup> for few seconds.
94	2 g CuCl <sub>2</sub> 40 mL HCl 40–80 mL ethanol (95 %) or methanol (95 %)	Submerged swabbing for few seconds to several minutes. Attacks ferrite more readily than austenite.
95	2 g CuCl <sub>2</sub> 40 mL HCl 40–80 mL ethanol (95 %) or methanol (95 %) 40 mL water	Immerse or swab few seconds to few minutes.
96	85 g NaOH 50 mL water	Electrolytic at 6 V for 5–10 s.
97	45 g KOH 60 mL water	Composition of solution is approximately 10 N. Electrolytic at 2.5 V for few seconds. Stains sigma and chi yellow to red brown, ferrite gray to blue gray, carbides barely touched, austenite not touched.
98	10 g K <sub>3</sub> Fe(CN) <sub>6</sub> † 10 g KOH or NaOH 100 mL water	Use a certified and tested hood—Can give off extremely poisonous hydrogen cyanide. Precaution—Also poisonous by ingestion as well as skin contact. Use fresh. (a) Immerse or swab 15–60 s. Stains carbides and sigma. (To differentiate, No. 31 electrolytic at 4 V will attack sigma, but not carbides. If pitting occurs, reduce voltage.) (b) Immerse in fresh, hot solution 2–20 min. Stains carbides dark, ferrite yellow, sigma blue. Austenite turns brown on overetching. (c) Swab 5–60 s. (Immersion will produce a stain etch). Follow with water rinse, alcohol rinse, dry.
99	25 mL HCl 3 g ammonium bifluoride 125 mL water few grains potassium metabisulfite	<i>Mix fresh.</i> (For stock solution, mix first three items. Add potassium metabisulfite just before use.) Immerse few seconds to a few minutes.
100	10 g FeCl <sub>3</sub> 90 mL water	Immerse few seconds.
101	2 g CrO <sub>3</sub> 20 mL HCl 80 mL water	Use a certified and tested hood—Immerse 5–60 s. (CrO <sub>3</sub> may be increased up to 20 g for difficult alloys. Staining and pitting increase as CrO <sub>3</sub> increased.)
102	concentrated NH <sub>4</sub> OH	Use a certified and tested hood. Electrolytic at 6 V for 30–60 s. Attacks carbides only.
103	20 mL HNO <sub>3</sub> 4 mL HCl 20 mL methanol (99 %)	Use a certified and tested hood. Immerse 10–60 s.
104	5 mL HNO <sub>3</sub> 45 mL HCl 50 mL water	Use a certified and tested hood. Immerse 10 min or longer.
105	5 mL H <sub>2</sub> SO <sub>4</sub> 3 mL HNO <sub>3</sub> 90 mL HCl	Use a certified and tested hood. Precaution—add H <sub>2</sub> SO <sub>4</sub> slowly to HCl with stirring, cool; then add HNO <sub>3</sub> . Properly discard when dark orange color. Swab 10–30 s.
106	7 mL HNO <sub>3</sub> 25 mL HCl 10 mL methanol (99 %)	Use a certified and tested hood—Use fresh to avoid pitting. Immerse or swab 10–60 s.

**TABLE 2** *Continued*

Etchant	Composition	Procedure
107	10 mL H <sub>3</sub> PO <sub>4</sub> 50 mL H <sub>2</sub> SO <sub>4</sub> 40 mL HNO <sub>3</sub>	Use a certified and tested hood. Precaution—Mix H <sub>3</sub> PO <sub>4</sub> and HNO <sub>3</sub> thoroughly, then add H <sub>2</sub> SO <sub>4</sub> slowly with stirring. Use fresh, but allow to cool. Electrolytic at 6 V for few seconds. Brown discoloration will form at edges of specimen. To slow reaction, add water (to 100 mL) very carefully with stirring. Attacks bakelite mounts.
108	3–10 mL H <sub>2</sub> SO <sub>4</sub> 100 mL water	Electrolytic at 6 V for 5–10 s. Tends to pit with longer times.
109	50 mL HCl 25 mL HNO <sub>3</sub> 1 g CuCl <sub>2</sub> 150 mL water	Make fresh but allow to stand 30 min to avoid plating out copper. Immerse few seconds to a few minutes.
110	10 mL HCl 5 mL HNO <sub>3</sub> 85 mL ethanol (95 %) or methanol (95 %)	Immerse to several minutes until deeply etched. Follow with light repolish.
111	5 mL H <sub>2</sub> SO <sub>4</sub> 8 g CrO <sub>3</sub> 85 mL H <sub>3</sub> PO <sub>4</sub>	Use a certified and tested hood. Electrolytic at 10 V (0.2 A/cm <sup>2</sup> ) for 5–30 s. Reveals Ti- and Cb-rich areas at a faster rate than grain boundaries.
112	60 mL acetic acid 30 mL H <sub>2</sub> O <sub>2</sub> (30 %)	Use a certified and tested hood. Immerse 8–15 s.
113	15 mL acetic acid 15 mL HNO <sub>3</sub> 60 mL glycerol	Use a certified and tested hood. Do not store. Use fresh solution at 80°C (176°F).
114	15 mL acetic acid 20 mL HNO <sub>3</sub> 80 mL water	Use a certified and tested hood. Use fresh solution at 40–42°C (104–108°F). Immerse 4–30 min depending on depth of worked metal layer. Clean with cotton in running water. Do not store.
115	100 mL acetic acid 10 mL H <sub>2</sub> O <sub>2</sub> (30 %)	Use a certified and tested hood. Immerse 10–30 min depending on depth of worked metal layer. Clean in HNO <sub>3</sub> if necessary.
116	5–10 g AgNO <sub>3</sub> 90 mL water	Swab.
117	10 mL HCl 90 mL water	(a) Immerse for ½–5 min. Follow with electrolytic etch at low current density in same solution. If specimen has considerable surface flow, immerse in concentrated HCl for a few seconds, then follow above procedure. (b) Immerse for ½–2 min.
118	1 mL HNO <sub>3</sub> 75 mL diethylene glycol 25 mL water	Swab 3–5 s for F and T6, 1–2 min for T4 and O temper.
119	1 mL HNO <sub>3</sub> 20 mL acetic acid 60 mL diethylene glycol 20 mL water	Use a certified and tested hood. Swab 1–3 s for F and T6, 10 s for T4 and O temper. Do not store.
120	10 mL HF 90 mL water	Immerse with gentle agitation 3–30 s.
121	0.7 mL H <sub>3</sub> PO <sub>4</sub> 4 g picric acid 100 mL ethanol (95 %) or methanol (95 %)	Composition critical. (a) Immerse with gentle agitation 10–30 s. (b) To increase staining immerse and withdraw with a meniscus layer. Lightly apply etchant over surface until dark stain develops.
122	2 g oxalic acid 100 mL water	Swab.
123	60 mL H <sub>3</sub> PO <sub>4</sub> 100 mL ethanol (95 %)	Electrolytic: Use stainless steel cathode. Space electrodes 2 cm apart. Start at 3 V dc. After 30 s maintain at 1½ V.
124	5 mL acetic acid 10 mL water 6 g picric acid 100 mL ethanol (95 %) or methanol (95 %)	Use a certified and tested hood. Immerse with gentle agitation 10–60 s.
125	10 mL acetic acid 6 g picric acid 100 mL ethanol (95 %) or methanol (95 %)	Use a certified and tested hood. Immerse with gentle agitation 15–30 s.
126	30 mL acetic acid 15 mL water 6 g picric acid 100 mL ethanol (95 %) or methanol (95 %)	Use a certified and tested hood. Immerse with gentle agitation 1–30 s.

**TABLE 2** *Continued*

Etchant	Composition	Procedure
127	20 mL acetic acid 20 mL water 3 g picric acid 50 mL ethanol (95 %) or methanol (95 %)	Use a certified and tested hood. Immerse with gentle agitation 5–30 s.
128	8 mL HF 5 mL HNO <sub>3</sub> 200 mL water	Use a certified and tested hood. Immerse with gentle agitation 5–15 s.
129	10 mL HF 30 mL HNO <sub>3</sub> 60 mL lactic acid	Swab 10–20 s. Vary HF to increase or decrease activity.
130	25 mL HCl 75 mL methanol	Caution—Keep below 24°C (75°F). Electrolytic at 30 V for 30 s.
131	5 mL H <sub>2</sub> SO <sub>4</sub> 1 mL HF 100 mL methanol (95 %)	Use a certified and tested hood. Electrolytic at 50–60 V for 10–20 s.
132	5 mL HF 10 mL HNO <sub>3</sub> 50 mL lactic acid	Use fresh. (a) Swab with heavy pressure for 5–10 s. Water rinse, alcohol rinse, dry, then etch with No. 98c. (b) Swab for 5–30 s.
133	50 mL HNO <sub>3</sub> 50 mL acetic acid	Use a certified and tested hood. Do not store. <i>Mix fresh</i> . Immerse or swab 5 to 30 s. Will chemically polish with longer times. Sulfidized grain boundaries etched before normal grain boundaries. Do not store.
134	70 mL H <sub>3</sub> PO <sub>4</sub> 30 mL water	Electrolytic 5–10 V for 5–60 s. (Polishes at high currents.)
135	80 mL HNO <sub>3</sub> 3 mL HF	Use a certified and tested hood. Warm specimen in boiling water prior to immersion for 10 to 120 s.
136	20 mL H <sub>3</sub> PO <sub>4</sub> 80 mL water	Electrolytic at 10–20 V for 10–15 s.
137	10 g NaNO <sub>3</sub> 100 mL water	Electrolytic, 0.2 A/cm <sup>2</sup> , 1 min.
138	5 g FeCl <sub>3</sub> 2 mL HCl 100 mL ethanol (95 %) or methanol (95 %)	Swab 10–60 s.
139	5 g KCN 100 mL water 0.5 mL H <sub>2</sub> O <sub>2</sub> (3 %)	Use a certified and tested hood—Can give off extremely poisonous hydrogen cyanide. Precaution—Also poisonous by ingestion as well as skin contact. Immerse 10–100 s.
140	50 mL acetic acid 50 mL HNO <sub>3</sub> 50 mL acetone	Use a certified and tested hood. Do not store. Decomposes with possible explosion on standing. Immerse 10–30 s.
141	3 g NH <sub>4</sub> Cl 3 g CrO <sub>3</sub> 10 mL HNO <sub>3</sub> 90 mL water	Use a certified and tested hood—Swab 5–30 s. Do not store.
142	5 mL HF 10 mL glycerol 85 mL water	Electrolytic at 2–3 V for 2–10 s.
144	A 10 g sodium thiosulfate 100 mL water B 10 mL HCl 90 mL water	Electrolytic in Solution A: specimen is cathode, 10 V, 5–10 s. Then electrolytic in Solution B: specimen is anode, 10 V, 5–10 s.
145	2 mL H <sub>2</sub> SO <sub>4</sub> 100 mL water	Electrolytic at 3–10 V for 5–15 s. Use platinum wires. H <sub>2</sub> SO <sub>4</sub> may be increased to 20 mL for deeper attack.
146	10 mL HF 100 mL HNO <sub>3</sub>	Immerse 30 s–3 min.
147	20 mL HNO <sub>3</sub> 80 mL HCl	Immerse 5–30 s.





TABLE 2 Continued

Etchant	Composition	Procedure
148	5 mL HNO <sub>3</sub> 100 mL water	Immerse 10–30 s.
149	50 mL HCl 2 mL H <sub>2</sub> O <sub>2</sub> (30 %) 50 mL water	Immerse 10–30 s. Do not store.
150	60 mL HCl 20 mL HNO <sub>3</sub> 40 mL glycerol	Use a certified and tested hood. Do not store. Swab few seconds to a minute. Properly discard when solution turns dark yellow.
151	10 mL HF 25 mL HNO <sub>3</sub> 150 mL water	Swab 5–30 s.
152	85 mL NH <sub>4</sub> OH 15 mL H <sub>2</sub> O <sub>2</sub> (30 %)	Use a certified and tested hood. Immerse 5–15 s. Do not store—Decomposes.
153	10 mL HNO <sub>3</sub> 50 mL HCl 60 mL glycerol	Use a certified and tested hood. Do not store. Add HNO <sub>3</sub> last. Properly discard when dark yellow. Immerse 10–60 s. Preheating specimen in boiling water hastens reaction.
154	50 mL HCl 50 mL ethanol (95 %) or methanol (95 %)	Immerse 10–100 s.
155	3 mL selenic acid 10 mL HCl 100 mL ethanol (95 %) or methanol (95 %)	Use a certified and tested hood. Immerse 1–15 min. (Up to 30 mL of HCl may be used for more vigorous action.) Stable for 3–90 days, depending on HCl concentrations. Use appropriate gloves.
156	1 g thiourea 1 mL H <sub>3</sub> PO <sub>4</sub> 1000 mL water	Electrolytic, 0.005–0.01 A/cm <sup>2</sup> , 1–2 min.
157	25 g CrO <sub>3</sub> 150 mL HCl 50 mL water	Use a certified and tested hood. Immerse 5–20 s.
158	10 mL HF 10 mL HNO <sub>3</sub> 20 mL glycerol	Swab 5–15 s. Do not store. Properly discard after use. Solution decomposes on standing.
159	5 mL HF 20 mL HNO <sub>3</sub> 50 mL acetic acid	Use a certified and tested hood. Swab 10–30 s. Do not store.
160	20 mL HF 15 mL H <sub>2</sub> SO <sub>4</sub> 5 mL HNO <sub>3</sub> 50 mL water	Immerse to 5 min.
161	25 mL HNO <sub>3</sub> 5 mL HF	Immerse 5–120 s.
162	A  50 mL lactic acid 30 mL HNO <sub>3</sub> 2 mL HF B 30 mL lactic acid 10 mL HNO <sub>3</sub> 10 mL HF	Swab 1–3 min in Solution A (acts as etch polish). To etch, swab with Solution B for 5 s. Repeat if necessary. The HF may be varied to give more or less etching. Do not store.
163	30 mL H <sub>2</sub> SO <sub>4</sub> 30 mL HF 3–5 drops H <sub>2</sub> O <sub>2</sub> (30 %) 30 mL water	Immerse 5–60 s. Use this solution for alternate etch and polishing.
164	50 mL HNO <sub>3</sub> 30 g ammonium bifluoride 20 mL water	Use a certified and tested hood. Swab 3–10 s.
165	10 mL HCl 90 mL ethanol	(a) Electrolytic at 10 V for 30 s. Use carbon cathode and platinum wire connection to specimen. For etch-polishing, use shorter time. (b) Electrolytic at 6 V for 10 s. Use stainless steel cathode and platinum or Nichrome wire contact to specimen.

**TABLE 2** *Continued*

Etchant	Composition	Procedure
166	A 20 g ammonium persulfate 90 mL water B 20 g KCN 90 mL water	Use a certified and tested hood—Can give off extremely poisonous hydrogen cyanide. Precaution—Also poisonous by ingestion as well as skin contact. Mix 1 + 1 ratio of Solution A and B just before use. (A mixture of 5 drops of each will cover the surface of a 1 in. dia mount.) Immerse to several minutes.
167	5 g NaCN 100 mL water	Use a certified and tested hood—Can give off extremely poisonous hydrogen cyanide. Precaution—Also poisonous by ingestion as well as skin contact. Electrolytic at 1–5 V ac for 1–2 min. Use platinum cathode.
168	20 mL HCl 35 g NaCl 80 mL water	Composition given will saturate the solution with NaCl. Electrolytic at 1½ V ac for 1 min.
169	5 mL HNO <sub>3</sub> 50 mL ethylene glycol 20 mL ethanol (95 %) or methanol (95 %)	Electrolytic at 0.05 A/cm <sup>2</sup> for 2 min. Use stainless steel cathode.
170	1 mL HF 30 mL HNO <sub>3</sub> 30 mL lactic acid	(a) Swab 5–30 s. Follow with water rinse, alcohol rinse, dry. (b) Swab for 10 s intervals. Increase HF to exaggerate grain boundaries.
171	concentrated HCl	Use a certified and tested hood. Electrolytic at 5 V ac for 1–2 min. For etch-polishing, use shorter times. Follow with water rinse, alcohol rinse, and dry.
172	A 5 g ammonium persulfate 100 mL water B 5 g KCN 100 mL water	Use a certified and tested hood—Can give off extremely poisonous hydrogen cyanide. Precaution—Also poisonous by ingestion as well as skin contact. Prepare 1 + 1 mixture of Solutions A and B just before use. (A mixture of 5 drops of each will cover the surface of a 1 in. dia mount.) Immerse 1–2 min.
173	50 mL NH <sub>4</sub> OH 10–30 mL H <sub>2</sub> O <sub>2</sub> (50 %)	Immerse few seconds to a minute.
174	A 25 mL HNO <sub>3</sub> 1 g K <sub>2</sub> Cr <sub>2</sub> O <sub>7</sub> 1000 mL water B 40 g CrO <sub>3</sub> 3 g Na <sub>2</sub> SO <sub>4</sub> 200 mL water	Use a certified and tested hood. Prepare 1 + 1 mixture of Solutions A and B. Apply with camel's hair brush. Nonadherent film of silver chromate should form. If film adheres, add more of Solution A, if none forms, add Solution B.
175	1 g CrO <sub>3</sub> 1 mL H <sub>2</sub> SO <sub>4</sub> 1000 mL water	Use a certified and tested hood. Immerse to 1 min.
176	2 g FeCl <sub>3</sub> 100 mL water	Immerse 5–30 s.
177	10 g NaOH 100 mL water	Swab or immerse 5–15 s.
178	20 mL HF 20 mL HNO <sub>3</sub> 60 mL lactic acid	Swab for 5–20 s. Do not store.
179	A 10 mL HF 10 mL HNO <sub>3</sub> 30 mL lactic acid B 10 mL HF 90 mL H <sub>2</sub> SO <sub>4</sub>	Use a certified and tested hood—Mix Solution B very slowly. Solution A is used as a chemical polish, though some etching will occur. Swab 2 or more minutes for desired surface. If surface is insufficiently etched use Solution B electrolytically at ½ –1 A/in. <sup>2</sup> of specimen. Use carbon cathode and platinum wire connection to specimen. Properly discard Solution B after 1 hr. Do not store.

**TABLE 2** *Continued*

Etchant	Composition	Procedure
180	10 mL HNO <sub>3</sub> 30 mL acetic acid 50 mL glycerol	Use a certified and tested hood. Immerse for ½–10 min at 38 to 42°C (100–108°F). Do not store. Properly discard after use. Solution decomposes on standing.
181	2 mL HCl 100 mL ethanol (95 %) or methanol (95 %)	Swab for 1–3 min.
182	10 mL HNO <sub>3</sub> 10 mL acetic acid 80 mL glycerol	Use a certified and tested hood. Immerse for ½–10 min at 38 to 42°C (100–108°F). Do not store. Properly discard after use. Solution decomposes on standing.
183	2 drops HF 1 drop HNO <sub>3</sub> 25 mL glycerol	Immerse for 1 min. Do not store. Properly discard after use. Solution decomposes on standing.
184	10 g FeCl <sub>3</sub> 2 mL HCl 100 mL water	Immerse for ½–5 min.
185	10 mL HF 10 mL HNO <sub>3</sub>	Swab for few seconds.
186	10 mL HF 5 mL HNO <sub>3</sub> 85 mL water	Swab 3–20 s.
187	10 mL HF 30 mL HNO <sub>3</sub> 50 mL water	Swab 3–20 s.
188	1 mL HF 2 mL HNO <sub>3</sub> 50 mL H <sub>2</sub> O <sub>2</sub> (30 %) 50 mL water	Use a certified and tested hood. Swab until stain is removed.
189	10 mL HF 25 mL HNO <sub>3</sub> 45 mL glycerol 20 mL water	Swab 3–20 s. Do not store. Properly discard after use. Solution decomposes on standing.
190	8 g KOH 10 mL H <sub>2</sub> O <sub>2</sub> (30 %) 60 mL water	Swab 3–20 s.
191	25 mL HF 18 g benzalkonium chloride 35 mL methanol (95 %) 40 mL glycerol	Swab 3–20 s.
192	1–3 mL HF 2–6 mL HNO <sub>3</sub> 100 mL water	Swab 3–10 s or immerse 10–30 s. (HF attacks and HNO <sub>3</sub> brightens the surface of titanium. Make concentration changes on this basis.)
193	2 drops HF 1 drop HNO <sub>3</sub> 3 mL HCl 25 mL glycerol	Swab 3–20 s. Do not store. Properly discard after use. Solution decomposes on standing.
194	20 mL HF 20 mL HNO <sub>3</sub> 60 mL glycerol	Immerse 5–30 s. Do not store. Properly discard after use. Solution decomposes on standing.
195	30 mL H <sub>3</sub> PO <sub>4</sub> 30 mL ethylene glycol 50 mL ethanol (95 %)	Electrolytic at 18–20 V (0.03 A/cm <sup>2</sup> ) for 5–15 min.
196	18 g CrO <sub>3</sub> 75 mL acetic acid 20 mL water	Use a certified and tested hood. Dissolve CrO <sub>3</sub> in hot water and cool before adding acetic acid. Keep solution below 2°C (35°F) during use. Electrolytic at 80 V for 5–30 min. Do not store.
197	5 g oxalic acid 100 mL water	Electrolytic at 6 V for 5–20 s.

**TABLE 2** *Continued*

Etchant	Composition	Procedure
198	30 mL HF 30 mL HNO <sub>3</sub> 30 mL glycerol	Swab for 60 s. Do not store. Properly discard after use. Solution decomposes on standing.
199	2 mL HF 5 g AgNO <sub>3</sub> 100 mL water	Swab for 5 s.
200	A 40 g CrO <sub>3</sub> 3 g Na <sub>2</sub> SO <sub>4</sub> 200 mL water B 40 g CrO <sub>3</sub> 200 mL water	Use a certified and tested hood. Immerse in Solution A with gentle agitation for several seconds. Rinse in Solution B.
201	A 40 g CrO <sub>3</sub> 1.5 g Na <sub>2</sub> SO <sub>4</sub> 200 mL water B 40 g CrO <sub>3</sub> 200 mL water	Use a certified and tested hood. Immerse in Solution A with gentle agitation for several seconds. Rinse in Solution B.
202	A 10 g CrO <sub>3</sub> 1 g Na <sub>2</sub> SO <sub>4</sub> 200 mL water B 40 g CrO <sub>3</sub> 200 mL water	Use a certified and tested hood. Immerse in Solution A for 2–5 s. Rinse in Solution B.
203	20 g CrO <sub>3</sub> 100 mL water	Use a certified and tested hood. Electrolytic at 0.2 A/cm <sup>2</sup> for 5 s.
204	10 mL perchloric acid 10 mL glycerol 70 mL ethanol (95 %) 10 mL water	Use in a wash down/prechloric rated fume hood. Precaution—Keep cool when mixing and use. Electrolytic at 15–50 V for 15–60 s.
205	5 mL HF 2 mL AgNO <sub>3</sub> (5 %) 100 mL water	Swab vigorously for 10–60 s. Wet cotton frequently.
206	5 mL HF 10 mL HNO <sub>3</sub> 100 mL glycerol	Precaution—Properly discard after use. Solution decomposes on standing. Electrolytic at 9–12 V for 1–10 min.
207	30 mL HNO <sub>3</sub> 30 mL acetic acid 30 mL water	Swab for 5–30 s. Do not store.
208	1 mL NH <sub>4</sub> OH 3 g ammonium persulfate 100 mL water	Immerse or swab few seconds to a minute.
209	15 mL HNO <sub>3</sub> 3 mL HF 80 mL water	Immerse 5–60 s.
210	50 mL water (cold) saturated with sodium thiosulfate 1 g potassium metabisulfite	First ingredient in stock solution. Add potassium metabisulfite before use. Solution good for several days, or longer. Immerse face up, gently agitate until coloration begins, allow to settle. Stop etch when surface is red-violet. Etch time varies with material. Colors matrix phases.
211	3 g potassium metabisulfite 10 g sodium thiosulfate 100 mL water	Use fresh solution. Immerse specimen face up, gently agitate solution until coloration begins, allow to settle. Stop etch when surface is red-violet. Etch time varies with material. Colors matrix phases.

**TABLE 2** *Continued*

Etchant	Composition	Procedure
212	10–50 % HCl in water 0.5–1.0 g potassium metabisulfite per 100 mL of aqueous HCl solution Optional: 1 g CuCl <sub>2</sub> 1–3 g FeCl <sub>3</sub> 2–10 g ammonium bifluoride	For more corrosion resistant alloys. Increase the HCl and potassium metabisulfite contents. Use optional ingredients to improve coloration, if needed. Colors matrix phases. Use by immersion only.
213	2–10 mL HCl 0.5–3 mL selenic acid 100 mL ethyl alcohol (95 %)	For more corrosion resistant alloys, increase the HCl and selenic acid content. For highly corrosion-resistant alloys, use 20–30 mL HCl. Colors second phase constituents. Use by immersion only.
214	1 g sodium molybdate 100 mL water	Add nitric acid to lower the pH to 2.5–3. Add 0.1–0.5 g ammonium bifluoride for carbon steels. Use by immersion only. Colors carbides. Immerse about 15 s.
215	240 g sodium thiosulfate 30 g citric acid 24 g lead acetate 1000 mL water	Mix in order given. Store in a dark bottle at least 24 h before use at 20°C. Lightly pre-etch specimen before use. Use small portion of stock solution for 4 h max. Pre-etch steel specimens with nital before tinting the MnS (add 0.2 g sodium nitrite to 100 mL of etch) white. Colors phosphides in cast iron. Colors matrix of Cu alloys.
216	8–15 g sodium metabisulfite 100 mL water	Do not store. Mix fresh. Immerse specimen face up. Agitate solution gently until coloration begins, allow to settle. Stop when surface is dark. Use crossed polarized light and sensitive tint to improve coloration.
217	5 g ammonium bifluoride 100 mL water	Mix fresh, use plastic coated tongs and polyethylene beaker. Immerse until surface is colored.
218	3 g ammonium bifluoride 4 mL HCl 100 mL water	Mix fresh, use plastic coated tongs and polyethylene beaker. Immerse until surface is colored. Works best with attack-polished specimens.
219	60 mL HNO <sub>3</sub> 40 mL water	Electrolytic etch, does not reveal twins in $\gamma$ stainless steel. Excellent grain boundary etch for ferritic stainless steels. Use at 1 V dc, 120 s, with stainless cathode; 0.6 V dc with platinum cathode.
220	20 g NaOH 100 mL water	Electrolytic etch, colors $\delta$ -ferrite in stainless steels. Use at 2–20 V dc, 5–20 s, stainless steel cathode. If $\delta$ is not colored, increase NaOH to 40 g.
221	50 mL water 50 mL ethyl alcohol 50 mL methyl alcohol 50 mL HCl 1 g CuCl <sub>2</sub> 2.5 g FeCl <sub>3</sub> 2.5 mL HNO <sub>3</sub>	Use by immersion. Will not attack sulfides in stainless steels.
222	8 g Na <sub>2</sub> SO <sub>4</sub> 100 mL water	(a) Few seconds to 1 minute. (b) Pre-etch 2 s in No. 74, rinse, and etch 20 s.
223	A 8 g oxalic acid 5 mL H <sub>2</sub> SO <sub>4</sub> 100 mL water B H <sub>2</sub> O <sub>2</sub> (30 %)	Mix equal volumes of Solutions A and B just before use. Etch 2–3 s; 3 s pre-etch in No. 74 may be needed.
224	10 mL H <sub>2</sub> O <sub>2</sub> (30 %) 20 mL 10 % aqueous NaOH	Immerse 10 s at 20°C (68°F).
225	4 g NaOH 100 mL saturated aqueous KMnO <sub>4</sub>	Immerse 10 s at 20°C (68°F).
226	15 mL HCl 10 mL acetic acid 5 mL HNO <sub>3</sub> 2 drops glycerol	<b>Use a certified and tested hood.</b> —Can give off nitrogen dioxide gas. <b>Precaution</b> —Mix HCl and glycerol thoroughly before adding HNO <sub>3</sub> . Do not store. Properly discard before solution attains a dark orange color. Use fresh or age up to 1 min. Immerse or swab few seconds to few minutes. Can increase HNO <sub>3</sub> to increase strength. Sometimes a few passes on the final polishing wheel is also necessary to remove a passive surface.

<sup>†</sup> Editorially corrected in May 2011.

**TABLE 3 Etchant Names**

Common Name	No.	Common Name	No.
Acetic glycergia	89, 226	Groesbeck's	19
Alkaline Sodium Picrate	85	Hatch	2
Aqua regia	12	Howarth's	84
Barker's	5	Kalling's 1	95
Beraha's	99, 155, 211–215	Kalling's 2	94
Carapella	138	Keller's	3
Chrome regia	101	Klemm's	210
Contrast	141	Kroll's	192, 187
CP 4	60	Marble's	25
El-1R	107	Marshall's	223
Flat	133	Murakami's	98
Flouregia	90, 158	Nital	74
Frank's	104	Palmerton	200
Fry's	79	Phoschromic	111
G	107	Picral	76
Glycergia	87	Ralph's	221
Gorsuch	75	Super Picral	77
Grard's No. 1	35	Vilella's	80
Green contrast	94	92-5-3	105

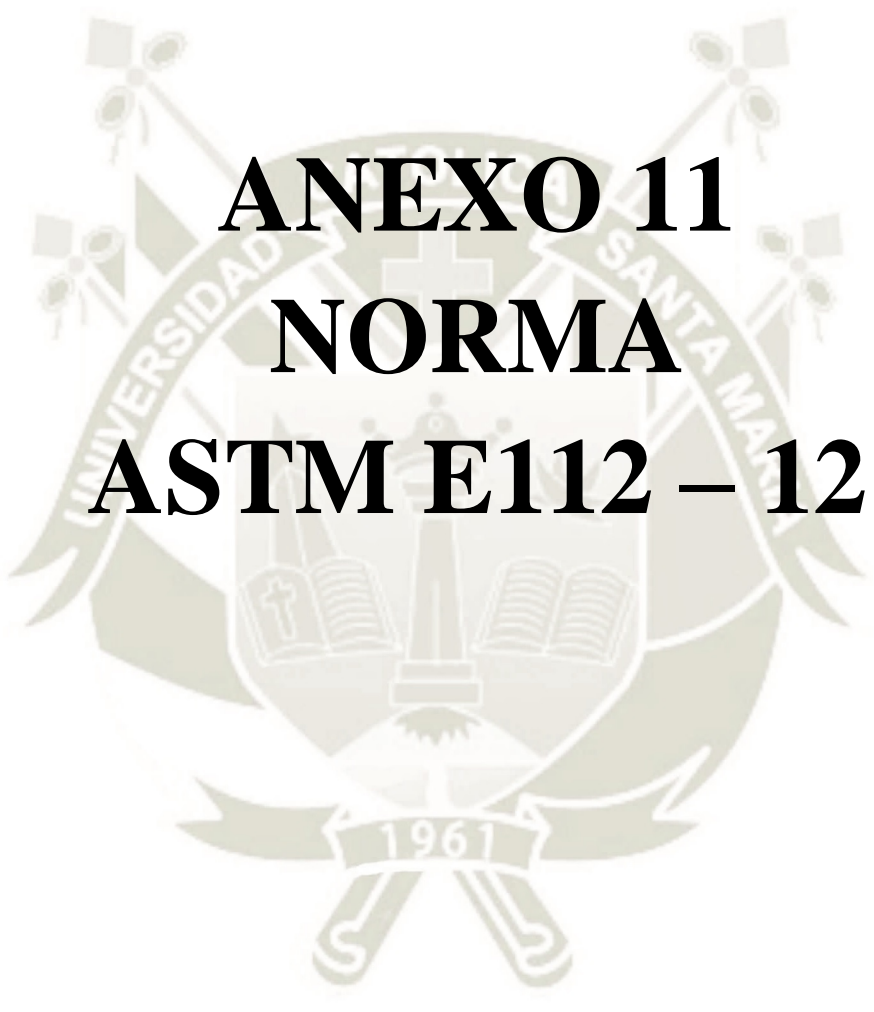
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**ANEXO 11**  
**NORMA**  
**ASTM E112 – 12**



# Standard Test Methods for Determining Average Grain Size<sup>1</sup>

This standard is issued under the fixed designation E112; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

*This standard has been approved for use by agencies of the Department of Defense.*

## INTRODUCTION

These test methods of determination of average grain size in metallic materials are primarily measuring procedures and, because of their purely geometric basis, are independent of the metal or alloy concerned. In fact, the basic procedures may also be used for the estimation of average grain, crystal, or cell size in nonmetallic materials. The comparison method may be used if the structure of the material approaches the appearance of one of the standard comparison charts. The intercept and planimetric methods are always applicable for determining average grain size. However, the comparison charts cannot be used for measurement of individual grains.

### 1. Scope

1.1 These test methods cover the measurement of average grain size and include the comparison procedure, the planimetric (or Jeffries) procedure, and the intercept procedures. These test methods may also be applied to nonmetallic materials with structures having appearances similar to those of the metallic structures shown in the comparison charts. These test methods apply chiefly to single phase grain structures but they can be applied to determine the average size of a particular type of grain structure in a multiphase or multiconstituent specimen.

1.2 These test methods are used to determine the average grain size of specimens with a unimodal distribution of grain areas, diameters, or intercept lengths. These distributions are approximately log normal. These test methods do not cover methods to characterize the nature of these distributions. Characterization of grain size in specimens with duplex grain size distributions is described in Test Methods E1181. Measurement of individual, very coarse grains in a fine grained matrix is described in Test Methods E930.

1.3 These test methods deal only with determination of planar grain size, that is, characterization of the two-dimensional grain sections revealed by the sectioning plane. Determination of spatial grain size, that is, measurement of the size of the three-dimensional grains in the specimen volume, is beyond the scope of these test methods.

<sup>1</sup> These test methods are under the jurisdiction of ASTM Committee E04 on Metallography and are the direct responsibility of Subcommittee E04.08 on Grain Size.

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1.4 These test methods describe techniques performed manually using either a standard series of graded chart images for the comparison method or simple templates for the manual counting methods. Utilization of semi-automatic digitizing tablets or automatic image analyzers to measure grain size is described in Test Methods E1382.

1.5 These test methods deal only with the recommended test methods and nothing in them should be construed as defining or establishing limits of acceptability or fitness of purpose of the materials tested.

1.6 The measured values are stated in SI units, which are regarded as standard. Equivalent inch-pound values, when listed, are in parentheses and may be approximate.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.8 The paragraphs appear in the following order:

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## 2. Referenced Documents

### 2.1 ASTM Standards:<sup>2</sup>

- [E3 Guide for Preparation of Metallographic Specimens](#)
- [E7 Terminology Relating to Metallography](#)
- [E407 Practice for Microetching Metals and Alloys](#)
- [E562 Test Method for Determining Volume Fraction by Systematic Manual Point Count](#)
- [E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method](#)
- [E883 Guide for Reflected-Light Photomicrography](#)
- [E930 Test Methods for Estimating the Largest Grain Observed in a Metallographic Section \(ALA Grain Size\)](#)
- [E1181 Test Methods for Characterizing Duplex Grain Sizes](#)
- [E1382 Test Methods for Determining Average Grain Size Using Semiautomatic and Automatic Image Analysis](#)

### 2.2 ASTM Adjuncts:

- 2.2.1 For a complete adjunct list, see [Appendix X2](#)

## 3. Terminology

3.1 *Definitions*—For definitions of terms used in these test methods, see Terminology [E7](#).

### 3.2 Definitions of Terms Specific to This Standard:

3.2.1 *ASTM grain size number*—the ASTM grain size number,  $G$ , was originally defined as:

$$N_{AE} = 2^{G-1} \quad (1)$$

where  $N_{AE}$  is the number of grains per square inch at 100X magnification. To obtain the number per square millimetre at 1X, multiply by 15.50.

3.2.2 *grain*—that area within the confines of the original (primary) boundary observed on the two-dimensional plane-of-polish or that volume enclosed by the original (primary) boundary in the three-dimensional object. In materials contain-

ing twin boundaries, the twin boundaries are ignored, that is, the structure on either side of a twin boundary belongs to the grain.

3.2.3 *grain boundary intersection count*—determination of the number of times a test line cuts across, or is tangent to, grain boundaries (triple point intersections are considered as 1-1/2 intersections).

3.2.4 *grain intercept count*—determination of the number of times a test line cuts through individual grains on the plane of polish (tangent hits are considered as one half an interception; test lines that end within a grain are considered as one half an interception).

3.2.5 *intercept length*—the distance between two opposed, adjacent grain boundary intersection points on a test line segment that crosses the grain at any location due to random placement of the test line.

### 3.3 Symbols:

- $\alpha$  = matrix grains in a two phase (constituent) microstructure.
- $A$  = test area.
- $\bar{A}$  = mean grain cross sectional area.
- $AI_\ell$  = grain elongation ratio or anisotropy index for a longitudinally oriented plane.
- $\bar{d}$  = mean planar grain diameter (Plate III).
- $\bar{D}$  = mean spatial (volumetric) grain diameter.
- $f$  = Jeffries multiplier for planimetric method.
- $G$  = ASTM grain size number.
- $\bar{\ell}$  = mean lineal intercept length.
- $\bar{\ell}_\alpha$  = mean lineal intercept length of the  $\alpha$  matrix phase in a two phase (constituent) microstructure.
- $\bar{\ell}_\ell$  = mean lineal intercept length on a longitudinally oriented surface for a non-equiaxed grain structure.
- $\bar{\ell}_t$  = mean lineal intercept length on a transversely oriented surface for a non-equiaxed grain structure.
- $\bar{\ell}_p$  = mean lineal intercept length on a planar oriented surface for a non-equiaxed grain structure.
- $\ell_0$  = base intercept length of 32.00 mm for defining the relationship between  $G$  and  $\ell$  (and  $N_L$ ) for macroscopically or microscopically determined grain size by the intercept method.
- $L$  = length of a test line.
- $M$  = magnification used.
- $M_b$  = magnification used by a chart picture series.
- $n$  = number of fields measured.
- $N_\alpha$  = number of  $\alpha$  grains intercepted by the test line in a two phase (constituent) microstructure.
- $N_A$  = number of grains per mm<sup>2</sup> at 1X.
- $N_{A\alpha}$  = number of  $\alpha$  grains per mm<sup>2</sup> at 1X in a two phase (constituent) microstructure.
- $N_{AE}$  = number of grains per inch<sup>2</sup> at 100X.
- $N_{A\ell}$  =  $N_A$  on a longitudinally oriented surface for a non-equiaxed grain structure.
- $N_{At}$  =  $N_A$  on a transversely oriented surface for a non-equiaxed grain structure.

<sup>2</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

$N_{Ap}$	= $N_A$ on a planar oriented surface for a non-equiaxed grain structure.
$N_I$	= number of intercepts with a test line.
$N_{\text{Inside}}$	= number of grains completely within a test circle.
$N_{\text{Intercepted}}$	= number of grains intercepted by the test circle.
$N_L$	= number of intercepts per unit length of test line.
$N_{L\ell}$	= $N_L$ on a longitudinally oriented surface for a non-equiaxed grain structure.
$N_{Lt}$	= $N_L$ on a transversely oriented surface for a non-equiaxed grain structure.
$N_{Lp}$	= $N_L$ on a planar oriented surface for a non-equiaxed grain structure.
$P_I$	= number of grain boundary intersections with a test line.
$P_L$	= number of grain boundary intersections per unit length of test line.
$P_{L\ell}$	= $P_L$ on a longitudinally oriented surface for a non-equiaxed grain structure.
$P_{Lt}$	= $P_L$ on a transversely oriented surface for a non-equiaxed grain structure.
$P_{Lp}$	= $P_L$ on a planar oriented surface for a non-equiaxed grain structure.
$Q$	= correction factor for comparison chart ratings using a non-standard magnification for microscopically determined grain sizes.
$Q_m$	= correction factor for comparison chart ratings using a non-standard magnification for macroscopically determined grain sizes.
$s$	= standard deviation.
$S_V$	= grain boundary surface area to volume ratio for a single phase structure.
$S_{V\alpha}$	= grain boundary surface area to volume ratio for a two phase (constituent) structure.
$t$	= students' $t$ multiplier for determination of the confidence interval.
$V_{V\alpha}$	= volume fraction of the $\alpha$ phase in a two phase (constituent) microstructure.
95 %CI	= 95 % confidence interval.
%RA	= percent relative accuracy.

#### 4. Significance and Use

4.1 These test methods cover procedures for estimating and rules for expressing the average grain size of all metals consisting entirely, or principally, of a single phase. The test methods may also be used for any structures having appearances similar to those of the metallic structures shown in the comparison charts. The three basic procedures for grain size estimation are:

4.1.1 *Comparison Procedure*—The comparison procedure does not require counting of either grains, intercepts, or intersections but, as the name suggests, involves comparison of the grain structure to a series of graded images, either in the form of a wall chart, clear plastic overlays, or an eyepiece reticle. There appears to be a general bias in that comparison grain size ratings claim that the grain size is somewhat coarser ( $1/2$  to 1  $G$  number lower) than it actually is (see X1.3.5). Repeatability and reproducibility of comparison chart ratings are generally  $\pm 1$  grain size number.

4.1.2 *Planimetric Procedure*—The planimetric method involves an actual count of the number of grains within a known area. The number of grains per unit area,  $N_A$ , is used to determine the ASTM grain size number,  $G$ . The precision of the method is a function of the number of grains counted. A precision of  $\pm 0.25$  grain size units can be attained with a reasonable amount of effort. Results are free of bias and repeatability and reproducibility are less than  $\pm 0.5$  grain size units. An accurate count does require marking off of the grains as they are counted.

4.1.3 *Intercept Procedure*—The intercept method involves an actual count of the number of grains intercepted by a test line or the number of grain boundary intersections with a test line, per unit length of test line, used to calculate the mean lineal intercept length,  $\bar{l}$ .  $\bar{l}$  is used to determine the ASTM grain size number,  $G$ . The precision of the method is a function of the number of intercepts or intersections counted. A precision of better than  $\pm 0.25$  grain size units can be attained with a reasonable amount of effort. Results are free of bias; repeatability and reproducibility are less than  $\pm 0.5$  grain size units. Because an accurate count can be made without need of marking off intercepts or intersections, the intercept method is faster than the planimetric method for the same level of precision.

4.2 For specimens consisting of equiaxed grains, the method of comparing the specimen with a standard chart is most convenient and is sufficiently accurate for most commercial purposes. For higher degrees of accuracy in determining average grain size, the intercept or planimetric procedures may be used. The intercept procedure is particularly useful for structures consisting of elongated grains.

4.3 In case of dispute, the intercept procedure shall be the referee procedure in all cases.

4.4 No attempt should be made to estimate the average grain size of heavily cold-worked material. Partially recrystallized wrought alloys and lightly to moderately cold-worked material may be considered as consisting of non-equiaxed grains, if a grain size measurement is necessary.

4.5 *Individual grain measurements should not be made based on the standard comparison charts.* These charts were constructed to reflect the typical log-normal distribution of grain sizes that result when a plane is passed through a three-dimensional array of grains. Because they show a distribution of grain dimensions, ranging from very small to very large, depending on the relationship of the planar section and the three-dimensional array of grains, the charts are not applicable to measurement of individual grains.

#### 5. Generalities of Application

5.1 It is important, in using these test methods, to recognize that the estimation of average grain size is not a precise measurement. A metal structure is an aggregate of three-dimensional crystals of varying sizes and shapes. Even if all these crystals were identical in size and shape, the grain cross sections, produced by a random plane (surface of observation) through such a structure, would have a distribution of areas varying from a maximum value to zero, depending upon where

the plane cuts each individual crystal. Clearly, no two fields of observation can be exactly the same.

5.2 The size and location of grains in a microstructure are normally completely random. No nominally random process of positioning a test pattern can improve this randomness, but random processes can yield poor representation by concentrating measurements in part of a specimen. *Representative* implies that all parts of the specimen contribute to the result, not, as sometimes has been presumed, that fields of average grain size are selected. Visual selection of fields, or casting out of extreme measurements, may not falsify the average when done by unbiased experts, but will in all cases give a false impression of high precision. For representative sampling, the area of the specimen is mentally divided into several equal coherent sub-areas and stage positions prespecified, which are approximately at the center of each sub-area. The stage is successively set to each of these positions and the test pattern applied blindly, that is, with the light out, the shutter closed, or the eye turned away. No touch-up of the position so selected is allowable. Only measurements made on fields chosen in this way can be validated with respect to precision and bias.

## 6. Sampling

6.1 Specimens should be selected to represent average conditions within a heat lot, treatment lot, or product, or to assess variations anticipated across or along a product or component, depending on the nature of the material being tested and the purpose of the study. Sampling location and frequency should be based upon agreements between the manufacturers and the users.

6.2 Specimens should not be taken from areas affected by shearing, burning, or other processes that will alter the grain structure.

## 7. Test Specimens

7.1 In general, if the grain structure is equiaxed, any specimen orientation is acceptable. However, the presence of an equiaxed grain structure in a wrought specimen can only be determined by examination of a plane of polish parallel to the deformation axis.

7.2 If the grain structure on a longitudinally oriented specimen is equiaxed, then grain size measurements on this plane, or any other, will be equivalent within the statistical precision of the test method. If the grain structure is not equiaxed, but elongated, then grain size measurements on specimens with different orientations will vary. In this case, the grain size should be evaluated on at least two of the three principle planes, transverse, longitudinal, and planar (or radial and transverse for round bar) and averaged as described in Section 16 to obtain the mean grain size. If directed test lines are used, rather than test circles, intercept counts on non-equiaxed grains in plate or sheet type specimens can be made using only two principle test planes, rather than all three as required for the planimetric method.

7.3 The surface to be polished should be large enough in area to permit measurement of at least five fields at the desired

magnification. In most cases, except for thin sheet or wire specimens, a minimum polished surface area of 160 mm<sup>2</sup> (0.25 in.<sup>2</sup>) is adequate.

7.4 The specimen shall be sectioned, mounted (if necessary), ground, and polished according to the recommended procedures in Practice E3. The specimen shall be etched using a reagent, such as listed in Practice E407, to delineate most, or all, of the grain boundaries (see also Annex A3).

**TABLE 1 Suggested Comparison Charts for Metallic Materials**

NOTE 1—These suggestions are based upon the customary practices in industry. For specimens prepared according to special techniques, the appropriate comparison standards should be selected on a structural-appearance basis in accordance with 8.2.

Material	Plate Number	Basic Magnification
Aluminum	I	100X
Copper and copper-base alloys (see Annex A4)	III or IV	75X, 100X
Iron and steel:		
Austenitic	II or IV	100X
Ferritic	I	100X
Carburized	IV	100X
Stainless	II	100X
Magnesium and magnesium-base alloys	I or II	100X
Nickel and nickel-base alloys	II	100X
Super-strength alloys	I or II	100X
Zinc and zinc-base alloys	I or II	100X

## 8. Calibration

8.1 Use a stage micrometer to determine the true linear magnification for each objective, eyepiece and bellows, or zoom setting to be used within  $\pm 2\%$ .

8.2 Use a ruler with a millimetre scale to determine the actual length of straight test lines or the diameter of test circles used as grids.

## 9. Preparation of Photomicrographs

9.1 When photomicrographs are used for estimating the average grain size, they shall be prepared in accordance with Guide E883.

## 10. Comparison Procedure

10.1 The comparison procedure shall apply to completely recrystallized or cast materials with equiaxed grains.

10.2 When grain size estimations are made by the more convenient comparison method, repeated checks by individuals as well as by interlaboratory tests have shown that unless the appearance of the standard reasonably well approaches that of the sample, errors may occur. To minimize such errors, the comparison charts are presented in four categories as follows:<sup>3</sup>

10.2.1 *Plate I*—Untwinned grains (flat etch). Includes grain size numbers 00, 0, 1/2, 1, 1 1/2, 2, 2 1/2, 3, 3 1/2, 4, 4 1/2, 5, 5 1/2, 6, 6 1/2, 7, 7 1/2, 8, 8 1/2, 9, 9 1/2, 10, at 100X.

<sup>3</sup> Plates I, II, III, and IV are available from ASTM Headquarters. Order Adjunct: ADJE11201P (Plate I), ADJE11202P (Plate II), ADJE11203P (Plate III), and ADJE11204P (Plate IV). A combination of all four plates is also available. Order Adjunct: ADJE112PS.

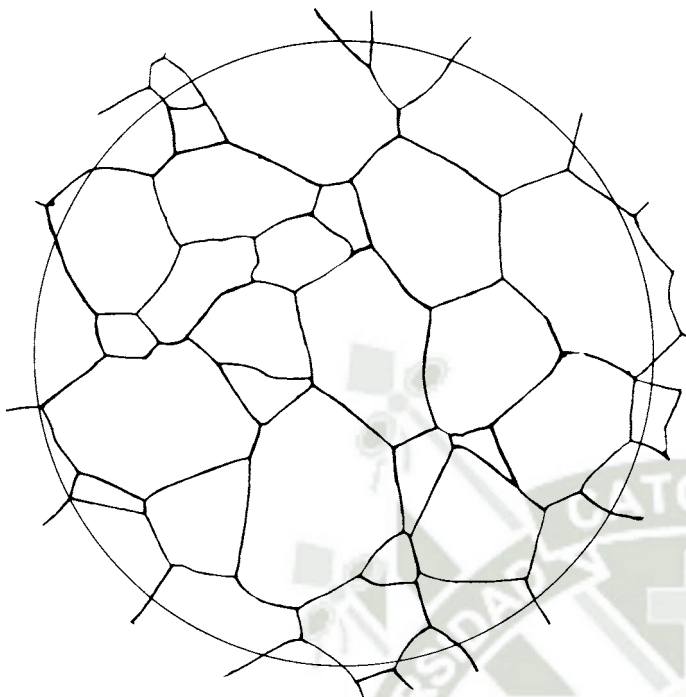


FIG. 1 Example of Untwinned Grains (Flat Etch) from Plate I. Grain Size No. 3 at 100X

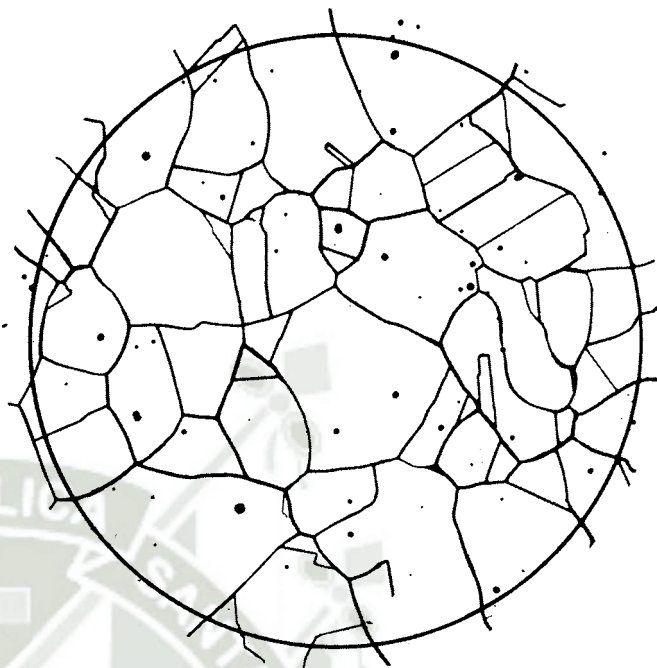


FIG. 2 Example of Twin Grains (Flat Etch) from Plate II. Grain Size No. 3 at 100X

10.2.2 *Plate II*—Twinned grains (flat etch). Includes grain size numbers, 1, 2, 3, 4, 5, 6, 7, 8, at 100X.

10.2.3 *Plate III*—Twinned grains (contrast etch). Includes nominal grain diameters of 0.200, 0.150, 0.120, 0.090, 0.070, 0.060, 0.050, 0.045, 0.035, 0.025, 0.020, 0.015, 0.010, 0.005 mm at 75X.

10.2.4 *Plate IV*—Austenite grains in steel (McQuaid-Ehn). Includes grain size numbers 1, 2, 3, 4, 5, 6, 7, 8, at 100X.

10.3 **Table 1** lists a number of materials and the comparison charts that are suggested for use in estimating their average grain sizes. For example, for twinned copper and brass with a contrast etch, use *Plate III*.

NOTE 1—Examples of grain-size standards from *Plates I, II, III, and IV* are shown in **Fig. 1**, **Fig. 2**, **Fig. 3**, and **Fig. 4**.

10.4 The estimation of microscopically-determined grain size should usually be made by direct comparison at the same magnification as the appropriate chart. Accomplish this by comparing a projected image or a photomicrograph of a representative field of the test specimen with the photomicrographs of the appropriate standard grain-size series, or with suitable reproductions or transparencies of them, and select the photomicrograph which most nearly matches the image of the test specimen or interpolate between two standards. Report this estimated grain size as the ASTM grain size number, or grain diameter, of the chart picture that most closely matches the image of the test specimen or as an interpolated value between two standard chart pictures.

10.5 Good judgment on the part of the observer is necessary to select the magnification to be used, the proper size of area (number of grains), and the number and location in the specimen of representative sections and fields for estimating



FIG. 3 Example of Twin Grains (Contrast Etch) from Plate III. Grain Size 0.090 mm at 75X

the characteristic or average grain size. It is not sufficient to visually select what appear to be areas of average grain size. Recommendations for choosing appropriate areas for all procedures have been noted in **5.2**.

10.6 Grain size estimations shall be made on three or more representative areas of each specimen section.

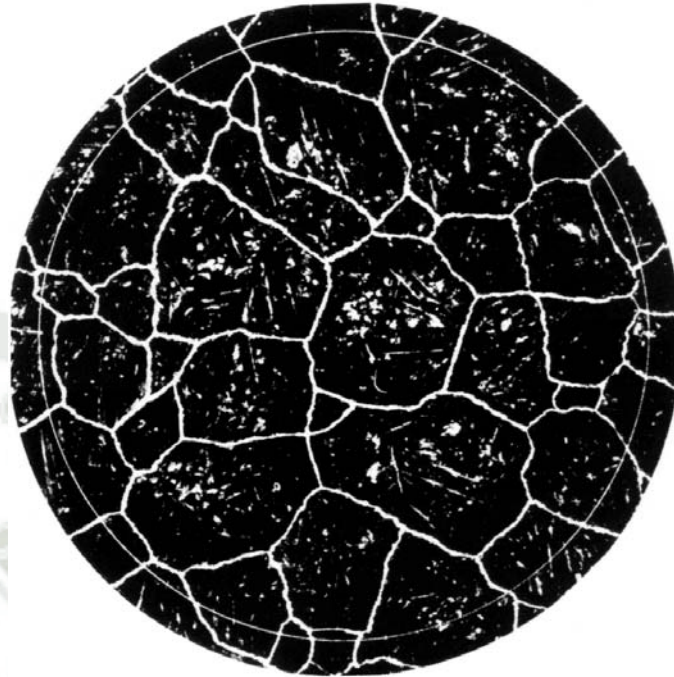


FIG. 4 Example of Austenite Grains in Steel from Plate IV. Grain Size No. 3 at 100X

TABLE 2 Microscopically Determined Grain Size Relationships Using Plate III at Various Magnifications

NOTE 1—First line—mean grain diameter,  $d$ , in mm; in parentheses—equivalent ASTM grain size number,  $G$ .

NOTE 2—Magnification for Plate III is 75X (row 3 data).

Magnification	Chart Picture Number (Plate III)													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
25X	0.015 (9.2)	0.030 (7.2)	0.045 (6.0)	0.060 (5.2)	0.075 (4.5)	0.105 (3.6)	0.135 (2.8)	0.150 (2.5)	0.180 (2.0)	0.210 (1.6)	0.270 (0.8)	0.360 (0)	0.451 (0/00)	0.600 (00 +)
50X	0.0075 (11.2)	0.015 (9.2)	0.0225 (8.0)	0.030 (7.2)	0.0375 (6.5)	0.053 (5.6)	0.0675 (4.8)	0.075 (4.5)	0.090 (4.0)	0.105 (3.6)	0.135 (2.8)	0.180 (2.0)	0.225 (1.4)	0.300 (0.5)
75X	0.005 (12.3)	0.010 (10.3)	0.015 (9.2)	0.020 (8.3)	0.025 (7.7)	0.035 (6.7)	0.045 (6.0)	0.050 (5.7)	0.060 (5.2)	0.070 (4.7)	0.090 (4.0)	0.120 (3.2)	0.150 (2.5)	0.200 (1.7)
100X	0.00375 (13.2)	0.0075 (11.2)	0.0112 (10.0)	0.015 (9.2)	0.019 (8.5)	0.026 (7.6)	0.034 (6.8)	0.0375 (6.5)	0.045 (6.0)	0.053 (5.6)	0.067 (4.8)	0.090 (4.0)	0.113 (3.4)	0.150 (2.5)
200X	0.0019 (15.2)	0.00375 (13.2)	0.0056 (12.0)	0.0075 (11.2)	0.009 (10.5)	0.013 (9.6)	0.017 (8.8)	0.019 (8.5)	0.0225 (8.0)	0.026 (7.6)	0.034 (6.8)	0.045 (6.0)	0.056 (5.4)	0.075 (4.5)
400X	—	0.0019 (15.1)	0.0028 (14.0)	0.0038 (13.1)	0.0047 (12.5)	0.0067 (11.5)	0.0084 (10.8)	0.009 (10.5)	0.012 (10.0)	0.0133 (9.5)	0.0168 (8.8)	0.0225 (8.0)	0.028 (7.3)	0.0375 (6.5)
500X	—	—	0.0022 (14.6)	0.003 (13.7)	0.00375 (13.1)	0.00525 (12.1)	0.0067 (11.5)	0.0075 (11.1)	0.009 (10.6)	0.010 (10.3)	0.0133 (9.5)	0.018 (8.7)	0.0225 (8.0)	0.03 (7.1)

10.7 When the grains are of a size outside the range covered by the standard photographs, or when magnifications of 75X or 100X are not satisfactory, other magnifications may be employed for comparison by using the relationships given in Note 2 and Table 2. It may be noted that alternative magnifications are usually simple multiples of the basic magnifications.

NOTE 2—If the grain size is reported in ASTM numbers, it is convenient to use the relationship:

$$Q = 2 \log_2 (M/M_b) \quad (2)$$

$$= 6.64 \log_{10} (M/M_b)$$

where  $Q$  is a correction factor that is added to the apparent micro-grain size of the specimen, as viewed at the magnification,  $M$ , instead of at the basic magnification,  $M_b$  (75X or 100X), to yield the true ASTM grain-size

number. Thus, for a magnification of 25X, the true ASTM grain-size number is four numbers lower than that of the corresponding photomicrograph at 100X ( $Q = -4$ ). Likewise, for 400X, the true ASTM grain-size number is four numbers higher ( $Q = +4$ ) than that of the corresponding photomicrograph at 100X. Similarly, for 300X, the true ASTM grain-size number is four numbers higher than that of the corresponding photomicrograph at 75X.

10.8 The small number of grains per field at the coarse end of the chart series, that is, size 00, and the very small size of the grains at the fine end make accurate comparison ratings difficult. When the specimen grain size falls at either end of the chart range, a more meaningful comparison can be made by changing the magnification so that the grain size lies closer to the center of the range.

**TABLE 3 Macroscopic Grain Size Relationships Computed for Uniform, Randomly Oriented, Equiaxed Grains**

NOTE 1—Macroscopically determined grain size numbers M-12.3, M-13.3, M-13.8 and M-14.3 correspond, respectively, to microscopically determined grain size numbers (*G*) 00, 0, 0.5 and 1.0.

Macro Grain Size No.	$\bar{N}_A$ Grains/Unit Area		$\bar{A}$ Average Grain Area		$\bar{d}$ Average Diameter		$\bar{\ell}$ Mean Intercept		$\bar{N}_L$ mm <sup>-1</sup>	$\bar{N}$ 100 mm
	No./mm <sup>2</sup>	No./in. <sup>2</sup>	mm <sup>2</sup>	in. <sup>2</sup>	mm	in.	mm	in.		
M-0	0.0008	0.50	1290.3	2.00	35.9	1.41	32.00	1.2	0.031	3.13
M-0.5	0.0011	0.71	912.4	1.41	30.2	1.19	26.91	1.0	0.037	3.72
M-1.0	0.0016	1.00	645.2	1.00	25.4	1.00	22.63	0.89	0.044	4.42
M-1.5	0.0022	1.41	456.2	0.707	21.4	0.841	19.03	0.74	0.053	5.26
M-2.0	0.0031	2.00	322.6	0.500	18.0	0.707	16.00	0.63	0.063	6.25
M-2.5	0.0044	2.83	228.1	0.354	15.1	0.595	13.45	0.53	0.074	7.43
M-3.0	0.0062	4.00	161.3	0.250	12.7	0.500	11.31	0.44	0.088	8.84
M-3.5	0.0088	5.66	114.0	0.177	10.7	0.420	9.51	0.37	0.105	10.51
M-4.0	0.0124	8.00	80.64	0.125	8.98	0.354	8.00	0.31	0.125	12.50
M-4.5	0.0175	11.31	57.02	0.0884	7.55	0.297	6.73	0.26	0.149	14.87
M-5.0	0.0248	16.00	40.32	0.0625	6.35	0.250	5.66	0.22	0.177	17.68
M-5.5	0.0351	22.63	28.51	0.0442	5.34	0.210	4.76	0.18	0.210	21.02
M-6.0	0.0496	32.00	20.16	0.0312	4.49	0.177	4.00	0.15	0.250	25.00
M-6.5	0.0701	45.26	14.26	0.0221	3.78	0.149	3.36	0.13	0.297	29.73
M-7.0	0.099	64.00	10.08	0.0156	3.17	0.125	2.83	0.11	0.354	35.36
M-7.5	0.140	90.51	7.13	0.0110	2.67	0.105	2.38	0.093	0.420	42.05
×10 <sup>-3</sup>										
M-8.0	0.198	128.0	5.04	7.812	2.25	88.4	2.00	78.7	0.500	50.00
M-8.5	0.281	181.0	3.56	5.524	1.89	74.3	1.68	66.2	0.595	59.46
M-9.0	0.397	256.0	2.52	3.906	1.59	62.5	1.41	55.7	0.707	70.71
M-9.5	0.561	362.1	1.78	2.762	1.33	52.6	1.19	46.8	0.841	84.09
M-10.0	0.794	512.0	1.26	1.953	1.12	44.2	1.00	39.4	1.00	100.0
M-10.5	1.122	724.1	0.891	1.381	0.994	37.2	0.841	33.1	1.19	118.9
M-11.0	1.587	1024.1	0.630	0.977	0.794	31.2	0.707	27.8	1.41	141.4
M-11.5	2.245	1448.2	0.445	0.690	0.667	26.3	0.595	23.4	1.68	168.2
M-12.0	3.175	2048.1	0.315	0.488	0.561	22.1	0.500	19.7	2.00	200.0
M-12.3	3.908	2521.6	0.256	0.397	0.506	19.9	0.451	17.7	2.22	221.9
M-12.5	4.490	2896.5	0.223	0.345	0.472	18.6	0.420	16.6	2.38	237.8
M-13.0	6.349	4096.3	0.157	0.244	0.397	15.6	0.354	13.9	2.83	282.8
M-13.3	7.817	5043.1	0.128	0.198	0.358	14.1	0.319	12.5	3.14	313.8
M-13.5	8.979	5793.0	0.111	0.173	0.334	13.1	0.297	11.7	3.36	336.4
M-13.8	11.055	7132.1	0.091	0.140	0.301	11.8	0.268	10.5	3.73	373.2
M-14.0	12.699	8192.6	0.079	0.122	0.281	11.0	0.250	9.84	4.00	400.0
M-14.3	15.634	10086.3	0.064	0.099	0.253	9.96	0.225	8.87	4.44	443.8

10.9 The use of transparencies<sup>4</sup> or prints of the standards, with the standard and the unknown placed adjacent to each other, is to be preferred to the use of wall chart comparison with the projected image on the microscope screen.

10.10 No particular significance should be attached to the fact that different observers often obtain slightly different results, provided the different results fall within the confidence limits reasonably expected with the procedure used.

10.11 There is a possibility when an operator makes repeated checks on the same specimen using the comparison method that they will be prejudiced by their first estimate. This disadvantage can be overcome, when necessary, by changes in

<sup>4</sup> Transparencies of the various grain sizes in Plate I are available from ASTM Headquarters. Order Adjunct: **ADJE112TS** for the set. Transparencies of individual grain size groupings are available on request. Order Adjunct: **ADJE11205T** (Grain Size 00), **ADJE11206T** (Grain Size 0), **ADJE11207T** (Grain Size 0.5), **ADJE11208T** (Grain Size 1.0), **ADJE11209T** (Grain Size 1.5), **ADJE11210T** (Grain Size 2.0), **ADJE11211T** (Grain Size 2.5), **ADJE11212T** (Grain Sizes 3.0, 3.5, and 4.0), **ADJE11213T** (Grain Sizes 4.5, 5.0, and 5.5), **ADJE11214T** (Grain Sizes 6.0, 6.5, and 7.0), **ADJE11215T** (Grain Sizes 7.5, 8.0, and 8.5), and **ADJE11216T** (Grain Sizes 9.0, 9.5, and 10.0). Charts illustrating grain size numbers 00 to 10 are on 8½ by 11 in. (215.9 by 279.4 mm) film. Transparencies for Plates II, III, and IV are not available.

magnification, through bellows extension, or objective or eyepiece replacement between estimates (1).<sup>5</sup>

10.12 Make the estimation of macroscopically-determined grain sizes (extremely coarse) by direct comparison, at a magnification of 1X, of the properly prepared specimen, or of a photograph of a representative field of the specimen, with photographs of the standard grain series shown in Plate I (for untwinned material) and Plates II and III (for twinned material). Since the photographs of the standard grain size series were made at 75 and 100 diameters magnification, grain sizes estimated in this way do not fall in the standard ASTM grain-size series and hence, preferably, should be expressed either as diameter of the average grain or as one of the macro-grain size numbers listed in **Table 3**. For the smaller macroscopic grain sizes, it may be preferable to use a higher magnification and the correction factor given in **Note 3**, particularly if it is desirable to retain this method of reporting.

NOTE 3—If the grain size is reported in ASTM macro-grain size numbers, it is convenient to use the relationship:

<sup>5</sup> The boldface numbers in parentheses refer to the list of references appended to these test methods.

**TABLE 4 Grain Size Relationships Computed for Uniform, Randomly Oriented, Equiaxed Grains**

Grain Size No. <i>G</i>	$\bar{N}_A$ Grains/Unit Area		$\bar{A}$ Average Grain Area		$\bar{d}$ Average Diameter		$\bar{\ell}$ Mean Intercept		$\bar{N}_L$ No./mm
	No./in. <sup>2</sup> at 100X	No./mm <sup>2</sup> at 1X	mm <sup>2</sup>	μm <sup>2</sup>	mm	μm	mm	μm	
00	0.25	3.88	0.2581	258064	0.5080	508.0	0.4525	452.5	2.21
0	0.50	7.75	0.1290	129032	0.3592	359.2	0.3200	320.0	3.12
0.5	0.71	10.96	0.0912	91239	0.3021	302.1	0.2691	269.1	3.72
1.0	1.00	15.50	0.0645	64516	0.2540	254.0	0.2263	226.3	4.42
1.5	1.41	21.92	0.0456	45620	0.2136	213.6	0.1903	190.3	5.26
2.0	2.00	31.00	0.0323	32258	0.1796	179.6	0.1600	160.0	6.25
2.5	2.83	43.84	0.0228	22810	0.1510	151.0	0.1345	134.5	7.43
3.0	4.00	62.00	0.0161	16129	0.1270	127.0	0.1131	113.1	8.84
3.5	5.66	87.68	0.0114	11405	0.1068	106.8	0.0951	95.1	10.51
4.0	8.00	124.00	0.00806	8065	0.0898	89.8	0.0800	80.0	12.50
4.5	11.31	175.36	0.00570	5703	0.0755	75.5	0.0673	67.3	14.87
5.0	16.00	248.00	0.00403	4032	0.0635	63.5	0.0566	56.6	17.68
5.5	22.63	350.73	0.00285	2851	0.0534	53.4	0.0476	47.6	21.02
6.0	32.00	496.00	0.00202	2016	0.0449	44.9	0.0400	40.0	25.00
6.5	45.25	701.45	0.00143	1426	0.0378	37.8	0.0336	33.6	29.73
7.0	64.00	992.00	0.00101	1008	0.0318	31.8	0.0283	28.3	35.36
7.5	90.51	1402.9	0.00071	713	0.0267	26.7	0.0238	23.8	42.04
8.0	128.00	1984.0	0.00050	504	0.0225	22.5	0.0200	20.0	50.00
8.5	181.02	2805.8	0.00036	356	0.0189	18.9	0.0168	16.8	59.46
9.0	256.00	3968.0	0.00025	252	0.0159	15.9	0.0141	14.1	70.71
9.5	362.04	5611.6	0.00018	178	0.0133	13.3	0.0119	11.9	84.09
10.0	512.00	7936.0	0.00013	126	0.0112	11.2	0.0100	10.0	100.0
10.5	724.08	11223.2	0.000089	89.1	0.0094	9.4	0.0084	8.4	118.9
11.0	1024.00	15872.0	0.000063	63.0	0.0079	7.9	0.0071	7.1	141.4
11.5	1448.15	22446.4	0.000045	44.6	0.0067	6.7	0.0060	5.9	168.2
12.0	2048.00	31744.1	0.000032	31.5	0.0056	5.6	0.0050	5.0	200.0
12.5	2896.31	44892.9	0.000022	22.3	0.0047	4.7	0.0042	4.2	237.8
13.0	4096.00	63488.1	0.000016	15.8	0.0040	4.0	0.0035	3.5	282.8
13.5	5792.62	89785.8	0.000011	11.1	0.0033	3.3	0.0030	3.0	336.4
14.0	8192.00	126976.3	0.000008	7.9	0.0028	2.8	0.0025	2.5	400.0

$$Q_m = 2 \log_2 M \quad (3)$$

$$= 6.64 \log_{10} M$$

where  $Q_M$  is a correction factor that is added to the apparent grain size of the specimen, when viewed at the magnification  $M$ , instead of at 1X, to yield the true ASTM macro-grain size number. Thus, for a magnification of 2X, the true ASTM macro-grain size number is two numbers higher ( $Q = +2$ ), and for 4X, the true ASTM macro-grain size number is four numbers higher ( $Q = +4$ ) than that of the corresponding photograph.

10.13 The comparison procedure shall be applicable for estimating the austenite grain size in ferritic steel after a McQuaid-Ehn test (see [Annex A3, A3.2](#)), or after the austenite grains have been revealed by any other means (see [Annex A3, A3.3](#)). Make the grain-size measurement by comparing the microscopic image, at magnification of 100X, with the standard grain size chart in Plate IV, for grains developed in a McQuaid-Ehn test (see [Annex A3](#)); for the measurement of austenite grains developed by other means (see [Annex A3](#)), measure by comparing the microscopic image with the plate having the most nearly comparable structure observed in Plates I, II, or IV.

10.14 The so-called “Shepherd Fracture Grain Size Method” of judging grain size from the appearance of the fracture of hardened steel (2), involves comparison of the specimen under investigation with a set of standard fractures.<sup>6</sup> It has been found that the arbitrarily numbered fracture grain size series agree well with the correspondingly numbered

ASTM grain sizes presented in [Table 4](#). This coincidence makes the fracture grain sizes interchangeable with the austenitic grain sizes determined microscopically. The sizes observed microscopically shall be considered the primary standard, since they can be determined with measuring instruments.

### 11. Planimetric (or Jeffries’) (3) Procedure

11.1 In the planimetric procedure inscribe a circle or rectangle of known area (usually 5000 mm<sup>2</sup> to simplify the calculations) on a micrograph, a monitor or on the ground-glass screen of the metallograph. Select a magnification which will give at least 50 grains in the field to be counted. When the image is focused properly, count the number of grains within this area. The sum of all the grains included completely within the known area plus one half the number of grains intersected by the circumference of the area gives the number of equivalent whole grains, measured at the magnification used, within the area. If this number is multiplied by the Jeffries’ multiplier,  $f$ , in the second column of [Table 5](#) opposite the appropriate magnification, the product will be the number of grains per square millimetre  $N_A$ . Count a minimum of three fields to ensure a reasonable average. The number of grains per square millimetre at 1X,  $N_A$ , is calculated from:

$$N_A = f \left( N_{\text{Inside}} + \frac{N_{\text{Intercepted}}}{2} \right) \quad (4)$$

where  $f$  is the Jeffries’ multiplier (see [Table 5](#)),  $N_{\text{Inside}}$  is the number of grains completely inside the test circle and  $N_{\text{Intercepted}}$  is the number of grains that intercept the test circle. The average grain area,  $\bar{A}$ , is the reciprocal of  $N_A$ , that is,  $1/N_A$ ,

<sup>6</sup> A photograph of the Shepherd standard fractures can be obtained from ASTM Headquarters. Order Adjunct: [ADJE011224](#).

**TABLE 5 Relationship Between Magnification Used and Jeffries' Multiplier,  $f$ , for an Area of 5000 mm<sup>2</sup> (a Circle of 79.8-mm Diameter) ( $f = 0.0002 M^2$ )**

Magnification Used, $M$	Jeffries' Multiplier, $f$ , to Obtain Grains/mm <sup>2</sup>
1	0.0002
10	0.02
25	0.125
50	0.5
75 <sup>A</sup>	1.125
100	2.0
150	4.5
200	8.0
250	12.5
300	18.0
500	50.0
750	112.5
1000	200.0

<sup>A</sup> At 75 diameters magnification, Jeffries' multiplier,  $f$ , becomes unity if the area used is 5625 mm<sup>2</sup> (a circle of 84.5-mm diameter).

while the mean grain diameter,  $d$ , as listed on Plate III (see 10.2.3), is the square root of  $\bar{A}$ . This grain diameter has no physical significance because it represents the side of a square grain of area  $\bar{A}$ , and grain cross sections are not square.

11.2 To obtain an accurate count of the number of grains completely within the test circle and the number of grains intersecting the circle, it is necessary to mark off the grains on the template, for example, with a grease pencil or felt tip pen. The precision of the planimetric method is a function of the number of grains counted (see Section 19). The number of grains within the test circle, however, should not exceed about 100 as counting becomes tedious and inaccurate. Experience suggests that a magnification that produces about 50 grains within the test circle is about optimum as to counting accuracy per field. Because of the need to mark off the grains to obtain an accurate count, the planimetric method is less efficient than the intercept method (see Section 12).

11.3 Fields should be chosen at random, without bias, as described in 5.2. Do not attempt to choose fields that appear to be typical. Choose the fields blindly and select them from different locations on the plane of polish.

11.4 By original definition, a microscopically-determined grain size of No. 1 has 1.000 grains/in.<sup>2</sup> at 100X, hence 15.500 grains/mm<sup>2</sup> at 1X. For areas other than the standard circle, determine the actual number of grains per square millimetre,  $N_A$ , and find the nearest size from Table 4. The ASTM grain size number,  $G$ , can be calculated from  $N_A$  (number of grains per mm<sup>2</sup> at 1X) using (Eq 1) in Table 6.

11.5 This approach assumes that, on average, half of the grains intersecting the test circle are within the circle while half are outside the circle. This assumption is valid for a straight line through a grain structure, but not necessarily for a curved line. The bias created by this assumption increases as the number of grains inside the test circle decreases. If the number of grains within the test circle is at least 50, the bias is about 2%.

11.5.1 There is a simple way (4) to avoid this bias, irrespective of the number of grains inside the test figure - use a square or rectangular test area. However, the counting procedure must be modified slightly. First, it is assumed that the grains

**TABLE 6 Grain Size Equations Relating Measured Parameters to the Microscopically Determined ASTM Grain Size,  $G$** 

NOTE 1—Determine the ASTM Grain Size,  $G$ , using the following equations:

NOTE 2—The second and third equations are for single phase grain structures.

NOTE 3—To convert micrometres to millimetres, divide by 1000.

NOTE 4—A calculated  $G$  value of  $-1$  corresponds to ASTM  $G = 00$ .

Equation	Units
$G = (3.321928 \log_{10} \bar{N}_A) - 2.954$	$N_A$ in mm <sup>-2</sup>
$G = (6.643856 \log_{10} \bar{N}_L) - 3.288$	$\bar{N}_L$ in mm <sup>-1</sup>
$G = (6.643856 \log_{10} P_L) - 3.288$	$P_L$ in mm <sup>-1</sup>
$G = (-6.643856 \log_{10} \ell) - 3.288$	$\ell$ in mm

intersecting each of the four corners are, on average, one fourth within the figures and three-fourths outside. These four corner grains together equal one grain within the test box.

11.5.2 Ignoring the four corner grains, a count is made of  $N_{Inside}$ , the grains completely within the box, and of  $N_{Intercepted}$ , the grains intersected by the four sides of the box. Eq 4 now becomes:

$$N_A = (M^2/A) (N_{Inside} + 0.5N_{Intercepted} + 1) \quad (5)$$

where  $M$  is the magnification,  $A$  is the test figure area in mm<sup>2</sup> and  $N_A$  is the number of grains per square millimeter at 1x. Select the fields at random, as described in 11.3. It is recommended that enough fields should be evaluated so that a total of ~700 grains are counted which will usually provide a 10% relative accuracy (see Appendix X1, paragraph X1.3.2).

11.5.3 The average grain area,  $\bar{A}$ , is the reciprocal of  $N_A$  and the mean grain diameter,  $d$ , is the square root of  $\bar{A}$ , as described in 11.1. The ASTM grain size number,  $G$ , can be estimated using the data in Table 4, or can be calculated from  $N_A$  using Eq (1) in Table 6.

## 12. General Intercept Procedures

12.1 Intercept procedures are more convenient to use than the planimetric procedure. These procedures are amenable to use with various types of machine aids. It is strongly recommended that at least a manual tally counter be used with all intercept procedures in order to prevent normal errors in counting and to eliminate bias which may occur when counts appear to be running higher or lower than anticipated.

12.2 Intercept procedures are recommended particularly for all structures that depart from the uniform equiaxed form. For anisotropic structures, procedures are available either to make separate size estimates in each of the three principal directions, or to rationally estimate the average size, as may be appropriate.

12.3 There is no direct mathematical relationship between the ASTM grain size number,  $G$ , and the mean lineal intercept, unlike the exact relationship between  $G$ ,  $N_{AE}$ ,  $N_A$  and  $\bar{A}$  (Eq 1) for the planimetric method. The relationship

$$\ell = \left( \frac{\pi}{4} \bar{A} \right)^{1/2} \quad (6)$$



between the mean lineal intercept,  $\ell$ , and the average grain area,  $\bar{A}$ , is exact for circles but not quite exact for a structure of uniform equiaxed grains (see A2.2.2). Consequently, the relationship between the ASTM grain size number  $G$  and the mean lineal intercept has been defined so that ASTM No. 0 has a mean intercept size of precisely 32.00 mm for the macroscopically determined grain size scale and of 32.00 mm on a field of view at 100X magnification for the microscopically determined grain size scale. Thus:

$$G = 2\log_2 \frac{\ell_0}{\ell} \quad (7)$$

$$G = 10.00 - 2\log_2 \bar{\ell} \quad (8)$$

$$G = 10.00 + 2\log_2 \bar{N}_L \quad (9)$$

where  $\ell_0$  is 32 mm and  $\bar{\ell}$  and  $\bar{N}_L$  are in millimetres at 1X or number of intercepts per mm for the macroscopically determined grain size numbers and in millimetres or number per mm on a field at 100X for the microscopically determined grain size numbers. Using this scale, measured grain size numbers are within about 0.01  $G$  units of grain size numbers determined by the planimetric method, that is, well within the precision of the test methods. Additional details concerning grain size relationships are given in Annex A1 and Annex A2.

12.4 The mean intercept distance,  $\bar{\ell}$ , measured on a plane section is an unbiased estimate of the mean intercept distance within the solid material in the direction, or over the range of directions, measured. The grain boundary surface area-to-volume ratio is given exactly by  $S_v = 2N_L$  when  $N_L$  is averaged over three dimensions. These relations are independent of grain shape.

### 13. Heyn (4) Lineal Intercept Procedure

13.1 Estimate the average grain size by counting (on the ground-glass screen, on a photomicrograph of a representative field of the specimen, a monitor or on the specimen itself) the number of grains intercepted by one or more straight lines sufficiently long to yield at least 50 intercepts. It is desirable to select a combination of test line length and magnification such that a single field will yield the required number of intercepts. One such test will nominally allow estimation of grain size to the nearest whole ASTM size number, at the location tested. Additional lines, in a predetermined array, should be counted to obtain the precision required. The precision of grain size estimates by the intercept method is a function of the number of grain interceptions counted (see Section 19). Because the ends of straight test lines will usually lie inside grains (see 14.3), precision will be reduced if the average count per test line is low. If possible, use either a longer test line or a lower magnification.

13.2 Make counts first on three to five blindly selected and widely separated fields to obtain a reasonable average for the specimen. If the apparent precision of this average (calculated as indicated in Section 15) is not adequate, make counts on sufficient additional fields to obtain the precision required for the specimen average.

13.3 An *intercept* is a segment of test line overlaying one grain. An *intersection* is a point where a test line is cut by a

grain boundary. Either may be counted, with identical results in a single phase material. When counting intercepts, segments at the end of a test line which penetrate into a grain are scored as half intercepts. When counting intersections, the end points of a test line are not intersections and are not counted except when the end appears to exactly touch a grain boundary, when  $\frac{1}{2}$  intersection should be scored. A tangential intersection with a grain boundary should be scored as one intersection. An intersection apparently coinciding with the junction of three grains should be scored as  $1\frac{1}{2}$ . With irregular grain shapes, the test line may generate two intersections with different parts of the same grain, together with a third intersection with the intruding grain. The two additional intersections are to be counted.

13.4 The effects of moderate departure from an equiaxed structure may be eliminated by making intercept counts on a line array containing lines having four or more orientations. The four straight lines of Fig. 5<sup>7</sup> may be used. The form of such arrays is not critical, provided that all portions of the field are measured with approximately equal weight. An array of lines radiating from a common point is therefore not suitable. The number of intercepts is to be counted for the entire array and single values of  $N_L$  and  $\ell$  determined for each array as a whole.

13.5 For distinctly non-equiaxed structures such as moderately worked metals, more information can be obtained by making separate size determinations along parallel line arrays that coincide with all three principal directions of the specimen. Longitudinal and transverse specimen sections are normally used, the normal section being added when necessary. Either of the 100-mm lines of Fig. 5 may be applied five times, using parallel displacements, placing the five “+” marks at the same point on the image. Alternatively, a transparent test grid with systematically spaced parallel test lines of known length can be made and used.

### 14. Circular Intercept Procedures

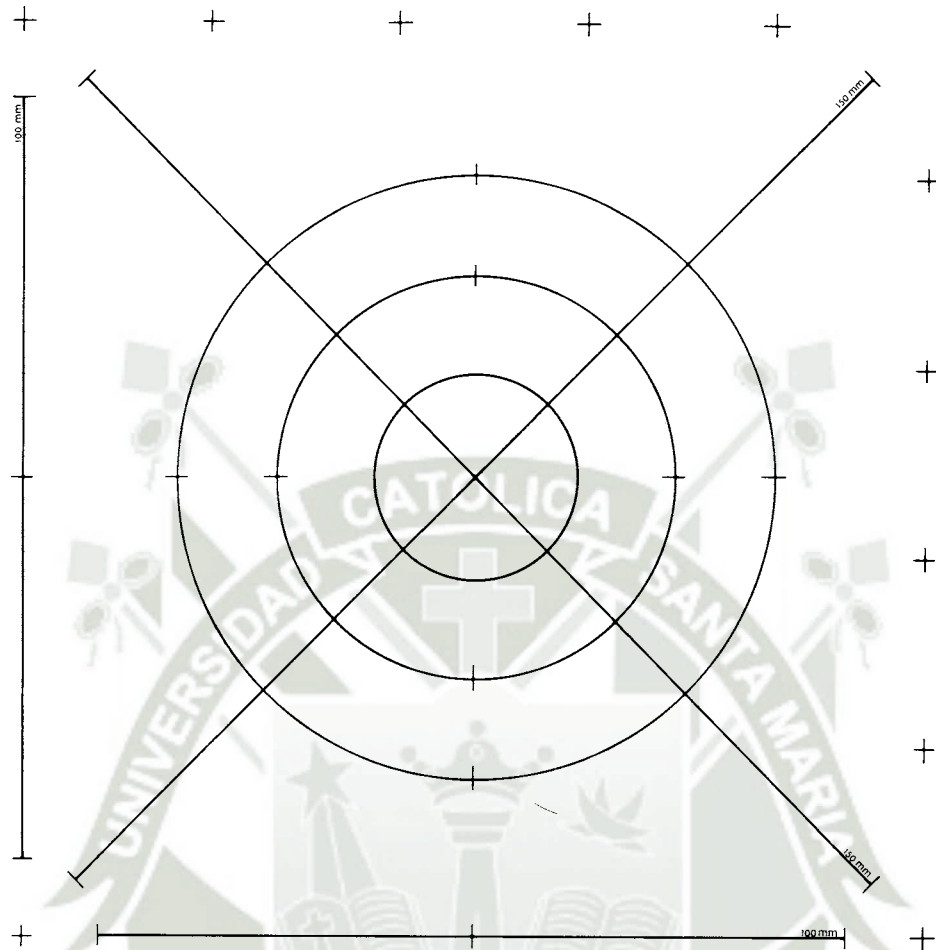
14.1 Use of circular test lines rather than straight test lines has been advocated by Underwood (6), Hilliard (7), and Abrams (8). Circular test arrays automatically compensate for departures from equiaxed grain shapes, without overweighting any local portion of the field. Ambiguous intersections at ends of test lines are eliminated. Circular intercept procedures are most suitable for use as fixed routine manual procedures for grain size estimation in quality control.

#### 14.2 Hilliard Single-Circle Procedure (7) :

14.2.1 When the grain shape is not equiaxed but is distorted by deformation or other processes, obtaining an average lineal intercept value using straight test lines requires averaging of values made at a variety of orientations. If this is not done carefully, bias may be introduced. Use of a circle as the test line eliminates this problem as the circle will test all orientations equally and without bias.

14.2.2 Any circle size of exactly known circumference may be used. Circumferences of 100, 200, or 250 mm are usually

<sup>7</sup> A true-size transparency of Fig. 5 is available from ASTM Headquarters. Order Adjunct:ADJE11217F.



NOTE 1—If reproduced to make straight lines marked length:  
Straight lines total: 500 mm

Circles are:	Circumference, mm,	Diameter, mm
	250.0	79.58
	166.7	53.05
	83.3	26.53
	<hr/>	
	Total 500.0	

NOTE 2—See Footnote 9.

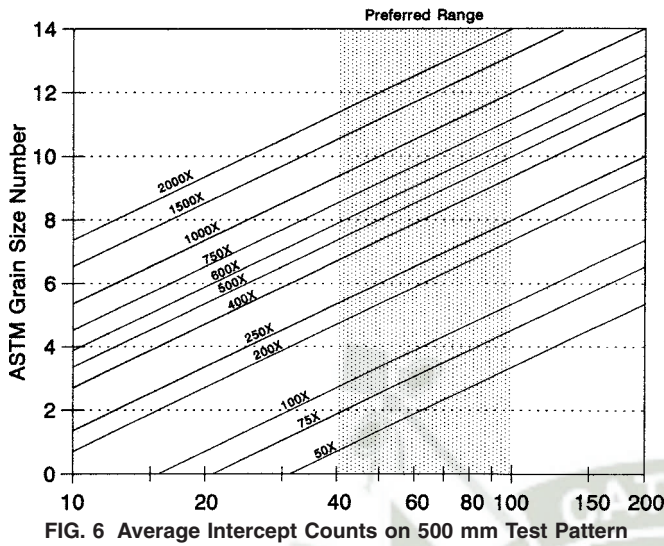
**FIG. 5 Test Pattern for Intercept Counting**

convenient. The test circle diameter should never be smaller than the largest observed grains. If the test circle is smaller than about three times the mean linear intercept, the distribution of the number of intercepts or intersections per field will not be Gaussian. Also, use of small test circles is rather inefficient as a great many fields must be evaluated to obtain a high degree of precision. A small reference mark is usually placed at the top of the circle to indicate the place to start and stop the count. Blindly apply the selected circle to the microscope image at a convenient known magnification and count the number of grain boundaries intersecting the circle for each application. Apply the circle only once to each field of view, adding fields in a representative manner, until sufficient counts are obtained to yield the required precision. The variation in counts per test circle application decreases as the circle size increases and, of course, is affected by the uniformity of the grain size distribution.

14.2.3 As with all intercept procedures, the precision of the measurement increases as the number of counts increases (see Section 19). The precision is based on the standard deviation of the counts of the number of intercepts or intersections per field. In general, for a given grain structure, the standard deviation is improved as the count per circle application and the total count (that is, the number of applications) increase. Hilliard recommended test conditions that produce about 35 counts per circle with the test circle applied blindly over as large a specimen area as feasible until the desired total number of counts is obtained.

14.3 *Abrams Three-Circle Procedure* (8) :

14.3.1 Based on an experimental finding that a total of 500 counts per specimen normally yields acceptable precision, Abrams developed a specific procedure for routine average grain size rating of commercial steels. Use of the chi-square



counting correctly at the count density recommended. Completely count each circle in turn, using a manually operated counter to accumulate the total number of grain boundary intersections with the test pattern. The manual counter is necessary to avoid bias toward unreal agreement between applications or toward a desired result, and to minimize memory errors. The operator should avoid keeping a mental score. When a tally counter is used, score any intersection of the circle with the junction of three grains as two rather than the correct value of 1½; the error introduced is very small.

14.3.3 For each field count, calculate  $N_L$  or  $P_L$  according to:

$$\bar{N}_L = \frac{N_i}{L/M} \tag{10}$$

$$\bar{P}_L = \frac{P_i}{L/M} \tag{11}$$

where  $N_i$  and  $P_i$  are the number of intercepts or intersections counted on the field,  $L$  is the total test line length (500 mm) and  $M$  is the magnification.

14.3.4 Calculate the mean lineal intercept value for each field,  $\bar{\ell}$  by:

$$\bar{\ell} = \frac{1}{\bar{N}_L} = \frac{1}{\bar{P}_L} \tag{12}$$

The average value of  $n$  determinations of  $N_L$ ,  $P_L$ , or  $\bar{\ell}$  is used to determine the microscopically measured ASTM grain size using the equations in Table 6, the data shown graphically in Fig. 6, or the data in Table 4.

## 15. Statistical Analysis

15.1 No determination of average grain size can be an exact measurement. Thus, no determination is complete without also calculating the precision within which the determined size may, with normal confidence, be considered to represent the actual average grain size of the specimen examined. In accordance with common engineering practice, this section assumes normal confidence to represent the expectation that the actual error will be within the stated uncertainty 95 % of the time.

15.1.1 Many specimens vary measurably in grain size from one field of view to another, this variation being responsible for a major portion of the uncertainty. Minimum effort in manual methods, to obtain a required precision, justifies individual counts whose precision is comparable to this natural variability (7). The high local precision that may be obtained by machine methods often will yield only a small increase in overall precision unless many fields also are measured, but does help distinguish natural variability from inaccuracies of counting.

15.2 After the desired number of fields have been measured, calculate the mean value of  $\bar{N}_A$  or  $\bar{\ell}$  from the individual field values according to:

$$\bar{X} = \frac{\sum X_i}{n} \tag{13}$$

where  $X_i$  represents an individual value,  $\bar{X}$  is the mean and  $n$  is the number of measurements.

15.3 Calculate the standard deviation of the individual measurements according to the usual equation:

test on real data demonstrated that the variation of intercept counts is close to normal, allowing the observations to be treated by the statistics of normal distributions. Thus both a measure of variability and the confidence limit of the result are computed for each average grain size determination.

14.3.2 The test pattern consists of three concentric and equally spaced circles having a total circumference of 500 mm, as shown in Fig. 5. Successively apply this pattern to at least five blindly selected and widely spaced fields, separately recording the count of intersections per pattern for each of the tests. Then, determine the mean lineal intercept, its standard deviation, 95 % confidence limit, and percent relative accuracy. For most work, a relative accuracy of 10 % or less represents an acceptable degree of precision. If the calculated relative accuracy is unacceptable for the application, count additional fields until the calculated percent relative accuracy is acceptable. The specific procedure is as follows:

14.3.2.1 Examine the grain structure and select a magnification that will yield from 40 to 100 intercepts or intersection counts per placement of the three circle test grid. Because our goal is to obtain a total of about 400 to 500 counts, the ideal magnification is that which yields about 100 counts per placement. However, as the count per placement increases from 40 to 100, errors in counting become more likely. Because the grain structure will vary somewhat from field to field, at least five widely spaced fields should be selected. Some metallographers feel more comfortable counting 10 fields with about 40 to 50 counts per field. For most grain structures, a total count of 400 to 500 intercepts or intersections over 5 to 10 fields produces better than 10 % relative accuracy. Fig. 6 shows the relationship between the average intercept count and the microscopically determined ASTM grain size number as a function of magnification.

14.3.2.2 Blindly select one field for measurement and apply the test pattern to the image. A transparency of the pattern may be applied directly to the ground glass, or to a photomicrograph when permanent records are desired. Direct counting using a properly sized reticle in the eyepiece is allowable, but it may here be expected that some operators will find difficulty in

**TABLE 7 95 % Confidence Internal Multipliers,  $t$** 

No. of Fields, $n$	$t$	No. of Fields, $n$	$t$
5	2.776	13	2.179
6	2.571	14	2.160
7	2.447	15	2.145
8	2.365	16	2.131
9	2.306	17	2.120
10	2.262	18	2.110
11	2.228	19	2.101
12	2.201	20	2.093

$$s = \left[ \frac{\sum (X_i - \bar{X})^2}{n - 1} \right]^{1/2} \quad (14)$$

where  $s$  is the standard deviation.

15.4 Calculate the 95 % confidence interval, 95 % CI, of each measurement according to:

$$95\% \text{ CI} = \frac{t \cdot s}{\sqrt{n}} \quad (15)$$

where the  $\cdot$  indicates a multiplication operation. Table 7 lists values of  $t$  as a function of  $n$ .

15.5 Calculate the percent relative accuracy, % RA, of the measurements by dividing the 95 % CI value by the mean and expressing the results as a percentage, that is:

$$\% \text{ RA} = \frac{95\% \text{ CI}}{\bar{X}} \cdot 100 \quad (16)$$

15.6 If the % RA is considered to be too high for the intended application, more fields should be measured and the calculations in 15.1-15.5 should be repeated. As a general rule, a 10 % RA (or lower) is considered to be acceptable precision for most purposes.

15.7 Convert the mean value of  $\bar{N}_A$  or  $\bar{\ell}$  to the ASTM grain size number,  $G$ , using Table 4 or the Eqs in Table 6.

## 16. Specimens with Non-equiaxed Grain Shapes

16.1 If the grain shape was altered by processing so that the grains are no longer equiaxed in shape, grain size measurements should be made on longitudinal ( $\ell$ ), transverse ( $t$ ) and planar ( $p$ ) oriented surfaces for rectangular bar, plate or sheet type material. For round bars, radial longitudinal and transverse sections are used. If the departure from equiaxed is not too great (see 16.2.2), a reasonable estimate of the grain size can be determined using a longitudinal specimen and the circular test grid. If directed test lines are used for the analysis, measurements in the three principal directions can be made using only two of the three principal test planes.

### 16.2 Planimetric Method:

16.2.1 When the grain shape is not equiaxed but elongated, make grain counts on each of the three principal planes, that is, planes of polish on longitudinal, transverse and planar-oriented surfaces. Determine the number of grains per  $\text{mm}^2$  at 1X on the longitudinal, transverse, and planar oriented surfaces,  $\bar{N}_{A\ell}$ ,  $\bar{N}_{At}$  and  $\bar{N}_{Ap}$ , respectively, and calculate the mean number of grains per unit area,  $\bar{N}_A$ , from the three  $\bar{N}_A$  values from the principal planes:

$$\bar{N} = (\bar{N}_{A\ell} \cdot \bar{N}_{At} \cdot \bar{N}_{Ap})^{1/3} \quad (17)$$

where  $\cdot$  indicates a multiplication operation and the bar above each quantity indicates an average value.

16.2.2 A reasonable estimate of the grain size can be made from  $\bar{N}_{A\ell}$  alone if the departure from an equiaxed shape is not excessive ( $\leq 3:1$  aspect ratio).

16.2.3 Calculate  $G$  from the mean value of  $\bar{N}_A$  from the averages made on each field. Perform the statistical analysis (15.1-15.5) only on the individual measurements on each field.

### 16.3 Intercept Method:

16.3.1 To assess the grain size of non-equiaxed grain structures, measurements can be made using circular test grids or randomly placed test lines on each of the three principal test planes, or by use of directed test lines in either three or six of the principal directions using either two or three of the principal test planes, see Fig. 7. For specimens where the departure from an equiaxed shape is not severe ( $\leq 3:1$  aspect ratio), a reasonable estimate of the grain size can be made using a circular test grid on the longitudinal plane only.

16.3.2 The grain size can be determined from measurements of the mean number of grain boundary intersections per unit length,  $\bar{P}_L$ , or the mean number of grains intercepted per unit length,  $\bar{N}_L$ . Both methods yield the same results for a single phase grain structure.  $\bar{P}_L$  or  $\bar{N}_L$  can be determined using either test circles on each of the principal planes or directed test lines in either three or six of the principal test directions shown in Fig. 7.

16.3.3 For the case of randomly determined values of  $\bar{P}_L$  or  $\bar{N}_L$  on the three principal planes, compute the average value according to:

$$\bar{P} = (\bar{P}_{L\ell} \cdot \bar{P}_{Lt} \cdot \bar{P}_{Lp})^{1/3} \quad (18)$$

or

$$\bar{N} = (\bar{N}_{L\ell} \cdot \bar{N}_{Lt} \cdot \bar{N}_{Lp})^{1/3} \quad (19)$$

Alternatively, calculate  $\bar{\ell}_\ell$ ,  $\bar{\ell}_t$  and  $\bar{\ell}_p$  from the  $\bar{P}_L$  or  $\bar{N}_L$  values on each plane using (Eq 12). Then, calculate the overall mean value of  $\bar{\ell}$  from:

$$\bar{\ell} = (\bar{\ell}_\ell \cdot \bar{\ell}_t \cdot \bar{\ell}_p)^{1/3} \quad (20)$$

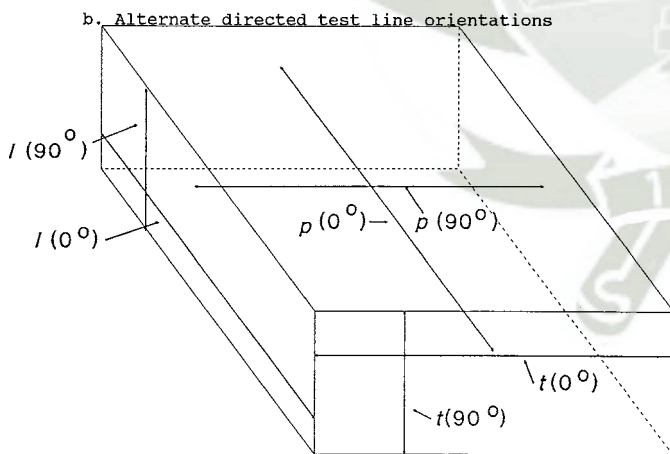
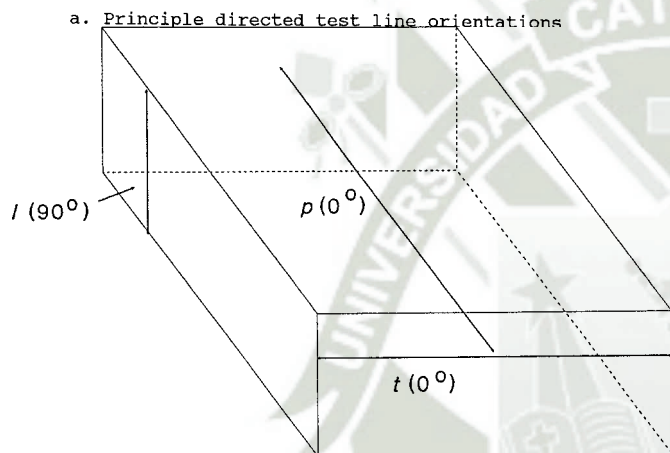
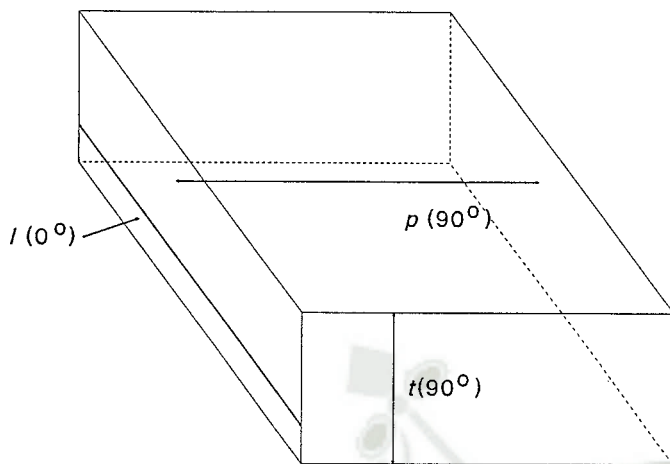
16.3.4 If directed test lines are used in the principal directions on the principal planes, only two of the principal planes are required to perform directed counts in the three principal directions and obtain an estimate of the grain size.

16.3.5 Additional information on grain shape may be obtained by determining  $\bar{\ell}$  parallel ( $0^\circ$ ) and perpendicular ( $90^\circ$ ) to the deformation axis on a longitudinally oriented surface. The grain elongation ratio, or the anisotropy index,  $AI$ , can be determined from:

$$AI_\ell = \bar{\ell}_{\ell(0^\circ)} / \bar{\ell}_{\ell(90^\circ)} \quad (21)$$

16.3.5.1 The three-dimensional mean grain size and shape may also be defined by the directed mean lineal intercept values on the three principal planes. These values would be expressed as:

$$\bar{\ell}_{\ell(0^\circ)} : \bar{\ell}_{\ell(90^\circ)} : \bar{\ell}_{\ell(90^\circ)} \quad (22)$$



c. All six directed test line orientations

NOTE 1—Measurements of rectangular bar, plate, strip or sheet type specimens with non-equiaxed grain structures.

FIG. 7 Schematic Showing the Six Possible Directed Test Line Orientations for Grain Size Measurement

16.3.5.2 Another approach that can be used is to normalize the three results by dividing each by the value of the smallest with the results expressed as ratios.

16.3.6 The mean value of  $\bar{l}$  for the measurements in the three principal test directions is obtained by averaging the directed  $\bar{N}_L$ , or  $\bar{P}_L$  values (as shown in (Eq 23)) and then

computing  $\bar{l}$  from this mean value; or, by calculating directed  $\bar{l}$  values in each of the three principal directions and then averaging them according to (Eq 24):

$$\bar{P} = (\bar{P}_{Ll(0^\circ)} \cdot \bar{P}_{Ll(90^\circ)} \cdot \bar{P}_{Ll(p(90^\circ))})^{1/3} \quad (23)$$

This is done in like manner for  $\bar{N}_L$ . For computing the grand mean  $\bar{l}$  from the directed mean values, use:

$$\bar{l} = (\bar{l}_{l(0^\circ)} \cdot \bar{l}_{l(90^\circ)} \cdot \bar{l}_{l(p(90^\circ))})^{1/3} \quad (24)$$

where the  $\cdot$  indicates a multiplication operation.

16.3.7 The mean grain size is determined from the overall averages of  $\bar{P}_L$ ,  $\bar{N}_L$  or  $\bar{l}$  using Table 4 or the equations in Table 6. Additional information on the measurement of grain size for non-equiaxed structures can be found in Annex A1 of Test Methods E1382.

16.4 Statistical analysis should be performed on the data from each plane or each principal test direction according to the procedure in 15.1-15.5.

### 17. Specimens Containing Two or More Phases or Constituents

17.1 Minor amounts of second phase particles, whether desirable or undesirable features, may be ignored in the determination of grain size, that is, the structure is treated as a single phase material and the previously described planimetric or intercept methods are used to determine the grain size. Unless stated otherwise, the effective average grain size shall be presumed to be the size of the matrix phase.

17.2 The identity of each measured phase and the percentage of field area occupied by each phase shall be determined and reported. The percentage of each phase can be determined according to Practice E562.

17.3 Comparison Method—The comparison chart rating procedure may provide acceptable precision for most commercial applications if the second phase (or constituent) consists of islands or patches of essentially the same size as the matrix grains; or, the amount and size of the second phase particles are both small and the particles are located primarily along grain boundaries.

17.4 Planimetric Method—The planimetric method may be applied if the matrix grain boundaries are clearly visible and the second phase (constituent) particles are mainly present between the matrix grains rather than within the grains. Determine the percentage of the test area occupied by the second phase, for example, by Practice E562. Always determine the amount of the phase of least concentration, usually the second phase or constituent. Then, determine the matrix phase by difference. Next, count the number of matrix grains completely within the test areas and the number of matrix grains intersecting the test area boundary, as described in Section 11. The test area must be reduced to that covered only by the matrix phase grains. The effective average grain size is then determined from the number of grains per unit net area of the matrix phase. Statistically analyze the number of grains per unit area of the  $\alpha$  matrix phase,  $N_A \alpha$ , from each field measurement using the approach described in Section 15.

Then, from the overall average,  $\bar{N}_A$ , determine the effective grain size of the matrix using [Table 4](#) or the appropriate equation in [Table 6](#).

**17.5 Intercept Method**—The same restrictions regarding applicability, as stated in [17.4](#), pertain to this method. Again, the amount of the matrix phase must be determined, as described in [17.4](#). A test grid consisting of one or more test circles, such as shown in [Fig. 5](#), is used. For this application, count the number of matrix grains,  $N_\alpha$ , intercepted by the test line. Determine the mean intercept length of the matrix phase according to:

$$\bar{\ell}_\alpha = \frac{(V_{V\alpha})(L/M)}{N_\alpha} \quad (25)$$

where the volume fraction of the  $\alpha$  matrix,  $V_{V\alpha}$ , is expressed as a fraction,  $L$  is the test line length and  $M$  is the magnification. The grain size of the  $\alpha$  grains is determined using [Table 4](#) or the equation in [Table 6](#). In practice, it is inconvenient to manually determine the volume fraction of the  $\alpha$  phase and the number of  $\alpha$  grains intercepting the test line for each field. If this is done, the mean linear intercept length of the  $\alpha$  phase for each field can be determined and this data can be statistically analyzed for each field according to the procedure described in [Section 15](#). If  $V_{V\alpha}$  and  $N_\alpha$  are not measured simultaneously for the same fields, then the statistical analysis can only be performed on the  $V_{V\alpha}$  and  $N_\alpha$  data.

**17.6** It is also possible to determine  $\bar{\ell}_\alpha$  by measurement of individual intercept lengths using parallel straight test lines applied randomly to the structure. Do not measure the partial intercepts at the ends of the test lines. This method is rather tedious unless it can be automated in some way. The individual intercepts are averaged and this value is used to determine  $G$  from [Table 4](#) or the equation in [Table 6](#). The individual intercepts may be plotted in a histogram, but this is beyond the scope of these test methods.

## 18. Report

**18.1** The test report should document all of the pertinent identifying information regarding the specimen, its composition, specification designation or trade name, customer or data requester, date of test, heat treatment or processing history, specimen location and orientation, etchant and etch method, grain size analysis method, and so forth, as required.

**18.2** List the number of fields measured, the magnification, and field area. The number of grains counted or the number of intercepts or intersections counted, may also be recorded. For a two-phase structure, list the area fraction of the matrix phase.

**18.3** A photomicrograph illustrating the typical appearance of the grain structure may be provided, if required or desired.

**18.4** List the mean measurement value, its standard deviation, 95 % confidence interval, percent relative accuracy, and the ASTM grain size number.

**18.4.1** For the comparison method, list only the estimated ASTM grain size number.

**18.5** For a non-equiaxed grain structure, list the method of analysis, planes examined, directions evaluated (if applicable), the grain size estimate per plane or direction, the grand mean

of the planar measurements, and the computed or estimated ASTM grain size number.

**18.6** For a two-phase structure, list the method of analysis, the amount of the matrix phase (if determined), the grain size measurement of the matrix phase (and the standard deviation, 95 % confidence interval, and percent relative accuracy), and the computed or estimated ASTM grain size number.

**18.7** If it is desired to express the average grain size of a group of specimens from a lot, do not simply average the ASTM grain size numbers. Instead, compute an arithmetic average of the actual measurements, such as, the  $\bar{N}_A$  or  $\ell$  values per specimen. Then, from the lot average, calculate or estimate the ASTM grain size for the lot. The specimen values of  $\bar{N}_A$  or  $\ell$  may also be statistically analyzed, according to the approach in [Section 15](#), to evaluate the grain size variability within the lot.

## 19. Precision and Bias

**19.1** The precision and bias of grain size measurements depend on the representativeness of the specimens selected and the areas on the plane-of-polish chosen for measurement. If the grain size varies within a product, specimen and field selection must adequately sample this variation.

**19.2** The relative accuracy of the grain size measurement of the product improves as the number of specimens taken from the product increases. The relative accuracy of the grain size measurement of each specimen improves as the number of fields sampled and the number of grains or intercepts counted increase.

**19.3** Bias in measurements will occur if specimen preparation is inadequate. The true structure must be revealed and the grain boundaries must be fully delineated for best measurement precision and freedom from bias. As the percentage of non-delineated grain boundaries increases, bias increases and precision, repeatability, and reproducibility become poorer.

**19.4** Inaccurate determination of the magnification of the grain structure will produce bias.

**19.5** If the grain structure is not equiaxed in shape, for example, if the grain shape is elongated or flattened by deformation, measurement of the grain size on only one plane, particularly the plane perpendicular to the deformation direction, will bias test results. Grain shape distortion is best detected using a test plane parallel to the deformation direction. The size of the deformed grains should be based on measurements made on two or three of the principal planes which are averaged as described in [Section 16](#).

**19.6** Specimens with a unimodal grain size distribution are measured for average grain size using the methods described in these test methods. Specimens with bimodal (or more complex) size distributions should not be tested using a method that yields a single average grain size value; they should be characterized using the methods described in [Test Methods E1181](#) and measured using the methods described in [Test Methods E112](#). The size of individual very large grains in a fine grained matrix should be determined using [Test Methods E930](#).

19.7 When using the comparison chart method, the chart selected should be consistent with the nature of the grains (that is, twinned or non-twinned, or carburized and slow cooled) and the etch (that is, flat etch or grain contrast etch) for best precision.

19.8 Grain size ratings using the comparison chart method by an individual metallographer will vary within  $\pm 0.5 G$  units. When a number of individuals rate the same specimen, the spread in ratings may be as great as 1.5 to 2.5  $G$  units.

19.9 The fracture grain size method is only applicable to hardened, relatively brittle, tool steels. Specimens should be in the as-quenched or lightly tempered condition so that the fracture surface is quite flat. An experienced metallographer can rate the prior-austenite grain size of a tool steel within  $\pm 0.5 G$  units by the Shepherd fracture grain size method.

19.10 A round robin test program (see [Appendix X1](#)), analyzed according to Practice [E691](#), revealed a rather consistent bias between comparison chart ratings using Plate I and grain size measurements using both the planimetric and intercept methods. Chart ratings were 0.5 to 1  $G$  unit coarser, that is, lower  $G$  numbers, than the measured values.

19.11 Grain sizes determined by either the planimetric or intercept methods produced similar results with no observed bias.

19.12 The relative accuracy of grain size measurements improved as the number of grains or intercepts counted increased. For a similar number of counts, the relative accuracy of intercept measurements was better than that of planimetric measurements of grain size. For the intercept method, 10 % RA (or less) was obtained with about 400 intercept or intersection counts while for the planimetric method, to obtain 10 % RA, or less, about 700 grains had to be counted. Repeatability

and reproducibility of measurements improved as the number of grains or intercepts counted increased and was better for the intercept method than for the planimetric method for the same count.

19.13 The planimetric method requires a marking off of the grains during counting in order to obtain an accurate count. The intercept method does not require marking in order to get an accurate count. Hence, the intercept method is easier to use and faster. Further, the round robin test showed that the intercept method provides better statistical precision for the same number of counts and is, therefore, the preferred measurement method.

19.14 An individual metallographer can usually repeat planimetric or intercept grain size measurements within  $\pm 0.1 G$  units. When a number of metallographers measure the same specimen, the spread of grain sizes is usually well within  $\pm 0.5 G$  units.

19.15 If the number of grains completely within a test circle decreases below 50, the grain size estimate using the planimetric method will be biased, with the degree of bias increasing as  $N_{inside}$  decreases from 50. To avoid this problem, select the magnification so that  $N_{inside}$  is  $\geq 50$ , or use a rectangular or square test figure and the counting method described in [11.5](#). Magnifications that yield  $N_{inside}$  of  $\sim 100$  and above lead to imprecision due to counting errors. A 10% relative accuracy in  $G$  will be obtained when at least 700 total grains are counted using multiple fields selected at random.

## 20. Keywords

20.1 ALA grain size; anisotropy index; area fraction; ASTM grain size number; calibration; equiaxed grains; etchant; grain boundary; grains; grain size; intercept count; intercept length; intersection count; non-equiaxed grains; twin boundaries

## ANNEXES

### (Mandatory Information)

#### A1. BASIS OF ASTM GRAIN SIZE NUMBERS

##### A1.1 Descriptions of Terms and Symbols

A1.1.1 The general term *grain size* is commonly used to designate size estimates or measurements made in several ways, employing various units of length, area, or volume. Of the various systems, only the ASTM grain size number,  $G$ , is essentially independent of the estimating system and measurement units used. The equations used to determine  $G$  from recommended measurements, as illustrated in [Fig. 6](#) and [Table 2](#) and [Table 4](#), are given in [A1.2](#) and [A1.3](#). The nominal relationships between commonly used measurements are given in [Annex A2](#). Measurements that appear in these equations, or in equations in the text, are as follows:

A1.1.1.1  $N$  = Number of grain sections counted on a known test area,  $A$ , or number of intercepts counted on a known test array of length =  $L$ , at some stated magnification,  $M$ . The average of counts on several fields is designated as  $\bar{N}$ .

A1.1.1.2 After correction for magnification,  $N_A$  is the number of grain sections per unit test area ( $\text{mm}^2$ ) at 1X;  $N_L$  is the number of grains intercepted per unit length (mm) of test lines at 1X; and  $P_L$  is the number of grain boundary intersections per unit length (mm) of test line at 1X.

A1.1.1.3  $\bar{l} = 1/N_L = 1/P_L$  where  $\bar{l}$  is the mean lineal intercept length in mm at 1X.

A1.1.1.4  $\bar{A} = 1/N_A$  where  $\bar{A}$  is the mean area of the grain sections ( $\text{mm}^2$ ) at 1X. The mean grain diameter,  $\bar{d}$ , is the square root of  $\bar{A}$ . Grain size values on Plate III are expressed in terms of  $\bar{d}$ . Note that **Table 2** lists the equivalent ASTM grain size number for each chart picture and for several different magnifications.

A1.1.1.5 The letters  $\ell$ ,  $t$  and  $p$  are used as subscripts when assessing the grain size of specimens with non-equiaxed grain structures. The three subscripts represent the principal planes for rectangular bar, plate, sheet, or strip specimens, that is, the longitudinal ( $\ell$ ), transverse ( $t$ ) and planar ( $p$ ) surfaces. They are mutually perpendicular to each other. On each plane, there are two principal directions that are perpendicular to each other (as illustrated in **Fig. 7**).

A1.1.1.6 The number of fields measured is designated by  $n$ .

A1.1.1.7 Other specific designations are defined by equations which follow.

### A1.2 Intercept Methods:

A1.2.1 Metric units,  $\bar{\ell}$  in millimetres at 100X for microscopically determined grain sizes and  $\bar{\ell}_m$  at 1X for macroscopically determined grain sizes, are used with the following equation relating  $\bar{\ell}$  or  $\bar{\ell}_m$  to  $G$ . For macroscopically determined grain sizes,  $\bar{\ell}_m$  is in mm at 100X:

$$G = 2 \log_2 \frac{\ell_0}{\bar{\ell}_m} \quad (\text{A1.1})$$

for  $G = 0$ ,  $\ell_0$  is established as 32.00 and  $\log_2 \ell_0 = 5$ .

$$G = +10.000 - 2 \log_2 \bar{\ell}_m \quad (\text{A1.2})$$

$$G = +10.0000 - 6.6439 \log_{10} \bar{\ell}_m \quad (\text{A1.3})$$

For microscopically determined grain sizes,  $\bar{\ell}$  is in millimetres at 1X and:

$$G = -3.2877 - 6.6439 \log_{10} \bar{\ell} \quad (\text{A1.4})$$

$$G = -3.2877 + 2 \log_2 \bar{N}_L \quad (\text{A1.5})$$

$$G = -3.2877 + 6.6439 \log_{10} \bar{N}_L \quad (\text{A1.6})$$

If  $\bar{P}_L$  is determined instead of  $\bar{N}_L$ , substitute  $\bar{P}_L$  for  $\bar{N}_L$  in **Eq A1.5** and **Eq A1.6**.

### A1.3 Planimetric Method:

A1.3.1 English units,  $\bar{N}_{AE}$  in number per square inches at 100X for microscopically determined grain sizes and at 1X for macroscopically determined grain sizes, are used with the following equations relating  $\bar{N}_{AE}$  to  $G$ :

$$G = 1.000 + \log_2 \bar{N}_{AE} \quad (\text{A1.7})$$

$$G = 1.000 + 3.3219 \log_{10} \bar{N}_{AE} \quad (\text{A1.8})$$

If  $\bar{N}_A$  is expressed in terms of the number of grains per square millimetres at 1X, for microscopically determined grain sizes, then:

$$G = -2.9542 + 3.3219 \log_{10} \bar{N}_A \quad (\text{A1.9})$$

## A2. EQUATIONS FOR CONVERSIONS AMONG VARIOUS GRAIN SIZE MEASUREMENTS

A2.1 *Change of Magnification*—If the apparent grain size has been observed at magnification  $M$ , but determined as if at the basic magnification  $M_b$  (100X or 1X), then the size value at the basic magnification is as follows:

### A2.1.1 Planimetric Count:

$$N_A = N_{A0} (M/M_b)^2 \quad (\text{A2.1})$$

where  $N_{A0}$  is the number of grains per unit area at magnification  $M_b$ .

### A2.1.2 Intercept Count:

$$N_i = N_{i0} (M/M_b) \quad (\text{A2.2})$$

where  $N_{i0}$  is the number of grains intercepted by the test line (the equation for  $P_i$  and  $P_{i0}$  is the same) at magnification  $M_b$ .

### A2.1.3 Any Length:

$$\bar{\ell} = \bar{\ell}_0 M_b / M \quad (\text{A2.3})$$

where  $\bar{\ell}_0$  is the mean lineal intercept at magnification  $M_b$ .

### A2.1.4 ASTM Grain Size Number:

$$G = G_0 + Q \quad (\text{A2.4})$$

where:

$$Q = 2 \log_2 (M/M_b)$$

$$\begin{aligned} &= 2 (\log_2 M - \log_2 M_b) \\ &= 6.6439 (\log_{10} M - \log_{10} M_b) \end{aligned}$$

where  $G_0$  is the apparent ASTM grain size number at magnification  $M_b$ .

### A2.1.5 Grains per $\text{mm}^2$ at 1X from grains per $\text{in.}^2$ at 100X:

$$N_A = N_{AE} (100/25.4)^2 \quad (\text{A2.5})$$

$$N_A = 15.5 N_{AE} \quad (\text{A2.6})$$

where  $N_A$  is the number of grains per  $\text{mm}^2$  at 1X and  $N_{AE}$  is the number of grains per  $\text{in.}^2$  at 100X.

A2.2 Other measurements shown in the tables may be computed from the following equations:

### A2.2.1 Area of Average Grain:

$$\bar{A} = 1/N_A \quad (\text{A2.7})$$

where  $\bar{A}$  is the average grain cross sectional area.

### A2.2.2 Intercept Width of a Circular Grain Section:

$$\bar{\ell} = \left( \frac{\pi}{4} \bar{A} \right)^{1/2} \quad (\text{A2.8})$$

The mean intercept distance for polygonal grains varies about this theoretical value, being decreased by anisotropy but



increased by a range of section sizes. The width computed by (Eq A2.8) is 0.52 % smaller than the width assigned to  $G$  by (Eq A1.4) in A1.2.1 ( $\Delta = +0.015$  ASTM No.).

A2.3 Other useful size indications are given by the following equations:

A2.3.1 The volumetric (spatial) diameter,  $\bar{D}$ , of similar size spheres in space is:

$$\bar{D} = 1.5\bar{\ell} \quad (\text{A2.9})$$

Similar relationships between  $\bar{\ell}$ , determined on the two-dimensional plane of polish, and the spatial diameter,  $\bar{D}$ , have been derived for a variety of potential grain shapes, and various assumptions about their size distribution. A number of

formulae, such as equation (Eq A2.7), have been proposed with different multiplying factors. A reasonable estimate of the spatial diameter,  $\bar{D}$ , based upon the tetrakaidecahedron shape model and a grain size distribution function (9), is:

$$\bar{D} = 1.571\bar{\ell} \quad (\text{A2.10})$$

A2.3.2 For a single phase microstructure, the grain boundary surface area per unit volume,  $S_V$ , has been shown to be an exact function of  $P_L$  or  $N_L$ :

$$S_V = 2P_L = 2N_L \quad (\text{A2.11})$$

while for a two phase microstructure, the phase boundary surface area per unit volume of the  $\alpha$  phase,  $S_{V\alpha}$ , is:

$$S_{V\alpha} = 2P_L = 4N_L \quad (\text{A2.12})$$

### A3. AUSTENITE GRAIN SIZE, FERRITIC AND AUSTENITIC STEELS

#### A3.1 Scope

A3.1.1 Because it is sometimes necessary to subject material to special treatments or techniques in order to develop certain grain characteristics prior to the estimation of grain size, the essential details of these treatments are set forth in the following sections.

#### A3.2 Establishing Austenite Grain Size

A3.2.1 *Ferritic Steels*— Unless otherwise specified, austenite grain size shall be established by one of the following procedures:

NOTE A3.1—The indications of carbon contents in the procedure headings are advisory only. Numerous methods are in use for establishing austenite grain size, and a knowledge of grain growth and grain coarsening behavior is helpful in deciding which method to use. The size of austenite grains, in any particular steel, depends primarily on the temperature to which that steel is heated and the time it is held at the temperature. It should be remembered that the atmosphere in heating may affect the grain growth at the outside of the piece. Austenite grain size is also influenced by most previous treatments to which the steel may have been subjected as, for example, austenitizing temperature, quenching, normalizing, hot working, and cold working. It is therefore advisable, when testing for austenite grain size, to consider the effects of prior or subsequent treatments, or both, on the precise piece (or typical piece) that is under consideration.

A3.2.1.1 *Correlation Procedure (Carbon and Alloy Steels)*—Test conditions should correlate with the actual heat-treatment cycle used to develop the properties for actual service. Heat the specimens at a temperature not over 50°F (28°C) above the normal heat-treating temperature and for not over 50 % more than the normal heat-treating time and under normal heat-treating atmosphere, the normal values being those mutually agreed upon. The rate of cooling depends on the method of treatment. Make the microscopical examination in compliance with Table 1.

A3.2.1.2 *Carburizing Procedure (Carbon and Alloy Steels; Carbon Generally Below 0.25 %)*—This procedure is usually referred to as the McQuaid—Ehn Test. Unless otherwise specified, carburize the specimens at 1700 ± 25°F (927 ±

14°C) for 8 h or until a case of approximately 0.050 in. (1.27 mm) is obtained. The carburizing compound must be capable of producing a hypereutectoid case in the time and at the temperature specified. Furnace cool the specimen to a temperature below the lower critical at a rate slow enough to precipitate cementite in the austenite grain boundaries of the hypereutectoid zone of the case. When cool, section the specimen to provide a fresh-cut surface, polish, and suitably etch to reveal the grain size of the hypereutectoid zone of the case. Make a microscopical examination in compliance with Table 1. While the McQuaid-Ehn test was designed for evaluating the grain growth characteristics of steels intended for carburizing applications, usually steels with <0.25 % carbon, it is frequently used to evaluate steels with higher carbon contents that will not be carburized. It must be recognized that the grain size of such steels when heat treated from austenitizing temperatures below 1700°F may be finer in size than that obtained by the McQuaid-Ehn test.

A3.2.1.3 *Mock Carburizing Procedure*—The heat treatment described in A3.2.1.2 is performed but a carburizing atmosphere is not used and the specimen must be quenched from the mock carburizing temperature at a rate fast enough to form martensite, rather than slowly cooled after carburizing. The specimen is sectioned (careful abrasive cut-off cutting is required to prevent burning), polished and etched with a reagent that will reveal the prior-austenite grain boundaries (such as saturated aqueous picric acid with a wetting agent, see Practice E407). Mock carburizing is sometimes preferred because the depth of the carburized case produced by the McQuaid-Ehn test may be quite thin with some steels. With a mock carburized specimen, all of the grains on the cross section can be examined. Problems such as banded grain size, duplex or ALA grains (see Test Methods E1181) are more easily detected with a mock carburized specimen due to the much greater surface area for examination.

A3.2.1.4 *Hypoeutectoid Steels (Carbon and Alloy Steels 0.25 to 0.60 % Carbon)*—Unless otherwise specified, heat specimens of steels with a carbon content of 0.35 % or less at

1625 ± 25°F (885 ± 14°C); heat specimens of steel with a carbon content of over 0.35 % at 1575 ± 25°F (857 ± 14°C) for a minimum of 30 min and cool in air or quench in water. The higher carbon steels in this range and alloy steels over approximately 0.40 % carbon may require an adjustment in cooling practice to outline clearly the austenite grain boundaries with ferrite. In such cases it is recommended that after holding the specimen for the required time at a hardening temperature, the temperature be reduced to approximately 1340 ± 25°F (727 ± 14°C) for 10 min, followed by water or oil quench. When cool, section the specimen to provide a fresh-cut surface, polish, and suitably etch to reveal the austenite grain size as outlined by precipitated ferrite in the grain boundaries. Make the microscopical examination in compliance with **Table 1**.

**A3.2.1.5 Oxidation Procedure (Carbon and Alloy Steels 0.25 to 0.60 % Carbon)**—Polish one of the surfaces of the specimen (approximately 400-grit or 15- $\mu$ m abrasive). Place the specimen with the polished side up in a furnace, and, unless otherwise specified, heat at 1575 ± 25°F (857 ± 14°C) for 1 h and quench in cold water or brine. Polish the quenched specimen to reveal the austenite grain size as developed in the oxidized surface. Make the microscopical examination in compliance with **Table 1**.

**A3.2.1.6 Direct Hardening Steels (Carbon and Alloy Steels; Carbon Generally Below 1.00 %)**—Unless otherwise specified, heat specimens of steels with a carbon content of 0.35 % or less at 1625 ± 25°F (885 ± 14°C); heat specimens of steels with a carbon content of over 0.35 % at 1575 ± 25°F (857 ± 14°C) for sufficient time and quench at a rate to produce full hardening. Polish the quenched specimen and etch to reveal the martensitic structure. Tempering for 15 min at 450 ± 25°F (232 ± 14°C) prior to etching improves the contrast. Make the microscopical examination in compliance with **Table 1**.

**A3.2.1.7 Hypereutectoid Steels (Carbon and Alloy Steels; Carbon Generally Over 1.00 %)**—Use a specimen approximately 1 in. (25.4 mm) in diameter or 1 in. square for this test. Unless otherwise specified, heat the specimen at 1500 ± 25°F (816 ± 14°C) for a minimum of 30 min, and furnace cool to a temperature below the lower critical temperature at a rate slow enough to precipitate cementite in the austenite grain boundaries. When cool, section the specimen to provide a fresh-cut surface, polish, and suitably etch to reveal the austenite grain size as outlined by precipitated cementite in the grain boundaries. Make the microscopical examination in compliance with **Table 1**.

**A3.2.2 Austenitic Steels**—With austenitic materials, the actual grain size of the metal has been established by prior heat-treatment.

### A3.3 Revealing the Grain Size

**A3.3.1 Ferritic Steels**—For revealing austenite grain size the following methods (see **Note A3.1**) are generally used:

**A3.3.1.1 Outlining the Grains with Cementite**—In the hypereutectoid zone of a carburizing (McQuaid—Ehn test) procedure or in hypereutectoid steels cooled from the austenitic condition, the austenite grain size is outlined by the cementite which precipitated in the grain boundaries. It is therefore

possible to rate the grain size by etching the micrographic specimen with a suitable etchant, such as nital, picral, or alkaline sodium picrate. (See Practice **E407**.)

**A3.3.1.2 Outlining the Grains with Ferrite**—In the hypoeutectoid zone of a carburized specimen, the austenite grain size is outlined by the ferrite that precipitated in the grain boundaries. Ferrite similarly outlines the former austenite grains in a medium-carbon steel (approximately 0.50 % carbon), when it has been cooled slowly from the austenite range. In low-carbon steels (approximately 0.20 % carbon), cooling slowly from the austenite range to room temperature, the amount of ferrite is so large that the former austenite grain size is masked; in this case, the steel may be cooled slowly to an intermediate temperature, to allow only a small amount of ferrite to precipitate, followed by quenching in water; an example would be a piece previously heated to 1675°F (913°C), transferred to a furnace at between 1350 to 1450°F (732 to 788°C), held at this temperature for perhaps 3 to 5 min, and then quenched in water; the austenite grain size would be revealed by small ferrite grains outlining low-carbon martensite grains.

**A3.3.1.3 Outlining the Grains by Oxidation**—The oxidation method depends on the fact that when steels are heated in an oxidizing atmosphere, oxidation takes place in part preferentially along the grain boundaries. A common procedure, therefore, is to polish the test specimen to a metallographic polish, heat it in air at the desired temperature for the desired length of time, and then repolish the specimen lightly so as merely to remove scale; whereupon the austenite grain boundaries are visible as outlined by oxide.

**A3.3.1.4 Outlining Martensite Grains with Fine Pearlite**—A method applicable particularly to eutectoid steels, which cannot be judged so readily by some other methods, is either to harden a bar of such a size that it is fully hardened at the outside but not quite fully hardened in the interior, or to employ a *gradient quench* in which the heated piece is for a portion of its length immersed in water and therefore fully hardened, the remainder of the piece projecting above the quenching bath, being therefore not hardened. With either method there will be a small zone which is almost but not quite fully hardened. In this zone, the former austenite grains will consist of martensite grains surrounded by small amounts of fine pearlite, thus revealing the grain size. These methods are also applicable to steels somewhat lower and higher than the eutectoid composition.

**A3.3.1.5 Etching of Martensite Grains**—The former austenite grain size may be revealed in steels fully hardened to martensite by using an etching reagent that develops contrast between the martensite grains. Tempering for 15 min at 450°F (232°C) prior to etching distinctly improves the contrast. A reagent that has been recommended is 1 g of picric acid, 5 mL of HCl (sp gr 1.19), and 95 mL of ethyl alcohol. An alternate approach is to use an etchant that reveals the prior-austenite grain boundaries preferentially. Many etchants have been developed for this purpose (see Practice **E407** and standard text books). The most successful consists of saturated aqueous picric acid containing a wetting agent, usually sodium tridecylbenzene sulfonate (the dodecyl version also works well). Specimens should be in the as-quenched condition or tempered

not above about 1000°F. Success with this etchant depends upon the presence of phosphorus in the alloy ( $\geq 0.005\%$  P required). Results may be enhanced by tempering the steel between 850 and 900°F for 8 h or more to drive phosphorus to the grain boundaries. For steels with substantial alloy additions, it may be necessary to add a few drops of hydrochloric acid to the etchant (per 100 mL of etchant). Etching usually takes at least 5 min. The etchant will attack sulfide inclusions. Lightly re-polishing the specimen on a stationary wheel to remove some of the unimportant background detail may make it easier to see the grain boundaries.

**A3.3.2 Austenitic Steels**—For revealing the grain size in austenitic materials, a suitable etching technique shall be used to develop grain size. Recognizing that twinning tends to confuse reading of grain size, the etching should be such that a minimum amount of twinning is evident.

**A3.3.2.1 Stabilized Material**—The specimen, as the anode, may be electrolytically etched in a water solution composed of 60 % concentrated nitric acid by volume, at ambient temperature. To minimize the appearance of twinning, a low voltage (1 to 1½ V) should be used. This etchant is also recommended for revealing ferrite grain boundaries in ferritic stainless steels and is used identically.

**A3.3.2.2 Unstabilized Material**—The grain boundary may be developed through precipitation of carbides by heating within the sensitizing temperature range, 482 to 704°C (900 to 1300°F). Any suitable carbide-revealing etchant should be used.

### A3.4 Reporting the Grain Size

**A3.4.1 Ferritic Steels**—Duplex, or mixed grain-sized structure (see Test Methods E1181) when observed, shall be reported with two representative ranges of grain size numbers. Whenever heat-treatments other than the carburizing (McQuaid—Ehn test) procedure are employed to develop austenite grain size, a complete report shall be made which includes:

A3.4.1.1 Temperature used in establishing the grain size,

A3.4.1.2 Time at temperature used in establishing the grain size,

A3.4.1.3 Method of revealing grain size, and

A3.4.1.4 Grain size.

**A3.4.2 Austenitic Steels**—In determining the size of austenitic grains, the twin boundaries within a grain shall not be counted.

## A4. FRACTURE GRAIN SIZE METHOD<sup>8</sup>

**A4.1** The fracture grain size method, developed by Arpi (10), and Shepherd (2), employs a graded series of ten fractured specimens to estimate the prior-austenite grain size of steel specimens (see Footnote 11 for applicable materials) by comparison. Carburized cases of carbon and alloy steels may also be evaluated for prior-austenite grain size by this method (but not the low-carbon core).

**A4.2** The ten fractured specimens are numbered from one to ten where the numbers correspond to ASTM grain size numbers. The sample to be rated is fractured, usually transverse to the hot working direction, and the fracture is compared to the ten test fractures of the Shepherd series.<sup>9</sup> The fracture appearance of the specimen is rated to the nearest whole number of the standard, but interpolation to one-half numbers is permitted. It is also possible to rate duplex conditions when the fracture exhibits two different fracture patterns.

**A4.3** Specimens can be fractured by striking the free end, while restraining the other end, or by three-point bending using a press, or a tensile machine (loaded in compression) or any other suitable method. Notching of specimens or refrigeration

prior to fracturing, or both, helps to ensure a flat fracture. For further information see Vander Voort (11).

**A4.4** The specimen to be rated must be predominantly martensitic, although large amounts of retained austenite do not invalidate the results. Appreciable amounts of residual carbide are also permitted. However, diffusion controlled transformation products, such as bainite, pearlite, or ferrite, if present in amounts more than a few percent, change the nature of the fracture appearance and invalidate fracture grain size ratings. Excessive tempering of martensitic tool steel structures also alters the fracture appearance and invalidates fracture grain size ratings. Ratings are most accurate for as-quenched or lightly tempered specimens. Flat, brittle fractures are desired to obtain the best accuracy.

**A4.5** Studies have shown that fracture grain size ratings of fully hardened, as-quenched tool steels correlate well with microscopically measured prior-austenite grain size ratings. For most tool steels, the fracture grain size rating will be within  $\pm 1$  unit of the microscopically determined prior-austenite grain size number, *G*.

**A4.6** The fracture grain size method cannot be used to rate grain sizes finer than ten. Fractures of specimens with prior-austenite grain sizes finer than ten cannot be discriminated by eye and will be rated as if they were a ten grain size. Fractures coarser than a grain size number of one will appear to be coarser than one but cannot be accurately rated by this method.

<sup>8</sup> This method is applicable only to high-hardness, brittle steels with a predominantly martensite microstructure, such as tool steels, high-carbon steels and martensitic stainless steels, and should be done with the specimen in the as-quenched or lightly tempered condition.

<sup>9</sup> For those individuals who do not possess a Shepherd standard series, a photographic reproduction is available from ASTM Headquarters. Order ADJE011224.

## A5. REQUIREMENTS FOR WROUGHT COPPER AND COPPER ALLOYS

A5.1 For wrought copper and copper alloy products under the jurisdiction of Committee B05 on Copper and Copper Alloys, it is mandatory that the following procedures be used:

A5.1.1 The specimen shall be prepared in accordance with Practice E3.

A5.1.2 The specimen used for the comparison method shall be contrast etched, and compared with Plate III, or, if given a flat etch, compared with Plate II.

A5.1.3 The grain size shall be expressed as the average grain diameter in mm; for example, 0.025 mm average grain diameter. The meaning of this expression is the diameter of the average cross section of grains lying in the plane of the metal being examined.

A5.1.4 Mixed grain sizes (see Test Methods E1181) are sometimes encountered, particularly in hot-worked metal. These shall be expressed by giving the estimated area percentages occupied by the two ranges of sizes. For example, 50 % of 0.015 mm; and 50 % of 0.070 mm; or, if a range exists, 40 % of 0.010 to 0.020 mm; and 60 % of 0.090 to 0.120 mm.

A5.1.5 For determining compliance of requirements for grain size with the specified limits, the estimated value shall be rounded in accordance with:

Grain Size	Calculated or Observed Value to Which Grain Size Should be Rounded
Up to 0.055 mm, incl	to the nearest multiple of 0.005 mm
Over 0.055 mm	to the nearest 0.010 mm

## A6. APPLICATION TO SPECIAL SITUATIONS

A6.1 Numerous specific practices for grain size measurement have become established in various segments of the metals and materials industries. The present listing of standard methods is not intended to imply that any such specific practice should be abandoned when experience has shown that practice to be adequate for the intended application. It is, however, strongly recommended that the statistical procedure of Section 15 be applied to the data from these traditional practices in order to ensure that they yield a confidence limit that is adequate for current requirements.

A6.2 It is characteristic of many special practices that they report a numerical result that is not conveniently related to commonly used size scales such as are shown in Table 4. Continued usage of the customary numbers is justified on the grounds that either they have inherent meaning in their own community, or that they have acquired meaning through long usage. It is, however, strongly recommended that such measurements be made comprehensible to a wider audience first by reexpression on one of the preferred metric scales (as used in Table 4), and then by conversion to the corresponding ASTM grain size numbers. Where the original measurements represent some form of intercept or planimetric count it may be said that the ASTM grain size number has in fact been determined. Where the original data are of a different nature, it should be stated that the measurement is equivalent to ASTM grain size

No. “x”. Conversions may be made either through Table 4 or through the relations shown in Annex A1 and Annex A2.

### A6.3 Examples:

A6.3.1 *Example 1*—The Snyder and Graff procedure (12) remains in general usage for estimating the austenitic grain size of tool steels. This is a specific version of the Heyn intercept method (see 13.1) in which the reported number is the average number of intercepts with a 5-in. (127-mm) test line applied to an image at 1000X. This count is more immediately useful than the ASTM grain size number itself, as important changes of quality are associated with a change of about two ASTM size numbers, which difference is not well resolved on the logarithmic size scale or by comparison or planimetric methods. The Snyder and Graff size number will become meaningful to others by multiplying by the factor 7.874 to yield  $N_L$  per millimetre, after which Table 4 will indicate, for example, that S&G No. 15 is ASTM grain size No. 10.5. Furthermore, as the precision of this practice does not attain 2 % of the count, the 5-in. (127-mm) test line could be replaced by a 125-mm test line without invalidating past records, making the multiplier 8.0, whereupon the total intercept count on eight test lines equals  $N_L$  directly. The confidence limit evaluation in Section 15 can be applied to single test lines, or to totals on fixed numbers of lines in each local area.

**X1. RESULTS OF INTERLABORATORY GRAIN SIZE DETERMINATIONS<sup>10</sup>**

X1.1 This interlaboratory test program was conducted to develop precision and bias estimates for the measurement of grain size by the chart comparison method, by the planimetric method, and by the intercept method (13).

**X1.2 Procedure**

X1.2.1 Photomicrographs (8 by 10 in.) of two different ferritic stainless steels, four of one specimen at different magnifications and three of the other specimen at different magnifications, were rated for grain size using the chart method with Plate I and by the planimetric and intercept methods. A drawing of the grain boundaries of a specimen of austenitic Hadfield's manganese steel, with a grain contrast etch, was also evaluated by all three methods. A number of other micrographs were rated only by the comparison method. In each case, the grain boundaries were clearly and fully delineated.

X1.2.2 For the planimetric method, each rater was given an 8 by 10 in. clear plastic template with five 79.8 mm diameter test circles and a grease pencil. For the intercept method, each rater was given a single three-circle template.

X1.2.3 For the planimetric method, the template was dropped onto the photograph and taped down to prevent movement. Because the circles grid and the micrograph were nearly the same size, grid placement should be rather consistent between raters. For the intercept method, the raters dropped their grid onto the micrograph five times at random. It was assumed that this difference in placement method would reduce the variability of the planimetric method relative to the intercept method.

**X1.3 Results**

X1.3.1 Figs. X1.1 and X1.2 show the grain size ratings for the two ferritic stainless steels, identified as Series A and B, as a function of the magnification of the micrographs, for the planimetric and intercept methods. Three people also made image analysis measurements of the images. As can be seen, the tightest spread occurred, for both sets of micrographs, at a

magnification of about 400X where the average grain count per planimetric measurement was about 30 to 35 and the average number of intercepts or intercepts was about 40 to 50 per three-circle application.

X1.3.2 Figs. X1.3 and X1.4 show how the percent relative accuracy of the measurements varied with the number of grains counted, Fig. X1.3, and with the number of intercepts or intersections counted, Fig. X1.4. All of the measurement data are included. Note that a percent RA of 10 %, or less, is obtained when about 700 or more grains are counted by the planimetric method and when about 400 grain boundary intersections or grain intercepts are counted for the intercept method. Because the grains must be marked off on the template as they are counted to ensure counting accuracy in the planimetric method, while marking is not needed for the intercept method, it is clear that the intercept method is a more efficient method.

X1.3.3 Tables X1.1 and X1.2 list the results of the analysis of repeatability and reproducibility according to Practice E691. In general, the intercept method outperformed the planimetric method in this study.

X1.3.4 Fig. X1.5 shows a plot of the planimetric versus the intercept grain size rating for each micrograph by each rater. Note that the data are scattered at random around the one-to-one trend line. This indicates that there was no bias in the grain size measurements by either method.

X1.3.5 Each micrograph that was rated for grain size could be considered in two ways, first as a rating for the true magnification of the micrograph and second for a rating as if the micrograph was at 100X. For evaluation of the comparison method, it was assumed that each micrograph was at 100X. The intercept and planimetric data were also computed using this assumption. Figs. X1.6 and X1.7 show plots of the chart comparison ratings versus the planimetric and intercept ratings, assuming all micrographs were at 100X. Note that the data are not scattered at random around the one-to-one trend line. This clearly shows that bias is occurring in the chart comparison ratings, which were typically 0.5 to 1 *G* unit lower, that is, coarser, than the planimetric or intercept measurements. The source of this bias is under study.

<sup>10</sup> Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:E04-1005.

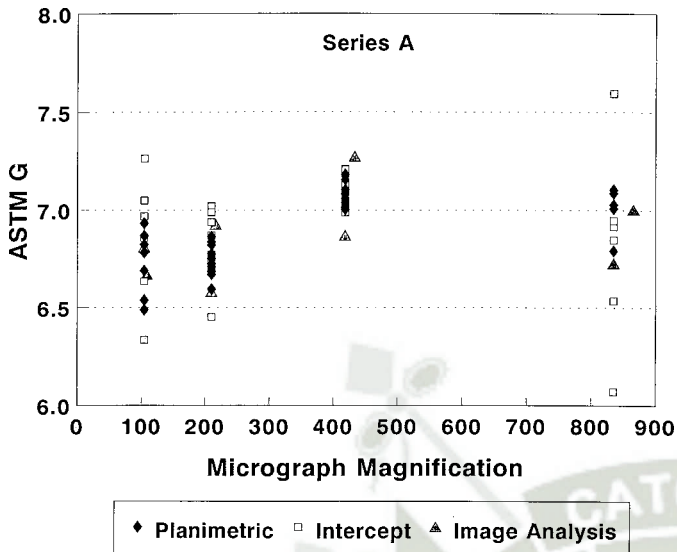


FIG. X1.1 Grain Size Measurements for the Series A Ferritic Stainless Steel Specimens

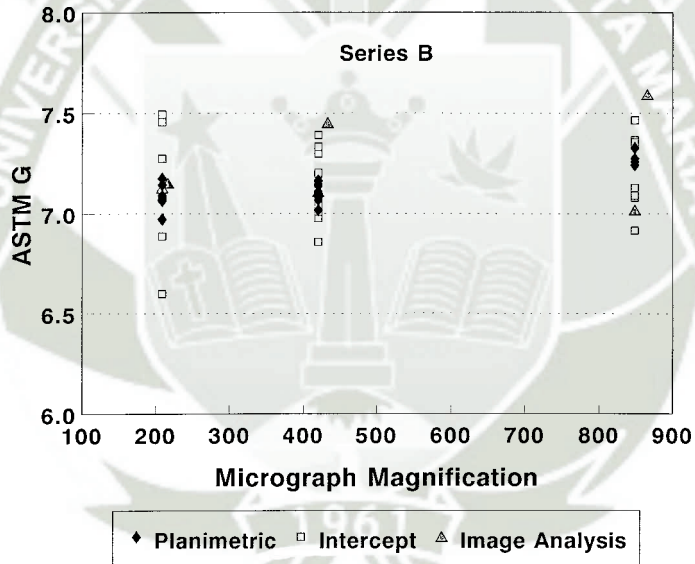
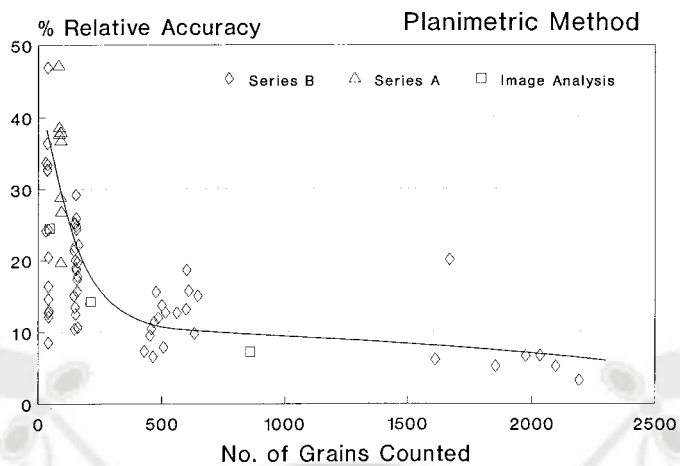
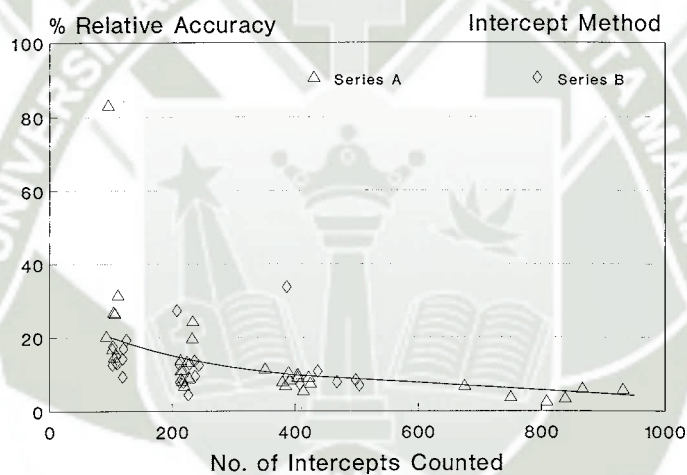


FIG. X1.2 Grain Size Measurements for the Series B Ferritic Stainless Steel Specimens



NOTE 1—The image analysis results for the same micrographs.

FIG. X1.3 Relationship Between the Number of Grains Counted and the Percent Relative Accuracy for the Planimetric Method



NOTE 1—The image analysis results for the same micrographs.

FIG. X1.4 Relationship Between the Number of Intercepts or Intersections Counted and the Percent Relative Accuracy for the Intercept Method

TABLE X1.1 Results of ASTM Grain Size Round Robin (Planimetric Method)

Image	No./sq. mm	ASTM G	Average No.	Repeatability 95 % CL	Reproducibility 95 % CL	Repeatability % RA	Reproducibility % RA
A1	846.64	6.77	1918.0	106.11	266.56	12.53	31.49
A2	831.61	6.75	474.5	209.68	239.88	25.21	28.85
A3	1046.98	7.08	150.5	499.42	489.10	47.70	46.72
A4	978.49	6.98	35.5	785.07	765.18	80.23	78.20
B1	1054.12	7.09	608.5	342.21	344.35	32.46	32.67
B2	1069.41	7.11	152.5	464.60	452.27	43.44	42.29
B3	1184.01	7.26	41.5	435.21	403.98	36.76	34.12

TABLE X1.2 Results of ASTM Grain Size Round Robin (Intercept Method)

Image	$\bar{r}$ ( $\mu\text{m}$ )	ASTM $G$	Average Intercepts	Repeatability 95 % CL	Reproducibility 95 % CL	Repeatability % RA	Reproducibility % RA
A1	29.9	6.84	811.5	3.25	9.37	10.87	31.35
A2	29.8	6.85	396.0	5.65	6.33	18.96	21.24
A3	27.2	7.11	222.5	8.28	8.16	30.43	30.00
A4	29.0	6.93	102.0	14.90	16.46	51.37	56.77
B1	26.1	7.23	450.0	4.96	7.96	19.01	30.51
B2	26.7	7.17	223.5	6.19	7.01	23.20	26.26
B3	26.6	7.18	113.0	8.84	9.86	33.24	37.08

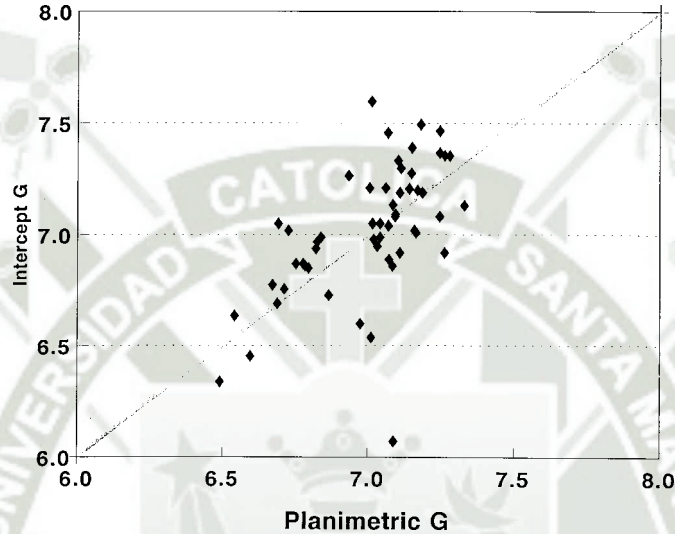
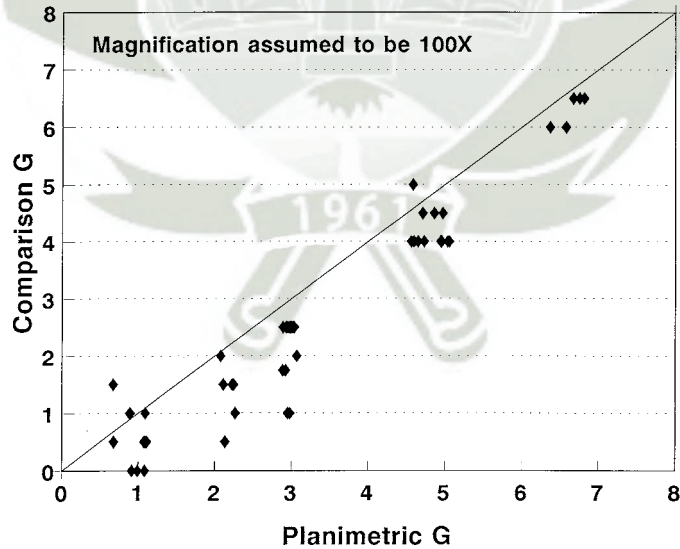


FIG. X1.5 Comparison of the Grain Size Measurements for Each Micrograph by Each Operator by the Planimetric and Intercept Methods



NOTE 1—Chart plots by each rater and assumes the micrographs are at 100X magnification. The data generally fall to one side of the one to one trend line indicating a bias.

FIG. X1.6 Plot of the Comparison Chart Grain Size Ratings for Each Micrograph Versus the Planimetric Method Rating for Each Micrograph



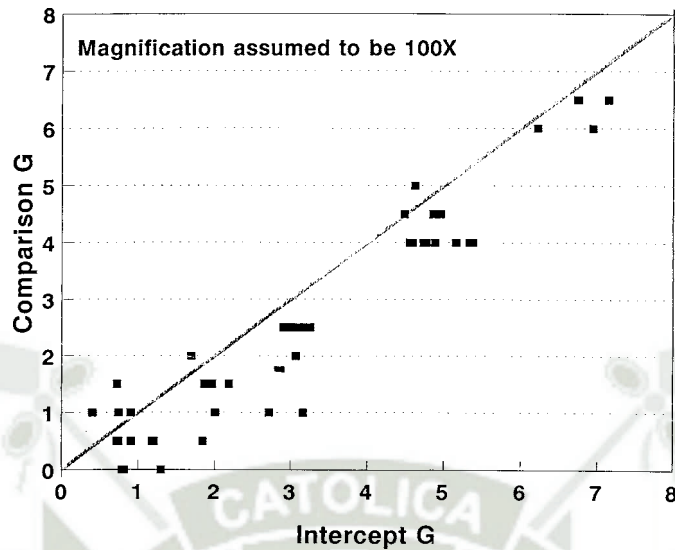


FIG. X1.7 Plot of the Comparison Chart Grain Size Ratings for Each Micrograph Versus the Intercept Method Rating for Each Micrograph

## X2. REFERENCED ADJUNCTS

X2.1 The following is a complete and updated list of adjuncts referenced in Test Methods E112. All adjuncts are available from ASTM.

Adjunct:	Order Adjunct:	Adjunct:	Order Adjunct:
Combination of 18 Components	ADJE112CS	Transparency, Grain Size 1.0	ADJE11208T
Combination of Plates I, II, III, and IV	ADJE112PS	Transparency, Grain Size 1.5	ADJE11209T
Plate I only	ADJE11201P	Transparency, Grain Size 2.0	ADJE11210T
Plate II only	ADJE11202P	Transparency, Grain Size 2.5	ADJE11211T
Plate III only	ADJE11203P	Transparency, Grain Sizes 3.0, 3.5, and 4.0	ADJE11212T
Plate IV only	ADJE11204P	Transparency, Grain Sizes 4.5, 5.0, and 5.5	ADJE11213T
Combination Transparencies, (Plate I) 00 through 10	ADJE112TS	Transparency, Grain Sizes 6.0, 6.5, and 7.0	ADJE11214T
Transparency, Grain Size 00	ADJE11205T	Transparency, Grain Sizes 7.5, 8.0, and 8.5	ADJE11215T
Transparency, Grain Size 0	ADJE11206T	Transparency, Grain Sizes 9.0, 9.5, and 10.0	ADJE11216T
Transparency, Grain Size 0.5	ADJE11207T	Adjunct:	Order ADJ:
		Fig. 5 only	E11217F
		Shepherd Series Reproduction	Order ADJ:
			ADJE011224

## REFERENCES

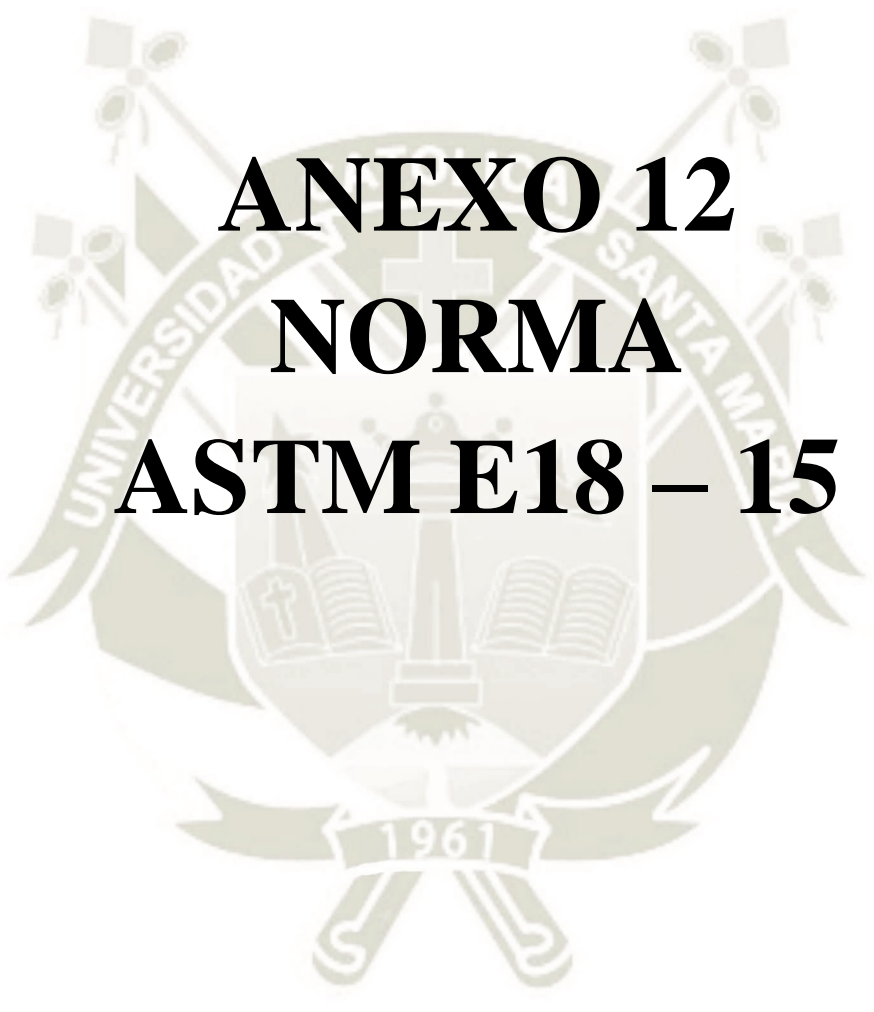
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**ANEXO 12**  
**NORMA**  
**ASTM E18 – 15**



# Standard Test Methods for Rockwell Hardness of Metallic Materials<sup>1,2</sup>

This standard is issued under the fixed designation E18; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

*This standard has been approved for use by agencies of the U.S. Department of Defense.*

## 1. Scope\*

1.1 These test methods cover the determination of the Rockwell hardness and the Rockwell superficial hardness of metallic materials by the Rockwell indentation hardness principle. This standard provides the requirements for Rockwell hardness machines and the procedures for performing Rockwell hardness tests.

1.2 This standard includes additional requirements in annexes:

Verification of Rockwell Hardness Testing Machines	Annex A1
Rockwell Hardness Standardizing Machines	Annex A2
Standardization of Rockwell Indenters	Annex A3
Standardization of Rockwell Hardness Test Blocks	Annex A4
Guidelines for Determining the Minimum Thickness of a Test Piece	Annex A5
Hardness Value Corrections When Testing on Convex Cylindrical Surfaces	Annex A6

1.3 This standard includes nonmandatory information in appendixes which relates to the Rockwell hardness test.

List of ASTM Standards Giving Hardness Values Corresponding to Tensile Strength	Appendix X1
Examples of Procedures for Determining Rockwell Hardness Uncertainty	Appendix X2

1.4 *Units*—At the time the Rockwell hardness test was developed, the force levels were specified in units of kilograms-force (kgf) and the indenter ball diameters were specified in units of inches (in.). This standard specifies the units of force and length in the International System of Units (SI); that is, force in Newtons (N) and length in millimeters (mm). However, because of the historical precedent and continued common usage, force values in kgf units and ball diameters in inch units are provided for information and much of the discussion in this standard refers to these units.

1.5 The test principles, testing procedures, and verification procedures are essentially identical for both the Rockwell and

Rockwell superficial hardness tests. The significant differences between the two tests are that the test forces are smaller for the Rockwell superficial test than for the Rockwell test. The same type and size indenters may be used for either test, depending on the scale being employed. Accordingly, throughout this standard, the term Rockwell will imply both Rockwell and Rockwell superficial unless stated otherwise.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

## 2. Referenced Documents

### 2.1 ASTM Standards:<sup>3</sup>

- A370 Test Methods and Definitions for Mechanical Testing of Steel Products
- A623 Specification for Tin Mill Products, General Requirements
- A623M Specification for Tin Mill Products, General Requirements [Metric]
- B19 Specification for Cartridge Brass Sheet, Strip, Plate, Bar, and Disks
- B36/B36M Specification for Brass Plate, Sheet, Strip, and Rolled Bar
- B96/B96M Specification for Copper-Silicon Alloy Plate, Sheet, Strip, and Rolled Bar for General Purposes and Pressure Vessels
- B103/B103M Specification for Phosphor Bronze Plate, Sheet, Strip, and Rolled Bar
- B121/B121M Specification for Leaded Brass Plate, Sheet, Strip, and Rolled Bar
- B122/B122M Specification for Copper-Nickel-Tin Alloy, Copper-Nickel-Zinc Alloy (Nickel Silver), and Copper-Nickel Alloy Plate, Sheet, Strip, and Rolled Bar
- B130 Specification for Commercial Bronze Strip for Bullet Jackets
- B134/B134M Specification for Brass Wire

<sup>1</sup> These test methods are under the jurisdiction of ASTM Committee E28 on Mechanical Testing and are the direct responsibility of Subcommittee E28.06 on Indentation Hardness Testing.

Current edition approved Feb. 1, 2015. Published March 2015. Originally approved in 1932. Last previous edition approved in 2014 as E18 – 14a. DOI: 10.1520/E0018-15.

<sup>2</sup> In this test method, the term Rockwell refers to an internationally recognized type of indentation hardness test as defined in Section 3, and not to the hardness testing equipment of a particular manufacturer.

<sup>3</sup> For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

\*A Summary of Changes section appears at the end of this standard

**B152/B152M** Specification for Copper Sheet, Strip, Plate, and Rolled Bar

**B370** Specification for Copper Sheet and Strip for Building Construction

**E29** Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

**E92** Test Method for Vickers Hardness of Metallic Materials (Withdrawn 2010)<sup>4</sup>

**E140** Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, Scleroscope Hardness, and Leeb Hardness

**E384** Test Method for Knoop and Vickers Hardness of Materials

**E691** Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

2.2 *American Bearings Manufacturer Association Standard:*

**ABMA 10-1989** Metal Balls<sup>5</sup>

2.3 *ISO Standards:*

**ISO 6508-1** Metallic Materials—Rockwell Hardness Test—Part 1: Test Method (scales A, B, C, D, E, F, G, H, K, N, T)<sup>6</sup>

**ISO/IEC 17011** Conformity Assessment—General Requirements for Accreditation Bodies Accrediting Conformity Assessment Bodies<sup>6</sup>

**ISO/IEC 17025** General Requirements for the Competence of Testing and Calibration Laboratories<sup>6</sup>

2.4 *Society of Automotive Engineers (SAE) Standard:*

**SAE J417** Hardness Tests and Hardness Number Conversions<sup>7</sup>

### 3. Terminology and Equations

3.1 *Definitions:*

3.1.1 *calibration*—determination of the values of the significant parameters by comparison with values indicated by a reference instrument or by a set of reference standards.

3.1.2 *verification*—checking or testing to assure conformance with the specification.

3.1.3 *standardization*—to bring in conformance to a known standard through verification or calibration.

3.1.4 *Rockwell hardness test*—an indentation hardness test using a verified machine to force a diamond spheroconical indenter or tungsten carbide (or steel) ball indenter, under specified conditions, into the surface of the material under test, and to measure the difference in depth of the indentation as the force on the indenter is increased from a specified preliminary test force to a specified total test force and then returned to the preliminary test force.

<sup>4</sup> The last approved version of this historical standard is referenced on [www.astm.org](http://www.astm.org).

<sup>5</sup> Available from American Bearing Manufacturers Association (ABMA), 2025 M Street, NW, Suite 800, Washington, DC 20036.

<sup>6</sup> Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, <http://www.ansi.org>.

<sup>7</sup> Available from Society of Automotive Engineers (SAE), 400 Commonwealth Dr., Warrendale, PA 15096-0001, <http://www.sae.org>.

3.1.5 *Rockwell superficial hardness test*—same as the Rockwell hardness test except that smaller preliminary and total test forces are used with a shorter depth scale.

3.1.6 *Rockwell hardness number*—a number derived from the net increase in the depth of indentation as the force on an indenter is increased from a specified preliminary test force to a specified total test force and then returned to the preliminary test force.

3.1.7 *Rockwell hardness machine*—a machine capable of performing a Rockwell hardness test and/or a Rockwell superficial hardness test and displaying the resulting Rockwell hardness number.

3.1.7.1 *Rockwell hardness testing machine*—a Rockwell hardness machine used for general testing purposes.

3.1.7.2 *Rockwell hardness standardizing machine*—a Rockwell hardness machine used for the standardization of Rockwell hardness indenters, and for the standardization of Rockwell hardness test blocks. The standardizing machine differs from a regular Rockwell hardness testing machine by having tighter tolerances on certain parameters.

3.2 *Equations:*

3.2.1 The average  $\bar{H}$  of a set of  $n$  hardness measurements  $H_1, H_2, \dots, H_n$  is calculated as:

$$\bar{H} = \frac{H_1 + H_2 + \dots + H_n}{n} \quad (1)$$

3.2.2 The error  $E$  in the performance of a Rockwell hardness machine at each hardness level, relative to a standardized scale, is determined as:

$$E = \bar{H} - H_{STD} \quad (2)$$

where:

$\bar{H}$  = average of  $n$  hardness measurements  $H_1, H_2, \dots, H_n$  made on a standardized test block as part of a performance verification, and

$H_{STD}$  = certified average hardness value of the standardized test block.

3.2.3 The *repeatability*  $R$  in the performance of a Rockwell hardness machine at each hardness level, under the particular verification conditions, is estimated by the range of  $n$  hardness measurements made on a standardized test block as part of a performance verification, defined as:

$$R = H_{max} - H_{min} \quad (3)$$

where:

$H_{max}$  = highest hardness value, and

$H_{min}$  = lowest hardness value.

### 4. Significance and Use

4.1 The Rockwell hardness test is an empirical indentation hardness test that can provide useful information about metallic materials. This information may correlate to tensile strength, wear resistance, ductility, and other physical characteristics of metallic materials, and may be useful in quality control and selection of materials.

4.2 Rockwell hardness tests are considered satisfactory for acceptance testing of commercial shipments, and have been used extensively in industry for this purpose.

4.3 Rockwell hardness testing at a specific location on a part may not represent the physical characteristics of the whole part or end product.

4.4 Adherence to this standard test method provides traceability to national Rockwell hardness standards except as stated otherwise.

**5. Principles of Test and Apparatus**

5.1 *Rockwell Hardness Test Principle*—The general principle of the Rockwell indentation hardness test is illustrated in Fig. 1. The test is divided into three steps of force application and removal.

*Step 1*—The indenter is brought into contact with the test specimen, and the preliminary test force  $F_0$  is applied. After holding the preliminary test force for a specified dwell time, the baseline depth of indentation is measured.

*Step 2*—The force on the indenter is increased at a controlled rate by the additional test force  $F_1$  to achieve the total test force  $F$ . The total test force is held for a specified dwell time.

*Step 3*—The additional test force is removed, returning to the preliminary test force. After holding the preliminary test force for a specified dwell time, the final depth of indentation is measured. The Rockwell hardness value is derived from the difference  $h$  in the final and baseline indentation depths while under the preliminary test force. The preliminary test force is removed and the indenter is removed from the test specimen.

5.1.1 There are two general classifications of the Rockwell test: the Rockwell hardness test and the Rockwell superficial hardness test. The significant difference between the two test classifications is in the test forces that are used. For the Rockwell hardness test, the preliminary test force is 10 kgf (98 N) and the total test forces are 60 kgf (589 N), 100 kgf (981 N), and 150 kgf (1471 N). For the Rockwell superficial hardness test, the preliminary test force is 3 kgf (29 N) and the total test forces are 15 kgf (147 N), 30 kgf (294 N), and 45 kgf (441 N).

5.1.2 Indenters for the Rockwell hardness test include a diamond spheroconical indenter and tungsten carbide ball indenters of specified diameters.

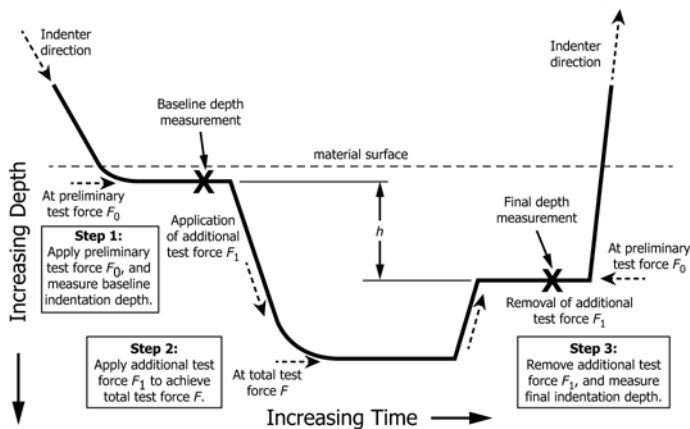


FIG. 1 Rockwell Hardness Test Method (Schematic Diagram)

5.1.2.1 Steel indenter balls may be used only for testing thin sheet tin mill products specified in Specifications A623 and A623M using the HR15T and HR30T scales with a diamond spot anvil. Testing of this product may give significantly differing results using a tungsten carbide ball as compared to historical test data using a steel ball.

NOTE 1—Previous editions of this standard have stated that the steel ball was the standard type of Rockwell indenter ball. The tungsten carbide ball is considered the standard type of Rockwell indenter ball. The use of tungsten carbide balls provide an improvement to the Rockwell hardness test because of the tendency of steel balls to flatten with use, which results in an erroneously elevated hardness value. The user is cautioned that Rockwell hardness tests comparing the use of steel and tungsten carbide balls have been shown to give different results. For example, depending on the material tested and its hardness level, Rockwell B scale tests using a tungsten carbide ball indenter have given results approximately one Rockwell point lower than when a steel ball indenter is used.

5.1.3 The Rockwell hardness scales are defined by the combinations of indenter and test forces that may be used. The standard Rockwell hardness scales and typical applications of the scales are given in Tables 1 and 2. Rockwell hardness values shall be determined and reported in accordance with one of these standard scales.

5.2 *Calculation of the Rockwell Hardness Number*—During a Rockwell test, the force on the indenter is increased from a preliminary test force to a total test force, and then returned to the preliminary test force. The difference in the two indentation depth measurements, while under the preliminary test force, is measured as  $h$  (see Fig. 1).

5.2.1 The unit measurement for  $h$  is mm. From the value of  $h$ , the Rockwell hardness number is derived. The Rockwell hardness number is calculated as:

5.2.1.1 For scales using a diamond spheroconical indenter (see Tables 1 and 2):

$$\text{Rockwell Hardness} = 100 - \frac{h}{0.002} \tag{4}$$

$$\text{Rockwell Superficial Hardness} = 100 - \frac{h}{0.001} \tag{5}$$

where  $h$  is in mm.

5.2.1.2 For scales using a ball indenter (see Tables 1 and 2):

$$\text{Rockwell Hardness} = 130 - \frac{h}{0.002} \tag{6}$$

$$\text{Rockwell Superficial Hardness} = 100 - \frac{h}{0.001} \tag{7}$$

where  $h$  is in mm.

5.2.2 The Rockwell hardness number is an arbitrary number, which, by method of calculation, results in a higher number for harder material.

5.2.3 Rockwell hardness values shall not be designated by a number alone because it is necessary to indicate which indenter and forces have been employed in making the test (see Tables 1 and 2). Rockwell hardness numbers shall be quoted with a scale symbol representing the indenter and forces used. The hardness number is followed by the symbol HR and the scale designation. When a ball indenter is used, the scale designation

TABLE 1 Rockwell Hardness Scales

Scale Symbol	Indenter	Total Test Force, kgf	Dial Figures	Typical Applications of Scales
B	1/16-in. (1.588-mm) ball	100	red	Copper alloys, soft steels, aluminum alloys, malleable iron, etc.
C	diamond	150	black	Steel, hard cast irons, pearlitic malleable iron, titanium, deep case hardened steel, and other materials harder than B100.
A	diamond	60	black	Cemented carbides, thin steel, and shallow case-hardened steel.
D	diamond	100	black	Thin steel and medium case hardened steel, and pearlitic malleable iron.
E	1/8-in. (3.175-mm) ball	100	red	Cast iron, aluminum and magnesium alloys, bearing metals.
F	1/16-in. (1.588-mm) ball	60	red	Annealed copper alloys, thin soft sheet metals.
G	1/16-in. (1.588-mm) ball	150	red	Malleable irons, copper-nickel-zinc and cupro-nickel alloys. Upper limit G92 to avoid possible flattening of ball.
H	1/8-in. (3.175-mm) ball	60	red	Aluminum, zinc, lead.
K	1/8-in. (3.175-mm) ball	150	red	Bearing metals and other very soft or thin materials. Use smallest ball and heaviest load that does not give anvil effect.
L	1/4-in. (6.350-mm) ball	60	red	
M	1/4-in. (6.350-mm) ball	100	red	
P	1/4-in. (6.350-mm) ball	150	red	
R	1/2-in. (12.70-mm) ball	60	red	
S	1/2-in. (12.70-mm) ball	100	red	
V	1/2-in. (12.70-mm) ball	150	red	

TABLE 2 Rockwell Superficial Hardness Scales

Total Test Force, kgf (N)	Scale Symbols				
	N Scale, Diamond Indenter	T Scale, 1/16-in. (1.588-mm) Ball	W Scale, 1/8-in. (3.175-mm) Ball	X Scale, 1/4-in. (6.350-mm) Ball	Y Scale, 1/2-in. (12.70-mm) Ball
15 (147)	15N	15T	15W	15X	15Y
30 (294)	30N	30T	30W	30X	30Y
45 (441)	45N	45T	45W	45X	45Y

is followed by the letter “W” to indicate the use of a tungsten carbide ball or the letter “S” to indicate the use of a steel ball (see 5.1.2.1).

5.2.3.1 Examples:

64 HRC = Rockwell hardness number of 64 on Rockwell C scale

81 HR30N = Rockwell superficial hardness number of 81 on the Rockwell 30N scale

72 HRBW = Rockwell hardness number of 72 on the Rockwell B scale using a tungsten carbide ball indenter

5.2.4 A reported Rockwell hardness number or the average value of Rockwell hardness measurements shall be rounded in accordance with Practice E29 with a resolution no greater than the resolution of the hardness value display of the testing machine. Typically, the resolution of a Rockwell hardness number should not be greater than 0.1 Rockwell units.

NOTE 2—When the Rockwell hardness test is used for the acceptance testing of commercial products and materials, the user should take into account the potential measurement differences between hardness testing machines allowed by this standard (see Section 10, Precision and Bias). Because of the allowable ranges in the tolerances for the repeatability and error of a testing machine, as specified in the verification requirements of Annex A1, one testing machine may have a test result that is one or more hardness points different than another testing machine, yet both machines can be within verification tolerances (see Table A1.3). Commonly for acceptance testing, Rockwell hardness values are rounded to whole numbers following Practice E29. Users are encouraged to address rounding practices with regards to acceptance testing within their quality management system, and make any special requirements known during contract review.

5.3 Rockwell Testing Machine—The Rockwell testing machine shall make Rockwell hardness determinations by applying the test forces and measuring the depth of indentation in accordance with the Rockwell hardness test principle.

5.3.1 See the Equipment Manufacturer’s Instruction Manual for a description of the machine’s characteristics, limitations, and respective operating procedures.

5.3.2 The Rockwell testing machine shall automatically convert the depth measurements to a Rockwell hardness number and indicate the hardness number and Rockwell scale by an electronic device or by a mechanical indicator.

5.4 Indenters—The standard Rockwell indenters are either diamond spheroconical indenters or tungsten carbide balls of 1.588 mm (1/16 in.), 3.175 mm (1/8 in.), 6.350 mm (1/4 in.), or 12.70 mm (1/2 in.) in diameter. Indenters shall meet the requirements defined in Annex A3. Steel ball indenters may be used in certain circumstances (see 5.1.2.1).

5.4.1 Dust, dirt, or other foreign materials shall not be allowed to accumulate on the indenter, as this will affect the test results.

NOTE 3—Indenters certified to revision E18-07 or later meet the requirements of this standard.

5.5 Specimen Support—A specimen support or “anvil” shall be used that is suitable for supporting the specimen to be tested. The seating and supporting surfaces of all anvils shall be clean and smooth and shall be free from pits, deep scratches, and foreign material. Damage to the anvil may occur from testing too thin material or accidental contact of the anvil by the indenter. If the anvil is damaged from any cause, it shall be repaired or replaced. Anvils showing the least visibly perceptible damage may give inaccurate results, particularly on thin material.

5.5.1 Common specimen support anvils should have a minimum hardness of 58 HRC. Some specialty support anvils require a lower material hardness.

5.5.2 Flat pieces should be tested on a flat anvil that has a smooth, flat bearing surface whose plane is perpendicular to the axis of the indenter.

5.5.3 Small diameter cylindrical pieces shall be tested with a hard V-grooved anvil with the axis of the V-groove directly under the indenter, or on hard, parallel, twin cylinders properly positioned and clamped in their base. These types of specimen supports shall support the specimen with the apex of the cylinder directly under the indenter.

5.5.4 For thin materials or specimens that are not perfectly flat, an anvil having an elevated, flat “spot” 3 mm (1/8 in.) to 12.5 mm (1/2 in.) in diameter should be used. This spot shall be polished smooth and flat. Very soft material should not be tested on the “spot” anvil because the applied force may cause the penetration of the anvil into the under side of the specimen regardless of its thickness.

5.5.5 When testing thin sheet metal with a ball indenter, it is recommended that a diamond spot anvil be used. The highly polished diamond surface shall have a diameter between 4.0 mm (0.157 in.) and 7.0 mm (0.2875 in.) and be centered within 0.5 mm (0.02 in.) of the test point.

5.5.5.1 CAUTION: A diamond spot anvil should only be used with a maximum total test force of 45 kgf (441 N) and a ball indenter. This recommendation should be followed except when directed otherwise by material specification.

5.5.6 Special anvils or fixtures, including clamping fixtures, may be required for testing pieces or parts that cannot be supported by standard anvils. Auxiliary support may be used for testing long pieces with so much overhang that the piece is not firmly seated by the preliminary force.

5.6 *Verification*—Rockwell testing machines shall be verified periodically in accordance with [Annex A1](#).

5.7 *Test Blocks*—Test blocks meeting the requirements of [Annex A4](#) shall be used to verify the testing machine in accordance with [Annex A1](#).

NOTE 4—Test blocks certified to revision E18-07 or later meet the requirements of this standard.

NOTE 5—It is recognized that appropriate standardized test blocks are not available for all geometric shapes, or materials, or both.

## 6. Test Piece

6.1 For best results, both the test surface and the bottom surface of the test piece should be smooth, even and free from oxide scale, foreign matter, and lubricants. An exception is made for certain materials such as reactive metals that may adhere to the indenter. In such situations, a suitable lubricant such as kerosene may be used. The use of a lubricant shall be defined on the test report.

6.2 Preparation shall be carried out in such a way that any alteration of the surface hardness of the test surface (for example, due to heat or cold-working) is minimized.

6.3 The thickness of the test piece or of the layer under test should be as defined in tables and presented graphically in [Annex A5](#). These tables were determined from studies on strips of carbon steel and have proven to give reliable results. For all other materials, it is recommended that the thickness should exceed 10 times the depth of indentation. In general, no

deformation should be visible on the back of the test piece after the test, although not all such marking is indicative of a bad test.

6.3.1 Special consideration should be made when testing parts that exhibit hardness gradients; for example, parts that were case-hardened by processes such as carburizing, carbonitriding, nitriding, induction, etc. The minimum thickness guidelines given in [Annex A5](#) only apply to materials of uniform hardness, and should not be used to determine the appropriate scale for measuring parts with hardness gradients. The selection of an appropriate Rockwell scale for parts with hardness gradients should be made by special agreement.

NOTE 6—A table listing the minimum effective case depth needed for different Rockwell scales is given in SAE J417.

6.4 When testing on convex cylindrical surfaces, the result may not accurately indicate the true Rockwell hardness; therefore, the corrections given in [Annex A6](#) shall be applied. For diameters between those given in the tables, correction factors may be derived by linear interpolation. Tests performed on diameters smaller than those given in [Annex A6](#) are not acceptable. Corrections for tests on spherical and concave surfaces should be the subject of special agreement.

NOTE 7—A table of correction values to be applied to test results made on spherical surfaces is given in ISO 6508-1.

6.5 When testing small diameter specimens, the accuracy of the test will be seriously affected by alignment between the indenter and the test piece, by surface finish, and by the straightness of the cylinder.

## 7. Test Procedure

7.1 A daily verification of the testing machine shall be performed in accordance with [A1.5](#) prior to making hardness tests. Hardness measurements shall be made only on the calibrated surface of the test block.

7.2 Rockwell hardness tests should be carried out at ambient temperature within the limits of 10 to 35°C (50 to 95°F). Users of the Rockwell hardness test are cautioned that the temperature of the test material and the temperature of the hardness tester may affect test results. Consequently, users should ensure that the test temperature does not adversely affect the hardness measurement.

7.3 The test piece shall be supported rigidly so that displacement of the test surface is minimized (see [5.5](#)).

7.4 *Test Cycle*—This standard specifies the Rockwell test cycle by stating recommendations or requirements for five separate parts of the cycle. These parts are illustrated for a Rockwell C scale test in [Fig. 2](#), and defined as follows:

(1) *Contact Velocity*,  $v_A$ —The velocity of the indenter at the point of contact with the test material.

(2) *Preliminary Force Dwell Time*,  $t_{PF}$ —The dwell time beginning when the preliminary force is fully applied and ending when the first baseline depth of indentation is measured, (also see [7.4.1.3](#)).

(3) *Additional Force Application Time*,  $t_{TA}$ —The time for applying the additional force to obtain the full total force.

(4) *Total Force Dwell Time*,  $t_{TF}$ —The dwell time while the total force is fully applied.



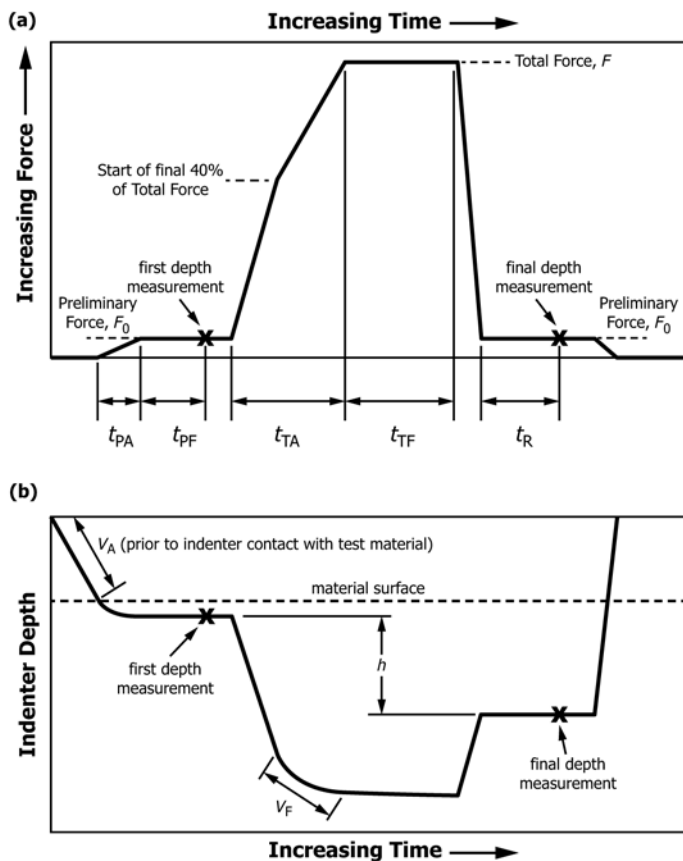


FIG. 2 Schematic of Force-Time Plot (a) and Indenter Depth-Time Plot (b) of an HRC Test Illustrating the Test Cycle Parts

(5) *Dwell Time for Elastic Recovery,  $t_R$* —The dwell time at the preliminary force level, beginning when the additional force is fully removed, and ending when the second and final depth of indentation is measured.

7.4.1 The standard Rockwell test cycle is specified in Table 3. The test cycle used for Rockwell hardness tests shall be in accordance with these test cycle values and tolerances (see Note 8), with the following exceptions.

7.4.1.1 *Precautions for Materials Having Excessive Time-Dependent Plasticity (Indentation Creep)*—In the case of materials exhibiting excessive plastic flow after application of the total test force, special considerations may be necessary since the indenter will continue to penetrate. When materials require the use of a longer total force dwell time than for the standard test cycle stated in Table 3, this should be specified in the product specification. In these cases, the actual extended

total force dwell time used shall be recorded and reported after the test results (for example, 65 HRFW, 10 s).

7.4.1.2 There are testing conditions that may require that the indenter contact velocity exceed the recommended maximum stated in Table 3. The user should ensure that the higher contact velocity does not cause a shock or overload which would affect the hardness result. It is recommended that comparison tests be made on the same test material using a test cycle within the requirements stated in Table 3.

7.4.1.3 For testing machines that take 1 s or longer to apply the preliminary force  $t_{PA}$ , the preliminary force dwell time value  $t_{PF}$  shall be adjusted before comparing the parameter with the tolerances of Table 3 by adding to it one half of  $t_{PA}$  as  $\frac{t_{PA}}{2} + t_{PF}$ . For testing machines that apply the preliminary force  $t_{PA}$  in 1 s or less, this adjustment to the preliminary force dwell time value  $t_{PF}$  is optional.

NOTE 8—It is recommended that the test cycle to be used with the hardness machine match, as closely as possible, the test cycle used for the indirect verification of the hardness machine. Varying the values of the testing cycle parameters within the tolerances of Table 3 can produce different hardness results.

7.5 *Test Procedure*—There are many designs of Rockwell hardness machines, requiring various levels of operator control. Some hardness machines can perform the Rockwell hardness test procedure automatically with almost no operator influence, while other machines require the operator to control most of the test procedure.

7.5.1 Bring the indenter into contact with the test surface in a direction perpendicular to the surface and, if possible, at a velocity within the recommended maximum contact velocity  $v_A$ .

7.5.2 Apply the preliminary test force  $F_0$  of 10 kgf (98 N) for the Rockwell hardness test or 3 kgf (29 N) for the Rockwell superficial hardness test.

7.5.3 Maintain the preliminary force for the specified preliminary force dwell time  $t_{PF}$ .

7.5.4 At the end of the preliminary force dwell time  $t_{PF}$ , immediately establish the reference position of the baseline depth of indentation (see manufacturer’s Instruction Manual).

7.5.5 Increase the force by the value of the additional test force  $F_1$  needed to obtain the required total test force  $F$  for a given hardness scale (see Tables 1 and 2). The additional force  $F_1$  shall be applied in a controlled manner within the specified application time range  $t_{TA}$ .

7.5.6 Maintain the total force  $F$  for the specified total force dwell time  $t_{TF}$ .

7.5.7 Remove the additional test force  $F_1$  while maintaining the preliminary test force  $F_0$ .

7.5.8 Maintain the preliminary test force  $F_0$  for an appropriate time to allow elastic recovery in the test material and the stretch of the frame to be factored out.

7.5.9 At the end of the dwell time for elastic recovery, immediately establish the final depth of indentation (see manufacturer’s Instruction Manual). The testing machine shall calculate the difference between the final and baseline depth measurements and indicate the resulting Rockwell hardness value. The Rockwell hardness number is derived from the

TABLE 3 Test Cycle Tolerances

Test Cycle Parameter	Tolerance
Indenter contact velocity, $v_A$ (recommended)	$\leq 2.5$ mm/s
Dwell time for preliminary force, $t_{PF}$ (when the time to apply the preliminary force $t_{PA} \geq 1$ s, then calculate this parameter as $\frac{t_{PA}}{2} + t_{PF}$ )	0.1 to 4.0 s
Time for application of additional force, $t_{TA}$	1.0 to 8.0 s
Dwell time for total force, $t_{TF}$	2.0 to 6.0 s
Dwell time for elastic recovery, $t_R$	0.2 to 5.0 s

differential increase in depth of indentation as defined in Eq 4, Eq 5, Eq 6, and Eq 7.

7.6 Throughout the test, the apparatus shall be protected from shock or vibration that could affect the hardness measurement result.

7.7 After each change, or removal and replacement, of the indenter or the anvil, at least two preliminary indentations shall be made to ensure that the indenter and anvil are seated properly. The results of the preliminary indentations shall be disregarded.

7.8 After each change of a test force or removal and replacement of the indenter or the anvil, it is strongly recommended that the operation of the machine be checked in accordance with the daily verification method specified in Annex A1.

7.9 *Indentation Spacing*—The hardness of the material immediately surrounding a previously made indentation will usually increase due to the induced residual stress and work-hardening caused by the indentation process. If a new indentation is made in this affected material, the measured hardness value will likely be higher than the true hardness of the material as a whole. Also, if an indentation is made too close to the edge of the material or very close to a previously made indentation, there may be insufficient material to constrain the deformation zone surrounding the indentation. This can result in an apparent lowering of the hardness value. Both of these circumstances can be avoided by allowing appropriate spacing between indentations and from the edge of the material.

7.9.1 The distance between the centers of two adjacent indentations shall be at least three times the diameter  $d$  of the indentation (see Fig. 3).

7.9.2 The distance from the center of any indentation to an edge of the test piece shall be at least two and a half times the diameter of the indentation (see Fig. 3).

**8. Conversion to Other Hardness Scales or Tensile Strength Values**

8.1 There is no general method of accurately converting the Rockwell hardness numbers on one scale to Rockwell hardness numbers on another scale, or to other types of hardness numbers, or to tensile strength values. Such conversions are, at best, approximations and, therefore, should be avoided except

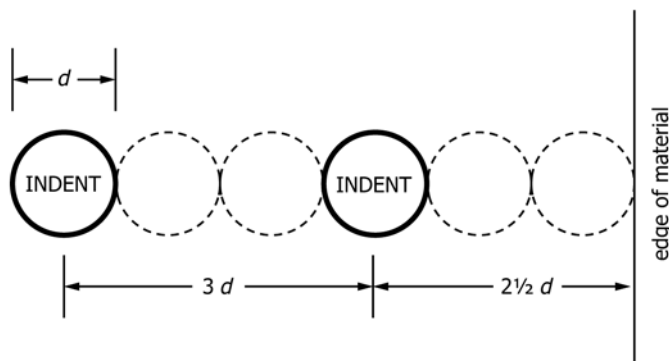


FIG. 3 Schematic of Minimum Indentation Spacing

for special cases where a reliable basis for the approximate conversion has been obtained by comparison tests.

NOTE 9—The Standard Hardness Conversion Tables for Metals, E140, give approximate conversion values for specific materials such as steel, austenitic stainless steel, nickel and high-nickel alloys, cartridge brass, copper alloys, and alloyed white cast irons. The Rockwell hardness data in the conversion tables of E140 was determined using steel ball indenters.

NOTE 10—ASTM standards giving approximate hardness-tensile strength relationships are listed in Appendix X1.

**9. Report**

9.1 The test report shall include the following information:

9.1.1 The Rockwell hardness number. All reports of Rockwell hardness numbers shall indicate the scale used. The reported number shall be rounded in accordance with Practice E29 (see 5.2.4 and Note 2),

9.1.2 The total force dwell time, if outside the specified standard test cycle tolerances (see Table 3), and

9.1.3 The ambient temperature at the time of test, if outside the limits of 10 to 35°C (50 to 95°F), unless it has been shown not to affect the measurement result.

**10. Precision and Bias<sup>8, 9</sup>**

10.1 *Precision*—A Rockwell hardness precision and bias study was conducted in 2000 in accordance with Practice E691. Tests were performed in the following six Rockwell scales: HRA, HRC, HRBS, HR30N, HR30TS, and HRES. The tests in the HRBS, HR30TS and HRES scales were made using steel ball indenters. A total of 18 Rockwell scale hardness test blocks of the type readily available were used for this study. Test blocks at three different hardness levels (high, medium, and low) in each scale were tested three times each. The results from the first study are filed under ASTM Research Report RR:E28-1021.<sup>8,9</sup>

10.2 Starting with version E18-05, this standard changed from the use of steel balls to carbide balls for all scales that use a ball indenter. Due to this change, a second study was conducted in 2006. The second study was performed in accordance with Practice E691 and was identical to the initial study except it was limited to the HRBW, HR30TW, and HREW scales, all of which use carbide ball indenters. The results from that study are filed under ASTM Research Report RR:E28-1022.

10.3 A total of 14 different labs participated in the two studies. Eight participated in the first study and nine in the second study. Three labs participated in both studies. The labs chosen to participate in this study were a combination of commercial testing labs (6), in-house labs (5) and test block manufacturer’s calibration labs (3). Each lab was instructed to test each block in three specific locations around the surface of the blocks. All testing was to be done according to ASTM E18-05.

10.4 The results given in Table 4 may be useful in interpreting measurement differences. It is a combination of the two

<sup>8</sup> Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:E28-1021.

<sup>9</sup> Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:E28-1022.

**TABLE 4 Results of the Precision and Bias Study**

Test Block	Average Hardness	$S_r$	$S_R$	$r_{PB}$	$R_{PB}$
Data from 2000 study					
62.8 HRA	62.50	0.164	0.538	0.459	1.506
73.1 HRA	73.04	0.138	0.358	0.387	1.002
83.9 HRA	84.54	0.085	0.468	0.238	1.309
25.0 HRC	24.99	0.335	0.440	0.937	1.232
45.0 HRC	45.35	0.156	0.259	0.438	0.725
65.0 HRC	65.78	0.153	0.389	0.427	1.089
45.9 HR30N	46.75	0.299	2.489	0.837	6.969
64.0 HR30N	64.74	0.248	0.651	0.694	1.822
81.9 HR30N	82.52	0.195	0.499	0.547	1.396
Data from 2006 study					
40 HRBW	43.90	0.492	0.668	1.378	1.871
60 HRBW	61.77	0.663	0.697	1.855	1.953
95 HRBW	91.09	0.250	0.292	0.701	0.817
62 HREW	64.07	0.346	0.675	0.970	1.890
81 HREW	81.61	0.232	0.406	0.649	1.136
100 HREW	96.22	0.177	0.322	0.497	0.901
22 HR30TW	18.33	0.702	0.901	1.965	2.522
56 HR30TW	58.0	0.476	0.517	1.333	1.447
79 HR30TW	81.0	0.610	0.851	1.709	2.382

studies. The diamond scales, HRC, HRA, and HR30N are from the first study and the ball scales, HRBW, HREW, and HR30TW are from the second study. This combination reflects the testing that is being done currently.

10.5 The value of  $r_{PB}$  indicates the typical amount of variation that can be expected between test results obtained for the same material by the same operator using the same hardness tester on the same day. When comparing two test results made under these conditions, a measurement difference of less than the  $r_{PB}$  value for that Rockwell scale is an indication that the results may be equivalent.

10.6 The value of  $R_{PB}$  indicates the typical amount of variation that can be expected between test results obtained for

the same material by different operators using different hardness testers on different days. When comparing two test results made under these conditions, a measurement difference of less than the  $R_{PB}$  value for that Rockwell scale is an indication that the results may be equivalent.

10.7 Any judgments based on 10.5 and 10.6 would have an approximately 95 % probability of being correct.

10.8 This precision and bias study was conducted on a selected number of the most commonly used Rockwell scales. For Rockwell scales not listed, the  $r_{PB}$  and  $R_{PB}$  values may be estimated using the conversion tables of E140 to determine a corresponding increment of hardness for the scale of interest at the hardness level of interest. The user is cautioned that estimating the  $r_{PB}$  and  $R_{PB}$  values in this way, decreases the probability of them being correct.

10.9 Although the precision values given in Table 4 provide guidance on interpreting differences in Rockwell hardness measurement results, a complete evaluation of measurement uncertainty will provide a more definitive interpretation of the results for the specific testing conditions.

10.10 The data generally indicated reasonable precision except for the 45.9 HR30N scale. In that scale the  $S_R$  and  $R_{PB}$  values are very high compared to all of the other scales. An examination of the raw data revealed that one lab's results were much higher than the others, significantly affecting the overall results in that scale. The results from all of the other scales seem to be reasonable.

10.11 *Bias*—There are no recognized standards by which to fully estimate the bias of this test method.

## 11. Keywords

11.1 hardness; mechanical test; metals; Rockwell

## ANNEXES

### (Mandatory Information)

#### A1. VERIFICATION OF ROCKWELL HARDNESS TESTING MACHINES

##### A1.1 Scope

A1.1.1 Annex A1 specifies three types of procedures for verifying Rockwell hardness testing machines: *direct verification*, *indirect verification*, and *daily verification*.

A1.1.2 Direct verification is a process for verifying that critical components of the hardness testing machine are within allowable tolerances by directly measuring the test forces, depth measuring system, machine hysteresis, and testing cycle.

A1.1.3 Indirect verification is a process for periodically verifying the performance of the testing machine by means of standardized test blocks and indenters.

A1.1.4 The daily verification is a process for monitoring the performance of the testing machine between indirect verifications by means of standardized test blocks.

A1.1.5 Adherence to this standard and annex provides traceability to national standards, except as stated otherwise.

##### A1.2 General Requirements

A1.2.1 The testing machine shall be verified at specific instances and at periodic intervals as specified in Table A1.1, and when circumstances occur that may affect the performance of the testing machine.

A1.2.2 The temperature at the verification site shall be measured with an instrument having an accuracy of at least  $\pm 2.0^\circ\text{C}$  or  $\pm 3.6^\circ\text{F}$ . It is recommended that the temperature be monitored throughout the verification period, and significant temperature variations be recorded and reported. The temperature at the verification site does not need to be measured for a

**TABLE A1.1 Verification Schedule for a Rockwell Testing Machine**

Verification Procedure	Schedule
Direct verification	When a testing machine is new, or when adjustments, modifications or repairs are made that could affect the application of the test forces, the depth measuring system, or the machine hysteresis. When a testing machine fails an indirect verification (see A1.4.9.4).
Indirect verification	Recommended every 12 months, or more often if needed. Shall be no longer than every 18 months. When a testing machine is installed or moved, [only a partial indirect verification is performed by following the procedure given in A1.4.7 for verifying the as-found condition]. This does not apply to machines that are designed to be moved or that move prior to each test, when it has been previously demonstrated that such a move will not affect the hardness result. Following a direct verification. To qualify an indenter that was not verified in the last indirect verification, (only a partial indirect verification is performed, see A1.4.10).
Daily verification	Required each day that hardness tests are to be made. Recommended whenever the indenter, anvil, or test force is changed.

daily verification or when qualifying additional user’s indenters in accordance with A1.4.10.

A1.2.3 All instruments used to make measurements required by this Annex shall be calibrated traceable to national standards when a system of traceability exists, except as noted otherwise.

A1.2.4 Direct verification of newly manufactured or rebuilt testing machines shall be performed at the place of manufacture, rebuild or repair. Direct verification may also be performed at the location of use.

A1.2.5 Indirect verification of the testing machine shall be performed at the location where it will be used.

NOTE A1.1—It is recommended that the calibration agency that is used to conduct the verifications of Rockwell hardness testing machines be accredited to the requirements of ISO 17025 (or an equivalent) by an accrediting body recognized by the International Laboratory Accreditation Cooperation (ILAC) as operating to the requirements of ISO/IEC 17011.

**A1.3 Direct Verification**

A1.3.1 A direct verification of the testing machine shall be performed at specific instances in accordance with Table A1.1. The test forces, depth-measuring system, machine hysteresis, and testing cycle shall be verified as follows.

NOTE A1.2—Direct verification is a useful tool for determining the sources of error in a Rockwell hardness testing machine. It is recommended that testing machines undergo direct verification periodically to make certain that errors in one component of the machine are not being offset by errors in another component.

A1.3.2 *Verification of the Test Forces*—For each Rockwell scale that will be used, the corresponding test forces (preliminary test force at loading, total test force, and preliminary test force during elastic recovery) shall be measured. The test forces shall be measured by means of a Class A elastic force measuring instrument having an accuracy of at least 0.25 %, as described in ASTM E74.

A1.3.2.1 Make three measurements of each force. The forces shall be measured as they are applied during testing.

A1.3.2.2 Each preliminary test force  $F_0$  and each total test force  $F$  shall be accurate to within the tolerances given in Table A1.2, and the range of the three force measurements (highest minus lowest) shall be within 75 % of the tolerances of Table A1.2.

A1.3.3 *Verification of the Depth Measuring System*—The depth measuring system shall be verified by means of an instrument, device or standard having an accuracy of at least 0.0002 mm.

A1.3.3.1 Verify the testing machine’s depth measurement system at not less than four evenly spaced increments covering the full range of the normal working depth measured by the testing machine. The normal working depth range shall correspond to the lowest and highest hardness values for the Rockwell scales that will be tested.

A1.3.3.2 The indentation-depth measuring device shall be accurate within  $\pm 0.001$  mm for the regular Rockwell hardness scales and  $\pm 0.0005$  mm for the Rockwell superficial hardness scales. These accuracies correspond to 0.5 hardness units.

A1.3.3.3 Some testing machines have a long-stroke depth measuring system where the location of the working range of the depth measuring system varies depending on the thickness of the test material. This type of testing machine shall have a system to electronically verify that the depth measuring device is continuous over its full range and free from dirt or other discontinuities that could affect its accuracy. These types of testers shall be verified using the following steps.

(1) At the approximate top, mid point, and bottom of the total stroke of the measuring device, verify the accuracy of the device at no less than four evenly spaced increments of approximately 0.05 mm at each of the three locations. The accuracy shall be within the tolerances defined above.

(2) Operate the actuator over its full range of travel and monitor the electronic continuity detection system. The system shall indicate continuity over the full range.

A1.3.4 *Verification of Machine Hysteresis*—Each time a Rockwell hardness test is made, the testing machine will undergo flexure in some of the machine components and the machine frame. If the flexure is not entirely elastic during the application and removal of the additional force  $F_1$ , the testing machine may exhibit hysteresis in the indenter-depth measurement system, resulting in an offset or bias in the test result. The goal of the hysteresis verification is to perform a purely elastic

**TABLE A1.2 Tolerances on Applied Force for a Rockwell Testing Machine**

Force		Tolerance	
kgf	N	kgf	N
10	98.07	0.20	1.96
60	588.4	0.45	4.41
100	980.7	0.65	6.37
150	1471	0.90	8.83
3	29.42	0.060	0.589
15	147.1	0.100	0.981
30	294.2	0.200	1.961
45	441.3	0.300	2.963

test that results in no permanent indentation. In this way, the level of hysteresis in the flexure of the testing machine can be determined.

A1.3.4.1 Perform repeated Rockwell tests using a blunt indenter (or the indenter holder surface) acting directly onto the anvil or a very hard test piece. The tests shall be conducted using the highest test force that is used during normal testing

A1.3.4.2 Repeat the hysteresis verification procedure for a maximum of ten measurements and average the last three tests. The average measurement shall indicate a hardness number of  $130 \pm 1.0$  Rockwell units when Rockwell ball scales B, E, F, G, H and K are used, or within  $100 \pm 1.0$  Rockwell units when any other Rockwell scale is used.

A1.3.5 *Verification of the Testing Cycle*—Section 7 specifies the Rockwell testing cycle by stating requirements and recommendations for five separate parameters of the cycle. The testing machine shall be verified to be capable of meeting the tolerances specified in Table 3 for the following four test cycle parameters: the dwell time for preliminary force, the time for application of additional force, the dwell time for total force and the dwell time for elastic recovery. The tolerance for the indenter contact velocity is a recommendation. Direct verification of the testing cycle is to be verified by the testing machine manufacturer at the time of manufacture, and when the testing machine is returned to the manufacturer for repair when a problem with the testing cycle is suspected. Verification of the testing cycle is not required as part of the direct verification at other times.

A1.3.5.1 Rockwell hardness testing machines manufactured before the implementation of E18–07 may not have undergone the direct verification of the machine’s testing cycle. Since this verification often must be performed at the manufacturer’s site, the test cycle verification requirement does not apply to testing machines manufactured before the implementation of E18–07, unless the testing machine is returned to the manufacturer for repair.

A1.3.6 *Direct Verification Failure*—If any of the direct verifications fail the specified requirements, the testing machine shall not be used until it is adjusted or repaired. If the test forces, depth measuring system, machine hysteresis, or testing cycle may have been affected by an adjustment or repair, the affected components shall be verified again by direct verification.

A1.3.7 An indirect verification shall follow a successful direct verification.

## A1.4 Indirect Verification

A1.4.1 An indirect verification of the testing machine shall be performed, at a minimum, in accordance with the schedule given in Table A1.1. The frequency of indirect verifications should be based on the usage of the testing machine.

A1.4.2 The testing machine shall be verified for each Rockwell scale that will be used prior to the next indirect verification. Hardness tests made using Rockwell scales that have not been verified within the schedule given in Table A1.1 do not meet this standard.

A1.4.3 Standardized test blocks meeting the requirements of Annex A4 (see Note 4) shall be used in the appropriate hardness ranges for each scale to be verified. These ranges are given in Table A1.3. Hardness measurements shall be made only on the calibrated surface of the test block.

A1.4.4 The indenters to be used for the indirect verification shall meet the requirements of Annex A3 (see Note 3).

A1.4.5 The testing cycle to be used for the indirect verification shall be the same as is typically used by the user.

A1.4.6 Prior to performing the indirect verification, ensure that the testing machine is working freely, and that the indenter and anvil are seated adequately. Make at least two hardness measurements on a suitable test piece to seat the indenter and anvil. The results of these measurements need not be recorded.

### A1.4.7 *As-found Condition:*

A1.4.7.1 It is recommended that the as-found condition of the testing machine be assessed as part of an indirect verification. This is important for documenting the historical performance of the machine in the scales used since the last indirect verification. This procedure should be conducted prior to any cleaning, maintenance, adjustments, or repairs.

A1.4.7.2 When the as-found condition of the testing machine is assessed, it shall be determined with the user’s indenter(s) that are normally used with the testing machine. At least two standardized test blocks, each from a different hardness range as defined in Table A1.3, should be tested for each Rockwell scale that will undergo indirect verification. The difference in hardness between any of the standardized test blocks shall be at least 5 hardness points for each Rockwell scale.

A1.4.7.3 On each standardized test block, make at least two measurements distributed uniformly over the test surface.

A1.4.7.4 Determine the repeatability  $R$  and the error  $E$  (Eq 2 and Eq 3) in the performance of the testing machine for each standardized test block that is measured.

A1.4.7.5 The error  $E$  and the repeatability  $R$  should be within the tolerances of Table A1.3. If the calculated values of error  $E$  or repeatability  $R$  fall outside of the specified tolerances, this is an indication that the hardness tests made since the last indirect verification may be suspect.

A1.4.8 *Cleaning and Maintenance*—Perform cleaning and routine maintenance of the testing machine (when required) in accordance with the manufacturer’s specifications and instructions.

A1.4.9 *Indirect Verification Procedure*—The indirect verification procedure requires that the testing machine be verified using one or more of the user’s indenters.

A1.4.9.1 One standardized test block shall be tested from each of the hardness ranges (usually three ranges) for each Rockwell scale to be verified, as given in Table A1.3. The difference in hardness between any of the standardized test blocks shall be at least 5 hardness points for each Rockwell scale. The user may find that high, medium and low range test blocks are unavailable commercially for some scales. In these cases, one of the following two procedures shall be followed.

**TABLE A1.3 Maximum Allowable Repeatability and Error of Testing Machines for Ranges of Standardized Test Blocks**

	Range of Standardized Test Blocks <sup>A</sup>	Maximum Repeatability, <i>R</i> (HR units)	Maximum Error, <i>E</i> (HR units)
HRA	< 70	2.0	± 1.0
	≧ 70 and < 80	1.5	± 1.0
	≧ 80	1.0	± 0.5
HRBW	< 60	2.0	± 1.5
	≧ 60 and < 80	1.5	± 1.0
	≧ 80	1.5	± 1.0
HRC	< 35	2.0	± 1.0
	≧ 35 and < 60	1.5	± 1.0
	≧ 60	1.0	± 0.5
HRD	< 51	2.0	± 1.0
	≧ 51 and < 71	1.5	± 1.0
	≧ 71	1.0	± 0.5
HREW	< 84	1.5	± 1.0
	≧ 84 and < 93	1.5	± 1.0
	≧ 93	1.0	± 1.0
HRFW	< 80	1.5	± 1.0
	≧ 80 and < 94	1.5	± 1.0
	≧ 94	1.0	± 1.0
HRGW	< 55	2.0	± 1.0
	≧ 55 and < 80	2.0	± 1.0
	≧ 80	2.0	± 1.0
HRHW	< 96	2.0	± 1.0
	≧ 96	2.0	± 1.0
		2.0	± 1.0
HRKW	< 65	1.5	± 1.0
	≧ 65 and < 85	1.0	± 1.0
	≧ 85	1.0	± 1.0
HRLW <sup>B</sup>		2.0	± 1.0
HRMW <sup>B</sup>		2.0	± 1.0
HRPW <sup>B</sup>		2.0	± 1.0
HRRW <sup>B</sup>		2.0	± 1.0
HRSW <sup>B</sup>		2.0	± 1.0
HRVW <sup>B</sup>		2.0	± 1.0
HR15N	< 78	2.0	± 1.0
	≧ 78 and < 90	1.5	± 1.0
	≧ 90	1.0	± 0.7
HR30N	< 55	2.0	± 1.0
	≧ 55 and < 77	1.5	± 1.0
	≧ 77	1.0	± 0.7
HR45N	< 37	2.0	± 1.0
	≧ 37 and < 66	1.5	± 1.0
	≧ 66	1.0	± 0.7
HR15TW	< 81	2.0	± 1.5
	≧ 81 and < 87	1.5	± 1.0
	≧ 87	1.5	± 1.0
HR30TW	< 57	2.0	± 1.5
	≧ 57 and < 70	1.5	± 1.0
	≧ 70	1.5	± 1.0
HR45TW	< 33	2.0	± 1.5
	≧ 33 and < 53	1.5	± 1.0
	≧ 53	1.5	± 1.0
HR15WW <sup>B</sup>		2.0	± 1.0
HR30WW <sup>B</sup>		2.0	± 1.0
HR45WW <sup>B</sup>		2.0	± 1.0
HR15XW <sup>B</sup>		2.0	± 1.0
HR30XW <sup>B</sup>		2.0	± 1.0
HR45XW <sup>B</sup>		2.0	± 1.0
HR15YW <sup>B</sup>		2.0	± 1.0
HR30YW <sup>B</sup>		2.0	± 1.0
HR45YW <sup>B</sup>		2.0	± 1.0

<sup>A</sup> The user may find that high, medium and low range test blocks are unavailable commercially for some scales. In these cases one or two standardized blocks where available may be used. It is recommended that all high range test blocks for Rockwell scales using a ball indenter should be less than 100 HR units.

<sup>B</sup> Appropriate ranges of standardized test blocks for the L, M, P, R, S, V, W, X, and Y scales shall be determined by dividing the usable range of the scale into two ranges, if possible.

(1) *Alternative Procedure 1*—The testing machine shall be verified using the standardized blocks from the one or two ranges that are available. Also, the testing machine shall be

verified on another Rockwell scale which uses the same test forces and for which three blocks are available. In this case, the testing machine is considered verified for the entire Rockwell scale.

(2) *Alternative Procedure 2*—This procedure may be used when standardized blocks from two ranges are available. The testing machine shall be verified using the standardized blocks from the two available ranges. In this case, the testing machine is considered verified for only the part of the scale bracketed by the levels of the blocks.

A1.4.9.2 On each standardized test block, make five measurements distributed uniformly over the test surface. Determine the error *E* and the repeatability *R* in the performance of the testing machine using Eq 2 and Eq 3 for each hardness level of each Rockwell scale to be verified.

A1.4.9.3 The error *E* and the repeatability *R* shall be within the tolerances of Table A1.3. The indirect verification shall be approved only when the testing machine measurements of repeatability and error meet the specified tolerances using at least one of the user's indenters.

A1.4.9.4 In the case that the testing machine cannot pass the repeatability and error verifications with the user's indenter, a number of corrective actions may be attempted to bring the testing machine within tolerances. These actions include cleaning and maintenance, replacing the anvil or using another of the user's indenters. The indirect verification procedures shall be repeated after making the allowed corrective actions.

NOTE A1.3—When a testing machine fails indirect verification, it is recommended that the testing machine be verified again using a Class A (or better) indenter for those scales and hardness levels that failed the indirect verification with the user's indenter. If the testing machine passes the repeatability and error tests with a Class A indenter, it is an indication that the user's indenter is out of tolerance. A new indenter may be acquired by the user as a corrective action (see A1.4.9.4) allowing the indirect verification procedures to be repeated without having to perform a direct verification. If the testing machine continues to fail the repeatability or error tests of an indirect verification with the Class A indenter, it is an indication that there is a problem with the machine and not the user's indenter.

A1.4.9.5 If the testing machine continues to fail the repeatability or error tests following corrective actions, the testing machine shall undergo adjustment and/or repair followed by a direct verification.

A1.4.10 *Qualifying Additional User's Indenters*—In cases where the testing machine passes indirect verification using only one of the user's indenters, only that one indenter is considered verified for use with the specific testing machine for the Rockwell scales that were indirectly verified using that indenter. Before any other indenter may be used for testing the same Rockwell scales, it must be verified for use with the specific verified testing machine. This requirement does not apply to changing an indenter ball. The indenter verifications may be made at any time after the indirect verification, and may be performed by the user as follows.

A1.4.10.1 The testing machine and indenter shall be verified together using the indirect verification procedures of A1.4.9 with the following exception. The verification shall be performed on at least two standardized test blocks (high and low ranges) for each Rockwell scale that the indenter will be used.

A1.4.10.2 The indenter may be used with the specific verified testing machine only when the verification measurements of repeatability and error meet the specified tolerances.

A1.4.11 The user shall identify and keep track of the indenters verified for use with the testing machine.

## A1.5 Daily Verification

A1.5.1 The daily verification is intended for the user to monitor the performance of the testing machine between indirect verifications. At a minimum, the daily verification shall be performed in accordance with the schedule given in **Table A1.1** for each Rockwell scale that will be used.

A1.5.2 It is recommended that the daily verification procedures be performed whenever the indenter, anvil, or test force is changed.

A1.5.3 *Daily Verification Procedures*—The procedures to use when performing a daily verification are as follows.

A1.5.3.1 Daily verification shall use standardized test block(s) that meet the requirements of **Annex A4** (see **Note 4**). Daily verification shall be done for each Rockwell scale that is to be used that day. At least one test block shall be used, and when commercially available, the hardness range of the test block shall be chosen to be within 15 Rockwell points of the hardness value that the testing machine is expected to measure. Alternatively, two test blocks can be used, (when commercially available), one higher and one lower than the hardness range that the testing machine is expected to measure. In cases where the configuration of the anvil to be used is not suitable for the testing of blocks, a suitable anvil or adapter for testing a test block must be used temporarily.

A1.5.3.2 The indenter to be used for the daily verification shall be the indenter that is normally used for testing.

A1.5.3.3 Before performing the daily verification tests, ensure that the testing machine is working freely, and that the indenter and anvil are seated adequately. Make at least two hardness measurements on a suitable test piece. The results of these measurements need not be recorded.

A1.5.3.4 Make at least two hardness measurements on each of the daily verification test blocks adhering to the spacing requirements given in **7.9**.

A1.5.3.5 For each test block, calculate the error  $E$  (see **Eq 2**) and the repeatability  $R$  (see **Eq 3**) from the measured hardness values. The testing machine with the indenter is regarded as performing satisfactorily if both  $E$  and  $R$  for all test blocks are within the maximum tolerances given in **Table A1.3**. Note that if the differences between the individual hardness values and the certified value for a test block are all within the maximum error  $E$  tolerances marked on the test block and given in **Table A1.3**, the above criteria will be met for that block and it is not necessary to calculate  $E$  and  $R$ .

A1.5.3.6 If the daily verification measurements for any of the test blocks do not meet the criteria of **A1.5.3.5**, the daily verification may be repeated with a different indenter or after cleaning the tester, or both (see the manufacturer's instructions). If any of the test block measurements continue to not meet the criteria of **A1.5.3.5**, an indirect verification shall be performed. Whenever a testing machine fails a daily

verification, the hardness tests made since the last valid daily verification may be suspect.

A1.5.3.7 If the anvil to be used for testing is different than the anvil used for the daily verification, it is recommended that the daily verification be repeated on an appropriate part of known hardness.

**NOTE A1.4**—It is highly recommended that the results obtained from the daily verification testing be recorded using accepted Statistical Process Control techniques, such as, but not limited to, X-bar (measurement averages) and R-charts (measurement ranges), and histograms.

## A1.6 Verification Report

A1.6.1 The verification report shall include the following information as a result of the type of verification performed.

### A1.6.2 *Direct Verification:*

A1.6.2.1 Reference to this ASTM test method.

A1.6.2.2 Identification of the hardness testing machine, including the serial number, manufacturer and model number.

A1.6.2.3 Identification of all devices (elastic proving devices, etc.) used for the verification, including serial numbers and identification of standards to which traceability is made.

A1.6.2.4 Test temperature at the time of verification (see **A1.2.2**).

A1.6.2.5 The individual measurement values and calculated results used to determine whether the testing machine meets the requirements of the verification performed. It is recommended that the uncertainty in the calculated results used to determine whether the testing machine meets the requirements of the verification performed also be reported.

A1.6.2.6 Description of adjustments or maintenance done to the testing machine, when applicable.

A1.6.2.7 Date of verification and reference to the verifying agency or department.

A1.6.2.8 Signature of the person performing the verification.

### A1.6.3 *Indirect Verification:*

A1.6.3.1 Reference to this ASTM test method.

A1.6.3.2 Identification of the hardness testing machine, including the serial number, manufacturer and model number.

A1.6.3.3 Identification of all devices (test blocks, indenters, etc.) used for the verification, including serial numbers and identification of standards to which traceability is made.

A1.6.3.4 Test temperature at the time of verification (see **A1.2.2**).

A1.6.3.5 The Rockwell hardness scale(s) verified.

A1.6.3.6 The individual measurement values and calculated results used to determine whether the testing machine meets the requirements of the verification performed. Measurements made to determine the as-found condition of the testing machine shall be included whenever they are made. It is recommended that the uncertainty in the calculated results used to determine whether the testing machine meets the requirements of the verification performed also be reported.

A1.6.3.7 Description of maintenance done to the testing machine, when applicable.

A1.6.3.8 Date of verification and reference to the verifying agency or department.

A1.6.3.9 Signature of the person performing the verification.

**A1.6.4 Daily Verification:**

A1.6.4.1 No verification report is required; however, it is recommended that records be kept of the daily verification

results, including the verification date, measurement results, certified value of the test block, test block identification, and the name of the person that performed the verification, etc. (see also **Note A1.4**). These records can be used to evaluate the performance of the hardness machine over time.

**A2. ROCKWELL HARDNESS STANDARDIZING MACHINES**

**A2.1 Scope**

A2.1.1 **Annex A2** specifies the requirements for the capabilities, usage, periodic verification, and monitoring of a Rockwell hardness standardizing machine. The Rockwell hardness standardizing machine differs from a Rockwell hardness testing machine by having tighter tolerances on certain performance attributes such as force application and machine hysteresis. A Rockwell standardizing machine is used for the standardization of Rockwell hardness indenters as described in **Annex A3**, and for the standardization of Rockwell test blocks as described in **Annex A4**.

A2.1.2 Adherence to this standard and annex provide traceability to national standards, except as stated otherwise.

**A2.2 Accreditation**

A2.2.1 The agency conducting direct and/or indirect verifications of Rockwell hardness standardizing machines shall be accredited to the requirements of ISO 17025 (or an equivalent) by an accrediting body recognized by the International Laboratory Accreditation Cooperation (ILAC) as operating to the requirements of ISO/IEC 17011. An agency accredited to perform verifications of Rockwell hardness standardizing machines may perform the verifications of its own standardizing machines. The standardizing laboratory shall have a certificate/scope of accreditation stating the types of verifications (direct and/or indirect) and the Rockwell scales that are covered by the accreditation.

NOTE A2.1—Accreditation is a new requirement starting with this edition of the standard.

**A2.3 Apparatus**

A2.3.1 The standardizing machine shall satisfy the requirements of Section 5 for a Rockwell hardness testing machine with the following additional requirements.

A2.3.1.1 The standardizing machine shall be designed so that: (1) each test force can be selected by the operator, and (2) adjustments to test forces cannot be made by the operator.

A2.3.1.2 The system for displaying the hardness measurement value shall be digital with a resolution of 0.1 Rockwell units or better.

A2.3.1.3 Deviation in parallelism between the indenter mounting surface and the anvil mounting surface shall not be greater than 0.002 mm/mm (0.002 in./in.). This characteristic of the standardizing machine is not likely to vary with time. As such, the accuracy of this dimension shall only be certified by

the machine manufacturer and need not be periodically verified by direct verification unless the components have been changed.

A2.3.1.4 **Indenters**—Class A ball indenters and Class A or Reference diamond indenters as described in **Annex A3** (see **Note 3**) shall be used.

A2.3.1.5 **Testing Cycle**—The standardizing machine shall be capable of meeting each part of the testing cycle within the tolerances specified in **Table A2.1**. The manufacturer of the standardizing machine shall verify each of the five components of the testing cycle at the time of manufacture, or when the testing machine is returned to the manufacturer for repair.

A2.3.1.6 It is important that the final portion of the additional force application be controlled. Two recommended procedures for properly applying the additional force are as follows: (1) the average indenter velocity  $v_F$  (see **Fig. 2**) during the final 40 % of additional force application should be between 0.020 mm/s and 0.040 mm/s, or (2) the amount of force applied during the final 10 % of the additional force application time should be less than 5 % of the additional force.

A2.3.1.7 During the period between verifications, no adjustments may be made to the force application system, the force measurement system, the indenter depth measurement system, or the test cycle that is used for each Rockwell scale.

**A2.4 Laboratory Environment**

A2.4.1 The standardizing machine shall be located in a temperature and relative-humidity controlled room with tolerances for these conditions given in **Table A2.2**. The accuracy of the temperature and relative-humidity measuring instruments shall be as given in **Table A2.2**. The display of the temperature measuring device shall have a resolution of at least 1°C.

A2.4.2 The temperature and relative-humidity of the standardizing laboratory shall be monitored beginning at least one hour prior to standardization and throughout the standardizing procedure.

**TABLE A2.1 Testing Cycle Requirements**

Test Cycle Parameter	Tolerance
Indenter contact velocity, $v_A$	$\leq 1.0$ mm/s
Dwell time for preliminary force, $t_{PF}$ (when the time to apply the preliminary force $t_{PA} \geq 1$ s, then calculate this parameter as $\frac{t_{PA}}{2} + t_{PF}$ )	$3.0 \pm 1.0$ s
Additional force application, $t_{TA}$ (see <b>A2.3.1.6</b> )	1.0 to 8.0 s
Dwell time for total force, $t_{TF}$	$5.0 \pm 1.0$ s
Dwell time for elastic recovery, $t_R$	$4.0 \pm 1.0$ s



**TABLE A2.2 Standardization Laboratory Environmental Requirements**

Environmental Parameter	Tolerance	Accuracy of Measuring Instrument
Temperature	23.0 ± 3.0°C (73.4 ± 5.4°F)	±1.0°C (1.8°F)
Relative humidity	≤70 %	±10 %

A2.4.3 The standardizing machine, indenter(s), and test blocks to be standardized must be in an environment meeting the tolerances of **Table A2.2** for at least one hour prior to standardization.

A2.4.4 During the standardization process, the standardizing machine shall be isolated from any vibration that may affect the measurements.

A2.4.5 The power supply to the standardizing machine shall be isolated from any electrical surges that could affect its performance.

## A2.5 Verifications

A2.5.1 The standardizing machine shall undergo direct and indirect verifications at periodic intervals and when circumstances occur that may affect the performance of the standardizing machine, according to the schedule given in **Table A2.3**.

NOTE A2.2—Periodic direct verification (every 12 months) is a new requirement starting with this edition of the standard. In previous editions of this standard, direct verification was required only when a standardizing machine was new, moved, or when adjustments, modifications or repairs were made that could affect the application of the test forces, the depth measuring system, or the machine hysteresis.

A2.5.2 A standardizing machine used for the standardization of test blocks shall undergo monitoring verifications each day that standardizations are made, according to the schedule given in **Table A2.3**.

A2.5.3 All instruments used to make measurements required by this Annex shall be calibrated traceable to national standards where a system of traceability exists, except as noted otherwise.

A2.5.4 The standardizing machine shall be directly and indirectly verified at the location where it will be used.

**TABLE A2.3 Verification Schedule for a Rockwell Hardness Standardizing Machine**

Verification Procedure	Schedule
Direct verification	Shall be every 12 months. When a standardizing machine is new, moved, or when adjustments, modifications or repairs are made that could affect the application of the test forces, the depth measuring system, or the machine hysteresis.
Indirect verification	Shall be within 12 months prior to standardization testing. Following a direct verification (limited number of scales).
Monitoring verification	Shall be before and after each lot is standardized, and at the end of each day and the start of the following day when a single lot is standardized over multiple days.

## A2.6 Periodic Verification Procedures

A2.6.1 *Perform Cleaning and Maintenance*—If required, cleaning and routine maintenance of the standardizing machine shall be made before conducting direct or indirect verifications in accordance with the manufacturer’s specifications and instructions.

A2.6.2 *Direct Verification*—Perform a direct verification of the standardizing machine in accordance with the schedule given in **Table A2.3**. The test forces, depth measuring system, and machine hysteresis shall be verified.

A2.6.2.1 *Verification of the Test Forces*—For each Rockwell scale that will be used, the associated forces (preliminary test force, total test force, and test force during elastic recovery) shall be measured. The test forces shall be measured by means of a Class AA elastic force measuring instrument having an accuracy of at least 0.05 %, as described in ASTM E74.

A2.6.2.2 Make three measurements of each force. The forces shall be measured as they are applied during testing.

A2.6.2.3 Each preliminary test force  $F_0$  and each total test force  $F$  shall be accurate to within 0.25 % in accordance with **Table A2.4**.

A2.6.2.4 *Verification of the Depth Measuring System*—The depth measuring system shall be verified by means of an instrument having an accuracy of at least 0.0001 mm.

A2.6.2.5 Verify the standardizing machine’s measurement of depth at not less than four evenly spaced increments of approximately 0.05 mm at the range of the normal working depth of the standardizing machine. The normal working depth range shall correspond to the lowest and highest hardness values for the Rockwell scales that will be standardized or that will be used for indenter calibrations.

A2.6.2.6 For testing machines with long stroke actuators and fixed anvils, the depth measurement verification shall be repeated at positions corresponding to each thickness of test block that will be standardized or that will be used for indenter calibrations.

A2.6.2.7 The indentation depth measuring device shall have an accuracy of at least 0.0002 mm over the normal working depth range which corresponds to 0.1 regular Rockwell hardness units and 0.2 Rockwell Superficial hardness units.

A2.6.2.8 *Verification of Machine Hysteresis*—Most Rockwell hardness machines will undergo flexure in the machine frame and some machine components each time a test is made. If the flexure is not entirely elastic during the application and removal of the additional force  $F_1$ , the testing machine may exhibit hysteresis in the indenter depth measuring system, resulting in an offset or bias in the test result. The goal of the

**TABLE A2.4 Tolerances on Applied Force for the Standardizing Machine**

Force, kgf (N)		Tolerance, kgf (N)	
10	(98.07)	0.025	(0.245)
60	(588.4)	0.150	(1.471)
100	(980.7)	0.250	(2.452)
150	(1471)	0.375	(3.678)
3	(29.42)	0.008	(0.074)
15	(147.1)	0.038	(0.368)
30	(294.2)	0.075	(0.736)
45	(441.3)	0.113	(1.103)

hysteresis verification is to perform a purely elastic test that results in no permanent indentation. In this way, the level of hysteresis in the flexure of the testing machine can be determined.

A2.6.2.9 Perform repeated Rockwell tests using a blunt indenter (or the indenter holder surface) acting directly onto the anvil or a very hard test piece. The tests shall be conducted on a Rockwell scale having the highest test force that is used for normal standardizations.

A2.6.2.10 Repeat the hysteresis tests for a maximum of ten measurements and average the last three tests. The average measurement shall indicate a hardness number within  $130 \pm 0.3$  Rockwell units when Rockwell ball scales B, E, F, G, H and K are used, or within  $100 \pm 0.3$  Rockwell units when any other Rockwell scale is used.

A2.6.2.11 *Direct Verification Failure*—If any of the direct verifications fail the specified requirements, the standardizing machine shall not be used until it is adjusted or repaired. Any parameter that may have been affected by an adjustment or repair shall be verified again by direct verification.

A2.6.3 *Indirect Verification*—Indirect verification involves verifying the performance of the standardizing machine by means of standardized test blocks and indenters. Prior to performing standardizations for any Rockwell scale, an indirect verification of the standardizing machine for that scale shall be made within the time period given in Table A2.3. A selected number of Rockwell scales shall be indirectly verified at the time of the direct verification as described below. The indirect verification of all other Rockwell scales may be made at any time as long as it occurs within the time period given in Table A2.3 prior to standardization.

A2.6.3.1 Immediately following the direct verification, indirect verifications of a selected number of scales shall be performed to determine the performance of the standardizing machine at each force level that the standardizing machine is capable of applying. An example of an indirect verification for a standardizing machine capable of applying all force levels is given in Table A2.5. It is recommended that Rockwell scales be chosen that will also verify each indenter that will be used. When national primary standardized test blocks (see Note A2.3) are available, they should be used for the periodic indirect verification.

NOTE A2.3—Primary standardized test blocks are certified at the national standardizing laboratory level. In the United States, the national Rockwell hardness standardizing laboratory is the National Institute of Standards and Technology (NIST), Gaithersburg, MD 20899.

**TABLE A2.5 Suggested Rockwell Scales for the Indirect Verification of Machines Capable of Performing Both Regular and Superficial Scale Tests and that Will Use Only Diamond and 1/16 in. (1.588 mm) Diameter Carbide Ball Indenters**

Preliminary Force kgf (N)	Total Force kgf (N)	Indenter Type	Rockwell Scale
10 (98.07)	60 (588.4)	diamond	HRA
10 (98.07)	100 (980.7)	1/16 in. ball	HRB
10 (98.07)	150 (1471)	diamond	HRC
3 (29.42)	15 (147.1)	diamond	HR15N
3 (29.42)	30 (294.2)	1/16 in. ball	HR30T
3 (29.42)	45 (441.3)	diamond	HR45N

A2.6.3.2 Standardized test blocks shall be used in the appropriate hardness ranges for each scale to be verified. These ranges are given in Table A2.6. The standardizing testing machine shall not be adjusted during the indirect verification procedures.

**TABLE A2.6 Maximum Allowable Repeatability and Error of Standardizing Machines**

	Range of Standardized Test Blocks	Maximum Repeatability, <i>R</i> (HR units)	Maximum Error, <i>E</i> (HR units)
HRA	20 to 65	1.0	± 0.5
	70 to 78	0.7	± 0.5
	80 to 84	0.5	± 0.3
HRBW	40 to 59	1.0	± 0.7
	60 to 79	0.7	± 0.5
	80 to 100	0.7	± 0.5
HRC	20 to 30	1.0	± 0.5
	35 to 55	0.7	± 0.5
	60 to 65	0.5	± 0.3
HRD	40 to 48	1.0	± 0.5
	51 to 67	0.7	± 0.5
	71 to 75	0.5	± 0.3
HREW	70 to 79	0.7	± 0.5
	84 to 90	0.7	± 0.5
	93 to 100	0.5	± 0.5
HRFW	60 to 75	0.7	± 0.5
	80 to 90	0.7	± 0.5
	94 to 100	0.5	± 0.5
HRGW	30 to 50	1.0	± 0.5
	55 to 75	1.0	± 0.5
	80 to 94	1.0	± 0.5
HRHW	80 to 94	1.0	± 0.5
	96 to 100	1.0	± 0.5
	HRKW	40 to 60	0.7
65 to 80		0.5	± 0.5
85 to 100		0.5	± 0.5
HRLW <sup>A</sup>		1.0	± 0.5
HRMW <sup>A</sup>		1.0	± 0.5
HRPW <sup>A</sup>		1.0	± 0.5
HRRW <sup>A</sup>		1.0	± 0.5
HRSW <sup>A</sup>		1.0	± 0.5
HRVW <sup>A</sup>		1.0	± 0.5
HR15N	70 to 77	1.0	± 0.5
	78 to 88	0.7	± 0.5
	90 to 92	0.5	± 0.4
HR30N	42 to 50	1.0	± 0.5
	55 to 73	0.7	± 0.5
	77 to 82	0.5	± 0.4
HR45N	20 to 31	1.0	± 0.5
	37 to 61	0.7	± 0.5
	66 to 72	0.5	± 0.4
HR15TW	74 to 80	1.0	± 0.7
	81 to 86	0.7	± 0.5
	87 to 93	0.7	± 0.5
HR30TW	43 to 56	1.0	± 0.7
	57 to 69	0.7	± 0.5
	70 to 83	0.7	± 0.5
HR45TW	13 to 32	1.0	± 0.7
	33 to 52	0.7	± 0.5
	53 to 73	0.7	± 0.5
HR15WW <sup>A</sup>		1.0	± 0.5
HR30WW <sup>A</sup>		1.0	± 0.5
HR45WW <sup>A</sup>		1.0	± 0.5
HR15XW <sup>A</sup>		1.0	± 0.5
HR30XW <sup>A</sup>		1.0	± 0.5
HR45XW <sup>A</sup>		1.0	± 0.5
HR15YW <sup>A</sup>		1.0	± 0.5
HR30YW <sup>A</sup>		1.0	± 0.5
HR45YW <sup>A</sup>		1.0	± 0.5

<sup>A</sup> Appropriate ranges of standardized test blocks for the L, M, P, R, S, V, W, X, and Y scales shall be determined by dividing the usable range of the scale into two ranges, high and low. Standardized test blocks for the R and S scales may be available at only one hardness level.

A2.6.3.3 The indenter(s) to be used for the indirect verification shall be the same indenter(s) that will be used for future standardizations. If more than one indenter will be used for the same hardness scale, an additional verification shall be made for each indenter.

A2.6.3.4 The test cycle to be used for the indirect verification should be the same as the test cycle used by the standardizing laboratory when calibrating the standardized test blocks.

A2.6.3.5 Prior to testing the standardized test blocks, ensure that the testing machine is working freely, and that the indenter and anvil are seated adequately. Make at least two hardness measurements on a uniform test piece for the scale to be verified. The results of these measurements need not be recorded.

A2.6.3.6 On each standardized block, make at least five hardness measurements distributed uniformly over the surface of the block.

A2.6.3.7 *Error*—Using Eq 2, determine the error  $E$  in the performance of the standardizing machine for each standardized test block that is measured. The error  $E$  shall be within the tolerances of Table A2.6.

A2.6.3.8 *Repeatability*—Using Eq 3, determine the repeatability  $R$  in the performance of the standardizing machine for each standardized test block that is measured. The repeatability  $R$  shall be within the tolerances of Table A2.6. If the calculated repeatability is outside the tolerances of Table A2.6, it may be due to the non-uniformity of the test block. The repeatability  $R$  may be determined again by making an additional five measurements on each standardized block in close proximity to each other adhering to indentation spacing restrictions (see Fig. 3). A pattern such as illustrated in Fig. A2.1 is recommended. The close proximity of the measurements will reduce the effect of test block non-uniformity.

A2.6.3.9 If any of the error  $E$  or repeatability  $R$  measurements fall outside of the specified tolerances, the standardizing machine shall not be considered to have passed the indirect verification. A number of corrective actions may be attempted to bring the standardizing machine within tolerances. These actions include cleaning and maintenance or replacing the anvil. No adjustments to the force application system, force

measurement system, or depth measuring system may be made. The indirect verification procedures may be repeated after making the allowed corrective actions. If the standardizing machine continues to fail the repeatability or error tests following corrective actions, the standardizing machine must undergo adjustment and/or repair followed by a direct verification.

A2.6.3.10 It is recommended that immediately following the successful completion of an indirect verification, user test blocks are calibrated for use as monitoring blocks as outlined in A2.7.

## A2.7 Monitoring Verification

A2.7.1 This section describes the monitoring procedures for a standardizing hardness machine used for the standardization of test blocks, and the calibration and use of monitoring test blocks.

A2.7.2 The standardizing laboratory shall monitor the performance of a standardizing machine used for the standardization of test blocks between periodic direct and indirect verifications by performing monitoring verifications each day that standardizations are made, according to the schedule given in Table A2.3. Monitoring verifications are indirect verifications performed with monitoring test blocks that bracket the standardization hardness level.

A2.7.3 The standardizing laboratory should track the performance of the standardizing machine using control-charting techniques or other comparable methods. The control charts are intended to indicate whether there is a loss of measurement control in the performance of the standardizing machine

A2.7.4 *Monitoring Test Blocks*—Test blocks that meet the physical requirements (see Table A4.1) and the uniformity requirements (see Table A4.2) of Annex A4 shall be used. The monitoring test blocks shall be at each of the appropriate hardness ranges of each hardness scale that will be used. These ranges are given in Table A2.6. It is to the advantage of the laboratory to use test blocks that exhibit high uniformity in hardness across the test surface. The laboratory may, in all cases, perform the monitoring tests using primary standardized test blocks.

A2.7.5 *Procedure for Calibrating Monitoring Test Blocks*—Monitoring test blocks for a specific Rockwell scale shall be calibrated by the standardizing laboratory following an indirect verification of the scales for which monitoring blocks will be calibrated. An adequate number of monitoring blocks should be calibrated for each hardness scale and hardness level. The number of blocks required is dependent on each laboratory's needs and experience.

A2.7.5.1 Prior to calibrating the monitoring test blocks, ensure that the testing machine is working freely, and that the indenter and anvil are seated adequately. Each time the hardness scale is changed, make at least two hardness measurements on a uniform test piece for the scale to be verified. The results of these measurements need not be recorded.

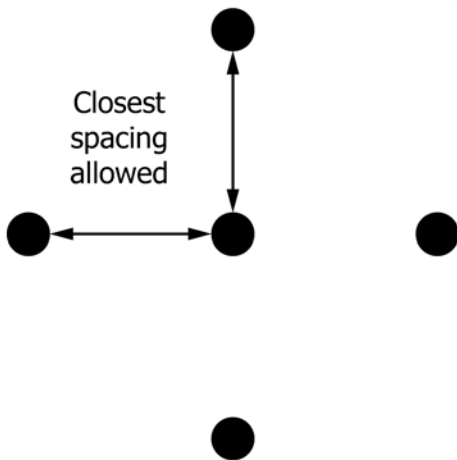


FIG. A2.1 Suggested Pattern for Repeatability Measurements

A2.7.5.2 Make at least five measurements distributed uniformly over the surface of one of the monitoring test blocks. Repeat this procedure, as required, for the quantity of blocks needed at the appropriate ranges of each Rockwell scale.

A2.7.5.3 For each of the monitoring test blocks, let  $\bar{H}_M$  be the average of the calibration values as measured by the standardizing machine. The value of  $\bar{H}_M$  may be corrected for the error  $E$  that was determined for that Rockwell scale and hardness level as a result of the indirect verification.

A2.7.6 For each monitoring block, the following information shall be recorded and retained for at least the time period during which the monitoring block calibration is valid.

A2.7.6.1 Serial number.

A2.7.6.2 Calibrated hardness value,  $\bar{H}_M$ .

A2.7.6.3 Date of calibration.

A2.7.7 *Monitoring Methods*—It is recommended that control charts or other comparable methods be used to monitor the performance of the standardizing machine between verifications. Control charts provide a method for detecting lack of statistical control. There are many publications available that discuss the design and use of control charts, such as the ASTM “Manual on Presentation of Data and Control Chart Analysis: 6th Edition,” prepared by Committee E11 on Quality and Statistics. The standardizing laboratory should develop and use control charts that best apply to their specific needs.

A2.7.8 *Monitoring Procedures*—The following monitoring procedures shall be performed before and after each lot of test blocks is standardized. When standardizations of a single lot of test blocks spans multiple days, the monitoring procedures shall be performed at the end of the work day and at the start of the following day during the period that the lot is standardized. In addition, the monitoring procedures shall be performed whenever the indenter, anvil, or test force is changed.

A2.7.8.1 At least two monitoring test blocks shall be used in the appropriate hardness ranges that bracket the hardness level to be standardized. These ranges are given in [Table A2.6](#). For some Rockwell scales (for example, HRR and HRS) there may be only one monitoring test block that can be used.

A2.7.8.2 Prior to testing the monitoring test blocks, ensure that the testing machine is working freely, and that the indenter and anvil are seated adequately. Make at least two hardness measurements on a uniform test piece for the scale to be verified. The results of these measurements need not be recorded. Repeat this procedure each time the hardness scale is changed.

A2.7.8.3 On each monitoring test block, make at least four measurements distributed uniformly over the surface of the block.

A2.7.8.4 *Error*—Determine the error  $E$  ([Eq 2](#)) in the performance of the standardizing machine for each monitoring test block that is measured. The error  $E$  shall be within the tolerances of [Table A2.6](#).

A2.7.8.5 *Repeatability*—Determine the repeatability  $R$  in the performance of the standardizing machine ([Eq 3](#)) for each standardized test block that is measured. The repeatability  $R$  shall be within the tolerances of [Table A2.6](#).

A2.7.8.6 If any of the error  $E$  measurements or the repeatability  $R$  measurements fall outside of the specified tolerances, the standardizing machine shall not be considered to have passed the monitoring verification, and shall not be used for standardizations. A number of corrective actions may be attempted to bring the standardizing machine within tolerances. These actions include cleaning and maintenance or replacing the anvil. No adjustments to the force application system, force measurement system, or depth measuring system may be made. The monitoring verification procedures may be repeated after making the allowed corrective actions. If the standardizing machine continues to fail the error tests following corrective actions, the standardizing machine must undergo adjustment and/or repair followed by a direct verification.

A2.7.8.7 Whenever a standardizing machine fails a monitoring verification, the standardizations made since the last valid monitoring verification may be suspect.

A2.7.8.8 Examine the measurement data using control charts or other monitoring systems that are being used (see [Note A2.4](#)). If the monitoring verification data indicates that the standardizing machine is within control parameters, standardizations are considered to be valid.

**NOTE A2.4**—Control chart data should be interpreted by the laboratory based on past experience. The need for corrective action does not depend solely on data falling outside the control limits, but also on the prior data leading to this occurrence. As a general rule, however, once the standardizing machine is determined to be in control, a single occurrence of data falling outside the control limits should alert the laboratory to a possible problem. The level of action that is required depends on the history of the machine performance. It may be precautionary such as increasing the monitoring frequency, or corrective such as performing new direct and indirect verifications.

## A2.8 Verification Report

### A2.8.1 *Direct Verification:*

A2.8.1.1 Reference to this ASTM test method.

A2.8.1.2 Identification of the hardness standardizing machine, including the serial number, manufacturer and model number.

A2.8.1.3 Identification of all devices (elastic proving devices, etc.) used for the verification, including serial numbers and identification of standards to which traceability is made.

A2.8.1.4 Test temperature at the time of verification reported to a resolution of at least 1°C.

A2.8.1.5 The individual measurement values and calculated results used to determine whether the standardizing machine meets the requirements of the verification performed. It is recommended that the uncertainty in the calculated results used to determine whether the standardizing machine meets the requirements of the verification performed also be reported.

A2.8.1.6 Description of adjustments or maintenance done to the standardizing machine, when applicable.

A2.8.1.7 Date of verification and reference to the verifying agency or department.

A2.8.1.8 Signature of the person performing the verification.

A2.8.1.9 Accreditation certification number.

### A2.8.2 *Indirect Verification:*

A2.8.2.1 Reference to this ASTM test method.

A2.8.2.2 Identification of the standardizing machine, including the serial number, manufacturer and model number.

A2.8.2.3 Identification of all devices (test blocks, indenters, etc.) used for the verification, including serial numbers and identification of standards to which traceability is made.

A2.8.2.4 Test temperature at the time of verification reported to a resolution of at least 1°C.

A2.8.2.5 The Rockwell hardness scale(s) verified.

A2.8.2.6 The individual measurement values and calculated results used to determine whether the standardizing machine meets the requirements of the verification performed. Measurements made to determine the as-found condition of the standardizing machine shall be included whenever they are made. It is recommended that the uncertainty in the calculated

results used to determine whether the standardizing machine meets the requirements of the verification performed also be reported.

A2.8.2.7 Description of maintenance done to the standardizing machine, when applicable.

A2.8.2.8 Date of verification and reference to the verifying agency or department.

A2.8.2.9 Signature of the person performing the verification.

A2.8.2.10 Accreditation certification number.

A2.8.3 *Monitoring Verification:*

A2.8.3.1 No verification report is required; however, it is required that records be kept of the monitoring verification results, see [A2.7.8.8](#).

### A3. STANDARDIZATION OF ROCKWELL INDENTERS

#### A3.1 Scope

A3.1.1 [Annex A3](#) specifies the requirements and procedures to manufacture and standardize the Rockwell diamond spheroconical indenter and Rockwell ball indenters for use with all Rockwell scales.

NOTE A3.1—Previous versions of this standard specified that diamond indenters used for calibrations meet the following geometrical requirements:

- included angle of  $120 \pm 0.1^\circ$ ;
- mean radius of  $0.200 \pm 0.005$  mm; and
- radius in each measured section of  $0.200 \pm 0.007$  mm.

It is believed that diamond indenters meeting these tolerances are not reliably available on the world market at this time. Consequently, for this revision, the tolerances for the geometric features of the Class A and Reference diamond indenters have been temporarily widened to the levels of Class B indenters until such time as indenters having tighter tolerances become reliably available.

A3.1.2 The Annex covers two levels of ball indenters, designated by this standard as Class B, and Class A. Class B indenters are intended for every day use with Rockwell hardness testing machines and for the indirect verification of Rockwell hardness testing machines in accordance with [Annex A1](#). Class A indenters are intended for the indirect verification of Rockwell standardizing machines in accordance with [Annex A2](#), and for the standardization of test blocks in accordance with [Annex A4](#).

A3.1.3 The Annex covers three levels of diamond indenters, designated by this standard as Class B, Class A and Reference indenters. Class B indenters are intended for every day use with Rockwell hardness testing machines. Class A indenters are intended for the standardization of Class B indenters in accordance with this Annex, and for the standardization of test blocks in accordance with [Annex A4](#). Reference indenters are intended for the standardization of Class A indenters.

A3.1.4 This Annex also provides the schedule for verifying indenters.

A3.1.5 Adherence to this standard and annex provides traceability to national standards, except as stated otherwise.

#### A3.2 Accreditation

A3.2.1 The agency conducting the standardizations of indenters shall be accredited to the requirements of ISO 17025 (or an equivalent) by an accrediting body recognized by the International Laboratory Accreditation Cooperation (ILAC) as operating to the requirements of ISO/IEC 17011. The standardizing laboratory shall have a certificate of accreditation stating the class and types of indenters that are covered by the accreditation. Only indenters of the class and types within the laboratory's scope of accreditation are considered to meet this standard, except as stated below.

NOTE A3.2—Accreditation is a new requirement starting with this edition of the standard.

#### A3.3 General Requirements

A3.3.1 The standard Rockwell hardness indenters are the *diamond spheroconical indenter*, and *tungsten carbide (WC) ball indenters* with diameters of  $\frac{1}{16}$  in. (1.588 mm),  $\frac{1}{8}$  in. (3.175 mm),  $\frac{1}{4}$  in. (6.350 mm), and  $\frac{1}{2}$  in. (12.70 mm) to be used for the Rockwell hardness scales as given in [Table A3.1](#). Steel ball indenters may be used in special circumstances (see [5.1.2.1](#)).

A3.3.2 The standardizing laboratory environment, the standardizing machine, and the standardizing test cycle shall satisfy the requirements of [Annex A2](#).

A3.3.3 All instruments used to make measurements required by this Annex shall be calibrated traceable to national standards where a system of traceability exists, except as noted otherwise.

A3.3.4 All classes of diamond indenters and ball indenters shall be verified for correct geometry and performance in accordance with the schedule specified in [Table A3.2](#).

#### A3.4 Ball Indenters

A3.4.1 Ball indenters frequently consist of a holder, a cap and a ball. The standardization process defined in this section

**TABLE A3.1 Indenter Types for Specific Rockwell Scales**

Scale Symbol	Indenter Type
HRA	Diamond Spheroconical
HRBW	WC Ball - 1/16 in. (1.588 mm)
HRC	Diamond Spheroconical
HRD	Diamond Spheroconical
HREW	WC Ball - 1/8 in. (3.175 mm)
HRFW	WC Ball - 1/16 in. (1.588 mm)
HRGW	WC Ball - 1/16 in. (1.588 mm)
HRHW	WC Ball - 1/8 in. (3.175 mm)
HRKW	WC Ball - 1/8 in. (3.175 mm)
HRLW	WC Ball - 1/4 in. (6.350 mm)
HRMW	WC Ball - 1/4 in. (6.350 mm)
HRPW	WC Ball - 1/4 in. (6.350 mm)
HRRW	WC Ball - 1/2 in. (12.70 mm)
HRSW	WC Ball - 1/2 in. (12.70 mm)
HRVW	WC Ball - 1/2 in. (12.70 mm)
HR15N	Diamond Spheroconical
HR30N	Diamond Spheroconical
HR45N	Diamond Spheroconical
HR15TW	WC Ball - 1/16 in. (1.588 mm)
HR30TW	WC Ball - 1/16 in. (1.588 mm)
HR45TW	WC Ball - 1/16 in. (1.588 mm)
HR15WW	WC Ball - 1/8 in. (3.175 mm)
HR30WW	WC Ball - 1/8 in. (3.175 mm)
HR45WW	WC Ball - 1/8 in. (3.175 mm)
HR15XW	WC Ball - 1/4 in. (6.350 mm)
HR30XW	WC Ball - 1/4 in. (6.350 mm)
HR45XW	WC Ball - 1/4 in. (6.350 mm)
HR15YW	WC Ball - 1/2 in. (12.70 mm)
HR30YW	WC Ball - 1/2 in. (12.70 mm)
HR45YW	WC Ball - 1/2 in. (12.70 mm)

**TABLE A3.2 Indenter Verification Schedule**

Indenter Type	Geometrical Features	Performance
Class B diamond	When an indenter is new.	When an indenter is new, and when suspected damage has occurred.
Class A diamond	When an indenter is new.	Shall be within 12 months prior to standardization testing and when suspected damage has occurred.
Reference diamond	When an indenter is new.	When an indenter is new, and when suspected damage has occurred.
Class A and Class B ball	Balls shall be verified for dimensions when new. Ball holders shall be verified for ball protrusion when new.	Ball holders shall be verified when new, and when suspected damage has occurred. (This requirement does not apply when simply replacing a ball.)

involves the assembled unit. The ball may be changed without affecting the assembly's verification provided the ball conforms to all the requirements in this section.

A3.4.2 One-piece fixed-ball indenters are allowed provided the indenter meets the same requirements as removable ball indenters. The manufacturer shall ensure that the method used to affix the ball to the holder does not affect the dimensions or properties of the ball.

A3.4.3 *Indenter Balls*—The balls shall meet the following requirements:

A3.4.3.1 The mean surface roughness of the ball shall not exceed 0.00005 mm (2 μin.).

A3.4.3.2 The diameter of Class B balls, when measured at not less than three positions, shall not differ from the nominal diameter by more than 0.0025 mm (0.0001 in.).

A3.4.3.3 The diameter of Class A balls, when measured at not less than three positions, shall not differ from the nominal diameter by more than 0.0010 mm (0.00004 in.).

NOTE A3.3—Balls that conform to ABMA Grade 24 satisfy the requirements for size and finish for Class A and Class B as specified in ABMA Standard 10-1989.

A3.4.3.4 The hardness of a tungsten carbide ball shall not be less than 1500 HV1 in accordance with Test Method E92 or E384.

A3.4.3.5 The material of tungsten carbide balls shall have a density of 14.8 ± 0.2 g/cm<sup>3</sup>, and the following chemical composition:

Total other carbides	2.0 % maximum
Cobalt (Co)	5.0 to 7.0 %
Tungsten carbide (WC)	balance

A3.4.3.6 The surface hardness of a steel ball shall not be less than 746 HV1 in accordance with Test Method E92 or E384.

A3.4.3.7 For the purpose of verifying the requirements of the ball given in A3.4.3, it is considered sufficient to test a sample set of balls selected at random from a batch in accordance with the schedule specified in Table A3.2. The balls verified for hardness shall be discarded.

A3.4.3.8 To meet the above requirements for indenter balls, the indenter standardizing laboratory may either verify that the balls meet the requirements, or obtain a certificate of verification from the ball manufacturer.

A3.4.4 *Ball Holder*—The ball holder shall meet the following requirements:

A3.4.4.1 The material used to manufacture the portion of the ball holder that supports the test force should have a minimum hardness of 25 HRC.

A3.4.4.2 The ball shall protrude outside the holder a minimum of 0.3 mm. This requirement may be verified by direct measurement or by performing the appropriate Rockwell scale test on a standardized test block that has an equivalent hardness of 10 HRBW or softer. The protrusion is sufficient if the hardness result is within ± 1.5 of the certified value of the block.

A3.4.5 *Performance Verification of Ball Indenter Holders*—The influence of the ball indenter on the hardness value is not due solely to the previously specified features of the ball, but also on characteristics of the ball holder that may vary due to manufacturing procedures. To examine these influences, the performance of each new Class B and Class A ball holder shall be verified in accordance with the schedule specified in Table A3.2.

A3.4.5.1 The performance verification is accomplished by making hardness measurements on test blocks meeting the manufacturing requirements of A4.3 and having been standardized using a standardizing machine which successfully passed direct verification in accordance with A2.6.2. At least one test block shall be tested for the Rockwell hardness scale and hardness range given in Table A3.3, corresponding to the ball size being verified. Some specially designed 1/16 in. (1.588 mm) Class B indenters may not be able to perform tests using the Rockwell scales required for verification of normal indenters in

**TABLE A3.3 Test Blocks to be Used for Class A and Class B Ball Indenter Performance Verifications and the Maximum Tolerance on the Performance with Respect to Standardized Reference Blocks**

Ball Size in. (mm)	Ranges of Required Test Blocks	Class A Tolerance	Class B Tolerance
1/16 (1.588)	20 to 100 HRBW	± 0.4 HRBW	± 0.8 HRBW
1/8 (3.175)	68 to 92 HREW	± 0.4 HREW	± 0.8 HREW
1/4 (6.350)	HRLW, HRMW, or HRPW (any level)	± 0.4 HR	± 0.8 HR
1/2 (12.70)	HRRW, HRSW, or HRVW (any level)	± 0.4 HR	± 0.8 HR

**Table A3.3.** For example, this applies to thin-tip 1/16 in. (1.588 mm) ball indenters that cannot support HRB scale test forces. These limited scale indenters may be used provided they are certified for the scale or scales they are designed to perform by using the test block or blocks for those scales as defined in **Table A3.4**. In all cases the test report shall define the scale or scales the indenter is certified to perform.

**A3.4.5.2** Prior to the performance verification, ensure that the testing machine is working freely, and that the indenter to be verified and anvil are seated adequately. Make at least two hardness measurements on a uniform test piece. The results of these measurements need not be recorded.

**A3.4.5.3** On the standardized test block, make at least three measurements distributed uniformly over the test surface. Determine the difference between the average of the three or more measurements and the calibrated value of the test block.

**A3.4.5.4** For acceptability, the difference shall be within the tolerances specified in **Table A3.3** for the class of indenter being verified or **Table A3.4** for the singular or limited scale indenter being verified.

**A3.4.6** Ball indenters frequently consist of a holder and a removable cap that allows periodic changing of the ball. Indenter caps can be damaged during use and therefore may have to be replaced. When the cap is replaced with a new cap, the ball indenter assembly shall be performance tested before use by performing a daily verification according to **A1.5.3.1**. The test block used should have a hardness equal to or softer than the softest material that is expected to be tested using the indenter. The verification may be performed by the indenter owner or a calibration agency. A testing machine that meets the requirements of **Annex A1** shall be used for this verification.

**TABLE A3.4 Test Blocks to be used for Singular or Limited Scale Ball Indenter Performance Verifications and the Maximum Tolerance on the Performance with Respect to Standardized Reference Blocks**

Ball Size in. (mm)	Ranges of Required Test Blocks	Tolerance
1/16 (1.588) HR15TW scale	67 to 90 HR15TW	± 0.8 HR15TW
1/16 (1.588) HR30TW scale	30 to 77 HR30TW	± 0.8 HR30TW

**A3.5 Class B Diamond Indenters**

**A3.5.1** Class B diamond indenters are intended for every day use to perform Rockwell hardness measurements. They shall be verified for correct geometry and performance in accordance with the schedule specified in **Table A3.2**.

**A3.5.2 Geometric Requirements of Class B Diamond Indenters:**

**A3.5.2.1** The polished portion of the diamond indenter shall be free from surface defects (cracks, chips, pits, etc.) when observed under a 20x magnification. The indenter shall be polished to such an extent that no unpolished part of its surface makes contact with the test piece when the indenter penetrates to a depth of 0.3 mm.

**A3.5.2.2** Verification of the following geometric features shall be made at not less than four approximately equally spaced full cross-section profiles. For example, four profiles would be spaced at approximately 45° intervals.

**A3.5.2.3** The diamond shall have an included angle of 120 ± 0.35° (see **Fig. A3.1**).

**A3.5.2.4** The tip of the diamond shall be spherical with a mean radius of 0.200 ± 0.010 mm (see **Fig. A3.1**). In each measured section, the radius shall be within 0.200 ± 0.015 mm, and local deviations from a true radius shall not exceed 0.002 mm.

**A3.5.2.5** The surfaces of the cone and spherical tip shall blend in a tangential manner.

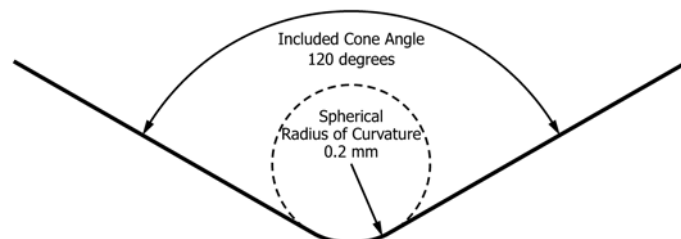
**A3.5.2.6** The instrument(s) used to verify the geometrical features shall be capable of measuring to the accuracies given in **Table A3.5**.

**A3.5.2.7** The verification of the geometrical features of the diamond may be made by direct measurement or by measurement of its projection on a screen provided the accuracy requirements are met.

**A3.5.2.8** When the projection on a screen method is used, the contour of the diamond projection is compared to lines on the screen that indicate the dimensional tolerance limits. In this case, measurement values for the geometrical features are not required. It is sufficient to state that the features are within tolerances.

**A3.5.3 Performance Verification of Class B Diamond Indenters:**

**A3.5.3.1** The influence of the diamond indenter on the hardness value is not due solely to the previously specified features of the indenter, but also on other characteristics that vary due to manufacturing procedures. To examine these influences, the performance of each Class B indenter shall be



**FIG. A3.1 Diagram of Cross-Sectional View of Spheroconical Diamond Indenter Tip**

**TABLE A3.5 Minimum Measuring Instrument Accuracies for Verifying the Geometrical Features of Class B, Class A and Reference Diamond Indenters**

Geometrical Feature	Minimum Accuracy
Angles	0.1°
Radius	0.001 mm
Straightness of the generatrix line of the cone (Class A and Reference indenters only)	0.001 mm

verified by comparison to the performance of a *qualifying* Class A or Reference indenter.

A3.5.3.2 Diamond indenters may be verified for use on limited Rockwell scales as follows: regular Rockwell scales only; superficial Rockwell scales only; or both regular and superficial Rockwell scales. Special diamond indenters intended for single or limited scale use and indenters, such as side cut diamond indenters, that because of their geometries cannot support the heavier loads of some Rockwell scales are also allowed. In all cases the test report shall define the scale or scales the indenter is certified to perform.

A3.5.3.3 The performance verification is accomplished by making hardness measurements on test blocks meeting the manufacturing requirements of A4.3.

A3.5.3.4 Prior to the performance verification, ensure that the testing machine is working freely, and that the indenter and anvil are seated adequately. Make at least two hardness measurements on a uniform test piece using a total force of 150 kgf, or the greatest test force that the indenter can support. The results of these measurements need not be recorded. This procedure shall be repeated each time the indenter is changed.

A3.5.3.5 Using the *qualifying* indenter, perform the daily verification procedures of A1.5.3 for the scales and hardness levels that will be used for the indenter performance verification. If any of the error *E* measurements or the repeatability *R* measurements fall outside of the specified tolerances, the standardizing machine shall not be considered to have passed the verification, and shall not be used for standardization until the problem is determined and corrections have been made. Once corrections have been made, the verification procedure shall be repeated. This verification procedure is required only at the start of the indenter performance verification.

A3.5.3.6 The following procedures for performance verification involve making *qualifying* hardness tests on test blocks with a Class A or Reference indenter, then performing *verification* tests on the same blocks with the Class B indenters to be verified.

A3.5.3.7 Using the *qualifying* indenter, perform one set of at least three *qualifying* tests on each test block from each range defined in Table A3.6 for the type of indenter to be verified. Special singular or limited scale indenters (see A3.5.3.2) shall be certified for use on singular or limited scales using the test blocks defined in Table A3.7. For example, if an HRA scale only diamond indenter is desired, the two HRA scale test blocks defined in the table would be used. If an indenter to be used in the 15N and 30N scales only is desired, then 4 test

**TABLE A3.6 Test Blocks to be Used Class B Diamond Indenter Performance Verifications and the Maximum Tolerance on the Performance Relative to the Class A or Reference Indenter**

Indenter Type	Ranges of Required Test Blocks	Class B Tolerance as Compared to Class A or Reference Indenter $\bar{H}_Q - \bar{H}_V$
Regular Scales Diamond	22 to 28 HRC	± 0.8 HRC
	60 to 65 HRC	± 0.4 HRC
Superficial Scales Diamond	88 to 94 HR15N	± 0.5 HR15N
	60 to 69 HR30N	± 0.5 HR30N
	22 to 29 HR45N	± 0.8 HR45N
Combination Regular and Superficial Scales Diamond	22 to 28 HRC	± 0.8 HRC
	60 to 65 HRC	± 0.5 HRC
	88 to 94 HR15N	± 0.5 HR15N
	60 to 69 HR30N	± 0.5 HR15N

**TABLE A3.7 Test Blocks to be Used for Singular or Limited Scale Diamond Indenter Performance Verifications and the Maximum Tolerance on the Performance Relative to the Class A or Reference Indenter**

Indenter Type	Ranges of Required Test Blocks	Tolerance as Compared to Class A or Reference Indenter $\bar{H}_Q - \bar{H}_V$
HRA Scale	61 to 65 HRA	± 0.8 HRA
	81 to 84 HRA	± 0.5 HRA
HRD Scale	41 to 46 HRD	± 0.8 HRD
	70 to 75 HRD	± 0.5 HRD
HR15N Scale	70 to 74 HR15N	± 0.8 HR15N
	88 to 94 HR15N	± 0.5 HR15N
HR30N Scale	43 to 49 HR30N	± 0.8 HR30N
	77 to 82 HR30N	± 0.5 HR30N

blocks would be used, 2 in the 15N scale and 2 in the 30N scale as defined in the table. Record each test result and the location of the indentation. Let  $\bar{H}_Q$  be the average of the *qualifying* measurements.

A3.5.3.8 Using the Class B indenter to be verified, perform *verification* tests on the test blocks previously tested with the Class A or Reference indenter. One *verification* test shall be made within 6 mm of each *qualifying* indent. Let  $\bar{H}_V$  be the average of the *verifying* measurements.

A3.5.3.9 The number of *verifying* tests that can be made adjacent to each *qualifying* test is limited by the requirements to be within 6 mm of the *qualifying* indent while adhering to the indent to indent spacing requirements given in 7.9. To make additional *verifying* tests, perform additional *qualifying* tests with the Class A or Reference indenter, and repeat the above *verifying* procedure. This process may be repeated until there is no longer space on the test block.

A3.5.3.10 For acceptability, the difference between the *qualifying* and *verifying* averages,  $\bar{H}_Q - \bar{H}_V$ , shall be within the tolerances for Class B indenters of Table A3.6 or Table A3.7 for the singular or limited scale indenter being verified.



### A3.6 Class A Diamond Indenters

A3.6.1 Class A indenters are intended to be used for the standardization of Class B indenters in accordance with this Annex; the standardization of Rockwell hardness test blocks as described in Annex A4, and as a troubleshooting tool during the indirect verification of Rockwell hardness testing machines in accordance with Annex A1. They are verified for correct geometry and performance in accordance with the schedule specified in Table A3.2.

A3.6.1.1 The instrument(s) used to verify the geometrical features shall be capable of measuring to the accuracies given in Table A3.5.

A3.6.2 A Class A diamond indenter shall meet all of the manufacture and geometric requirements for a Class B diamond indenter given in A3.5.2 with the following additional requirements. See also Note A3.1.

A3.6.2.1 The deviation from straightness of the generatrix line of the diamond cone adjacent to the blend shall not exceed 0.002 mm over a minimum length of 0.40 mm.

A3.6.2.2 The angle between the axis of the indenter and the axis normal to the seating surface of the indenter shall not exceed 0.5°.

A3.6.3 Class A diamond indenters have tighter performance tolerances than Class B diamond indenters. The performance of each Class A indenter shall be verified by comparison to the performance of a Reference indenter.

A3.6.4 Perform the qualifying and verifying measurements as described in A3.5.3 for a Class B diamond indenter, except that the qualifying measurements shall be made using a Reference diamond indenter on each test block from each range defined in Table A3.8 for the type of indenter to be verified.

A3.6.4.1 For acceptability, the difference of the average of the three qualifying measurements and the average of the three verifying measurements,  $\bar{H}_Q - \bar{H}_V$ , shall be within the tolerance specified for Class A diamond indenters in Table A3.8.

### A3.7 Reference Diamond Indenters

A3.7.1 Reference diamond indenters are intended for the standardization of Class A diamond indenters. The reference indenter shall have tighter performance tolerances than Class A and Class B indenters and shall be verified for performance by comparison to an indenter recognized as the national reference indenter(s) of a national Rockwell hardness standardizing laboratory (see Note A3.4).

NOTE A3.4—In the United States, the national Rockwell hardness standardizing laboratory is the National Institute of Standards and Technology (NIST).

A3.7.2 *Geometric Requirements of Reference Diamond Indenters:*

A3.7.2.1 Verification of the following geometric features of a Reference diamond spheroconical indenter shall be made at not less than eight approximately equally spaced full cross-section profiles. For example, eight profiles would be spaced at approximately 22.5 degree intervals.

A3.7.3 A Reference diamond indenter shall meet all of the manufacture and geometric requirements for a Class A diamond indenter given in A3.6.2. See also Note A3.1.

A3.7.4 *Performance Verification of Reference Diamond Indenters:*

A3.7.4.1 The performance comparison shall be performed by a national Rockwell hardness standardizing laboratory, and shall meet the performance tolerances of Table A3.9.

A3.7.4.2 Perform the qualifying and verifying measurements as described in A3.5.3 for a Class B indenter, except that at least four qualifying measurements shall be made using a national reference indenter (see A3.7.1) on each test block from each range defined in Table A3.9 for the type of indenter to be verified.

A3.7.4.3 For acceptability, the difference of the average of the five qualifying measurements and the average of the five verifying measurements,  $\bar{H}_Q - \bar{H}_V$ , shall be within the tolerance specified for Reference indenters in Table A3.9 for each test block used in the verification.

**TABLE A3.8 Test Blocks to be Used for Class A Diamond Indenter Performance Verifications and the Maximum Tolerance on the Performance Relative to the Reference Indenter**

Indenter Type	Ranges of Required Test Blocks	Class A Tolerance as Compared to Reference Indenter $\bar{H}_Q - \bar{H}_V$
Regular Scales Diamond	80 to 83 HRA	± 0.3 HRA
	22 to 28 HRC	± 0.4 HRC
	42 to 50 HRC	± 0.4 HRC
	60 to 65 HRC	± 0.3 HRC
Superficial Scales Diamond	88 to 94 HR15N	± 0.3 HR15N
	60 to 69 HR30N	± 0.3 HR30N
	42 to 50 HR30N	± 0.4 HR45N
	22 to 29 HR45N	± 0.4 HR45N
Combination Regular and Superficial Scales Diamond	22 to 28 HRC	± 0.4 HRC
	60 to 65 HRC	± 0.3 HRC
	88 to 94 HR15N	± 0.3 HR15N
	60 to 69 HR30N	± 0.3 HR30N

**TABLE A3.9 Test Blocks to be Used for Reference Indenter Performance Verifications and the Maximum Tolerance on the Performance Relative to a National Reference Indenter**

Indenter Type	Ranges of Required Test Blocks	Reference Indenter Tolerance as Compared to a National Reference Indenter $\bar{H}_Q - \bar{H}_V$
Regular Scales Diamond	22 to 28 HRC	± 0.3 HRC
	62 to 65 HRC	± 0.3 HRC
Superficial Scales Diamond	88 to 94 HR15N	± 0.3 HR15N
	40 to 48 HR45N	± 0.3 HR45N
	20 to 28 HRC	± 0.3 HRC
Combination Regular and Superficial Scales Diamond	62 to 65 HRC	± 0.3 HRC
	88 to 94 HR15N	± 0.3 HR15N
	40 to 48 HR45N	± 0.3 HR45N

### A3.8 Marking

A3.8.1 All indenters shall be serialized. When it is not practical to mark the serial number on the indenter due to size limitations, the serial number shall be marked on the container.

A3.8.2 Diamond indenters should be marked to indicate the scales that they are certified to perform. For example, regular scale diamond indenters may be marked with a “C” and superficial scale diamond indenters may be marked with an “N”. Combination indenters may be marked with both a “C” and an “N”.

A3.8.3 Single or limited scale indenters shall be marked to indicate the scale(s) they are certified to perform. When it is not practical to mark the scale on the indenter due to size limitations, the scale shall be marked on the container.

### A3.9 Certificate

A3.9.1 *Ball Indenters*—Each Class B and Class A ball indenter holder shall have a calibration certificate with the following information:

A3.9.1.1 Reference to this ASTM test method.

A3.9.1.2 Serial number of the indenter.

A3.9.1.3 Date of standardization.

A3.9.1.4 A statement declaring that the indenter meets all of the material hardness, ball protrusion and performance requirements for the particular Class of Rockwell ball indenter.

A3.9.1.5 Accreditation agency certification number.

A3.9.1.6 The scale(s) that the indenter is certified to perform when certified for singular or limited scales.

A3.9.2 Indenter balls for Class B and Class A indenters shall have a report, applicable to one or more balls, with the following information:

A3.9.2.1 Reference to this ASTM test method.

A3.9.2.2 Identification of the lot or batch.

A3.9.2.3 A statement declaring that the ball meets all of the geometrical, density, chemical composition and hardness requirements for the particular Class of Rockwell ball indenter.

A3.9.3 *Class B Diamond Indenters*—Each Class B diamond indenter shall have a calibration certificate with the following information:

A3.9.3.1 Reference to this ASTM test method.

A3.9.3.2 Serial number of the indenter.

A3.9.3.3 Date of standardization.

A3.9.3.4 A statement declaring that the indenter meets all of the geometrical and performance requirements for a Class B indenter.

A3.9.3.5 Accreditation agency certification number.

A3.9.3.6 The scale(s) that the indenter is certified to perform when certified for singular or limited scales.

A3.9.4 *Class A Diamond Indenters*—Each Class A diamond indenter shall have a calibration certificate with the following information:

A3.9.4.1 Reference to this ASTM test method.

A3.9.4.2 Serial number of the indenter.

A3.9.4.3 Date of standardization.

A3.9.4.4 The results of all geometrical verifications.

A3.9.4.5 All qualifying and verifying performance measurements with the hardness levels of the test blocks used.

A3.9.4.6 The performance differences between the Reference standardizing indenter and the verified Class A indenter  $\bar{H}_Q - \bar{H}_V$  for each test block used.

A3.9.4.7 A statement declaring that the indenter meets all of the geometrical and performance requirements for a Class A indenter.

A3.9.4.8 Accreditation agency certification number.

A3.9.5 *Reference Diamond Indenters*—Each Reference diamond indenter shall have a calibration certificate or report with the following information:

A3.9.5.1 Serial number of the indenter.

A3.9.5.2 Date of standardization.

A3.9.5.3 The results of all geometrical verifications.

A3.9.5.4 Serial number of the reference indenter.

A3.9.5.5 All qualifying and verifying performance measurements with the hardness levels of the test blocks used.

A3.9.5.6 The performance differences between the reference indenter and the verified Reference indenter  $\bar{H}_Q - \bar{H}_V$  for each test block used.

## A4. STANDARDIZATION OF ROCKWELL HARDNESS TEST BLOCKS

### A4.1 Scope

A4.1.1 **Annex A4** specifies the requirements and procedures for the standardization of Rockwell hardness test blocks that are traceable to specific Rockwell hardness standards. These standardized test blocks are to be used for the verification of the performance of Rockwell and Rockwell superficial hardness testing machines by way of daily verifications and indirect verifications as described in **Annex A1**. The standardized test blocks are also to be used for the monitoring verifications of Rockwell standardizing machines as described in **Annex A2**.

A4.1.2 Adherence to this standard and annex provides traceability to national standards, except as stated otherwise.

### A4.2 Accreditation

A4.2.1 The agency conducting the standardizations of test blocks shall be accredited to the requirements of ISO 17025 (or an equivalent) by an accrediting body recognized by the International Laboratory Accreditation Cooperation (ILAC) as operating to the requirements of ISO/IEC 17011. The standardizing agency shall have a certificate/scope of accreditation

stating the Rockwell hardness scales that are covered by the accreditation, and the standards to which the test block standardizations are traceable.

NOTE A4.1—Accreditation is a new requirement starting with this edition of the standard.

### A4.3 Manufacture

A4.3.1 The attention of the manufacturer of test blocks is drawn to the need to use material and a manufacturing process which will give the necessary homogeneity, stability of structure, and uniformity of surface hardness. For quality control purposes, test blocks should be examined for homogeneity and uniformity of surface hardness in accordance with a statistically acceptable sampling procedure.

A4.3.2 The test blocks, if of steel, shall be demagnetized at the end of the manufacturing process.

A4.3.3 To assure that material is not removed from the test surface after standardization, an identifying mark shall be made on the test surface. The mark shall be such that it can not be removed by any method other than removal of test block material.

A4.3.4 The standardized test block shall meet the physical requirements of Table A4.1.

### A4.4 General Requirements

A4.4.1 The standardizing laboratory environment, the standardizing machine, and the standardizing test cycle shall satisfy the requirements of Annex A2.

A4.4.2 All instruments used to make measurements required by this Annex shall have been calibrated traceable to national standards where a system of traceability exists, except as noted otherwise.

### A4.5 Standardization Procedure

A4.5.1 A test block is standardized by calibrating the average hardness of the test surface to a specific Rockwell hardness standard. Only one surface of the test block shall be calibrated. When possible, the test blocks should be calibrated traceable to national Rockwell standards (see Note A4.2). The Rockwell standard to which the test blocks are traceable shall be stated in the certification.

NOTE A4.2—In the United States, the national Rockwell hardness standardizing laboratory is the National Institute of Standards and Technology (NIST), Gaithersburg, MD 20899.

NOTE A4.3—Primary standardized test blocks are available as Standard Reference Material from NIST, Gaithersburg, MD 20899.

A4.5.2 Class A ball indenters and Class A or Reference diamond indenters as described in Annex A3 (see Note 3) shall be used for the standardization of test blocks.

A4.5.3 The standardization procedure involves making hardness measurements on the test block surface using the forces and type of indenter that are appropriate for the hardness scale.

A4.5.3.1 Make at least five measurements distributed uniformly over the test surface.

A4.5.4 Determine the nonuniformity range  $H_R$  of the measurements as:

$$H_R = H_{max} - H_{min} \quad (A4.1)$$

where:

$H_{max}$  = highest hardness value, and

$H_{min}$  = lowest hardness value.

A4.5.4.1 The nonuniformity range  $H_R$  of the standardizing measurements provides an indication of the non-uniformity of the test block hardness. For acceptability, the nonuniformity range  $H_R$  shall be within the tolerances of Table A4.2.

A4.5.5 The standardized value of the test block is defined as the average of the standardization measurements  $\bar{H}$ .

A4.5.6 In some cases, a more accurate standardized value for the test block may be obtained by correcting the measured average hardness value by a performance offset value for the standardizing machine. The offset value may be based on the error  $E$  values measured during the last indirect verification of the standardizing machine. For example, an appropriate offset correction curve for each standardizing machine may be calculated for a specific Rockwell scale by fitting a linear line to the error values measured during the indirect verification.

TABLE A4.2 Maximum Nonuniformity for Standardized Test Blocks

Nominal Hardness of Standardized Test Block	Max. Nonuniformity Range, $H_R$ (HR units)
HRA	1.0
	0.5
HRBW	1.5
	1.0
HRC	1.0
	0.5
HRD	1.0
	0.5
HREW, HRFW, HRGW, HRHW, HRKW, HRLW, HRMW, HRPW, HRRW, HRSW, HRVW	1.0
HR15N	1.0
	0.7
HR30N	1.0
	0.7
HR45N	1.0
	0.7
HR15TW, HR30TW, HR45TW	1.0
HR15WW, HR30WW, HR45WW, HR15XW, HR30XW, HR45XW, HR15YW, HR30YW, HR45YW	1.0

TABLE A4.1 Physical Requirements of Standardized Test Blocks

Test Block Parameter	Tolerance
Thickness	≥6.0 mm (0.236 in.)
	≤16.0 mm (0.630 in.)
Test surface area	≤2600 mm <sup>2</sup> (4 in. <sup>2</sup> )
Deviation from surface flatness (test & bottom)	≤0.005 mm (0.0002 in.)
Deviation from surface parallelism (test & bottom)	≤0.0002 mm per mm (0.0002 in. per in.)
Mean surface roughness (test & bottom)	$R_a$ ≤ 0.003 mm (12 μin.) center line average

The laboratory should be cautioned that the validity of calculating a correction curve in this way is dependent on the linearity of the fit of the offset data across the entire scale.

**A4.6 Marking**

A4.6.1 Markings placed on the side of the block shall be upright when the calibrated test surface is the upper surface.

A4.6.2 Each standardized block shall be marked with the following.

A4.6.2.1 The standardized hardness value,  $\bar{H}$ , of the test block, rounded to no less than one decimal place in accordance with Practice E29, for example 61.4 HRC.

A4.6.2.2 The appropriate tolerance value for error  $E$  given in Table A1.3.

A4.6.2.3 Name or identifying mark of the standardizing agency.

A4.6.2.4 A mark identifying the test surface, which will be obliterated if the surface is reground.

A4.6.2.5 Unique serial number.

A4.6.2.6 Year of standardization. It is sufficient that the year of standardization be incorporated into the serial number of the block.

**A4.7 Certificate**

A4.7.1 Each standardized test block shall be supplied with a certificate from the standardizing laboratory stating the following standardization information:

A4.7.1.1 Serial number of the test block.

A4.7.1.2 The standardized hardness value,  $\bar{H}$ , of the test block with the scale designation, rounded to no less than one decimal place in accordance with Practice E29, for example 61.4 HRC.

A4.7.1.3 Value of the uncertainty in the standardized value with a detailed explanation of how the uncertainty was calculated.

A4.7.1.4 The individual standardizing hardness measurements.

A4.7.1.5 A description of the testing cycle used, including the dwell times for the preliminary force, total force and elastic recovery.

A4.7.1.6 The body that maintains the Rockwell scale to which the test block is traceable. For example, the national Rockwell C scale maintained at NIST.

A4.7.1.7 Date of standardization.

A4.7.1.8 Accreditation agency certification number.

**A5. GUIDELINES FOR DETERMINING THE MINIMUM THICKNESS OF A TEST PIECE**

**TABLE A5.1 A Minimum Thickness Guide for Selection of Scales Using the Diamond Indenter (see Fig. A5.1)**

NOTE 1—For any given thickness, the indicated Rockwell hardness is the minimum value acceptable for testing. For a given hardness, material of any greater thickness than that corresponding to that hardness can be tested on the indicated scale.

Minimum Thickness		Rockwell Scale		
		Hardness Reading	A	C
in.	mm		Approximate Hardness C-Scale <sup>A</sup>	Hardness Reading
0.014	0.36	...	...	...
0.016	0.41	86	69	...
0.018	0.46	84	65	...
0.020	0.51	82	61.5	...
0.022	0.56	79	56	69
0.024	0.61	76	50	67
0.026	0.66	71	41	65
0.028	0.71	67	32	62
0.030	0.76	60	19	57
0.032	0.81	...	...	52
0.034	0.86	...	...	45
0.036	0.91	...	...	37
0.038	0.96	...	...	28
0.040	1.02	...	...	20

<sup>A</sup> These approximate hardness numbers are for use in selecting a suitable scale and should not be used as hardness conversions. If necessary to convert test readings to another scale, refer to Hardness Conversion Tables E140 (Relationship Between Brinell Hardness, Vickers Hardness, Rockwell Hardness, Rockwell Superficial Hardness, and Knoop Hardness).

**TABLE A5.2 A Minimum Thickness Guide for Selection of Scales Using the 1/16 in. (1.588 mm) Diameter Ball Indenter (see Fig. A5.2)**

NOTE 1—For any given thickness, the indicated Rockwell hardness is the minimum value acceptable for testing. For a given hardness, material of any greater thickness than that corresponding to that hardness can be tested on the indicated scale.

Minimum Thickness		Rockwell Scale		
		F		B
in.	mm	Hardness Reading	Approximate Hardness B-Scale <sup>A</sup>	Hardness Reading
0.022	0.56	...	...	...
0.024	0.61	98	72	94
0.026	0.66	91	60	87
0.028	0.71	85	49	80
0.030	0.76	77	35	71
0.032	0.81	69	21	62
0.034	0.86	...	...	52
0.036	0.91	...	...	40
0.038	0.96	...	...	28
0.040	1.02	...	...	...

<sup>A</sup> These approximate hardness numbers are for use in selecting a suitable scale and should not be used as hardness conversions. If necessary to convert test readings to another scale refer to Hardness Conversion Tables E140 (Relationship Between Brinell Hardness, Vickers Hardness, Rockwell Hardness, Rockwell Superficial Hardness and Knoop Hardness).

**TABLE A5.3 A Minimum Thickness Guide for Selection of Scales Using the Diamond Indenter (see Fig. A5.1)**

NOTE 1—For any given thickness, the indicated Rockwell hardness is the minimum value acceptable for testing. For a given hardness, material of any greater thickness than that corresponding to that hardness can be tested on the indicated scale.

Minimum Thickness		Rockwell Superficial Scale					
		15N		30N		45N	
in.	mm	Hardness Reading	Approximate Hardness C-Scale <sup>A</sup>	Hardness Reading	Approximate Hardness C-Scale <sup>A</sup>	Hardness Reading	Approximate Hardness C-Scale <sup>A</sup>
0.006	0.15	92	65	...	...	...	...
0.008	0.20	90	60	...	...	...	...
0.010	0.25	88	55	...	...	...	...
0.012	0.30	83	45	82	65	77	69.5
0.014	0.36	76	32	78.5	61	74	67
0.016	0.41	68	18	74	56	72	65
0.018	0.46	...	...	66	47	68	61
0.020	0.51	...	...	57	37	63	57
0.022	0.56	...	...	47	26	58	52.5
0.024	0.61	...	...	...	...	51	47
0.026	0.66	...	...	...	...	37	35
0.028	0.71	...	...	...	...	20	20.5
0.030	0.76	...	...	...	...	...	...

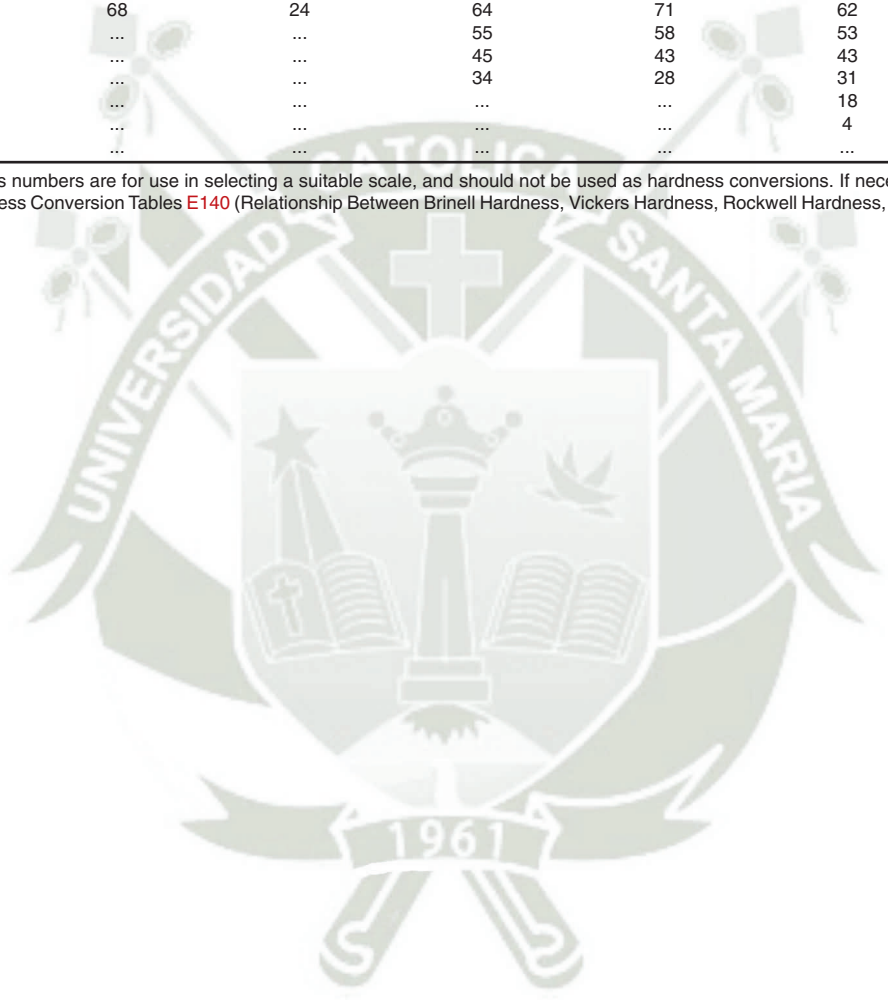
<sup>A</sup> These approximate hardness numbers are for use in selecting a suitable scale, and should not be used as hardness conversions. If necessary to convert test readings to another scale, refer to Hardness Conversion Tables E140 (Relationship Between Brinell Hardness, Vickers Hardness, Rockwell Hardness, Rockwell Superficial Hardness and Knoop Hardness).

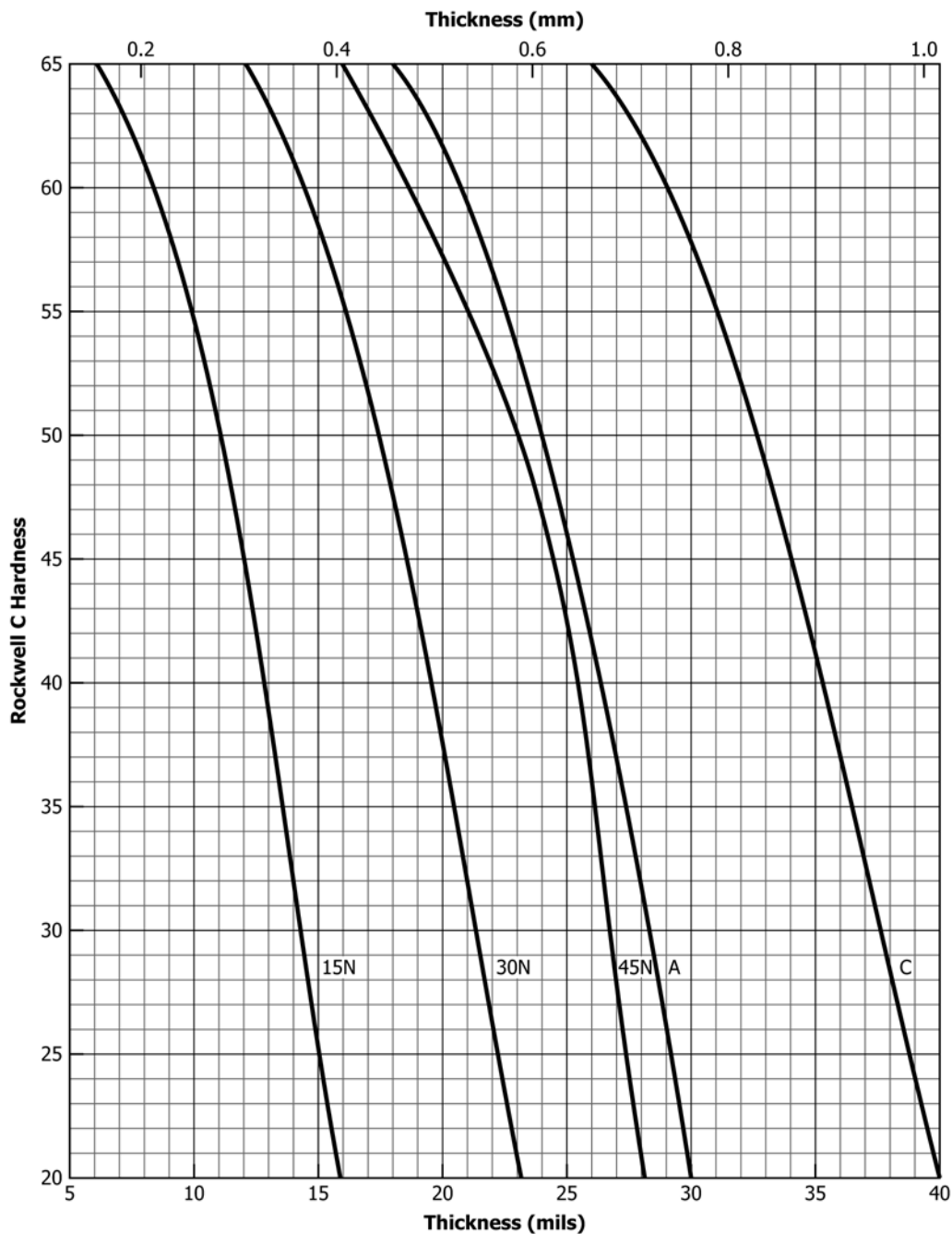
**TABLE A5.4 A Minimum Thickness Guide for Selection of Scales Using the 1/16 in. (1.588 mm) Diameter Ball Indenter (see Fig. A5.2)**

NOTE 1—For any given thickness, the indicated Rockwell hardness is the minimum value acceptable for testing. For a given hardness, material of any greater thickness than that corresponding to that hardness can be tested on the indicated scale.

Minimum Thickness		Rockwell Superficial Scale					
		15T		30T		45T	
in.	mm	Hardness Reading	Approximate Hardness B-Scale <sup>A</sup>	Hardness Reading	Approximate Hardness B-Scale <sup>A</sup>	Hardness Reading	Approximate Hardness B-Scale <sup>A</sup>
0.010	0.25	91	93	...	...	...	...
0.012	0.30	86	78	...	...	...	...
0.014	0.36	81	62	80	96	...	...
0.016	0.41	75	44	72	84	71	99
0.018	0.46	68	24	64	71	62	90
0.020	0.51	...	...	55	58	53	80
0.022	0.56	...	...	45	43	43	70
0.024	0.61	...	...	34	28	31	58
0.026	0.66	...	...	...	...	18	45
0.028	0.71	...	...	...	...	4	32
0.030	0.76	...	...	...	...	...	...

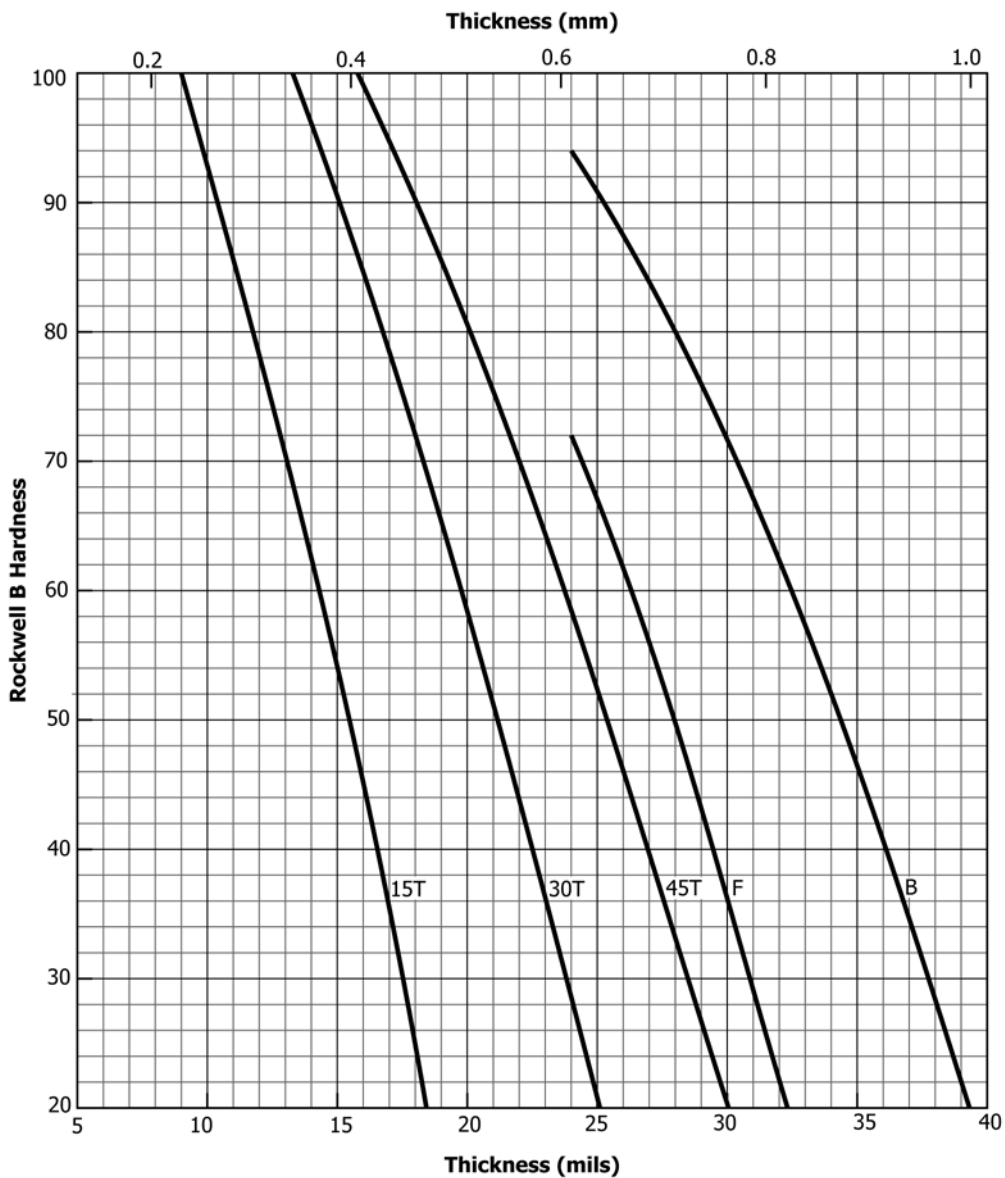
<sup>A</sup> These approximate hardness numbers are for use in selecting a suitable scale, and should not be used as hardness conversions. If necessary to convert test readings to another scale refer to Hardness Conversion Tables E140 (Relationship Between Brinell Hardness, Vickers Hardness, Rockwell Hardness, Rockwell Superficial Hardness and Knoop Hardness).





NOTE 1—Locate a point corresponding to the thickness-hardness combination to be tested. Only scales falling to the left of this point may be used to test this combination.

FIG. A5.1 Thickness Limits for Rockwell Hardness Testing Using the Diamond Indenter



NOTE 1—Locate a point corresponding to the thickness-hardness combination to be tested. Only scales falling to the left of this point may be used to test this combination.

FIG. A5.2 Thickness Limits for Rockwell Hardness Testing Using the 1/16-in. (1.588-mm) Diameter Ball Indenter

#### A6. HARDNESS VALUE CORRECTIONS WHEN TESTING ON CONVEX CYLINDRICAL SURFACES



**TABLE A6.1 Corrections to be Added to Rockwell C, A, and D Values Obtained on Convex Cylindrical Surfaces of Various Diameters<sup>A</sup>**

Dial Reading	Diameters of Convex Cylindrical Surfaces								
	¼ in. (6.4 mm)	⅜ in. (10 mm)	½ in. (13 mm)	⅝ in. (16 mm)	¾ in. (19 mm)	⅞ in. (22 mm)	1 in. (25 mm)	1¼ in. (32 mm)	1½ in. (38 mm)
Corrections to be Added to Rockwell C, A, and D Values <sup>B</sup>									
20	6.0	4.5	3.5	2.5	2.0	1.5	1.5	1.0	1.0
25	5.5	4.0	3.0	2.5	2.0	1.5	1.0	1.0	1.0
30	5.0	3.5	2.5	2.0	1.5	1.5	1.0	1.0	0.5
35	4.0	3.0	2.0	1.5	1.5	1.0	1.0	0.5	0.5
40	3.5	2.5	2.0	1.5	1.0	1.0	1.0	0.5	0.5
45	3.0	2.0	1.5	1.0	1.0	1.0	0.5	0.5	0.5
50	2.5	2.0	1.5	1.0	1.0	0.5	0.5	0.5	0.5
55	2.0	1.5	1.0	1.0	0.5	0.5	0.5	0.5	0
60	1.5	1.0	1.0	0.5	0.5	0.5	0.5	0	0
65	1.5	1.0	1.0	0.5	0.5	0.5	0.5	0	0
70	1.0	1.0	0.5	0.5	0.5	0.5	0.5	0	0
75	1.0	0.5	0.5	0.5	0.5	0.5	0	0	0
80	0.5	0.5	0.5	0.5	0.5	0	0	0	0
85	0.5	0.5	0.5	0	0	0	0	0	0
90	0.5	0	0	0	0	0	0	0	0

<sup>A</sup> When testing cylindrical specimens, the accuracy of the test will be seriously affected by alignment of elevating screw, V-anvil, indenters, surface finish, and the straightness of the cylinder.

<sup>B</sup> These corrections are approximate only and represent the averages to the nearest 0.5 Rockwell number, of numerous actual observations.

**TABLE A6.2 Corrections to be Added to Rockwell B, F, and G Values Obtained on Convex Cylindrical Surfaces of Various Diameters<sup>A</sup>**

Hardness Reading	Diameters of Convex Cylindrical Surfaces						
	¼ in. (6.4 mm)	⅜ in. (10 mm)	½ in. (13 mm)	⅝ in. (16 mm)	¾ in. (19 mm)	⅞ in. (22 mm)	1 in. (25 mm)
Corrections to be Added to Rockwell B, F, and G Values <sup>B</sup>							
0	12.5	8.5	6.5	5.5	4.5	3.5	3.0
10	12.0	8.0	6.0	5.0	4.0	3.5	3.0
20	11.0	7.5	5.5	4.5	4.0	3.5	3.0
30	10.0	6.5	5.0	4.5	3.5	3.0	2.5
40	9.0	6.0	4.5	4.0	3.0	2.5	2.5
50	8.0	5.5	4.0	3.5	3.0	2.5	2.0
60	7.0	5.0	3.5	3.0	2.5	2.0	2.0
70	6.0	4.0	3.0	2.5	2.0	2.0	1.5
80	5.0	3.5	2.5	2.0	1.5	1.5	1.5
90	4.0	3.0	2.0	1.5	1.5	1.5	1.0
100	3.5	2.5	1.5	1.5	1.0	1.0	0.5

<sup>A</sup> When testing cylindrical specimens, the accuracy of the test will be seriously affected by alignment of elevating screw, V-anvil, indenters, surface finish, and the straightness of the cylinder.

<sup>B</sup> These corrections are approximate only and represent the averages to the nearest 0.5 Rockwell number, of numerous actual observations.

**TABLE A6.3 Corrections to be Added to Rockwell Superficial 15N, 30N, and 45N Values Obtained on Convex Cylindrical Surfaces of Various Diameters<sup>A</sup>**

Hardness Reading	Diameters of Convex Cylindrical Surfaces					
	⅛ in. (3.2 mm)	¼ in. (6.4 mm)	⅜ in. (10 mm)	½ in. (13 mm)	¾ in. (19 mm)	1 in. (25 mm)
Corrections to be Added to Rockwell Superficial 15N, 30N, and 45N Values <sup>B</sup>						
20	6.0	3.0	2.0	1.5	1.5	1.5
25	5.5	3.0	2.0	1.5	1.5	1.0
30	5.5	3.0	2.0	1.5	1.0	1.0
35	5.0	2.5	2.0	1.5	1.0	1.0
40	4.5	2.5	1.5	1.5	1.0	1.0
45	4.0	2.0	1.5	1.0	1.0	1.0
50	3.5	2.0	1.5	1.0	1.0	0.5
55	3.5	2.0	1.5	1.0	0.5	0.5
60	3.0	1.5	1.0	1.0	0.5	0.5
65	2.5	1.5	1.0	0.5	0.5	0.5
70	2.0	1.0	1.0	0.5	0.5	0.5
75	1.5	1.0	0.5	0.5	0.5	0
80	1.0	0.5	0.5	0.5	0	0
85	0.5	0.5	0.5	0.5	0	0
90	0	0	0	0	0	0

<sup>A</sup> When testing cylindrical specimens the accuracy of the test will be seriously affected by alignment of elevating screw, V-anvil, indenters, surface finish, and the straightness of the cylinder.

<sup>B</sup> These corrections are approximate only and represent the averages, to the nearest 0.5 Rockwell superficial number, of numerous actual observations.

**TABLE A6.4 Corrections to be Added to Rockwell Superficial 15T, 30T, and 45T Values Obtained on Convex Cylindrical Surfaces of Various Diameters<sup>A</sup>**

Hardness Reading	Diameters of Convex Cylindrical Surfaces						
	1/8 in. (3.2 mm)	1/4 in. (6.4 mm)	3/8 in. (10 mm)	1/2 in. (13 mm)	5/8 in. (16 mm)	3/4 in. (19 mm)	1 in. (25 mm)
Corrections to be Added to Rockwell Superficial 15T, 30T, and 45T Values <sup>B</sup>							
20	13.0	9.0	6.0	4.5	4.5	3.0	2.0
30	11.5	7.5	5.0	3.5	3.5	2.5	2.0
40	10.0	6.5	4.5	3.5	3.0	2.5	2.0
50	8.5	5.5	4.0	3.0	2.5	2.0	1.5
60	6.5	4.5	3.0	2.5	2.0	1.5	1.5
70	5.0	3.5	2.5	2.0	1.5	1.0	1.0
80	3.0	2.0	1.5	1.5	1.0	1.0	0.5
90	1.5	1.0	1.0	0.5	0.5	0.5	0.5

<sup>A</sup> When testing cylindrical specimens, the accuracy of the test will be seriously affected by alignment of elevating screw, V-anvil, indenters, surface finish, and the straightness of the cylinder.

<sup>B</sup> These corrections are approximate only and represent the averages to the nearest 0.5 Rockwell number, of numerous actual observations.

## APPENDIXES

### (Nonmandatory Information)

#### X1. LIST OF ASTM SPECIFICATIONS GIVING HARDNESS VALUES CORRESPONDING TO TENSILE STRENGTH

X1.1 The following ASTM standards give approximate Rockwell hardness or Rockwell superficial hardness values corresponding to the tensile strength values specified for the materials covered: Test Methods and Definitions [A370](#) and

Specifications [B19](#), [B36/B36M](#), [B96/B96M](#), [B103/B103M](#), [B121/B121M](#), [B122/B122M](#), [B130](#), [B134/B134M](#), [B152/B152M](#), and [B370](#).

#### X2. EXAMPLES OF PROCEDURES FOR DETERMINING ROCKWELL HARDNESS UNCERTAINTY

##### X2.1 Scope

X2.1.1 The intent of this appendix is to provide a basic approach to evaluating the uncertainty of Rockwell hardness measurement values in order to simplify and unify the interpretation of uncertainty by users of Rockwell hardness.

X2.1.2 This appendix provides basic procedures for determining the uncertainty of the following values of hardness:

X2.1.2.1 *The Hardness Machine “Error” Determined as Part of an Indirect Verification* (see [X2.6](#))—As part of an indirect verification, a number of Rockwell hardness measurements are made on a reference test block. The average of the measurement values is compared to the certified value of the reference block to determine the “error” (see [3.2.2](#)) of the hardness machine. The procedure described in section [X2.6](#) provides a method for determining the uncertainty in this measurement “error” of the hardness machine. The uncertainty value may be reported on the verification certificate and report.

X2.1.2.2 *Rockwell Hardness Value Measured by a User* (see [X2.7](#))—The procedure provides a method for determining the uncertainty in the hardness values measured by a user during the normal use of a Rockwell hardness machine. The user may report the uncertainty value with the measurement value.

X2.1.2.3 *Certified Value of a Rockwell Hardness Test Block* (see [X2.8](#))—The procedure provides a method for determining the uncertainty in the certified value of standardized test

blocks. The standardizing agency may report the uncertainty value on the test block certificate.

NOTE X2.1—When calculated, uncertainty values reported by a field calibration agency (see [X2.6](#)) are not the measurement uncertainties of the hardness machine in operation, but only that of the measurements made at the time of verification to determine machine “error.”

NOTE X2.2—The procedures outlined in this appendix for the determination of uncertainties are based primarily on measurements made as part of the verification and standardization procedures of this test method. This is done to provide a method that is based on familiar procedures and practices of Rockwell hardness users and standardizing agencies. The reader should be aware that there are other methods that may be employed to determine the same uncertainties, which may provide more accurate estimations of the uncertainty values.

NOTE X2.3—This standard states tolerances or limits on the acceptable repeatability and error of a Rockwell hardness machine ([Table A1.3](#)) and the nonuniformity of standardized blocks ([Table A4.2](#)). These limit values were originally established based on the testing experience of many users of the Rockwell hardness test, and therefore reflect the normal performance of a properly functioning Rockwell hardness machine, including the normal errors associated with the measurement procedure and the machine’s performance. Because the limits are based on testing experience, it is believed that the stated limit values take into account a level of uncertainty that is typical for valid Rockwell hardness measurements. Consequently, when determining compliance with [Table A1.3](#) and [Table A4.2](#), the user’s measurement uncertainty should not be subtracted from the tolerance limit values given in the tables, as is commonly done for other types of metrological measurements. The calculated values for repeatability, error or block nonuniformity should be directly compared to the tolerance limits given in the tables.

NOTE X2.4—Most product specification tolerances for Rockwell hardness were established based on testing and performance experience. The

tolerance values reflect the normal performance of a properly functioning Rockwell hardness machine, including the normal acceptable errors associated with the hardness measurement process. For these products, the stated tolerance limits take into account a level of uncertainty that is typical for valid Rockwell hardness measurements. Consequently, when acceptance testing most products for Rockwell hardness, the user's measurement uncertainty should not be subtracted from the tolerance limit values given in the specification. The measured hardness values should be directly compared to the tolerances. There may be exceptional circumstances where the hardness of a product must fall within determined ranges to a high level of confidence. In these rare occasions, special agreement between the parties involved should be obtained before the hardness measurement uncertainty is subtracted from the tolerance limits. Before such an agreement is made, it is recommended that the product design take into consideration the anticipated influence of material and metallurgical factors on the product variation as well as typical industry hardness uncertainty values.

X2.1.3 This appendix does not address uncertainties at the primary reference standardizing level.

## X2.2 Equations

X2.2.1 The average (*AVG*),  $\bar{H}$ , of a set of  $n$  hardness measurements  $H_1, H_2, \dots, H_n$  is calculated as:

$$AVG(H_1, H_2, \dots, H) = \bar{H} = \frac{H_1 + H_2 + \dots + H_n}{n} \quad (X2.1)$$

X2.2.2 The standard deviation (*STDEV*) of a set of  $n$  hardness measurements  $H_1, H_2, \dots, H_n$  is calculated as:

$$STDEV(H_1, H_2, \dots, H_n) = \sqrt{\frac{(H_1 - \bar{H})^2 + \dots + (H_n - \bar{H})^2}{n - 1}} \quad (X2.2)$$

where  $\bar{H}$  is the average of the set of  $n$  hardness measurements  $H_1, H_2, \dots, H_n$  as defined in Eq X2.1.

X2.2.3 The absolute value (*ABS*) of a number is the magnitude of the value irrespective of the sign, for example:

$$\begin{aligned} ABS(0.12) &= 0.12 \\ \text{and} \\ ABS(-0.12) &= 0.12 \end{aligned}$$

## X2.3 General Requirements

X2.3.1 The approach for determining uncertainty presented in this appendix considers only those uncertainties associated with the overall measurement performance of the Rockwell hardness machine with respect to reference standards. These performance uncertainties reflect the combined effect of the separate uncertainties associated with the numerous individual components of the machine, such as the force application system and indentation depth measuring system. Therefore, the uncertainties associated with the individual components of the machine are not included in the calculations. Because of this approach, it is important that the individual machine components are operating within tolerances. It is strongly recommended that this procedure be applied only after successfully passing a direct verification.

X2.3.2 The procedures given in this appendix are appropriate only when the Rockwell hardness machine has passed an indirect verification in accordance with the procedures and schedules of this test method standard.

X2.3.3 The procedures for calculating the uncertainty of Rockwell hardness measurement values are similar for both a standardizing machine and testing machine. The principal difference is in the hierarchy level of the reference test blocks normally used for the indirect verification. Generally, standardizing machines are verified using primary reference standards, and testing machines are standardized using secondary reference standards.

X2.3.4 To estimate the overall uncertainty of Rockwell hardness measurement values, contributing components of uncertainty must be determined. Because many of the uncertainties may vary depending on the specific hardness scale and hardness level, an individual measurement uncertainty should be determined for each hardness scale and hardness level of interest. In many cases, a single uncertainty value may be applied to a range of hardness levels based on the laboratory's experience and knowledge of the operation of the hardness machine.

X2.3.5 Uncertainty should be determined with respect to a country's highest level of reference standard or the national reference standard of another country. In some cases, the highest level of reference standard may be a commercial reference standard.

## X2.4 General Procedure

X2.4.1 This procedure calculates a combined standard uncertainty  $u_c$  by combining the contributing components of uncertainty  $u_1, u_2, \dots, u_n$ , such that:

$$u_c = \sqrt{u_1^2 + u_2^2 + \dots + u_n^2} \quad (X2.3)$$

X2.4.2 Measurement uncertainty is usually expressed as an expanded uncertainty  $U$  which is calculated by multiplying the combined standard uncertainty  $u_c$  by a numerical coverage factor  $k$ , such that:

$$U = k \times u_c \quad (X2.4)$$

X2.4.3 A coverage factor is chosen that depends on how well the standard uncertainty was estimated (number of measurements), and the level of uncertainty that is desired. For this analysis, a coverage factor of  $k = 2$  should be used. This coverage factor provides a confidence level of approximately 95 %.

X2.4.4 The measurement bias  $B$  of the hardness machine is the difference between the expected hardness measurement values as displayed by the hardness machine and the "true" hardness of a material. Ideally, measurement biases should be corrected. When test systems are not corrected for measurement bias, as often occurs in Rockwell hardness testing, the bias then contributes to the overall uncertainty in a measurement. There are a number of possible methods for incorporating biases into an uncertainty calculation, each of which has both advantages and disadvantages. A simple and conservative method is to combine the bias with the calculation of the expanded uncertainty as:

$$U = ku_c + ABS(B) \quad (X2.5)$$

where  $ABS(B)$  is the absolute value of the bias.

X2.4.5 Because several approaches may be used to evaluate and express measurement uncertainty, a brief description of what the reported uncertainty values represent should be included with the reported uncertainty value.

## X2.5 Sources of Uncertainty

X2.5.1 This section describes the most significant sources of uncertainty in a Rockwell hardness measurement and provides procedures and formulas for calculating the total uncertainty in the hardness value. In later sections, it will be shown how these sources of uncertainty contribute to the total measurement uncertainty for the three measurement circumstances described in X2.1.2.

X2.5.2 The sources of uncertainty to be discussed are (1) the hardness machine's lack of repeatability, (2) the non-uniformity in hardness of the material under test, (3) the hardness machine's lack of reproducibility, (4) the resolution of the hardness machine's measurement display, and (5) the uncertainty in the certified value of the reference test block standards. An estimation of the measurement bias and its inclusion into the expanded uncertainty will also be discussed.

X2.5.3 *Uncertainty Due to Lack of Repeatability ( $u_{Repeat}$ ) and when Combined with Non-uniformity ( $u_{Rep\& NU}$ )*—The repeatability of a hardness machine is an indication of how well it can continually produce the same hardness value each time a measurement is made. Imagine there is a material, which is perfectly uniform in hardness over its entire surface. Also imagine that hardness measurements are made repeatedly on this uniform material over a short period of time without varying the testing conditions (including the operator). Even though the actual hardness of every test location is exactly the same, it would be found that due to random errors each measurement value would differ from all other measurement values (assuming sufficient measurement resolution). Therefore, lack of repeatability prevents the hardness machine from being able to always measure the true hardness of the material, and hence contributes to the uncertainty in the measurement.

X2.5.3.1 The contribution that a hardness machine's lack of repeatability makes to the overall measurement uncertainty is determined differently depending on whether a single measurement value or an average of multiple measurements is to be reported. Additionally, in cases where the reported average measurement value is intended to be an estimate of the average hardness of the material tested, the uncertainty contributions due to the machine's lack of repeatability and the non-uniformity in the hardness of the test material are difficult to separate and must be determined together. The uncertainty contributions for each of these circumstances may be estimated as follows.

X2.5.3.2 *Single Hardness Measurement*—For a future single hardness measurement, the standard uncertainty contribution  $u_{Repeat}$  due to the lack of repeatability, may be estimated by the standard deviation of the values from a number of hardness measurements made on a uniform test sample as:

$$u_{Repeat} = STDEV(H_1, H_2, \dots, H_n) \quad (X2.6)$$

where  $H_1, H_2, \dots, H_n$  are the  $n$  hardness values. In general, the estimate of repeatability is improved as the number of hardness measurements is increased. Usually, the hardness values measured during an indirect verification will provide an adequate estimate of  $u_{Repeat}$ ; however, the caution given in Note X2.6 should be considered. It may be more appropriate for the user to determine a value of  $u_{Repeat}$  by making hardness measurements close together (within spacing limitations) on a uniform material, such as a test block.

NOTE X2.5—The uncertainty  $u_{Repeat}$  due to the lack of repeatability of a hardness machine as discussed above, should not be confused with the historically defined "repeatability" that is a requirement to be met as part of an indirect verification (see 3.2.3). The calculations of the uncertainty  $u_{Repeat}$  and of the historically defined repeatability do not produce the same value. The uncertainty  $u_{Repeat}$  is the contribution to the overall uncertainty of a hardness measurement value due to a machine's lack of repeatability, while the historically defined repeatability is the range of hardness values measured during an indirect verification.

NOTE X2.6—All materials exhibit some degree of hardness non-uniformity across the test surface. Therefore, the above evaluation of the uncertainty contribution due to the lack of repeatability will also include a contribution due to the hardness non-uniformity of the measured material. When evaluating repeatability as discussed above, any uncertainty contribution due to the hardness non-uniformity should be minimized as much as possible. The laboratory should be cautioned that if the measurements of repeatability are based on tests made across the surface of the material, then the repeatability value will likely include a significant uncertainty contribution due to the material's non-uniformity. A machine's repeatability is better evaluated by making hardness measurements close together (within spacing limitations).

X2.5.3.3 *Average of Multiple Measurements*—When the average of multiple hardness test values is to be reported, the standard uncertainty contribution  $u_{Repeat}$ , due to the lack of repeatability of the hardness machine, may be estimated by dividing the standard uncertainty contribution  $u_{Repeat}$  (previously calculated from a number of hardness measurements made on a uniform test sample, see X2.5.3.1) by the square-root of the number of hardness test values being averaged, as:

$$\overline{u_{Repeat}} = \frac{u_{Repeat}}{\sqrt{n_T}} \quad (X2.7)$$

where  $u_{Repeat}$  is calculated by Eq X2.6 and  $n_T$  is the number of individual hardness test values being averaged.

X2.5.3.4 *Estimate of the Material Hardness*—Hardness measurements are often made at several locations and the values averaged in order to estimate the average hardness of the material as a whole. For example, this may be done when making quality control measurements during the manufacture of many types of products; when determining the machine "error" as part of an indirect verification; and when calibrating a test block. Because all materials exhibit some degree of hardness non-uniformity across the test surface, the extent of a material's non-uniformity also contributes to the uncertainty in this estimate of the average hardness of the material. When the average of multiple hardness measurement values is calculated as an estimate of the average material or product hardness, it may be desired to state the uncertainty in this value with respect to the true hardness of the material. In this case, the combined uncertainty contributions due to the lack of repeatability in the hardness machine and the non-uniformity in the test material may be estimated from the "standard deviation of

the mean” of the hardness measurement values. This is calculated as the standard deviation of the hardness values, divided by the square-root of the number of measurements as:

$$u_{Rep\& NU} = \frac{STDEV(H_{T1}, H_{T2}, \dots, H_{Tn})}{\sqrt{n_T}} \quad (X2.8)$$

where  $H_{T1}, H_{T2}, \dots, H_{Tn}$  are the  $n_T$  measurement values.

**X2.5.4 Uncertainty Due to Lack of Reproducibility ( $u_{Reprod}$ )**—The day-to-day variation in the performance of the hardness machine is known as its level of reproducibility. Variations such as different machine operators and changes in the test environment often influence the performance of the hardness machine. The level of reproducibility is best determined by monitoring the performance of the hardness machine over an extended period of time during which the hardness machine is subjected to the extremes of variations in the testing variables. It is very important that the test machine be in control during the assessment of reproducibility. If the machine is in need of maintenance or is operated incorrectly, the lack of reproducibility will be over estimated.

**X2.5.5** An assessment of a hardness machine’s lack of reproducibility should be based on periodic monitoring measurements of the hardness machine, such as daily verification measurements made on the same test block over time. The uncertainty contribution may be estimated by the standard deviation of the average of each set of monitoring values, as:

$$u_{Reprod} = STDEV(M_1, M_2, \dots, M_n) \quad (X2.9)$$

where  $M_1, M_2, \dots, M_n$  are individual averages of each of the  $n$  sets of multiple monitoring measurement values.

**NOTE X2.7**—The uncertainty contribution due to the lack of reproducibility, as calculated in **Eq X2.10**, also includes a contribution due to the machine’s lack of repeatability and the non-uniformity of the monitoring test block; however, these contributions are based on the average of multiple measurements and should not significantly over-estimate the reproducibility uncertainty.

**X2.5.6 Uncertainty Due to the Resolution of the Hardness Measurement Display ( $u_{Resol}$ )**—The finite resolution of the hardness value display prevents the hardness machine from providing an absolutely accurate hardness value. However, the influence of the display resolution on the measurement uncertainty is usually only significant when the hardness display resolution is no better than 0.5 Rockwell hardness units, such as for some dial displays. The uncertainty contribution  $u_{Resol}$  due to the influence of the display resolution, may be described by a rectangular distribution and estimated as:

$$u_{Resol} = \frac{r/2}{\sqrt{3}} = \frac{r}{\sqrt{12}} \quad (X2.10)$$

where  $r$  is the resolution limit that a hardness value can be estimated from the measurement display in Rockwell hardness units.

**X2.5.7 Standard Uncertainty in the Certified Average Hardness Value of the Reference Test Block ( $u_{RefBlk}$ )**—Reference test blocks provide the link to the Rockwell standard to which traceability is claimed. The certificate accompanying reference test blocks should provide an uncertainty in the stated certified value, and should state to which Rockwell standard the

reference test block value is traceable. This uncertainty contributes to the measurement uncertainty of hardness machines calibrated or verified with the reference test blocks. Note that the uncertainty reported on reference test block certificates is typically stated as an expanded uncertainty. As indicated by **Eq X2.4**, the expanded uncertainty is calculated by multiplying the standard uncertainty by a coverage factor (often 2). This analysis uses the standard uncertainty and not the expanded uncertainty value. Thus, the uncertainty value due to the uncertainty in the certified value of the reference test block usually may be calculated as:

$$u_{RefBlk} = \frac{U_{RefBlk}}{k_{RefBlk}} \quad (X2.11)$$

where  $U_{RefBlk}$  is the reported expanded uncertainty of the certified value of the reference test block, and  $k_{RefBlk}$  is the coverage factor used to calculate the uncertainty in the certified value of the reference standard (usually 2).

**X2.5.8 Measurement Bias ( $B$ )**—The measurement bias is the difference between the hardness measurement values as displayed by the hardness machine and the “true” hardness of a material. The measurement bias  $B$  may be estimated by the “error” determined as part of the indirect verification as:

$$B = \bar{H} - \bar{H}_{RefBlk} \quad (X2.12)$$

where  $\bar{H}$  is the mean hardness value as measured by the hardness machine during the indirect verification, and  $\bar{H}_{RefBlk}$  is the certified average hardness value of the reference test block standard used for the indirect verification.

## X2.6 Procedure for Calculating Uncertainty: Indirect Verification

**X2.6.1** As part of an indirect verification, the “error” of the hardness machine is determined from the average value of measurements made on a reference test block (see **3.2.2**). This value provides an indication of how well the hardness machine can measure the “true” hardness of a material. Since there is always uncertainty in a hardness measurement, it follows that there must be uncertainty in the determination of the average value of the measurements, and thus the determination of the machine “error.” This section provides a procedure that can be used, for example by a field calibration agency, to estimate the uncertainty  $U_{Mach}$  in the measurement “error” of the hardness machine determined as the difference between the average of the measurement values and the certified value of the reference block used for the verification.

**X2.6.2** The contributions to the standard uncertainty of the measurement “error,”  $u_{Mach}$ , are (1)  $u_{Rep\& NU}$  (*Ref. Block*), the uncertainty due to the lack of repeatability of the hardness machine combined with the uncertainty due to the non-uniformity in the reference test block (**Eq X2.9**), which is determined from the hardness measurements made on a reference test block to determine the “error” of the hardness machine, (2)  $u_{Resol}$ , the uncertainty due to the resolution of the hardness machine measurement display (**Eq X2.11**), and (3)  $u_{RefBlk}$ , the standard uncertainty in the certified value of the reference test block (**Eq X2.12**). The notation (*Ref. Block*) is added to the term  $u_{Rep\& NU}$  to clarify that the uncertainty is

determined from measurements made on the reference block used for the indirect verification.

X2.6.3 The combined standard uncertainty  $u_{Mach}$  and the expanded uncertainty  $U_{Mach}$  are calculated by combining the appropriate uncertainty components described above for each hardness level of each Rockwell scale as:

$$u_{Mach} = \sqrt{u_{Rep\& NU}^2(Ref. Block) + u_{Resol}^2 + u_{RefBlk}^2} \quad (X2.13)$$

and

$$U_{Mach} = k u_{Mach} \quad (X2.14)$$

X2.6.4 For this analysis, a coverage factor of  $k = 2$  should be used. This coverage factor provides a confidence level of approximately 95 %.

NOTE X2.8—The uncertainty contribution  $u_{Mach}$  as calculated in Eq X2.14 does not include a contribution due to the machine’s lack of reproducibility. This is because it is assumed that the indirect verification is made while the hardness machine is operating at its optimal performance level with the best possible environmental conditions.

NOTE X2.9—The expanded uncertainty  $U_{Mach}$  will commonly be larger than the value of the hardness machine “error.”

X2.6.5 *Reporting the Measurement Uncertainty*—This expanded uncertainty  $U_{Mach}$  may be reported by a verification agency to its customer as an indication of the uncertainty in the hardness machine “error” reported as part of the indirect verification of the Rockwell hardness machine. The value of  $U_{Mach}$  should be supplemented with a statement defining to what Rockwell scale and hardness level the uncertainty is applicable, with an explanatory statement such as, “The expanded uncertainty of the hardness machine “error” reported as part of the indirect verification for the stated Rockwell scale(s) and hardness level(s) is with respect to Rockwell hardness reference standards maintained at \_\_\_\_\_ (for example, NIST), and was calculated in accordance with Appendix X2 of ASTM E18 with a coverage factor of 2 representing a confidence level of approximately 95 %.”

X2.6.6 The standard uncertainty value  $u_{Mach}$  can be used as an uncertainty contribution when determining the measurement uncertainty of future measurements made with the hardness machine (see X2.7 and X2.8).

X2.6.7 *Example X2.1*—As part of an indirect verification of a Rockwell hardness machine, a verification agency needs to report an estimate of the uncertainty of the hardness machine “error.” For this example, an evaluation will only be made for measurements made on the low range of the HRC scale. The hardness machine has a digital display with a resolution of 0.1 HRC. The agency performs five verification measurements on a low range HRC hardness block. The reported certified value of the reference test block is 25.7 HRC with an expanded uncertainty of  $U_{RefBlk} = 0.45$  HRC. The five verification measurements values are: 25.4, 25.3, 25.5, 25.3, and 25.7 HRC, resulting in an average value of 25.44 HRC, a repeatability (range) value of 0.4 HRC and an “error” of  $-0.26$  HRC. Therefore:

$$u_{Rep\& NU}(Ref. Block) = \frac{STDEV(25.4, 25.3, 25.5, 25.3, 25.7)}{\sqrt{5}}$$

$$\text{or } u_{Rep\& NU}(Ref. Block) = 0.075 \text{ HRC}$$

$$u_{Resol} = \frac{0.1}{\sqrt{12}} = 0.029 \text{ HRC, and}$$

$$u_{RefBlk} = \frac{0.45}{2} = 0.225 \text{ HRC}$$

Thus,

$$u_{Mach} = \sqrt{0.075^2 + 0.029^2 + 0.225^2} = 0.239 \text{ HRC, and}$$

$$U_{Mach} = (2 \times 0.239) = 0.48 \text{ HRC}$$

Therefore, the uncertainty in the  $-0.26$  HRC “error” in the hardness machine is 0.48 HRC. Although this evaluation was made on material having a hardness of approximately 25 HRC, the uncertainty may be considered to apply to the entire low range of the HRC scale. This calculation must be made for the mid and high ranges of the HRC scale, as well as for the ranges of the other Rockwell scales that are verified.

NOTE X2.10—The reader should be aware that in computing the final uncertainty value in all examples in this appendix, no rounding of results was done between steps. Consequently, if individual equations are solved using the rounded values that are given at each step of this example, some computed results might differ in value in the last decimal place from the results stated.

## X2.7 Procedure for Calculating Uncertainty: Rockwell Hardness Measurement Values

X2.7.1 The uncertainty  $U_{Meas}$  in a hardness value measured by a user may be thought of as an indication of how well the measured value agrees with the “true” value of the hardness of the material.

X2.7.2 *Single Measurement Value*—When measurement uncertainty for a single hardness measurement value is to be determined, the contributions to the standard uncertainty  $u_{Meas}$  are (1)  $u_{Repeat}$ , the uncertainty due to the machine’s lack of repeatability (Eq X2.6), (2)  $u_{Reprod}$ , the uncertainty contribution due to the lack of reproducibility (Eq X2.10), (3)  $u_{Resol}$ , the uncertainty due to the resolution of the hardness machine measurement display (Eq X2.11), and (4)  $u_{Mach}$ , the uncertainty in determining the “error” of the hardness machine (Eq X2.14). The combined standard uncertainty  $u_{Meas}$  is calculated by combining the appropriate uncertainty components described above for the applicable hardness level and Rockwell scale as:

$$u_{Meas} = \sqrt{u_{Repeat}^2 + u_{Reprod}^2 + u_{Resol}^2 + u_{Mach}^2} \quad (X2.15)$$

X2.7.3 *Average Measurement Value*—In the case that measurement uncertainty is to be determined for an average value of multiple hardness measurements, made either on the same test piece or multiple test pieces, the contributions to the standard uncertainty  $u_{Meas}$  are (1)  $u_{Repeat}$ , the uncertainty due to the machine’s lack of repeatability based on the average of multiple measurements (Eq X2.8), (2)  $u_{Reprod}$ , the uncertainty contribution due to the lack of reproducibility (Eq X2.10), (3)  $u_{Resol}$ , the uncertainty due to the resolution of the hardness machine measurement display (Eq X2.11), and (4)  $u_{Mach}$ , the uncertainty in determining the “error” of the hardness machine (Eq X2.14). The combined standard uncertainty  $u_{Meas}$  is calculated by combining the appropriate uncertainty components described above for the applicable hardness level and Rockwell scale as:

$$u_{Meas} = \sqrt{u_{Repeat}^2 + u_{Reprod}^2 + u_{Resol}^2 + u_{Mach}^2} \quad (X2.16)$$

X2.7.4 The measurement uncertainty discussed above for the single and average hardness values only represents the uncertainties of the measurement process and are independent of any test material non-uniformity.

X2.7.5 *Average Measurement Value as an Estimate of the Average Material Hardness*—Measurement laboratories and manufacturing facilities often measure the Rockwell hardness of a test sample or product for the purpose of estimating the average hardness of the test material. Usually, multiple hardness measurements are made across the surface of the test piece, and then the average of the hardness values is reported as an estimation of the average hardness of the material. If it is desired to report the uncertainty as an indication of how well the average measurement value represents the true average hardness of the material, then the contributions to the standard uncertainty  $u_{Meas}$  are (1)  $u_{Rep\& NU (Material)}$ , the uncertainty due to the machine’s lack of repeatability combined with the uncertainty due to the material’s non-uniformity (Eq X2.9), which is determined from the hardness measurements made on the test material, (2)  $u_{Reprod}$ , the uncertainty contribution due to the lack of reproducibility (Eq X2.10), (3)  $u_{Resol}$ , the uncertainty due to the resolution of the hardness machine measurement display (Eq X2.11), and (4)  $u_{Mach}$ , the uncertainty in determining the “error” of the hardness machine (Eq X2.14). The notation (*Material*) is added to the term  $u_{Rep\& NU}$  to clarify that the uncertainty is determined from measurements made on the material under test. The combined standard uncertainty  $u_{Meas}$  is calculated by combining the appropriate uncertainty components described above for the applicable hardness level and Rockwell scale as:

$$u_{Meas} = \sqrt{u_{Rep\& NU (Material)}^2 + u_{Reprod}^2 + u_{Resol}^2 + u_{Mach}^2} \quad (X2.17)$$

X2.7.6 When reporting uncertainty as an indication of how well the average measurement value represents the true average hardness of the material, it is important to assure that a sufficient number of measurements are made at the appropriate test locations to provide an appropriate sampling of any variations in the hardness of the material.

X2.7.7 The expanded uncertainty  $U_{Meas}$  is calculated for the three cases discussed above as:

$$U_{Meas} = k u_{Meas} + ABS(B) \quad (X2.18)$$

For this analysis, a coverage factor of  $k = 2$  should be used. This coverage factor provides a confidence level of approximately 95 %.

X2.7.8 *Reporting Measurement Uncertainty:*

X2.7.8.1 *Single and Average Measurement Values*—When the reported measurement value is for a single hardness test or the average of multiple hardness tests, then the value of  $U_{Meas}$  should be supplemented with an explanatory statement such as, “The expanded measurement uncertainty of the reported hardness value (or average hardness value) is with respect to Rockwell hardness reference standards maintained at \_\_\_\_\_ [for example, NIST], and was calculated in accordance with Appendix X2 of ASTM E18 with a coverage factor of 2 representing a confidence level of approximately 95 %.”

X2.7.8.2 *Average Measurement Value as an Estimate of the Average Material Hardness*—When it is desired to report the

uncertainty as an indication of how well the average measurement value represents the true average hardness of the material, then the value of  $U_{Meas}$  should be supplemented with an explanatory statement such as, “The expanded uncertainty of the reported average hardness of the material under test is based on uncertainty contributions from the measurement process and from the hardness non-uniformity of the material. The uncertainty is with respect to Rockwell hardness reference standards maintained at \_\_\_\_\_ [for example, NIST], and was calculated in accordance with Appendix X2 of ASTM E18 with a coverage factor of 2 representing a confidence level of approximately 95 %.” If the test report does not state the number of measurements that were averaged and the locations that the measurements were made, then this information should also be included as part of the brief explanation of how the uncertainty was calculated.

X2.7.8.3 *Example X2.2*—For this example, a company tests its product by making six Rockwell hardness measurements across its surface as an estimate of the product hardness. The hardness machine has a dial display that is judged to have a reading resolution of 0.5 HRC. The values of the hardness measurements of the product were 33, 31.5, 31.5, 32, 31, 32.5, resulting in an average value of 31.92 HRC. The testing facility would like to determine the measurement uncertainty in the average hardness value. A hardness of 31.92 HRC is closest to the low range of the HRC scale (see Table A1.3). The last indirect verification of the low range of the HRC scale reported  $U_{Mach} = 0.8$  HRC and an “error” of  $-0.3$  HRC. Therefore:

$$u_{Rep\& NU (Material)} = \frac{STDEV(33, 31.5, 31.5, 32, 31, 32.5)}{\sqrt{6}} \text{ or } u_{Rep\& NU (Material)} = 0.300 \text{ HRC}$$

For this example, assume the hardness machine has been monitored for an extended period of time, and from Eq X2.10, it was determined that  $u_{Reprod} = 0.21$  HRC for the low range of the HRC scale. Other uncertainty contributions are calculated as:

$$u_{Resol} = \frac{0.5}{\sqrt{12}} = 0.144 \text{ HRC and}$$

$$u_{Mach} = \frac{0.8}{2} = 0.4 \text{ HRC, therefore}$$

$$u_{Meas} = \sqrt{0.300^2 + 0.21^2 + 0.144^2 + 0.4^2} = 0.561 \text{ HRC}$$

and since  $B = -0.3$  HRC,  $U_{Meas} = (2 \times 0.561) + ABS(-0.3)$ , or  $U_{Meas} = 1.42$  HRC for the average value of the hardness measurements made on the single product item.

X2.8 **Procedure for Calculating Uncertainty: Certified Value of Standardized Test Blocks**

X2.8.1 Standardizing laboratories engaged in the calibration of reference test blocks must determine the uncertainty in the reported certified value. This uncertainty  $UCert$  provides an indication of how well the certified value would agree with the “true” average hardness of the test block.

X2.8.2 Test blocks are certified as having an average hardness value based on calibration measurements made across the surface of the test block. This analysis is essentially identical to the analysis given in 5.3.1 for measuring the

average hardness of a product. In this case, the product is a calibrated reference test block. The contributions to the standard uncertainty  $u_{Cert}$  of the certified average value of the test block are (1)  $u_{Rep\& NU} (Calib. Block)$ , the uncertainty due to the standardizing machine’s lack of repeatability combined with the uncertainty due to the calibrated block’s non-uniformity (Eq X2.9), which is determined from the calibration measurements made on the test block, (2)  $u_{Reprod}$ , the uncertainty contribution due to the lack of reproducibility (Eq X2.10), (3)  $u_{Resol}$ , the uncertainty due to the resolution of the standardizing machine’s measurement display (Eq X2.11), and (4)  $u_{Mach}$ , the uncertainty in determining the “error” of the standardizing machine (Eq X2.14). The notation (*Calib. Block*) is added to the term  $u_{Rep\& NU}$  to clarify that the uncertainty is determined from calibration measurements made on the calibrated block.

X2.8.3 The combined standard uncertainty  $u_{Cert}$  and the expanded uncertainty  $U_{Cert}$  are calculated by combining the appropriate uncertainty components described above for each hardness level of each Rockwell scale as:

$$u_{Cert} = \sqrt{u_{Rep\& NU}^2 (Calib. Block) + u_{Reprod}^2 + u_{Resol}^2 + u_{Mach}^2} \quad (X2.19)$$

and

$$U_{Cert} = ku_{Cert} + ABS(B) \quad (X2.20)$$

X2.8.4 For this analysis, a coverage factor of  $k = 2$  should be used. This coverage factor provides a confidence level of approximately 95 %.

X2.8.5 *Reporting the Measurement Uncertainty*—The value of  $U_{Cert}$  is an estimate of the uncertainty in the reported certified average hardness value of a reference test block. The reported value should be supplemented with a statement defining to what Rockwell scale and hardness level the uncertainty is applicable, with an explanatory statement such as, “The expanded uncertainty in the certified value of the test block is with respect to Rockwell hardness reference standards

maintained at \_\_\_\_\_ [for example, NIST], and was calculated in accordance with Appendix X2 of ASTM E18 with a coverage factor of 2 representing a confidence level of approximately 95 %.”

X2.8.6 *Example X2.3*— A secondary level test-block standardizing laboratory has completed the calibration of a test block in the hardness range of 40 HRC. The values of the calibration measurements of the block were 40.61, 40.72, 40.65, 40.61, and 40.55 HRC, resulting in an average value of 40.63 HRC and an E18 repeatability range of 0.17 HRC. The laboratory must determine the uncertainty in the certified average hardness value of the block. A hardness of 40 HRC is considered within the mid-range of the HRC scale (see Table A1.3). The last indirect verification of the mid range of the HRC scale reported  $U_{Mach} = 0.16$  HRC and an “error” of +0.11 HRC. The standardizing machine has a digital display with a resolution of 0.01 HRC. Therefore:

$$u_{Rep\& NU} (Calib. Block) = \frac{STDEV(40.61, 40.72, 40.65, 40.61, 40.55)}{\sqrt{5}} \text{ or } u_{Rep\& NU} (Calib. Block) = 0.028 \text{ HRC}$$

For this example, let’s assume that the standardizing machine has been monitored for an extended period of time, and from Eq X2.10, it was determined that  $u_{Reprod} = 0.125$  HRC for the mid range of the HRC scale. Other uncertainty contributions are calculated as:

$$u_{Resol} = \frac{0.01}{\sqrt{12}} = 0.003 \text{ HRC and } u_{Mach} = \frac{0.16}{2} = 0.08 \text{ HRC therefore, } u_{Cert} = \sqrt{0.028^2 + 0.125^2 + 0.003^2 + 0.08^2} = 0.151 \text{ HRC}$$

and, since  $B = +0.11$  HRC,  $U_{Cert} = (2 \times 0.151) + ABS(+0.11)$ , or  $U_{Cert} = 0.41$  HRC for the certified hardness value of the single calibrated test block.

## SUMMARY OF CHANGES

Committee E28 has identified the location of selected changes to this standard since the last issue (E18–14a) that may impact the use of this standard. (Approved February 1, 2015.)

(1) A1.5.3.4 was revised.

Committee E28 has identified the location of selected changes to this standard since the last issue (E18–14) that may impact the use of this standard. (Approved Oct. 1, 2014.)

(1) A3.9.1.6 was revised.

(2) A3.9.3.6 was revised.

Committee E28 has identified the location of selected changes to this standard since the last issue (E18–12) that may impact the use of this standard. (Approved Jan. 1, 2014.)

(1) A3.4.5.1 was revised.

(3) A3.5.3.2 was revised.

(2) A3.4.5.4 was revised.

(4) A3.5.3.7 was revised.



- (5) A3.8.2 was added.
- (6) A3.8.3 was added.
- (7) A3.9.1.6 was added.

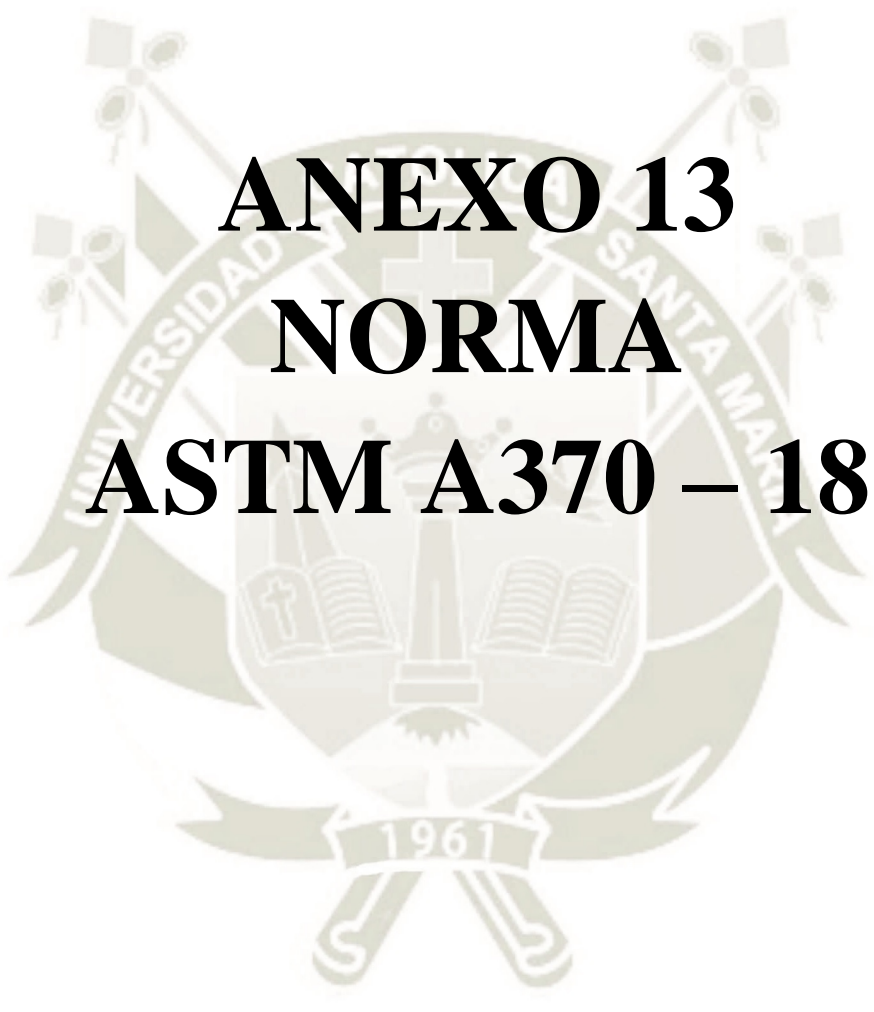
- (8) A3.9.3.6 was added.
- (9) New Table A3.4 was added.
- (10) New Table A3.7 was added.

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**ANEXO 13**  
**NORMA**  
**ASTM A370 – 18**



## Designation: A370 – 18

# Standard Test Methods and Definitions for Mechanical Testing of Steel Products<sup>1</sup>

This standard is issued under the fixed designation A370; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

*This standard has been approved for use by agencies of the U.S. Department of Defense.*

## 1. Scope\*

1.1 These test methods<sup>2</sup> cover procedures and definitions for the mechanical testing of steels, stainless steels, and related alloys. The various mechanical tests herein described are used to determine properties required in the product specifications. Variations in testing methods are to be avoided, and standard methods of testing are to be followed to obtain reproducible and comparable results. In those cases in which the testing requirements for certain products are unique or at variance with these general procedures, the product specification testing requirements shall control.

1.2 The following mechanical tests are described:

	Sections
Tension	6 to 14
Bend	15
Hardness	16
Brinell	17
Rockwell	18
Portable	19
Impact	20 to 30
Keywords	32

1.3 Annexes covering details peculiar to certain products are appended to these test methods as follows:

Bar Products	Annex A1
Tubular Products	Annex A2
Fasteners	Annex A3
Round Wire Products	Annex A4
Significance of Notched-Bar Impact Testing	Annex A5
Converting Percentage Elongation of Round Specimens to Equivalents for Flat Specimens	Annex A6
Testing Multi-Wire Strand	Annex A7
Rounding of Test Data	Annex A8
Methods for Testing Steel Reinforcing Bars	Annex A9
Procedure for Use and Control of Heat-Cycle Simulation	Annex A10

1.4 The values stated in inch-pound units are to be regarded as the standard.

1.5 When this document is referenced in a metric product specification, the yield and tensile values may be determined in inch-pound (ksi) units then converted into SI (MPa) units. The elongation determined in inch-pound gauge lengths of 2 or 8 in. may be reported in SI unit gauge lengths of 50 or 200 mm, respectively, as applicable. Conversely, when this document is referenced in an inch-pound product specification, the yield and tensile values may be determined in SI units then converted into inch-pound units. The elongation determined in SI unit gauge lengths of 50 or 200 mm may be reported in inch-pound gauge lengths of 2 or 8 in., respectively, as applicable.

1.5.1 The specimen used to determine the original units must conform to the applicable tolerances of the original unit system given in the dimension table not that of the converted tolerance dimensions.

NOTE 1—This is due to the specimen SI dimensions and tolerances being hard conversions when this is not a dual standard. The user is directed to Test Methods A1058 if the tests are required in SI units.

1.6 Attention is directed to ISO/IEC 17025 when there may be a need for information on criteria for evaluation of testing laboratories.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.8 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

## 2. Referenced Documents

### 2.1 ASTM Standards:<sup>3</sup>

A623 Specification for Tin Mill Products, General Requirements

<sup>1</sup> These test methods and definitions are under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel and Related Alloys and are the direct responsibility of Subcommittee A01.13 on Mechanical and Chemical Testing and Processing Methods of Steel Products and Processes.

Current edition approved Dec. 1, 2018. Published January 2019. Originally approved in 1953. Last previous edition approved in 2017 as A370 – 17a. DOI: 10.1520/A0370-18.

<sup>2</sup> For ASME Boiler and Pressure Vessel Code applications see related Specification SA-370 in Section II of that Code.

<sup>3</sup> For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For Annual Book of ASTM Standards volume information, refer to the standard's Document Summary page on the ASTM website.

\*A Summary of Changes section appears at the end of this standard

- A623M Specification for Tin Mill Products, General Requirements [Metric]
  - A833 Test Method for Indentation Hardness of Metallic Materials by Comparison Hardness Testers
  - A956/A956M Test Method for Leeb Hardness Testing of Steel Products
  - A1038 Test Method for Portable Hardness Testing by the Ultrasonic Contact Impedance Method
  - A1058 Test Methods for Mechanical Testing of Steel Products—Metric
  - A1061/A1061M Test Methods for Testing Multi-Wire Steel Prestressing Strand
  - E4 Practices for Force Verification of Testing Machines
  - E6 Terminology Relating to Methods of Mechanical Testing
  - E8/E8M Test Methods for Tension Testing of Metallic Materials
  - E10 Test Method for Brinell Hardness of Metallic Materials
  - E18 Test Methods for Rockwell Hardness of Metallic Materials
  - E23 Test Methods for Notched Bar Impact Testing of Metallic Materials
  - E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
  - E83 Practice for Verification and Classification of Extensometer Systems
  - E110 Test Method for Rockwell and Brinell Hardness of Metallic Materials by Portable Hardness Testers
  - E190 Test Method for Guided Bend Test for Ductility of Welds
  - E290 Test Methods for Bend Testing of Material for Ductility
- 2.2 *ASME Document*:<sup>4</sup>
- ASME Boiler and Pressure Vessel Code, Section VIII, Division I, Part UG-8
- 2.3 *ISO Standard*:<sup>5</sup>
- ISO/IEC 17025 General Requirements for the Competence of Testing and Calibration Laboratories

### 3. Significance and Use

3.1 The primary use of these test methods is testing to determine the specified mechanical properties of steel, stainless steel, and related alloy products for the evaluation of conformance of such products to a material specification under the jurisdiction of ASTM Committee A01 and its subcommittees as designated by a purchaser in a purchase order or contract.

3.1.1 These test methods may be and are used by other ASTM Committees and other standards writing bodies for the purpose of conformance testing.

3.1.2 The material condition at the time of testing, sampling frequency, specimen location and orientation, reporting requirements, and other test parameters are contained in the pertinent material specification or in a General Requirement Specification for the particular product form.

<sup>4</sup> Available from American Society of Mechanical Engineers (ASME), ASME International Headquarters, Two Park Ave., New York, NY 10016-5990, <http://www.asme.org>.

<sup>5</sup> Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, <http://www.ansi.org>.

3.1.3 Some material specifications require the use of additional test methods not described herein; in such cases, the required test method is described in that material specification or by reference to another appropriate test method standard.

3.2 These test methods are also suitable to be used for testing of steel, stainless steel and related alloy materials for other purposes, such as incoming material acceptance testing by the purchaser or evaluation of components after service exposure.

3.2.1 As with any mechanical testing, deviations from either specification limits or expected as-manufactured properties can occur for valid reasons besides deficiency of the original as-fabricated product. These reasons include, but are not limited to: subsequent service degradation from environmental exposure (for example, temperature, corrosion); static or cyclic service stress effects, mechanically-induced damage, material inhomogeneity, anisotropic structure, natural aging of select alloys, further processing not included in the specification, sampling limitations, and measuring equipment calibration uncertainty. There is statistical variation in all aspects of mechanical testing and variations in test results from prior tests are expected. An understanding of possible reasons for deviation from specified or expected test values should be applied in interpretation of test results.

### 4. General Precautions

4.1 Certain methods of fabrication, such as bending, forming, and welding, or operations involving heating, may affect the properties of the material under test. Therefore, the product specifications cover the stage of manufacture at which mechanical testing is to be performed. The properties shown by testing prior to fabrication may not necessarily be representative of the product after it has been completely fabricated.

4.2 Improperly machined specimens should be discarded and other specimens substituted.

4.3 Flaws in the specimen may also affect results. If any test specimen develops flaws, the retest provision of the applicable product specification shall govern.

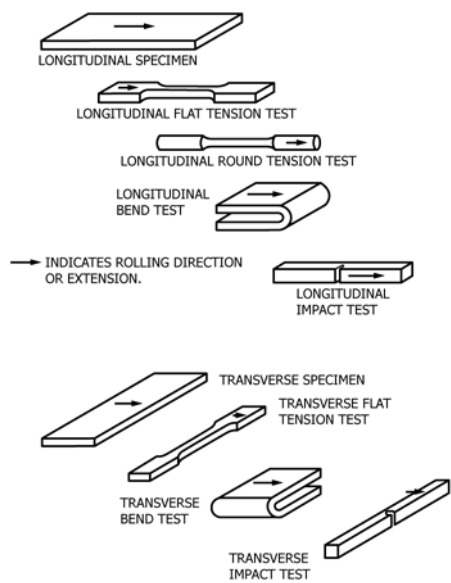
4.4 If any test specimen fails because of mechanical reasons such as failure of testing equipment or improper specimen preparation, it may be discarded and another specimen taken.

### 5. Orientation of Test Specimens

5.1 The terms “longitudinal test” and “transverse test” are used only in material specifications for wrought products and are not applicable to castings. When such reference is made to a test coupon or test specimen, the following definitions apply:

5.1.1 *Longitudinal Test*, unless specifically defined otherwise, signifies that the lengthwise axis of the specimen is parallel to the direction of the greatest extension of the steel during rolling or forging. The stress applied to a longitudinal tension test specimen is in the direction of the greatest extension, and the axis of the fold of a longitudinal bend test specimen is at right angles to the direction of greatest extension (Fig. 1, Fig. 2a, and Fig. 2b).

5.1.2 *Transverse Test*, unless specifically defined otherwise, signifies that the lengthwise axis of the specimen is at right



**FIG. 1 Relation of Test Coupons and Test Specimens to Rolling Direction or Extension (Applicable to General Wrought Products)**

angles to the direction of the greatest extension of the steel during rolling or forging. The stress applied to a transverse tension test specimen is at right angles to the greatest extension, and the axis of the fold of a transverse bend test specimen is parallel to the greatest extension (Fig. 1).

5.2 The terms “radial test” and “tangential test” are used in material specifications for some wrought circular products and are not applicable to castings. When such reference is made to a test coupon or test specimen, the following definitions apply:

5.2.1 *Radial Test*, unless specifically defined otherwise, signifies that the lengthwise axis of the specimen is perpendicular to the axis of the product and coincident with one of the radii of a circle drawn with a point on the axis of the product as a center (Fig. 2a).

5.2.2 *Tangential Test*, unless specifically defined otherwise, signifies that the lengthwise axis of the specimen is perpendicular to a plane containing the axis of the product and tangent to a circle drawn with a point on the axis of the product as a center (Fig. 2a, Fig. 2b, Fig. 2c, and Fig. 2d).

## TENSION TEST

### 6. Description

6.1 The tension test related to the mechanical testing of steel products subjects a machined or full-section specimen of the material under examination to a measured load sufficient to cause rupture. The resulting properties sought are defined in Terminology E6.

6.2 In general, the testing equipment and methods are given in Test Methods E8/E8M. However, there are certain exceptions to Test Methods E8/E8M practices in the testing of steel, and these are covered in these test methods.

### 7. Terminology

7.1 For definitions of terms pertaining to tension testing, including tensile strength, yield point, yield strength, elongation, and reduction of area, reference should be made to Terminology E6.

### 8. Testing Apparatus and Operations

8.1 *Loading Systems*—There are two general types of loading systems, mechanical (screw power) and hydraulic. These differ chiefly in the variability of the rate of load application. The older screw power machines are limited to a small number of fixed free running crosshead speeds. Some modern screw power machines, and all hydraulic machines permit stepless variation throughout the range of speeds.

8.2 The tension testing machine shall be maintained in good operating condition, used only in the proper loading range, and calibrated periodically in accordance with the latest revision of Practices E4.

NOTE 2—Many machines are equipped with stress-strain recorders for autographic plotting of stress-strain curves. It should be noted that some recorders have a load measuring component entirely separate from the load indicator of the testing machine. Such recorders are calibrated separately.

8.3 *Loading*—It is the function of the gripping or holding device of the testing machine to transmit the load from the heads of the machine to the specimen under test. The essential requirement is that the load shall be transmitted axially. This implies that the centers of the action of the grips shall be in alignment, insofar as practicable, with the axis of the specimen at the beginning and during the test and that bending or twisting be held to a minimum. For specimens with a reduced section, gripping of the specimen shall be restricted to the grip section. In the case of certain sections tested in full size, nonaxial loading is unavoidable and in such cases shall be permissible.

8.4 *Speed of Testing*—The speed of testing shall not be greater than that at which load and strain readings can be made accurately. In production testing, speed of testing is commonly expressed: (1) in terms of free running crosshead speed (rate of movement of the crosshead of the testing machine when not under load), (2) in terms of rate of separation of the two heads of the testing machine under load, (3) in terms of rate of stressing the specimen, or (4) in terms of rate of straining the specimen. The following limitations on the speed of testing are recommended as adequate for most steel products:

NOTE 3—Tension tests using closed-loop machines (with feedback control of rate) should not be performed using load control, as this mode of testing will result in acceleration of the crosshead upon yielding and elevation of the measured yield strength.

8.4.1 Any convenient speed of testing may be used up to one half the specified yield point or yield strength. When this point is reached, the free-running rate of separation of the crossheads shall be adjusted so as not to exceed 1/16 in. per min per inch of reduced section, or the distance between the grips for test specimens not having reduced sections. This speed shall be maintained through the yield point or yield strength. In determining the tensile strength, the free-running rate of

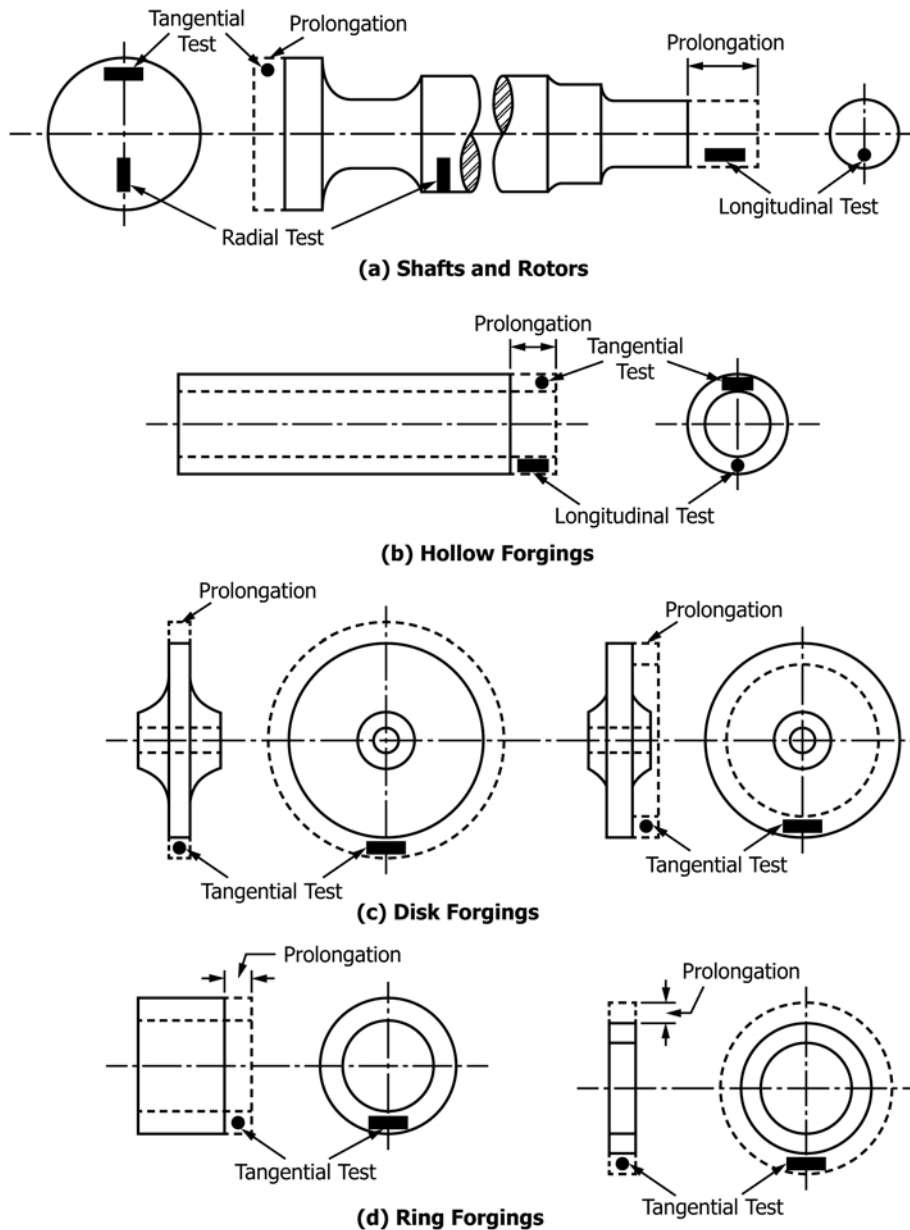


FIG. 2 Location of Longitudinal Tension Test Specimens in Rings Cut from Tubular Products

separation of the heads shall not exceed  $\frac{1}{2}$  in. per min per inch of reduced section, or the distance between the grips for test specimens not having reduced sections. In any event, the minimum speed of testing shall not be less than  $\frac{1}{10}$  the specified maximum rates for determining yield point or yield strength and tensile strength.

8.4.2 It shall be permissible to set the speed of the testing machine by adjusting the free running crosshead speed to the above specified values, inasmuch as the rate of separation of heads under load at these machine settings is less than the specified values of free running crosshead speed.

8.4.3 As an alternative, if the machine is equipped with a device to indicate the rate of loading, the speed of the machine from half the specified yield point or yield strength through the yield point or yield strength may be adjusted so that the rate of stressing does not exceed 100 000 psi (690 MPa)/min.

However, the minimum rate of stressing shall not be less than 10 000 psi (70 MPa)/min.

## 9. Test Specimen Parameters

9.1 *Selection*—Test coupons shall be selected in accordance with the applicable product specifications.

9.1.1 *Wrought Steels*—Wrought steel products are usually tested in the longitudinal direction, but in some cases, where size permits and the service justifies it, testing is in the transverse, radial, or tangential directions (see Figs. 1 and 2).

9.1.2 *Forged Steels*—For open die forgings, the metal for tension testing is usually provided by allowing extensions or prolongations on one or both ends of the forgings, either on all or a representative number as provided by the applicable product specifications. Test specimens are normally taken at mid-radius. Certain product specifications permit the use of a

representative bar or the destruction of a production part for test purposes. For ring or disk-like forgings test metal is provided by increasing the diameter, thickness, or length of the forging. Upset disk or ring forgings, which are worked or extended by forging in a direction perpendicular to the axis of the forging, usually have their principal extension along concentric circles and for such forgings tangential tension specimens are obtained from extra metal on the periphery or end of the forging. For some forgings, such as rotors, radial tension tests are required. In such cases the specimens are cut or trepanned from specified locations.

**9.2 Size and Tolerances**—Test specimens shall be (1) the full cross section of material, or (2) machined to the form and dimensions shown in **Figs. 3-6**. The selection of size and type of specimen is prescribed by the applicable product specification. Full cross section specimens shall be tested in 8-in. (200-mm) gauge length unless otherwise specified in the product specification.

**9.3 Procurement of Test Specimens**—Specimens shall be extracted by any convenient method taking care to remove all distorted, cold-worked, or heat-affected areas from the edges of the section used in evaluating the material. Specimens usually have a reduced cross section at mid-length to ensure uniform distribution of the stress over the cross section and localize the zone of fracture.

**9.4 Aging of Test Specimens**—Unless otherwise specified, it shall be permissible to age tension test specimens. The time-temperature cycle employed must be such that the effects of previous processing will not be materially changed. It may be accomplished by aging at room temperature 24 to 48 h, or in shorter time at moderately elevated temperatures by boiling in water, heating in oil or in an oven.

**9.5 Measurement of Dimensions of Test Specimens:**

**9.5.1 Standard Rectangular Tension Test Specimens**—These forms of specimens are shown in **Fig. 3**. To determine the cross-sectional area, the center width dimension shall be measured to the nearest 0.005 in. (0.13 mm) for the 8-in. (200-mm) gauge length specimen and 0.001 in. (0.025 mm) for the 2-in. (50-mm) gauge length specimen in **Fig. 3**. The center thickness dimension shall be measured to the nearest 0.001 in. for both specimens.

**9.5.2 Standard Round Tension Test Specimens**—These forms of specimens are shown in **Fig. 4** and **Fig. 5**. To determine the cross-sectional area, the diameter shall be measured at the center of the gauge length to the nearest 0.001 in. (0.025 mm) (see **Table 1**).

**9.6 General**—Test specimens shall be either substantially full size or machined, as prescribed in the product specifications for the material being tested.

**9.6.1** It is desirable to have the cross-sectional area of the specimen smallest at the center of the gauge length to ensure fracture within the gauge length. This is provided for by the taper in the gauge length permitted for each of the specimens described in the following sections.

**9.6.2** For brittle materials it is desirable to have fillets of large radius at the ends of the gauge length.

## 10. Plate-Type Specimens

**10.1** The standard plate-type test specimens are shown in **Fig. 3**. Such specimens are used for testing metallic materials in the form of plate, structural and bar-size shapes, and flat material having a nominal thickness of  $\frac{3}{16}$  in. (5 mm) or over. When product specifications so permit, other types of specimens may be used.

**NOTE 4**—When called for in the product specification, the 8-in. (200-mm) gauge length specimen of **Fig. 3** may be used for sheet and strip material.

## 11. Sheet-Type Specimen

**11.1** The standard sheet-type test specimen is shown in **Fig. 3**. This specimen is used for testing metallic materials in the form of sheet, plate, flat wire, strip, band, and hoop ranging in nominal thickness from 0.005 to 1 in. (0.13 to 25 mm). When product specifications so permit, other types of specimens may be used, as provided in Section 10 (see **Note 4**).

## 12. Round Specimens

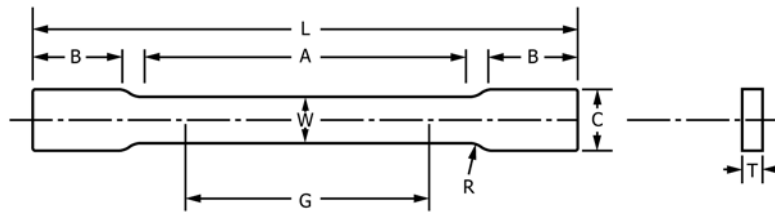
**12.1** The standard 0.500-in. (12.5-mm) diameter round test specimen shown in **Fig. 4** is frequently used for testing metallic materials.

**12.2** **Fig. 4** also shows small size specimens proportional to the standard specimen. These may be used when it is necessary to test material from which the standard specimen or specimens shown in **Fig. 3** cannot be prepared. Other sizes of small round specimens may be used. In any such small size specimen it is important that the gauge length for measurement of elongation be four times the diameter of the specimen (see **Note 5, Fig. 4**).

**12.3** The type of specimen ends outside of the gauge length shall accommodate the shape of the product tested, and shall properly fit the holders or grips of the testing machine so that axial loads are applied with a minimum of load eccentricity and slippage. **Fig. 5** shows specimens with various types of ends that have given satisfactory results.

## 13. Gauge Marks

**13.1** The specimens shown in **Figs. 3-6** shall be gauge marked with a center punch, scribe marks, multiple device, or drawn with ink. The purpose of these gauge marks is to determine the percent elongation. Punch marks shall be light, sharp, and accurately spaced. The localization of stress at the marks makes a hard specimen susceptible to starting fracture at the punch marks. The gauge marks for measuring elongation after fracture shall be made on the flat or on the edge of the flat tension test specimen and within the parallel section; for the 8-in. gauge length specimen, **Fig. 3**, one or more sets of 8-in. gauge marks may be used, intermediate marks within the gauge length being optional. Rectangular 2-in. gauge length specimens, **Fig. 3**, and round specimens, **Fig. 4**, are gauge marked with a double-pointed center punch or scribe marks. One or more sets of gauge marks may be used; however, one set must be approximately centered in the reduced section. These same precautions shall be observed when the test specimen is full section.


**DIMENSIONS**

	Standard Specimens						Subsize Specimen	
	Plate-Type, 1½-in. (40-mm) Wide						Sheet-Type, ½ in. (12.5-mm) Wide	
	8-in. (200-mm) Gauge Length		2-in. (50-mm) Gauge Length		Sheet-Type, ½ in. (12.5-mm) Wide		¼-in. (6-mm) Wide	
	in.	mm	in.	mm	in.	mm	in.	mm
G—Gauge length (Notes 1 and 2)	8.00 ± 0.01	200 ± 0.25	2.000 ± 0.005	50.0 ± 0.10	2.000 ± 0.005	50.0 ± 0.10	1.000 ± 0.003	25.0 ± 0.08
W—Width (Notes 3, 5, and 6)	1½ + ⅛ – ¼	40 + 3 – 6	1½ + ⅛ – ¼	40 + 3 – 6	0.500 ± 0.010	12.5 ± 0.25	0.250 ± 0.002	6.25 ± 0.05
T—Thickness (Note 7)	Thickness of Material							
R—Radius of fillet, min (Note 4)	½	13	½	13	½	13	¼	6
L—Overall length, min (Notes 2 and 8)	18	450	8	200	8	200	4	100
A—Length of reduced section, min	9	225	2¼	60	2¼	60	1¼	32
B—Length of grip section, min (Note 9)	3	75	2	50	2	50	1¼	32
C—Width of grip section, approxi- mate (Notes 4, 10, and 11)	2	50	2	50	¾	20	⅜	10

NOTE 1—For the 1½-in. (40-mm) wide specimens, punch marks for measuring elongation after fracture shall be made on the flat or on the edge of the specimen and within the reduced section. For the 8-in. (200-mm) gauge length specimen, a set of nine or more punch marks 1 in. (25 mm) apart, or one or more pairs of punch marks 8 in. (200 mm) apart may be used. For the 2-in. (50-mm) gauge length specimen, a set of three or more punch marks 1 in. (25 mm) apart, or one or more pairs of punch marks 2 in. (50 mm) apart may be used.

NOTE 2—For the ½-in. (12.5-mm) wide specimen, punch marks for measuring the elongation after fracture shall be made on the flat or on the edge of the specimen and within the reduced section. Either a set of three or more punch marks 1 in. (25 mm) apart or one or more pairs of punch marks 2 in. (50 mm) apart may be used.

NOTE 3—For the four sizes of specimens, the ends of the reduced section shall not differ in width by more than 0.004, 0.004, 0.002, or 0.001 in. (0.10, 0.10, 0.05, or 0.025 mm), respectively. Also, there may be a gradual decrease in width from the ends to the center, but the width at either end shall not be more than 0.015 in., 0.015 in., 0.005 in., or 0.003 in. (0.40, 0.40, 0.10, or 0.08 mm), respectively, larger than the width at the center.

NOTE 4—For each specimen type, the radii of all fillets shall be equal to each other with a tolerance of 0.05 in. (1.25 mm), and the centers of curvature of the two fillets at a particular end shall be located across from each other (on a line perpendicular to the centerline) within a tolerance of 0.10 in. (2.5 mm).

NOTE 5—For each of the four sizes of specimens, narrower widths (*W* and *C*) may be used when necessary. In such cases, the width of the reduced section should be as large as the width of the material being tested permits; however, unless stated specifically, the requirements for elongation in a product specification shall not apply when these narrower specimens are used. If the width of the material is less than *W*, the sides may be parallel throughout the length of the specimen.

NOTE 6—The specimen may be modified by making the sides parallel throughout the length of the specimen, the width and tolerances being the same as those specified above. When necessary, a narrower specimen may be used, in which case the width should be as great as the width of the material being tested permits. If the width is 1½ in. (38 mm) or less, the sides may be parallel throughout the length of the specimen.

NOTE 7—The dimension *T* is the thickness of the test specimen as provided for in the applicable product specification. Minimum nominal thickness of 1 to 1½-in. (40-mm) wide specimens shall be ⅜ in. (5 mm), except as permitted by the product specification. Maximum nominal thickness of ½-in. (12.5-mm) and ¼-in. (6-mm) wide specimens shall be 1 in. (25 mm) and ¼ in. (6 mm), respectively.

NOTE 8—To aid in obtaining axial loading during testing of ¼-in. (6-mm) wide specimens, the overall length should be as large as the material will permit.

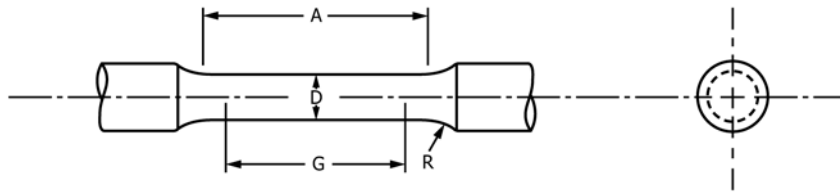
NOTE 9—It is desirable, if possible, to make the length of the grip section large enough to allow the specimen to extend into the grips a distance equal to two thirds or more of the length of the grips. If the thickness of ½-in. (13-mm) wide specimens is over ⅜ in. (10 mm), longer grips and correspondingly longer grip sections of the specimen may be necessary to prevent failure in the grip section.

NOTE 10—For standard sheet-type specimens and subsize specimens, the ends of the specimen shall be symmetrical with the center line of the reduced section within 0.01 and 0.005 in. (0.25 and 0.13 mm), respectively, except that for steel if the ends of the ½-in. (12.5-mm) wide specimen are symmetrical within 0.05 in. (1.0 mm), a specimen may be considered satisfactory for all but referee testing.

NOTE 11—For standard plate-type specimens, the ends of the specimen shall be symmetrical with the center line of the reduced section within 0.25 in. (6.35 mm), except for referee testing in which case the ends of the specimen shall be symmetrical with the center line of the reduced section within 0.10 in. (2.5 mm).

**FIG. 3 Rectangular Tension Test Specimens**





DIMENSIONS

Nominal Diameter	Standard Specimen		Small-Size Specimens Proportional to Standard							
	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm
	0.500	12.5	0.350	8.75	0.250	6.25	0.160	4.00	0.113	2.50
G—Gauge length	2.00± 0.005	50.0 ± 0.10	1.400± 0.005	35.0 ± 0.10	1.000± 0.005	25.0 ± 0.10	0.640± 0.005	16.0 ± 0.10	0.450± 0.005	10.0 ± 0.10
D—Diameter (Note 1)	0.500± 0.010	12.5± 0.25	0.350± 0.007	8.75 ± 0.18	0.250± 0.005	6.25 ± 0.12	0.160± 0.003	4.00 ± 0.08	0.113± 0.002	2.50 ± 0.05
R—Radius of fillet, min	3/8	10	1/4	6	3/16	5	5/32	4	3/32	2
A—Length of reduced section, min (Note 2)	2 1/4	60	1 3/4	45	1 1/4	32	3/4	20	5/8	16

NOTE 1—The reduced section may have a gradual taper from the ends toward the center, with the ends not more than 1 % larger in diameter than the center (controlling dimension).

NOTE 2—If desired, the length of the reduced section may be increased to accommodate an extensometer of any convenient gauge length. Reference marks for the measurement of elongation should, nevertheless, be spaced at the indicated gauge length.

NOTE 3—The gauge length and fillets should be as shown, but the ends may be of any form to fit the holders of the testing machine in such a way that the load shall be axial (see Fig. 9). If the ends are to be held in wedge grips it is desirable, if possible, to make the length of the grip section great enough to allow the specimen to extend into the grips a distance equal to two thirds or more of the length of the grips.

NOTE 4—On the round specimens in Fig. 5 and Fig. 6, the gauge lengths are equal to four times the nominal diameter. In some product specifications other specimens may be provided for, but unless the 4-to-1 ratio is maintained within dimensional tolerances, the elongation values may not be comparable with those obtained from the standard test specimen.

NOTE 5—The use of specimens smaller than 0.250-in. (6.25-mm) diameter shall be restricted to cases when the material to be tested is of insufficient size to obtain larger specimens or when all parties agree to their use for acceptance testing. Smaller specimens require suitable equipment and greater skill in both machining and testing.

NOTE 6—Five sizes of specimens often used have diameters of approximately 0.505, 0.357, 0.252, 0.160, and 0.113 in., the reason being to permit easy calculations of stress from loads, since the corresponding cross sectional areas are equal or close to 0.200, 0.100, 0.0500, 0.0200, and 0.0100 in.<sup>2</sup>, respectively. Thus, when the actual diameters agree with these values, the stresses (or strengths) may be computed using the simple multiplying factors 5, 10, 20, 50, and 100, respectively. (The metric equivalents of these fixed diameters do not result in correspondingly convenient cross sectional area and multiplying factors.)

FIG. 4 Standard 0.500-in. (12.5-mm) Round Tension Test Specimen with 2-in. (50-mm) Gauge Length and Examples of Small-Size Specimens Proportional to Standard Specimens

## 14. Determination of Tensile Properties

14.1 *Yield Point*—Yield point is the first stress in a material, less than the maximum obtainable stress, at which an increase in strain occurs without an increase in stress. Yield point is intended for application only for materials that may exhibit the unique characteristic of showing an increase in strain without an increase in stress. The stress-strain diagram is characterized by a sharp knee or discontinuity. Determine yield point by one of the following methods:

14.1.1 *Drop of the Beam or Halt of the Pointer Method*—In this method, apply an increasing load to the specimen at a uniform rate. When a lever and poise machine is used, keep the beam in balance by running out the poise at approximately a steady rate. When the yield point of the material is reached, the increase of the load will stop, but run the poise a trifle beyond the balance position, and the beam of the machine will drop for a brief but appreciable interval of time. When a machine equipped with a load-indicating dial is used there is a halt or hesitation of the load-indicating pointer corresponding to the drop of the beam. Note the load at the “drop of the beam” or the “halt of the pointer” and record the corresponding stress as the yield point.

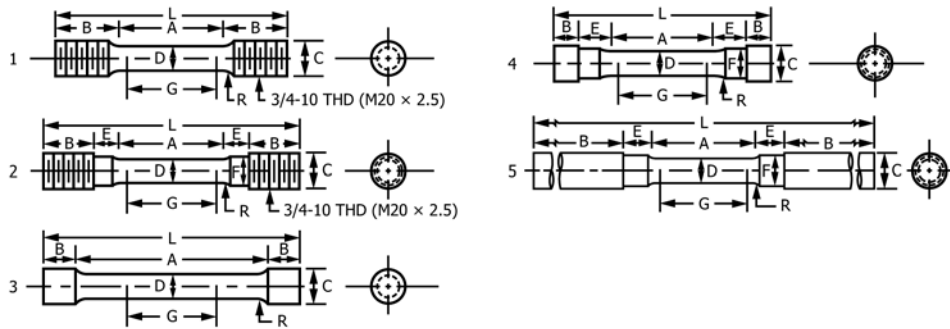
14.1.2 *Autographic Diagram Method*—When a sharp-kneed stress-strain diagram is obtained by an autographic recording device, take the stress corresponding to the top of the knee (Fig. 7), or the stress at which the curve drops as the yield point.

14.1.3 *Total Extension Under Load Method*—When testing material for yield point and the test specimens may not exhibit a well-defined disproportionate deformation that characterizes a yield point as measured by the drop of the beam, halt of the pointer, or autographic diagram methods described in 14.1.1 and 14.1.2, a value equivalent to the yield point in its practical significance may be determined by the following method and may be recorded as yield point: Attach a Class C or better extensometer (Notes 5 and 6) to the specimen. When the load producing a specified extension (Note 7) is reached record the stress corresponding to the load as the yield point (Fig. 8).

NOTE 5—Automatic devices are available that determine the load at the specified total extension without plotting a stress-strain curve. Such devices may be used if their accuracy has been demonstrated. Multiplying calipers and other such devices are acceptable for use provided their accuracy has been demonstrated as equivalent to a Class C extensometer.

NOTE 6—Reference should be made to Practice E83.

NOTE 7—For steel with a yield point specified not over 80 000 psi



DIMENSIONS

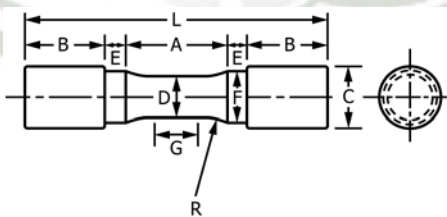
	Specimen 1		Specimen 2		Specimen 3		Specimen 4		Specimen 5	
	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm
G—Gauge length	2.000± 0.005	50.0 ± 0.10	2.000± 0.005	50.0 ± 0.10	2.000± 0.005	50.0 ± 0.10	2.000± 0.005	50.0 ± 0.10	2.00± 0.005	50.0 ± 0.10
D—Diameter (Note 1)	0.500 ± 0.010	12.5± 0.25	0.500 ± 0.010	12.5± 0.25	0.500 ± 0.010	12.5± 0.25	0.500 ± 0.010	12.5± 0.25	0.500± 0.010	12.5 ± 0.25
R—Radius of fillet, min	3/8	10	3/8	10	1/16	2	3/8	10	3/8	10
A—Length of reduced section	2 1/4, min	60, min	2 1/4, min	60, min	4, ap- proximately	100, ap- proximately	2 1/4, min	60, min	2 1/4, min	60, min
L—Overall length, approximate	5	125	5 1/2	140	5 1/2	140	4 3/4	120	9 1/2	240
B—Grip section (Note 2)	1 3/8, ap- proximately	35, ap- proximately	1, ap- proximately	25, ap- proximately	3/4, ap- proximately	20, ap- proximately	1/2, ap- proximately	13, ap- proximately	3, min	75, min
C—Diameter of end section	3/4	20	3/4	20	23/32	18	7/8	22	3/4	20
E—Length of shoulder and fillet section, approximate	...	...	5/8	16	...	...	3/4	20	5/8	16
F—Diameter of shoulder	...	...	5/8	16	...	...	5/8	16	1 9/32	15

NOTE 1—The reduced section may have a gradual taper from the ends toward the center with the ends not more than 0.005 in. (0.10 mm) larger in diameter than the center.

NOTE 2—On Specimen 5 it is desirable, if possible, to make the length of the grip section great enough to allow the specimen to extend into the grips a distance equal to two thirds or more of the length of the grips.

NOTE 3—The types of ends shown are applicable for the standard 0.500-in. round tension test specimen; similar types can be used for subsize specimens. The use of UNF series of threads (3/4 by 16, 1/2 by 20, 3/8 by 24, and 1/4 by 28) is suggested for high-strength brittle materials to avoid fracture in the thread portion.

FIG. 5 Suggested Types of Ends for Standard Round Tension Test Specimens



DIMENSIONS

	Specimen 1		Specimen 2		Specimen 3	
	in.	mm	in.	mm	in.	mm
G—Length of parallel	Shall be equal to or greater than diameter <i>D</i>					
D—Diameter	0.500 ± 0.010	12.5± 0.25	0.750 ± 0.015	20.0 ± 0.40	1.25 ± 0.025	30.0 ± 0.60
R—Radius of fillet, min	1	25	1	25	2	50
A—Length of reduced section, min	1 1/4	32	1 1/2	38	2 1/4	60
L—Over-all length, min	3 3/4	95	4	100	6 3/8	160
B—Grip section, approximate	1	25	1	25	1 3/4	45
C—Diameter of end section, approximate	3/4	20	1 1/8	30	1 1/8	48
E—Length of shoulder, min	1/4	6	1/4	6	5/16	8
F—Diameter of shoulder	5/8 ± 1/64	16.0 ± 0.40	15/16 ± 1/64	24.0 ± 0.40	17/16 ± 1/64	36.5 ± 0.40

NOTE 1—The reduced section and shoulders (dimensions *A*, *D*, *E*, *F*, *G*, and *R*) shall be shown, but the ends may be of any form to fit the holders of the testing machine in such a way that the load shall be axial. Commonly the ends are threaded and have the dimensions *B* and *C* given above.

FIG. 6 Standard Tension Test Specimens for Cast Iron

TABLE 1 Multiplying Factors to Be Used for Various Diameters of Round Test Specimens

Standard Specimen			Small Size Specimens Proportional to Standard					
0.500 in. Round			0.350 in. Round			0.250 in. Round		
Actual Diameter, in.	Area, in. <sup>2</sup>	Multiplying Factor	Actual Diameter, in.	Area, in. <sup>2</sup>	Multiplying Factor	Actual Diameter, in.	Area, in. <sup>2</sup>	Multiplying Factor
0.490	0.1886	5.30	0.343	0.0924	10.82	0.245	0.0471	21.21
0.491	0.1893	5.28	0.344	0.0929	10.76	0.246	0.0475	21.04
0.492	0.1901	5.26	0.345	0.0935	10.70	0.247	0.0479	20.87
0.493	0.1909	5.24	0.346	0.0940	10.64	0.248	0.0483	20.70
0.494	0.1917	5.22	0.347	0.0946	10.57	0.249	0.0487	20.54
0.495	0.1924	5.20	0.348	0.0951	10.51	0.250	0.0491	20.37
0.496	0.1932	5.18	0.349	0.0957	10.45	0.251	0.0495	20.21
0.497	0.1940	5.15	0.350	0.0962	10.39	(0.05) <sup>A</sup>	0.0499	(20.0) <sup>A</sup>
0.498	0.1948	5.13	0.351	0.0968	10.33	(0.05) <sup>A</sup>	0.0503	(20.0) <sup>A</sup>
0.499	0.1956	5.11	0.352	0.0973	10.28	(0.05) <sup>A</sup>	0.0507	(20.0) <sup>A</sup>
0.500	0.1963	5.09	0.353	0.0979	10.22	0.254	0.0511	19.74
0.501	0.1971	5.07	0.354	0.0984	10.16	0.255	...	19.58
0.502	0.1979	5.05	0.355	0.0990	10.10	...	...	...
0.503	0.1987	5.03	0.356	0.0995	10.05	...	...	...
0.504	0.1995	5.01	0.357	(0.1) <sup>A</sup>	(10.0) <sup>A</sup>	...	...	...
0.505	(0.2) <sup>A</sup>	(5.0) <sup>A</sup>	...	(0.1) <sup>A</sup>	(10.0) <sup>A</sup>	...	...	...
0.506	0.2003	4.99	...	...	...	...	...	...
0.507	(0.2) <sup>A</sup>	(5.0) <sup>A</sup>	...	...	...	...	...	...
0.508	0.2011	4.97	...	...	...	...	...	...
0.509	(0.2) <sup>A</sup>	(5.0) <sup>A</sup>	...	...	...	...	...	...
0.510	0.2019	4.95	...	...	...	...	...	...
0.511	0.2027	4.93	...	...	...	...	...	...
0.512	0.2035	4.91	...	...	...	...	...	...
0.513	0.2043	4.90	...	...	...	...	...	...

<sup>A</sup> The values in parentheses may be used for ease in calculation of stresses, in pounds per square inch, as permitted in Note 5 of Fig. 4.

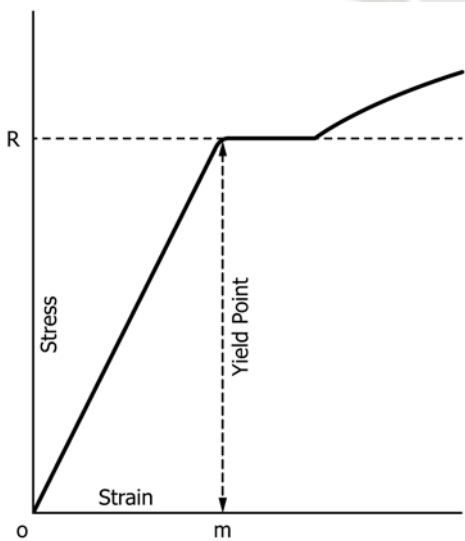


FIG. 7 Stress-Strain Diagram Showing Yield Point Corresponding with Top of Knee

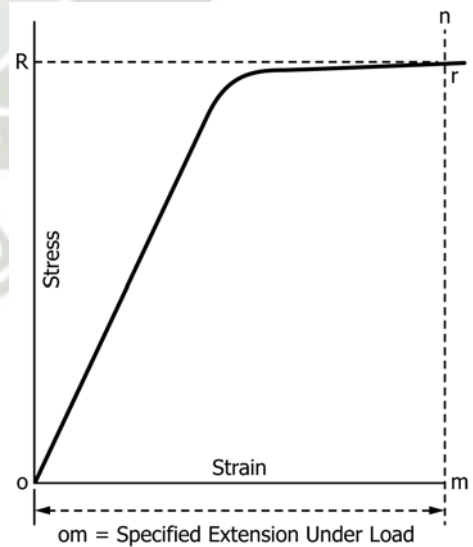


FIG. 8 Stress-Strain Diagram Showing Yield Point or Yield Strength by Extension Under Load Method

(550 MPa), an appropriate value is 0.005 in./in. of gauge length. For values above 80 000 psi, this method is not valid unless the limiting total extension is increased.

NOTE 8—The shape of the initial portion of an autographically determined stress-strain (or a load-elongation) curve may be influenced by numerous factors such as the seating of the specimen in the grips, the straightening of a specimen bent due to residual stresses, and the rapid loading permitted in 8.4.1. Generally, the aberrations in this portion of the curve should be ignored when fitting a modulus line, such as that used to determine the extension-under-load yield, to the curve. In practice, for a number of reasons, the straight-line portion of the stress-strain curve may not go through the origin of the stress-strain diagram. In these cases it is not the origin of the stress-strain diagram, but rather where the straight-line portion of the stress-strain curve, intersects the strain axis that is pertinent. All offsets and extensions should be calculated from the intersection of the straight-line portion of the stress-strain curve with the strain axis, and not necessarily from the origin of the stress-strain diagram. See also Test Methods E8/E8M, Note 32.

14.2 *Yield Strength*—Yield strength is the stress at which a material exhibits a specified limiting deviation from the proportionality of stress to strain. The deviation is expressed in terms of strain, percent offset, total extension under load, and so forth. Determine yield strength by one of the following methods:

14.2.1 *Offset Method*—To determine the yield strength by the “offset method,” it is necessary to secure data (autographic or numerical) from which a stress-strain diagram with a distinct modulus characteristic of the material being tested may be drawn. Then on the stress-strain diagram (Fig. 9) lay off  $Om$  equal to the specified value of the offset, draw  $mn$  parallel to  $OA$ , and thus locate  $r$ , the intersection of  $mn$  with the stress-strain curve corresponding to load  $R$ , which is the yield-strength load. In recording values of yield strength obtained by this method, the value of offset specified or used,

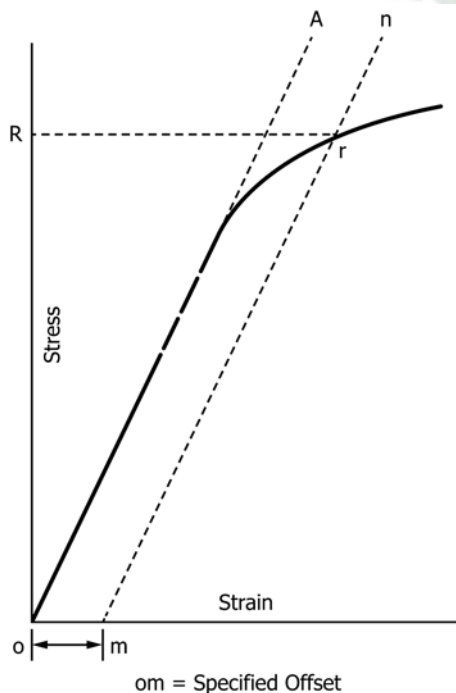


FIG. 9 Stress-Strain Diagram for Determination of Yield Strength by Offset Method

or both, shall be stated in parentheses after the term yield strength, for example:

$$\text{Yield strength (0.2\% offset)} = 52\,000 \text{ psi (360 MPa)} \quad (1)$$

When the offset is 0.2 % or larger, the extensometer used shall qualify as a Class B2 device over a strain range of 0.05 to 1.0 %. If a smaller offset is specified, it may be necessary to specify a more accurate device (that is, a Class B1 device) or reduce the lower limit of the strain range (for example, to 0.01 %) or both. See also Note 10 for automatic devices.

NOTE 9—For stress-strain diagrams not containing a distinct modulus, such as for some cold-worked materials, it is recommended that the extension under load method be utilized. If the offset method is used for materials without a distinct modulus, a modulus value appropriate for the material being tested should be used: 30 000 000 psi (207 000 MPa) for carbon steel; 29 000 000 psi (200 000 MPa) for ferritic stainless steel; 28 000 000 psi (193 000 MPa) for austenitic stainless steel. For special alloys, the producer should be contacted to discuss appropriate modulus values.

14.2.2 *Extension Under Load Method*—For tests to determine the acceptance or rejection of material whose stress-strain characteristics are well known from previous tests of similar material in which stress-strain diagrams were plotted, the total strain corresponding to the stress at which the specified offset (see Notes 10 and 11) occurs will be known within satisfactory limits. The stress on the specimen, when this total strain is reached, is the value of the yield strength. In recording values of yield strength obtained by this method, the value of “extension” specified or used, or both, shall be stated in parentheses after the term yield strength, for example:

$$\text{Yield strength (0.5\% EUL)} = 52\,000 \text{ psi (360 MPa)} \quad (2)$$

The total strain can be obtained satisfactorily by use of a Class B1 extensometer (Note 5, Note 6, and Note 8).

NOTE 10—Automatic devices are available that determine offset yield strength without plotting a stress-strain curve. Such devices may be used if their accuracy has been demonstrated.

NOTE 11—The appropriate magnitude of the extension under load will obviously vary with the strength range of the particular steel under test. In general, the value of extension under load applicable to steel at any strength level may be determined from the sum of the proportional strain and the plastic strain expected at the specified yield strength. The following equation is used:

$$\text{Extension under load, in./in. of gauge length} = (YS/E) + r \quad (3)$$

where:

$YS$  = specified yield strength, psi or MPa,  
 $E$  = modulus of elasticity, psi or MPa, and  
 $r$  = limiting plastic strain, in./in.

14.3 *Tensile Strength*—Calculate the tensile strength by dividing the maximum load the specimen sustains during a tension test by the original cross-sectional area of the specimen. If the upper yield strength is the maximum stress recorded and if the stress-strain curve resembles that of Test Methods E8/E8M–15a Fig. 25, the maximum stress after discontinuous yielding shall be reported as the tensile strength unless otherwise stated by the purchaser.

#### 14.4 *Elongation:*

14.4.1 Fit the ends of the fractured specimen together carefully and measure the distance between the gauge marks to

the nearest 0.01 in. (0.25 mm) for gauge lengths of 2 in. and under, and to the nearest 0.5 % of the gauge length for gauge lengths over 2 in. A percentage scale reading to 0.5 % of the gauge length may be used. The elongation is the increase in length of the gauge length, expressed as a percentage of the original gauge length. In recording elongation values, give both the percentage increase and the original gauge length.

14.4.2 If any part of the fracture takes place outside of the middle half of the gauge length or in a punched or scribed mark within the reduced section, the elongation value obtained may not be representative of the material. If the elongation so measured meets the minimum requirements specified, no further testing is indicated, but if the elongation is less than the minimum requirements, discard the test and retest.

14.4.3 Automated tensile testing methods using extensometers allow for the measurement of elongation in a method described below. Elongation may be measured and reported either this way, or as in the method described above, fitting the broken ends together. Either result is valid.

14.4.4 Elongation at fracture is defined as the elongation measured just prior to the sudden decrease in force associated with fracture. For many ductile materials not exhibiting a sudden decrease in force, the elongation at fracture can be taken as the strain measured just prior to when the force falls below 10 % of the maximum force encountered during the test.

14.4.4.1 Elongation at fracture shall include elastic and plastic elongation and may be determined with autographic or automated methods using extensometers verified over the strain range of interest. Use a class B2 or better extensometer for materials having less than 5 % elongation; a class C or better extensometer for materials having elongation greater than or equal to 5 % but less than 50 %; and a class D or better extensometer for materials having 50 % or greater elongation. In all cases, the extensometer gauge length shall be the nominal gauge length required for the specimen being tested. Due to the lack of precision in fitting fractured ends together, the elongation after fracture using the manual methods of the preceding paragraphs may differ from the elongation at fracture determined with extensometers.

14.4.4.2 Percent elongation at fracture may be calculated directly from elongation at fracture data and be reported instead of percent elongation as calculated in 14.4.1. However, these two parameters are not interchangeable. Use of the elongation at fracture method generally provides more repeatable results.

14.5 *Reduction of Area*—Fit the ends of the fractured specimen together and measure the mean diameter or the width and thickness at the smallest cross section to the same accuracy as the original dimensions. The difference between the area thus found and the area of the original cross section expressed as a percentage of the original area is the reduction of area.

## BEND TEST

### 15. Description

15.1 The bend test is one method for evaluating ductility, but it cannot be considered as a quantitative means of predicting service performance in all bending operations. The severity

of the bend test is primarily a function of the angle of bend of the inside diameter to which the specimen is bent, and of the cross section of the specimen. These conditions are varied according to location and orientation of the test specimen and the chemical composition, tensile properties, hardness, type, and quality of the steel specified. Test Methods E190 and E290 may be consulted for methods of performing the test.

15.2 Unless otherwise specified, it shall be permissible to age bend test specimens. The time-temperature cycle employed must be such that the effects of previous processing will not be materially changed. It may be accomplished by aging at room temperature 24 to 48 h, or in shorter time at moderately elevated temperatures by boiling in water or by heating in oil or in an oven.

15.3 Bend the test specimen at room temperature to an inside diameter, as designated by the applicable product specifications, to the extent specified. The speed of bending is ordinarily not an important factor.

## HARDNESS TEST

### 16. General

16.1 A hardness test is a means of determining resistance to penetration and is occasionally employed to obtain a quick approximation of tensile strength. Tables 2-5 are for the conversion of hardness measurements from one scale to another or to approximate tensile strength. These conversion values have been obtained from computer-generated curves and are presented to the nearest 0.1 point to permit accurate reproduction of those curves. All converted hardness values must be considered approximate. All converted Rockwell and Vickers hardness numbers shall be rounded to the nearest whole number.

#### 16.2 *Hardness Testing:*

16.2.1 If the product specification permits alternative hardness testing to determine conformance to a specified hardness requirement, the conversions listed in Tables 2-5 shall be used.

16.2.2 When recording converted hardness numbers, the measured hardness and test scale shall be indicated in parentheses, for example: 353 HBW (38 HRC). This means that a hardness value of 38 was obtained using the Rockwell C scale and converted to a Brinell hardness of 353.

### 17. Brinell Test

#### 17.1 *Description:*

17.1.1 A specified load is applied to a flat surface of the specimen to be tested, through a tungsten carbide ball of specified diameter. The average diameter of the indentation is used as a basis for calculation of the Brinell hardness number. The quotient of the applied load divided by the area of the surface of the indentation, which is assumed to be spherical, is termed the Brinell hardness number (HBW) in accordance with the following equation:

$$HBW = P / \left[ (\pi D / 2) \left( D - \sqrt{D^2 - d^2} \right) \right] \quad (4)$$

**TABLE 2 Approximate Hardness Conversion Numbers for Non-austenitic Steels<sup>A</sup> (Rockwell C to Other Hardness Numbers)**

Rockwell C Scale, 150-kgf Load, Diamond Penetrator	Vickers Hardness Number	Brinell Hardness 3000-kgf Load, 10-mm Ball	Knoop Hardness, 500-gf Load and Over	Rockwell A Scale, 60-kgf Load, Diamond Penetrator	Rockwell Superficial Hardness			Approximate Tensile Strength, ksi (MPa)
					15N Scale, 15-kgf Load, Diamond Penetrator	30N Scale 30- kgf Load, Diamond Penetrator	45N Scale, 45-kgf Load, Diamond Penetrator	
68	940	...	920	85.6	93.2	84.4	75.4	...
67	900	...	895	85.0	92.9	83.6	74.2	...
66	865	...	870	84.5	92.5	82.8	73.3	...
65	832	739	846	83.9	92.2	81.9	72.0	...
64	800	722	822	83.4	91.8	81.1	71.0	...
63	772	706	799	82.8	91.4	80.1	69.9	...
62	746	688	776	82.3	91.1	79.3	68.8	...
61	720	670	754	81.8	90.7	78.4	67.7	...
60	697	654	732	81.2	90.2	77.5	66.6	...
59	674	634	710	80.7	89.8	76.6	65.5	351 (2420)
58	653	615	690	80.1	89.3	75.7	64.3	338 (2330)
57	633	595	670	79.6	88.9	74.8	63.2	325 (2240)
56	613	577	650	79.0	88.3	73.9	62.0	313 (2160)
55	595	560	630	78.5	87.9	73.0	60.9	301 (2070)
54	577	543	612	78.0	87.4	72.0	59.8	292 (2010)
53	560	525	594	77.4	86.9	71.2	58.6	283 (1950)
52	544	512	576	76.8	86.4	70.2	57.4	273 (1880)
51	528	496	558	76.3	85.9	69.4	56.1	264 (1820)
50	513	482	542	75.9	85.5	68.5	55.0	255 (1760)
49	498	468	526	75.2	85.0	67.6	53.8	246 (1700)
48	484	455	510	74.7	84.5	66.7	52.5	238 (1640)
47	471	442	495	74.1	83.9	65.8	51.4	229 (1580)
46	458	432	480	73.6	83.5	64.8	50.3	221 (1520)
45	446	421	466	73.1	83.0	64.0	49.0	215 (1480)
44	434	409	452	72.5	82.5	63.1	47.8	208 (1430)
43	423	400	438	72.0	82.0	62.2	46.7	201 (1390)
42	412	390	426	71.5	81.5	61.3	45.5	194 (1340)
41	402	381	414	70.9	80.9	60.4	44.3	188 (1300)
40	392	371	402	70.4	80.4	59.5	43.1	182 (1250)
39	382	362	391	69.9	79.9	58.6	41.9	177 (1220)
38	372	353	380	69.4	79.4	57.7	40.8	171 (1180)
37	363	344	370	68.9	78.8	56.8	39.6	166 (1140)
36	354	336	360	68.4	78.3	55.9	38.4	161 (1110)
35	345	327	351	67.9	77.7	55.0	37.2	156 (1080)
34	336	319	342	67.4	77.2	54.2	36.1	152 (1050)
33	327	311	334	66.8	76.6	53.3	34.9	149 (1030)
32	318	301	326	66.3	76.1	52.1	33.7	146 (1010)
31	310	294	318	65.8	75.6	51.3	32.5	141 (970)
30	302	286	311	65.3	75.0	50.4	31.3	138 (950)
29	294	279	304	64.6	74.5	49.5	30.1	135 (930)
28	286	271	297	64.3	73.9	48.6	28.9	131 (900)
27	279	264	290	63.8	73.3	47.7	27.8	128 (880)
26	272	258	284	63.3	72.8	46.8	26.7	125 (860)
25	266	253	278	62.8	72.2	45.9	25.5	123 (850)
24	260	247	272	62.4	71.6	45.0	24.3	119 (820)
23	254	243	266	62.0	71.0	44.0	23.1	117 (810)
22	248	237	261	61.5	70.5	43.2	22.0	115 (790)
21	243	231	256	61.0	69.9	42.3	20.7	112 (770)
20	238	226	251	60.5	69.4	41.5	19.6	110 (760)

<sup>A</sup> This table gives the approximate interrelationships of hardness values and approximate tensile strength of steels. It is possible that steels of various compositions and processing histories will deviate in hardness-tensile strength relationship from the data presented in this table. The data in this table should not be used for austenitic stainless steels, but have been shown to be applicable for ferritic and martensitic stainless steels. The data in this table should not be used to establish a relationship between hardness values and tensile strength of hard drawn wire. Where more precise conversions are required, they should be developed specially for each steel composition, heat treatment, and part. Caution should be exercised if conversions from this table are used for the acceptance or rejection of product. The approximate interrelationships may affect acceptance or rejection.

where:

- HBW = Brinell hardness number,
- P = applied load, kgf,
- D = diameter of the tungsten carbide ball, mm, and
- d = average diameter of the indentation, mm.

NOTE 12—The Brinell hardness number is more conveniently secured from standard tables such as Table 6, which show numbers corresponding to the various indentation diameters, usually in increments of 0.05 mm.

NOTE 13—In Test Method E10 the values are stated in SI units, whereas in this section kg/m units are used.

17.1.2 The standard Brinell test using a 10-mm tungsten carbide ball employs a 3000-kgf load for hard materials and a 1500 or 500-kgf load for thin sections or soft materials (see Annex A2 on Steel Tubular Products). Other loads and different size indentors may be used when specified. In recording

**TABLE 3 Approximate Hardness Conversion Numbers for Non-austenitic Steels<sup>A</sup> (Rockwell B to Other Hardness Numbers)**

Rockwell B Scale, 100- kgf Load 1/16- in. (1.588- mm) Ball	Vickers Hardness Number	Brinell Hardness, 3000-kgf Load, 10-mm Ball	Knoop Hardness, 500-gf Load & Over	Rockwell A Scale, 60-kgf Load, Diamond Penetrator	Rockwell F Scale, 60-kgf Load, 1/16-in. (1.588-mm) Ball	Rockwell Superficial Hardness			Approximate Tensile Strength ksi (MPa)
						15T Scale, 15-kgf Load, 1/16- in. (1.588- mm) Ball	30T Scale, 30-kgf Load, 1/16- in. (1.588- mm) Ball	45T Scale, 45-kgf Load, 1/16- in. (1.588- mm) Ball	
100	240	240	251	61.5	...	93.1	83.1	72.9	116 (800)
99	234	234	246	60.9	...	92.8	82.5	71.9	114 (785)
98	228	228	241	60.2	...	92.5	81.8	70.9	109 (750)
97	222	222	236	59.5	...	92.1	81.1	69.9	104 (715)
96	216	216	231	58.9	...	91.8	80.4	68.9	102 (705)
95	210	210	226	58.3	...	91.5	79.8	67.9	100 (690)
94	205	205	221	57.6	...	91.2	79.1	66.9	98 (675)
93	200	200	216	57.0	...	90.8	78.4	65.9	94 (650)
92	195	195	211	56.4	...	90.5	77.8	64.8	92 (635)
91	190	190	206	55.8	...	90.2	77.1	63.8	90 (620)
90	185	185	201	55.2	...	89.9	76.4	62.8	89 (615)
89	180	180	196	54.6	...	89.5	75.8	61.8	88 (605)
88	176	176	192	54.0	...	89.2	75.1	60.8	86 (590)
87	172	172	188	53.4	...	88.9	74.4	59.8	84 (580)
86	169	169	184	52.8	...	88.6	73.8	58.8	83 (570)
85	165	165	180	52.3	...	88.2	73.1	57.8	82 (565)
84	162	162	176	51.7	...	87.9	72.4	56.8	81 (560)
83	159	159	173	51.1	...	87.6	71.8	55.8	80 (550)
82	156	156	170	50.6	...	87.3	71.1	54.8	77 (530)
81	153	153	167	50.0	...	86.9	70.4	53.8	73 (505)
80	150	150	164	49.5	...	86.6	69.7	52.8	72 (495)
79	147	147	161	48.9	...	86.3	69.1	51.8	70 (485)
78	144	144	158	48.4	...	86.0	68.4	50.8	69 (475)
77	141	141	155	47.9	...	85.6	67.7	49.8	68 (470)
76	139	139	152	47.3	...	85.3	67.1	48.8	67 (460)
75	137	137	150	46.8	99.6	85.0	66.4	47.8	66 (455)
74	135	135	147	46.3	99.1	84.7	65.7	46.8	65 (450)
73	132	132	145	45.8	98.5	84.3	65.1	45.8	64 (440)
72	130	130	143	45.3	98.0	84.0	64.4	44.8	63 (435)
71	127	127	141	44.8	97.4	83.7	63.7	43.8	62 (425)
70	125	125	139	44.3	96.8	83.4	63.1	42.8	61 (420)
69	123	123	137	43.8	96.2	83.0	62.4	41.8	60 (415)
68	121	121	135	43.3	95.6	82.7	61.7	40.8	59 (405)
67	119	119	133	42.8	95.1	82.4	61.0	39.8	58 (400)
66	117	117	131	42.3	94.5	82.1	60.4	38.7	57 (395)
65	116	116	129	41.8	93.9	81.8	59.7	37.7	56 (385)
64	114	114	127	41.4	93.4	81.4	59.0	36.7	...
63	112	112	125	40.9	92.8	81.1	58.4	35.7	...
62	110	110	124	40.4	92.2	80.8	57.7	34.7	...
61	108	108	122	40.0	91.7	80.5	57.0	33.7	...
60	107	107	120	39.5	91.1	80.1	56.4	32.7	...
59	106	106	118	39.0	90.5	79.8	55.7	31.7	...
58	104	104	117	38.6	90.0	79.5	55.0	30.7	...
57	103	103	115	38.1	89.4	79.2	54.4	29.7	...
56	101	101	114	37.7	88.8	78.8	53.7	28.7	...
55	100	100	112	37.2	88.2	78.5	53.0	27.7	...
54	...	...	111	36.8	87.7	78.2	52.4	26.7	...
53	...	...	110	36.3	87.1	77.9	51.7	25.7	...
52	...	...	109	35.9	86.5	77.5	51.0	24.7	...
51	...	...	108	35.5	86.0	77.2	50.3	23.7	...
50	...	...	107	35.0	85.4	76.9	49.7	22.7	...
49	...	...	106	34.6	84.8	76.6	49.0	21.7	...
48	...	...	105	34.1	84.3	76.2	48.3	20.7	...
47	...	...	104	33.7	83.7	75.9	47.7	19.7	...
46	...	...	103	33.3	83.1	75.6	47.0	18.7	...
45	...	...	102	32.9	82.6	75.3	46.3	17.7	...
44	...	...	101	32.4	82.0	74.9	45.7	16.7	...
43	...	...	100	32.0	81.4	74.6	45.0	15.7	...
42	...	...	99	31.6	80.8	74.3	44.3	14.7	...
41	...	...	98	31.2	80.3	74.0	43.7	13.6	...
40	...	...	97	30.7	79.7	73.6	43.0	12.6	...
39	...	...	96	30.3	79.1	73.3	42.3	11.6	...
38	...	...	95	29.9	78.6	73.0	41.6	10.6	...
37	...	...	94	29.5	78.0	72.7	41.0	9.6	...
36	...	...	93	29.1	77.4	72.3	40.3	8.6	...
35	...	...	92	28.7	76.9	72.0	39.6	7.6	...
34	...	...	91	28.2	76.3	71.7	39.0	6.6	...
33	...	...	90	27.8	75.7	71.4	38.3	5.6	...
32	...	...	89	27.4	75.2	71.0	37.6	4.6	...
31	...	...	88	27.0	74.6	70.7	37.0	3.6	...

TABLE 3 Continued

Rockwell B Scale, 100-kgf Load 1/16-in. (1.588-mm) Ball	Vickers Hardness Number	Brinell Hardness, 3000-kgf Load, 10-mm Ball	Knoop Hardness, 500-gf Load & Over	Rockwell A Scale, 60-kgf Load, Diamond Penetrator	Rockwell F Scale, 60-kgf Load, 1/16-in. (1.588-mm) Ball	Rockwell Superficial Hardness			Approximate Tensile Strength ksi (MPa)
						15T Scale, 15-kgf Load, 1/16-in. (1.588-mm) Ball	30T Scale, 30-kgf Load, 1/16-in. (1.588-mm) Ball	45T Scale, 45-kgf Load, 1/16-in. (1.588-mm) Ball	
30	...	...	87	26.6	74.0	70.4	36.3	2.6	...

<sup>A</sup> This table gives the approximate interrelationships of hardness values and approximate tensile strength of steels. It is possible that steels of various compositions and processing histories will deviate in hardness-tensile strength relationship from the data presented in this table. The data in this table should not be used for austenitic stainless steels, but have been shown to be applicable for ferritic and martensitic stainless steels. The data in this table should not be used to establish a relationship between hardness values and tensile strength of hard drawn wire. Where more precise conversions are required, they should be developed specially for each steel composition, heat treatment, and part.

TABLE 4 Approximate Hardness Conversion Numbers for Austenitic Steels (Rockwell C to other Hardness Numbers)

Rockwell C Scale, 150-kgf Load, Diamond Penetrator	Rockwell A Scale, 60-kgf Load, Diamond Penetrator	Rockwell Superficial Hardness		
		15N Scale, 15-kgf Load, Diamond Penetrator	30N Scale, 30-kgf Load, Diamond Penetrator	45N Scale, 45-kgf Load, Diamond Penetrator
48	74.4	84.1	66.2	52.1
47	73.9	83.6	65.3	50.9
46	73.4	83.1	64.5	49.8
45	72.9	82.6	63.6	48.7
44	72.4	82.1	62.7	47.5
43	71.9	81.6	61.8	46.4
42	71.4	81.0	61.0	45.2
41	70.9	80.5	60.1	44.1
40	70.4	80.0	59.2	43.0
39	69.9	79.5	58.4	41.8
38	69.3	79.0	57.5	40.7
37	68.8	78.5	56.6	39.6
36	68.3	78.0	55.7	38.4
35	67.8	77.5	54.9	37.3
34	67.3	77.0	54.0	36.1
33	66.8	76.5	53.1	35.0
32	66.3	75.9	52.3	33.9
31	65.8	75.4	51.4	32.7
30	65.3	74.9	50.5	31.6
29	64.8	74.4	49.6	30.4
28	64.3	73.9	48.8	29.3
27	63.8	73.4	47.9	28.2
26	63.3	72.9	47.0	27.0
25	62.8	72.4	46.2	25.9
24	62.3	71.9	45.3	24.8
23	61.8	71.3	44.4	23.6
22	61.3	70.8	43.5	22.5
21	60.8	70.3	42.7	21.3
20	60.3	69.8	41.8	20.2

hardness values, the diameter of the ball and the load must be stated except when a 10-mm ball and 3000-kgf load are used.

17.1.3 A range of hardness can properly be specified only for quenched and tempered or normalized and tempered material. For annealed material a maximum figure only should be specified. For normalized material a minimum or a maximum hardness may be specified by agreement. In general, no hardness requirements should be applied to untreated material.

17.1.4 Brinell hardness may be required when tensile properties are not specified.

17.2 Apparatus—Equipment shall meet the following requirements:

17.2.1 Testing Machine—A Brinell hardness testing machine is acceptable for use over a loading range within which its load measuring device is accurate to  $\pm 1\%$ .

17.2.2 Measuring Microscope—The divisions of the micrometer scale of the microscope or other measuring devices used for the measurement of the diameter of the indentations shall be such as to permit the direct measurement of the diameter to 0.1 mm and the estimation of the diameter to 0.05 mm.

NOTE 14—This requirement applies to the construction of the microscope only and is not a requirement for measurement of the indentation, see 17.4.3.

17.2.3 Standard Ball—The standard tungsten carbide ball for Brinell hardness testing is 10 mm (0.3937 in.) in diameter with a deviation from this value of not more than 0.005 mm (0.0002 in.) in any diameter. A tungsten carbide ball suitable for use must not show a permanent change in diameter greater than 0.01 mm (0.0004 in.) when pressed with a force of



**TABLE 5 Approximate Hardness Conversion Numbers for Austenitic Steels (Rockwell B to other Hardness Numbers)**

Rockwell B Scale, 100-kgf Load, 1/16-in. (1.588-mm) Ball	Brinell Indentation Diameter, mm	Brinell Hardness, 3000-kgf Load, 10-mm Ball	Rockwell A Scale, 60-kgf Load, Diamond Penetrator	Rockwell Superficial Hardness		
				15T Scale, 15-kgf Load, 1/16-in. (1.588-mm) Ball	30T Scale, 30-kgf Load, 1/16-in. (1.588-mm) Ball	45T Scale, 45-kgf Load, 1/16-in. (1.588-mm) Ball
100	3.79	256	61.5	91.5	80.4	70.2
99	3.85	248	60.9	91.2	79.7	69.2
98	3.91	240	60.3	90.8	79.0	68.2
97	3.96	233	59.7	90.4	78.3	67.2
96	4.02	226	59.1	90.1	77.7	66.1
95	4.08	219	58.5	89.7	77.0	65.1
94	4.14	213	58.0	89.3	76.3	64.1
93	4.20	207	57.4	88.9	75.6	63.1
92	4.24	202	56.8	88.6	74.9	62.1
91	4.30	197	56.2	88.2	74.2	61.1
90	4.35	192	55.6	87.8	73.5	60.1
89	4.40	187	55.0	87.5	72.8	59.0
88	4.45	183	54.5	87.1	72.1	58.0
87	4.51	178	53.9	86.7	71.4	57.0
86	4.55	174	53.3	86.4	70.7	56.0
85	4.60	170	52.7	86.0	70.0	55.0
84	4.65	167	52.1	85.6	69.3	54.0
83	4.70	163	51.5	85.2	68.6	52.9
82	4.74	160	50.9	84.9	67.9	51.9
81	4.79	156	50.4	84.5	67.2	50.9
80	4.84	153	49.8	84.1	66.5	49.9

3000 kgf against the test specimen. Steel ball indentors are no longer permitted for use in Brinell hardness testing in accordance with these test methods.

17.3 *Test Specimen*—Brinell hardness tests are made on prepared areas and sufficient metal must be removed from the surface to eliminate decarburized metal and other surface irregularities. The thickness of the piece tested must be such that no bulge or other marking showing the effect of the load appears on the side of the piece opposite the indentation.

#### 17.4 Procedure:

17.4.1 It is essential that the applicable product specifications state clearly the position at which Brinell hardness indentations are to be made and the number of such indentations required. The distance of the center of the indentation from the edge of the specimen or edge of another indentation must be at least two and one-half times the diameter of the indentation.

17.4.2 Apply the load for 10 to 15 s.

17.4.3 Measure diameters of the indentation in accordance with Test Method E10.

17.4.4 The Brinell hardness test is not recommended for materials above 650 HBW.

17.4.4.1 If a ball is used in a test of a specimen which shows a Brinell hardness number greater than the limit for the ball as detailed in 17.4.4, the ball shall be either discarded and replaced with a new ball or remeasured to ensure conformance with the requirements of Test Method E10.

#### 17.5 Brinell Hardness Values:

17.5.1 Brinell hardness values shall not be designated by a number alone because it is necessary to indicate which indenter and which force has been employed in making the test. Brinell hardness numbers shall be followed by the symbol HBW, and be supplemented by an index indicating the test conditions in the following order:

17.5.1.1 Diameter of the ball, mm,

17.5.1.2 A value representing the applied load, kgf, and,

17.5.1.3 The applied force dwell time, s, if other than 10 to 15 s.

17.5.1.4 The only exception to the above requirement is for the HBW 10/3000 scale when a 10 to 15 s dwell time is used. Only in the case of this one Brinell hardness scale may the designation be reported simply as HBW.

17.5.1.5 *Examples:* 220 HBW = Brinell hardness of 220 determined with a ball of 10 mm diameter and with a test force of 3000 kgf applied for 10 to 15 s; 350 HBW 5/1500 = Brinell hardness of 350 determined with a ball of 5 mm diameter and with a test force of 1500 kgf applied for 10 to 15 s.

17.6 *Detailed Procedure*—For detailed requirements of this test, reference shall be made to the latest revision of Test Method E10.

## 18. Rockwell Test

### 18.1 Description:

18.1.1 In this test a hardness value is obtained by determining the depth of penetration of a diamond point or a tungsten carbide ball into the specimen under certain arbitrarily fixed conditions. A minor load of 10 kgf is first applied which causes an initial penetration, sets the penetrator on the material and holds it in position. A major load which depends on the scale being used is applied increasing the depth of indentation. The major load is removed and, with the minor load still acting, the Rockwell number, which is proportional to the difference in penetration between the major and minor loads is determined; this is usually done by the machine and shows on a dial, digital display, printer, or other device. This is an arbitrary number which increases with increasing hardness. The scales most frequently used are as follows:

**TABLE 6 Brinell Hardness Numbers<sup>A</sup>**  
 (Ball 10 mm in Diameter, Applied Loads of 500, 1500, and 3000 kgf)

Diameter of Indentation, mm	Brinell Hardness Number			Diameter of Indentation, mm	Brinell Hardness Number			Diameter of Indentation, mm	Brinell Hardness Number			Diameter of Indentation, mm	Brinell Hardness Number		
	500-kgf Load	1500-kgf Load	3000-kgf Load		500-kgf Load	1500-kgf Load	3000-kgf Load		500-kgf Load	1500-kgf Load	3000-kgf Load		500-kgf Load	1500-kgf Load	3000-kgf Load
2.00	158	473	945	3.25	58.6	176	352	4.50	29.8	89.3	179	5.75	17.5	52.5	105
2.01	156	468	936	3.26	58.3	175	350	4.51	29.6	88.8	178	5.76	17.4	52.3	105
2.02	154	463	926	3.27	57.9	174	347	4.52	29.5	88.4	177	5.77	17.4	52.1	104
2.03	153	459	917	3.28	57.5	173	345	4.53	29.3	88.0	176	5.78	17.3	51.9	104
2.04	151	454	908	3.29	57.2	172	343	4.54	29.2	87.6	175	5.79	17.2	51.7	103
2.05	150	450	899	3.30	56.8	170	341	4.55	29.1	87.2	174	5.80	17.2	51.5	103
2.06	148	445	890	3.31	56.5	169	339	4.56	28.9	86.8	174	5.81	17.1	51.3	103
2.07	147	441	882	3.32	56.1	168	337	4.57	28.8	86.4	173	5.82	17.0	51.1	102
2.08	146	437	873	3.33	55.8	167	335	4.58	28.7	86.0	172	5.83	17.0	50.9	102
2.09	144	432	865	3.34	55.4	166	333	4.59	28.5	85.6	171	5.84	16.9	50.7	101
2.10	143	428	856	3.35	55.1	165	331	4.60	28.4	85.4	170	5.85	16.8	50.5	101
2.11	141	424	848	3.36	54.8	164	329	4.61	28.3	84.8	170	5.86	16.8	50.3	101
2.12	140	420	840	3.37	54.4	163	326	4.62	28.1	84.4	169	5.87	16.7	50.2	100
2.13	139	416	832	3.38	54.1	162	325	4.63	28.0	84.0	168	5.88	16.7	50.0	99.9
2.14	137	412	824	3.39	53.8	161	323	4.64	27.9	83.6	167	5.89	16.6	49.8	99.5
2.15	136	408	817	3.40	53.4	160	321	4.65	27.8	83.3	167	5.90	16.5	49.6	99.2
2.16	135	404	809	3.41	53.1	159	319	4.66	27.6	82.9	166	5.91	16.5	49.4	98.8
2.17	134	401	802	3.42	52.8	158	317	4.67	27.5	82.5	165	5.92	16.4	49.2	98.4
2.18	132	397	794	3.43	52.5	157	315	4.68	27.4	82.1	164	5.93	16.3	49.0	98.0
2.19	131	393	787	3.44	52.2	156	313	4.69	27.3	81.8	164	5.94	16.3	48.8	97.7
2.20	130	390	780	3.45	51.8	156	311	4.70	27.1	81.4	163	5.95	16.2	48.7	97.3
2.21	129	386	772	3.46	51.5	155	309	4.71	27.0	81.0	162	5.96	16.2	48.5	96.9
2.22	128	383	765	3.47	51.2	154	307	4.72	26.9	80.7	161	5.97	16.1	48.3	96.6
2.23	126	379	758	3.48	50.9	153	306	4.73	26.8	80.3	161	5.98	16.0	48.1	96.2
2.24	125	376	752	3.49	50.6	152	304	4.74	26.6	79.9	160	5.99	16.0	47.9	95.9
2.25	124	372	745	3.50	50.3	151	302	4.75	26.5	79.6	159	6.00	15.9	47.7	95.5
2.26	123	369	738	3.51	50.0	150	300	4.76	26.4	79.2	158	6.01	15.9	47.6	95.1
2.27	122	366	732	3.52	49.7	149	298	4.77	26.3	78.9	158	6.02	15.8	47.4	94.8
2.28	121	363	725	3.53	49.4	148	297	4.78	26.2	78.5	157	6.03	15.7	47.2	94.4
2.29	120	359	719	3.54	49.2	147	295	4.79	26.1	78.2	156	6.04	15.7	47.0	94.1
2.30	119	356	712	3.55	48.9	147	293	4.80	25.9	77.8	156	6.05	15.6	46.8	93.7
2.31	118	353	706	3.56	48.6	146	292	4.81	25.8	77.5	155	6.06	15.6	46.7	93.4
2.32	117	350	700	3.57	48.3	145	290	4.82	25.7	77.1	154	6.07	15.5	46.5	93.0
2.33	116	347	694	3.58	48.0	144	288	4.83	25.6	76.8	154	6.08	15.4	46.3	92.7
2.34	115	344	688	3.59	47.7	143	286	4.84	25.5	76.4	153	6.09	15.4	46.2	92.3
2.35	114	341	682	3.60	47.5	142	285	4.85	25.4	76.1	152	6.10	15.3	46.0	92.0
2.36	113	338	676	3.61	47.2	142	283	4.86	25.3	75.8	152	6.11	15.3	45.8	91.7
2.37	112	335	670	3.62	46.9	141	282	4.87	25.1	75.4	151	6.12	15.2	45.7	91.3
2.38	111	332	665	3.63	46.7	140	280	4.88	25.0	75.1	150	6.13	15.2	45.5	91.0
2.39	110	330	659	3.64	46.4	139	278	4.89	24.9	74.8	150	6.14	15.1	45.3	90.6
2.40	109	327	653	3.65	46.1	138	277	4.90	24.8	74.4	149	6.15	15.1	45.2	90.3
2.41	108	324	648	3.66	45.9	138	275	4.91	24.7	74.1	148	6.16	15.0	45.0	90.0
2.42	107	322	643	3.67	45.6	137	274	4.92	24.6	73.8	148	6.17	14.9	44.8	89.6
2.43	106	319	637	3.68	45.4	136	272	4.93	24.5	73.5	147	6.18	14.9	44.7	89.3
2.44	105	316	632	3.69	45.1	135	271	4.94	24.4	73.2	146	6.19	14.8	44.5	89.0
2.45	104	313	627	3.70	44.9	135	269	4.95	24.3	72.8	146	6.20	14.7	44.3	88.7
2.46	104	311	621	3.71	44.6	134	268	4.96	24.2	72.5	145	6.21	14.7	44.2	88.3
2.47	103	308	616	3.72	44.4	133	266	4.97	24.1	72.2	144	6.22	14.7	44.0	88.0
2.48	102	306	611	3.73	44.1	132	265	4.98	24.0	71.9	144	6.23	14.6	43.8	87.7
2.49	101	303	606	3.74	43.9	132	263	4.99	23.9	71.6	143	6.24	14.6	43.7	87.4
2.50	100	301	601	3.75	43.6	131	262	5.00	23.8	71.3	143	6.25	14.5	43.5	87.1
2.51	99.4	298	597	3.76	43.4	130	260	5.01	23.7	71.0	142	6.26	14.5	43.4	86.7
2.52	98.6	296	592	3.77	43.1	129	259	5.02	23.6	70.7	141	6.27	14.4	43.2	86.4
2.53	97.8	294	587	3.78	42.9	129	257	5.03	23.5	70.4	141	6.28	14.4	43.1	86.1
2.54	97.1	291	582	3.79	42.7	128	256	5.04	23.4	70.1	140	6.29	14.3	42.9	85.8
2.55	96.3	289	578	3.80	42.4	127	255	5.05	23.3	69.8	140	6.30	14.2	42.7	85.5
2.56	95.5	287	573	3.81	42.2	127	253	5.06	23.2	69.5	139	6.31	14.2	42.6	85.2
2.57	94.8	284	569	3.82	42.0	126	252	5.07	23.1	69.2	138	6.32	14.1	42.4	84.9
2.58	94.0	282	564	3.83	41.7	125	250	5.08	23.0	68.9	138	6.33	14.1	42.3	84.6
2.59	93.3	280	560	3.84	41.5	125	249	5.09	22.9	68.6	137	6.34	14.0	42.1	84.3
2.60	92.6	278	555	3.85	41.3	124	248	5.10	22.8	68.3	137	6.35	14.0	42.0	84.0
2.61	91.8	276	551	3.86	41.1	123	246	5.11	22.7	68.0	136	6.36	13.9	41.8	83.7
2.62	91.1	273	547	3.87	40.9	123	245	5.12	22.6	67.7	135	6.37	13.9	41.7	83.4
2.63	90.4	271	543	3.88	40.6	122	244	5.13	22.5	67.4	135	6.38	13.8	41.5	83.1
2.64	89.7	269	538	3.89	40.4	121	242	5.14	22.4	67.1	134	6.39	13.8	41.4	82.8
2.65	89.0	267	534	3.90	40.2	121	241	5.15	22.3	66.9	134	6.40	13.7	41.2	82.5
2.66	88.4	265	530	3.91	40.0	120	240	5.16	22.2	66.6	133	6.41	13.7	41.1	82.2
2.67	87.7	263	526	3.92	39.8	119	239	5.17	22.1	66.3	133	6.42	13.6	40.9	81.9
2.68	87.0	261	522	3.93	39.6	119	237	5.18	22.0	66.0	132	6.43	13.6	40.8	81.6
2.69	86.4	259	518	3.94	39.4	118	236	5.19	21.9	65.8	132	6.44	13.5	40.6	81.3

**TABLE 6** *Continued*

Diameter of Indentation, mm	Brinell Hardness Number			Diameter of Indentation, mm	Brinell Hardness Number			Diameter of Indentation, mm	Brinell Hardness Number			Diameter of Indentation, mm	Brinell Hardness Number		
	500-kgf Load	1500-kgf Load	3000-kgf Load		500-kgf Load	1500-kgf Load	3000-kgf Load		500-kgf Load	1500-kgf Load	3000-kgf Load		500-kgf Load	1500-kgf Load	3000-kgf Load
2.70	85.7	257	514	3.95	39.1	117	235	5.20	21.8	65.5	131	6.45	13.5	40.5	81.0
2.71	85.1	255	510	3.96	38.9	117	234	5.21	21.7	65.2	130	6.46	13.4	40.4	80.7
2.72	84.4	253	507	3.97	38.7	116	232	5.22	21.6	64.9	130	6.47	13.4	40.2	80.4
2.73	83.8	251	503	3.98	38.5	116	231	5.23	21.6	64.7	129	6.48	13.4	40.1	80.1
2.74	83.2	250	499	3.99	38.3	115	230	5.24	21.5	64.4	129	6.49	13.3	39.9	79.8
2.75	82.6	248	495	4.00	38.1	114	229	5.25	21.4	64.1	128	6.50	13.3	39.8	79.6
2.76	81.9	246	492	4.01	37.9	114	228	5.26	21.3	63.9	128	6.51	13.2	39.6	79.3
2.77	81.3	244	488	4.02	37.7	113	226	5.27	21.2	63.6	127	6.52	13.2	39.5	79.0
2.78	80.8	242	485	4.03	37.5	113	225	5.28	21.1	63.3	127	6.53	13.1	39.4	78.7
2.79	80.2	240	481	4.04	37.3	112	224	5.29	21.0	63.1	126	6.54	13.1	39.2	78.4
2.80	79.6	239	477	4.05	37.1	111	223	5.30	20.9	62.8	126	6.55	13.0	39.1	78.2
2.81	79.0	237	474	4.06	37.0	111	222	5.31	20.9	62.6	125	6.56	13.0	38.9	78.0
2.82	78.4	235	471	4.07	36.8	110	221	5.32	20.8	62.3	125	6.57	12.9	38.8	77.6
2.83	77.9	234	467	4.08	36.6	110	219	5.33	20.7	62.1	124	6.58	12.9	38.7	77.3
2.84	77.3	232	464	4.09	36.4	109	218	5.34	20.6	61.8	124	6.59	12.8	38.5	77.1
2.85	76.8	230	461	4.10	36.2	109	217	5.35	20.5	61.5	123	6.60	12.8	38.4	76.8
2.86	76.2	229	457	4.11	36.0	108	216	5.36	20.4	61.3	123	6.61	12.8	38.3	76.5
2.87	75.7	227	454	4.12	35.8	108	215	5.37	20.3	61.0	122	6.62	12.7	38.1	76.2
2.88	75.1	225	451	4.13	35.7	107	214	5.38	20.3	60.8	122	6.63	12.7	38.0	76.0
2.89	74.6	224	448	4.14	35.5	106	213	5.39	20.2	60.6	121	6.64	12.6	37.9	75.7
2.90	74.1	222	444	4.15	35.3	106	212	5.40	20.1	60.3	121	6.65	12.6	37.7	75.4
2.91	73.6	221	441	4.16	35.1	105	211	5.41	20.0	60.1	120	6.66	12.5	37.6	75.2
2.92	73.0	219	438	4.17	34.9	105	210	5.42	19.9	59.8	120	6.67	12.5	37.5	74.9
2.93	72.5	218	435	4.18	34.8	104	209	5.43	19.9	59.6	119	6.68	12.4	37.3	74.7
2.94	72.0	216	432	4.19	34.6	104	208	5.44	19.8	59.3	119	6.69	12.4	37.2	74.4
2.95	71.5	215	429	4.20	34.4	103	207	5.45	19.7	59.1	118	6.70	12.4	37.1	74.1
2.96	71.0	213	426	4.21	34.2	103	205	5.46	19.6	58.9	118	6.71	12.3	36.9	73.9
2.97	70.5	212	423	4.22	34.1	102	204	5.47	19.5	58.6	117	6.72	12.3	36.8	73.6
2.98	70.1	210	420	4.23	33.9	102	203	5.48	19.5	58.4	117	6.73	12.2	36.7	73.4
2.99	69.6	209	417	4.24	33.7	101	202	5.49	19.4	58.2	116	6.74	12.2	36.6	73.1
3.00	69.1	207	415	4.25	33.6	101	201	5.50	19.3	57.9	116	6.75	12.1	36.4	72.8
3.01	68.6	206	412	4.26	33.4	100	200	5.51	19.2	57.7	115	6.76	12.1	36.3	72.6
3.02	68.2	205	409	4.27	33.2	99.7	199	5.52	19.2	57.5	115	6.77	12.1	36.2	72.3
3.03	67.7	203	406	4.28	33.1	99.2	198	5.53	19.1	57.2	114	6.78	12.0	36.0	72.1
3.04	67.3	202	404	4.29	32.9	98.8	198	5.54	19.0	57.0	114	6.79	12.0	35.9	71.8
3.05	66.8	200	401	4.30	32.8	98.3	197	5.55	18.9	56.8	114	6.80	11.9	35.8	71.6
3.06	66.4	199	398	4.31	32.6	97.8	196	5.56	18.9	56.6	113	6.81	11.9	35.7	71.3
3.07	65.9	198	395	4.32	32.4	97.3	195	5.57	18.8	56.3	113	6.82	11.8	35.5	71.1
3.08	65.5	196	393	4.33	32.3	96.8	194	5.58	18.7	56.1	112	6.83	11.8	35.4	70.8
3.09	65.0	195	390	4.34	32.1	96.4	193	5.59	18.6	55.9	112	6.84	11.8	35.3	70.6
3.10	64.6	194	388	4.35	32.0	95.9	192	5.60	18.6	55.7	111	6.85	11.7	35.2	70.4
3.11	64.2	193	385	4.36	31.8	95.5	191	5.61	18.5	55.5	111	6.86	11.7	35.1	70.1
3.12	63.8	191	383	4.37	31.7	95.0	190	5.62	18.4	55.2	110	6.87	11.6	34.9	69.9
3.13	63.3	190	380	4.38	31.5	94.5	189	5.63	18.3	55.0	110	6.88	11.6	34.8	69.6
3.14	62.9	189	378	4.39	31.4	94.1	188	5.64	18.3	54.8	110	6.89	11.6	34.7	69.4
3.15	62.5	188	375	4.40	31.2	93.6	187	5.65	18.2	54.6	109	6.90	11.5	34.6	69.2
3.16	62.1	186	373	4.41	31.1	93.2	186	5.66	18.1	54.4	109	6.91	11.5	34.5	68.9
3.17	61.7	185	370	4.42	30.9	92.7	185	5.67	18.1	54.2	108	6.92	11.4	34.3	68.7
3.18	61.3	184	368	4.43	30.8	92.3	185	5.68	18.0	54.0	108	6.93	11.4	34.2	68.4
3.19	60.9	183	366	4.44	30.6	91.8	184	5.69	17.9	53.7	107	6.94	11.4	34.1	68.2
3.20	60.5	182	363	4.45	30.5	91.4	183	5.70	17.8	53.5	107	6.95	11.3	34.0	68.0
3.21	60.1	180	361	4.46	30.3	91.0	182	5.71	17.8	53.3	107	6.96	11.3	33.9	67.7
3.22	59.8	179	359	4.47	30.2	90.5	181	5.72	17.7	53.1	106	6.97	11.3	33.8	67.5
3.23	59.4	178	356	4.48	30.0	90.1	180	5.73	17.6	52.9	106	6.98	11.2	33.6	67.3
3.24	59.0	177	354	4.49	29.9	89.7	179	5.74	17.6	52.7	105	6.99	11.2	33.5	67.0

<sup>A</sup> Prepared by the Engineering Mechanics Section, Institute for Standards Technology.

Scale Symbol	Penetrator	Major Load, kgf	Minor Load, kgf
B	1/16-in. tungsten carbide ball	100	10
C	Diamond brale	150	10

18.1.2 Rockwell superficial hardness machines are used for the testing of very thin steel or thin surface layers. Loads of 15, 30, or 45 kgf are applied on a tungsten carbide (or a hardened steel) ball or diamond penetrator, to cover the same range of hardness values as for the heavier loads. Use of a hardened steel ball is permitted only for testing thin sheet tin mill products as found in Specifications **A623** and **A623M** using HR15T and HR30T scales with a diamond spot anvil. (Testing of this product using a tungsten carbide indenter may give significantly different results as compared to historical test data obtained using a hardened steel ball.) The superficial hardness scales are as follows:

Scale Symbol	Penetrator	Major Load, kgf	Minor Load, kgf
15T	1/16-in. tungsten carbide or steel ball	15	3
30T	1/16-in. tungsten carbide or steel ball	30	3
45T	1/16-in. tungsten carbide ball	45	3
15N	Diamond brale	15	3
30N	Diamond brale	30	3
45N	Diamond brale	45	3

18.2 *Reporting Hardness*—In recording hardness values, the hardness number shall always precede the scale symbol, for example: 96 HRBW, 40 HRC, 75 HR15N, 56 HR30TS, or 77 HR30TW. The suffix *W* indicates use of a tungsten carbide ball. The suffix *S* indicates use of a hardened steel ball as permitted in 18.1.2.

18.3 *Test Blocks*—Machines should be checked to make certain they are in good order by means of standardized Rockwell test blocks.

18.4 *Detailed Procedure*—For detailed requirements of this test, reference shall be made to the latest revision of Test Methods **E18**.

## 19. Portable Hardness Test

19.1 Although this standard generally prefers the use of fixed-location Brinell or Rockwell hardness test methods, it is not always possible to perform the hardness test using such equipment due to the part size, location, or other logistical reasons. In this event, hardness testing using portable equipment as described in Test Methods **A956/A956M**, **A1038**, and **E110** shall be used with strict compliance for reporting the test results in accordance with the selected standard (see examples below).

19.1.1 *Practice A833*—The measured hardness number shall be reported in accordance with the standard methods and given the HBC designation followed by the comparative test bar hardness to indicate that it was determined by a portable comparative hardness tester, as in the following example:

19.1.1.1 *232 HBC/240* where 232 is the hardness test result using the portable comparative test method (HBC) and 240 is the Brinell hardness of the comparative test bar.

19.1.2 *Test Method A956/A956M*:

19.1.2.1 The measured hardness number shall be reported in accordance with the standard methods and appended with a

Leeb impact device in parenthesis to indicate that it was determined by a portable hardness tester, as in the following example:

(1) *350 HLD* where 350 is the hardness test result using the portable Leeb hardness test method with the HLD impact device.

19.1.2.2 When hardness values converted from the Leeb number are reported, the portable instrument used shall be reported in parentheses, for example:

(1) *350 HB (HLD)* where the original hardness test was performed using the portable Leeb hardness test method with the HLD impact device and converted to the Brinell hardness value (HB)

19.1.3 *Test Method A1038*—The measured hardness number shall be reported in accordance with the standard methods and appended with UCI in parenthesis to indicate that it was determined by a portable hardness tester, as in the following example:

19.1.3.1 *446 HV (UCI) 10* where 446 is the hardness test result using the portable UCI test method under a force of 10 kgf.

19.1.4 *Test Method E110*—The measured hardness number shall be reported in accordance with the standard methods and appended with a */P* to indicate that it was determined by a portable hardness tester, as follows:

19.1.4.1 *Rockwell Hardness Examples*:

(1) *40 HRC/P* where 40 is the hardness test result using the Rockwell C portable test method.

(2) *72 HRBW/P* where 72 is the hardness test result using the Rockwell B portable test method using a tungsten carbide ball indenter.

19.1.4.2 *Brinell Hardness Examples*:

(1) *220 HBW/P 10/3000* where 220 is the hardness test result using the Brinell portable test method with a ball of 10 mm diameter and with a test force of 3000 kgf (29.42 kN) applied for 10 s to 15 s.

(2) *350 HBW/P 5/750* where 350 is the hardness test result using the Brinell portable test method with a ball of 5 mm diameter and with a test force of 750 kgf (7.355 kN) applied for 10 s to 15 s.

## CHARPY IMPACT TESTING

### 20. Summary

20.1 A Charpy V-notch impact test is a dynamic test in which a notched specimen is struck and broken by a single blow in a specially designed testing machine. The measured test values may be the energy absorbed, the percentage shear fracture, the lateral expansion opposite the notch, or a combination thereof.

20.2 Testing temperatures other than room (ambient) temperature often are specified in product or general requirement specifications (hereinafter referred to as the specification). Although the testing temperature is sometimes related to the expected service temperature, the two temperatures need not be identical.

## 21. Significance and Use

21.1 *Ductile vs. Brittle Behavior*—Body-centered-cubic or ferritic alloys exhibit a significant transition in behavior when impact tested over a range of temperatures. At temperatures above transition, impact specimens fracture by a ductile (usually microvoid coalescence) mechanism, absorbing relatively large amounts of energy. At lower temperatures, they fracture in a brittle (usually cleavage) manner absorbing appreciably less energy. Within the transition range, the fracture will generally be a mixture of areas of ductile fracture and brittle fracture.

21.2 The temperature range of the transition from one type of behavior to the other varies according to the material being tested. This transition behavior may be defined in various ways for specification purposes.

21.2.1 The specification may require a minimum test result for absorbed energy, fracture appearance, lateral expansion, or a combination thereof, at a specified test temperature.

21.2.2 The specification may require the determination of the transition temperature at which either the absorbed energy or fracture appearance attains a specified level when testing is performed over a range of temperatures. Alternatively the specification may require the determination of the fracture appearance transition temperature (FATT<sub>n</sub>) as the temperature at which the required minimum percentage of shear fracture (n) is obtained.

21.3 Further information on the significance of impact testing appears in [Annex A5](#).

## 22. Apparatus

### 22.1 Testing Machines:

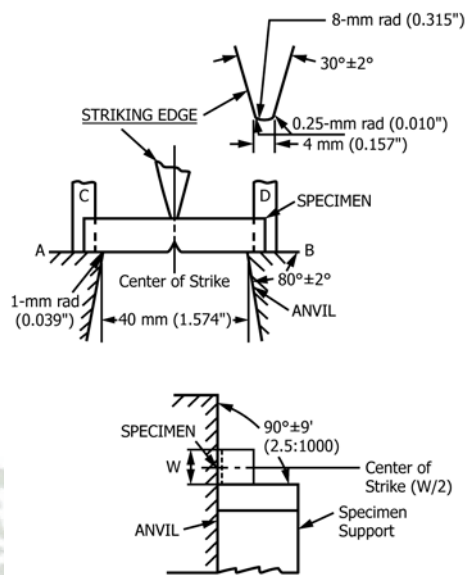
22.1.1 A Charpy impact machine is one in which a notched specimen is broken by a single blow of a freely swinging pendulum. The pendulum is released from a fixed height. Since the height to which the pendulum is raised prior to its swing, and the mass of the pendulum are known, the energy of the blow is predetermined. A means is provided to indicate the energy absorbed in breaking the specimen.

22.1.2 The other principal feature of the machine is a fixture (see [Fig. 10](#)) designed to support a test specimen as a simple beam at a precise location. The fixture is arranged so that the notched face of the specimen is vertical. The pendulum strikes the other vertical face directly opposite the notch. The dimensions of the specimen supports and striking edge shall conform to [Fig. 10](#).

22.1.3 Charpy machines used for testing steel generally have capacities in the 220 to 300 ft-lbf (300 to 400 J) energy range. Sometimes machines of lesser capacity are used; however, the capacity of the machine should be substantially in excess of the absorbed energy of the specimens (see [Test Methods E23](#)). The linear velocity at the point of impact should be in the range of 16 to 19 ft/s (4.9 to 5.8 m/s).

NOTE 15—An investigation of striker radius effect is available.<sup>6</sup>

### 22.2 Temperature Media:



All dimensional tolerances shall be ±0.05 mm (0.002 in.) unless otherwise specified.

NOTE 1—A shall be parallel to B within 2:1000 and coplanar with B within 0.05 mm (0.002 in.).

NOTE 2—C shall be parallel to D within 20:1000 and coplanar with D within 0.125 mm (0.005 in.).

NOTE 3—Finish on unmarked parts shall be 4 μm (125 μin.).

NOTE 4—Tolerance for the striker corner radius shall be -0.05 mm (0.002 in.)/+0.50 mm (0.020 in.).

FIG. 10 Charpy (Simple-Beam) Impact Test

22.2.1 For testing at other than room temperature, it is necessary to condition the Charpy specimens in media at controlled temperatures.

22.2.2 Low temperature media usually are chilled fluids (such as water, ice plus water, dry ice plus organic solvents, or liquid nitrogen) or chilled gases.

22.2.3 Elevated temperature media are usually heated liquids such as mineral or silicone oils. Circulating air ovens may be used.

22.3 *Handling Equipment*—Tongs, especially adapted to fit the notch in the impact specimen, normally are used for removing the specimens from the medium and placing them on the anvil (refer to [Test Methods E23](#)). In cases where the machine fixture does not provide for automatic centering of the test specimen, the tongs may be precision machined to provide centering.

## 23. Sampling and Number of Specimens

### 23.1 Sampling:

23.1.1 Test location and orientation should be addressed by the specifications. If not, for wrought products, the test location shall be the same as that for the tensile specimen and the orientation shall be longitudinal with the notch perpendicular to the major surface of the product being tested.

#### 23.1.2 Number of Specimens.

23.1.2.1 All specimens used for a Charpy impact test shall be taken from a single test coupon or test location.

23.1.2.2 When the specification calls for a minimum average test result, three specimens shall be tested.

<sup>6</sup> Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:A01-1001.

23.1.2.3 When the specification requires determination of a transition temperature, eight to twelve specimens are usually needed.

23.2 Type and Size:

23.2.1 Use a standard full size Charpy V-notch specimen as shown in Fig. 11, except as allowed in 23.2.2.

23.2.2 Subsize Specimens.

23.2.2.1 For flat material less than 7/16 in. (11 mm) thick, or when the absorbed energy is expected to exceed 80 % of full scale, use standard subsize test specimens.

23.2.2.2 For tubular materials tested in the transverse direction, where the relationship between diameter and wall thickness does not permit a standard full size specimen, use standard subsize test specimens or standard size specimens containing outer diameter (OD) curvature as follows:

(1) Standard size specimens and subsize specimens may contain the original OD surface of the tubular product as shown in Fig. 12. All other dimensions shall comply with the requirements of Fig. 11.

NOTE 16—For materials with toughness levels in excess of about 50 ft-lbs, specimens containing the original OD surface may yield values in excess of those resulting from the use of conventional Charpy specimens.

23.2.2.3 If a standard full-size specimen cannot be prepared, the largest feasible standard subsize specimen shall be prepared. The specimens shall be machined so that the specimen does not include material nearer to the surface than 0.020 in. (0.5 mm).

23.2.2.4 Tolerances for standard subsize specimens are shown in Fig. 11. Standard subsize test specimen sizes are: 10 × 7.5 mm, 10 × 6.7 mm, 10 × 5 mm, 10 × 3.3 mm, and 10 × 2.5 mm.

23.2.2.5 Notch the narrow face of the standard subsize specimens so that the notch is perpendicular to the 10 mm wide face.

23.3 Notch Preparation—The machining (for example, milling, broaching, or grinding) of the notch is critical, as minor deviations in both notch radius and profile, or tool marks at the bottom of the notch may result in variations in test data, particularly in materials with low-impact energy absorption. (see Annex A5).

24. Calibration

24.1 Accuracy and Sensitivity—Calibrate and adjust Charpy impact machines in accordance with the requirements of Test Methods E23.

25. Conditioning—Temperature Control

25.1 When a specific test temperature is required by the specification or purchaser, control the temperature of the heating or cooling medium within ±2°F (1°C).

NOTE 17—For some steels there may not be a need for this restricted temperature, for example, austenitic steels.

NOTE 18—Because the temperature of a testing laboratory often varies from 60 to 90°F (15 to 32°C) a test conducted at “room temperature” might be conducted at any temperature in this range.

26. Procedure

26.1 Temperature:

26.1.1 Condition the specimens to be broken by holding them in the medium at test temperature for at least 5 min in liquid media and 30 min in gaseous media.

26.1.2 Prior to each test, maintain the tongs for handling test specimens at the same temperature as the specimen so as not to affect the temperature at the notch.

26.2 Positioning and Breaking Specimens:

26.2.1 Carefully center the test specimen in the anvil and release the pendulum to break the specimen.

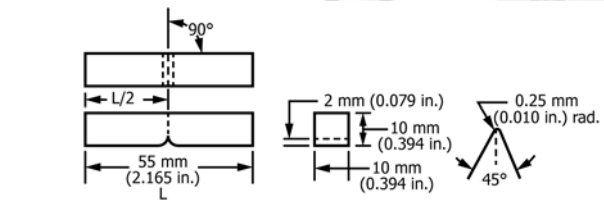
26.2.2 If the pendulum is not released within 5 s after removing the specimen from the conditioning medium, do not break the specimen. Return the specimen to the conditioning medium for the period required in 26.1.1.

26.3 Recovering Specimens—In the event that fracture appearance or lateral expansion must be determined, recover the matched pieces of each broken specimen before breaking the next specimen.

26.4 Individual Test Values:

26.4.1 Impact energy—Record the impact energy absorbed to the nearest ft·lbf (J).

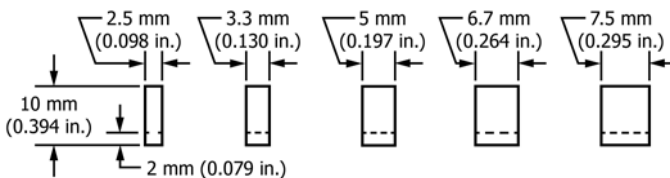
26.4.2 Fracture Appearance:



NOTE 1—Permissible variations shall be as follows:

Notch length to edge	90 ± 2°
Adjacent sides shall be at	90° ± 10 min
Cross-section dimensions	±0.075 mm (±0.003 in.)
Length of specimen (L)	+ 0, - 2.5 mm (+ 0, - 0.100 in.)
Centering of notch (L/2)	±1 mm (±0.039 in.)
Angle of notch	±1°
Radius of notch	±0.025 mm (±0.001 in.)
Notch depth	±0.025 mm (±0.001 in.)
Finish requirements	2 μm (63 μin.) on notched surface and opposite face; 4 μm (125 μin.) on other two surfaces

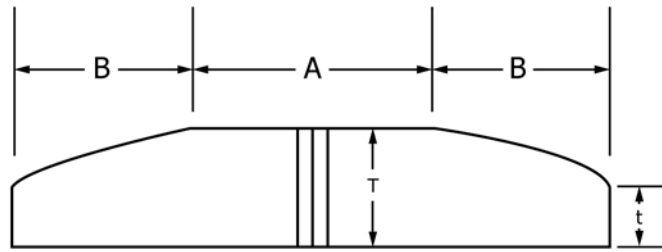
(a) Standard Full Size Specimen



(b) Standard Subsize Specimens

NOTE 2—On subsize specimens, all dimensions and tolerances of the standard specimen remain constant with the exception of the width, which varies as shown above and for which the tolerance shall be ±1 %.

FIG. 11 Charpy (Simple Beam) Impact Test Specimens



Dimension	Description	Requirement
A	Machined Surface	28 mm Minimum
B	Original OD Surface	13.5 mm Maximum
T	Specimen Thickness	Figure 11
t	End Thickness	1/2 T Minimum

FIG. 12 Tubular Impact Specimen Containing Original OD Surface

26.4.2.1 Determine the percentage of shear fracture area by any of the following methods:

(1) Measure the length and width of the brittle portion of the fracture surface, as shown in Fig. 13 and determine the percent shear area from either Table 7 or Table 8 depending on the units of measurement.

(2) Compare the appearance of the fracture of the specimen with a fracture appearance chart as shown in Fig. 14.

(3) Magnify the fracture surface and compare it to a precalibrated overlay chart or measure the percent shear fracture area by means of a planimeter.

(4) Photograph the fractured surface at a suitable magnification and measure the percent shear fracture area by means of a planimeter.

26.4.2.2 Determine the individual fracture appearance values to the nearest 5 % shear fracture and record the value.

26.4.3 Lateral Expansion:

26.4.3.1 Lateral expansion is the increase in specimen width, measured in thousandths of an inch (mils), on the compression side, opposite the notch of the fractured Charpy V-notch specimen as shown in Fig. 15.

26.4.3.2 Examine each specimen half to ascertain that the protrusions have not been damaged by contacting the anvil, machine mounting surface, and so forth. Discard such samples since they may cause erroneous readings.

26.4.3.3 Check the sides of the specimens perpendicular to the notch to ensure that no burrs were formed on the sides during impact testing. If burrs exist, remove them carefully by rubbing on emery cloth or similar abrasive surface, making

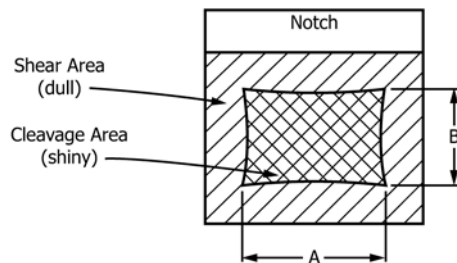
sure that the protrusions being measured are not rubbed during the removal of the burr.

26.4.3.4 Measure the amount of expansion on each side of each half relative to the plane defined by the undeformed portion of the side of the specimen using a gauge similar to that shown in Figs. 16 and 17.

26.4.3.5 Since the fracture path seldom bisects the point of maximum expansion on both sides of a specimen, the sum of the larger values measured for each side is the value of the test. Arrange the halves of one specimen so that compression sides are facing each other. Using the gauge, measure the protrusion on each half specimen, ensuring that the same side of the specimen is measured. Measure the two broken halves individually. Repeat the procedure to measure the protrusions on the opposite side of the specimen halves. The larger of the two values for each side is the expansion of that side of the specimen.

26.4.3.6 Measure the individual lateral expansion values to the nearest mil (0.025 mm) and record the values.

26.4.3.7 With the exception described as follows, any specimen that does not separate into two pieces when struck by a single blow shall be reported as unbroken. The lateral expansion of an unbroken specimen can be reported as broken if the specimen can be separated by pushing the hinged halves together once and then pulling them apart without further fatiguing the specimen, and the lateral expansion measured for the unbroken specimen (prior to bending) is equal to or greater than that measured for the separated halves. In the case where a specimen cannot be separated into two halves, the lateral



NOTE 1—Measure average dimensions A and B to the nearest 0.02 in. or 0.5 mm.

NOTE 2—Determine the percent shear fracture using Table 7 or Table 8.

FIG. 13 Determination of Percent Shear Fracture

**TABLE 7 Percent Shear for Measurements Made in Inches**

NOTE 1—Since this table is set up for finite measurements or dimensions *A* and *B*, 100% shear is to be reported when either *A* or *B* is zero.

Dimension <i>B</i> , in.	Dimension <i>A</i> , in.																
	0.05	0.10	0.12	0.14	0.16	0.18	0.20	0.22	0.24	0.26	0.28	0.30	0.32	0.34	0.36	0.38	0.40
0.05	98	96	95	94	94	93	92	91	90	90	89	88	87	86	85	85	84
0.10	96	92	90	89	87	85	84	82	81	79	77	76	74	73	71	69	68
0.12	95	90	88	86	85	83	81	79	77	75	73	71	69	67	65	63	61
0.14	94	89	86	84	82	80	77	75	73	71	68	66	64	62	59	57	55
0.16	94	87	85	82	79	77	74	72	69	67	64	61	59	56	53	51	48
0.18	93	85	83	80	77	74	72	68	65	62	59	56	54	51	48	45	42
0.20	92	84	81	77	74	72	68	65	61	58	55	52	48	45	42	39	36
0.22	91	82	79	75	72	68	65	61	57	54	50	47	43	40	36	33	29
0.24	90	81	77	73	69	65	61	57	54	50	46	42	38	34	30	27	23
0.26	90	79	75	71	67	62	58	54	50	46	41	37	33	29	25	20	16
0.28	89	77	73	68	64	59	55	50	46	41	37	32	28	23	18	14	10
0.30	88	76	71	66	61	56	52	47	42	37	32	27	23	18	13	9	3
0.31	88	75	70	65	60	55	50	45	40	35	30	25	20	18	10	5	0

**TABLE 8 Percent Shear for Measurements Made in Millimetres**

NOTE 1—Since this table is set up for finite measurements or dimensions *A* and *B*, 100% shear is to be reported when either *A* or *B* is zero.

Dimension <i>B</i> , mm	Dimension <i>A</i> , mm																		
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10
1.0	99	98	98	97	96	96	95	94	94	93	92	92	91	91	90	89	89	88	88
1.5	98	97	96	95	94	93	92	92	91	90	89	88	87	86	85	84	83	82	81
2.0	98	96	95	94	92	91	90	89	88	86	85	84	82	81	80	79	77	76	75
2.5	97	95	94	92	91	89	88	86	84	83	81	80	78	77	75	73	72	70	69
3.0	96	94	92	91	89	87	85	83	81	79	77	76	74	72	70	68	66	64	62
3.5	96	93	91	89	87	85	82	80	78	76	74	72	69	67	65	63	61	58	56
4.0	95	92	90	88	85	82	80	77	75	72	70	67	65	62	60	57	55	52	50
4.5	94	92	89	86	83	80	77	75	72	69	66	63	61	58	55	52	49	46	44
5.0	94	91	88	85	81	78	75	72	69	66	62	59	56	53	50	47	44	41	37
5.5	93	90	86	83	79	76	72	69	66	62	59	55	52	48	45	42	38	35	31
6.0	92	89	85	81	77	74	70	66	62	59	55	51	47	44	40	36	33	29	25
6.5	92	88	84	80	76	72	67	63	59	55	51	47	43	39	35	31	27	23	19
7.0	91	87	82	78	74	69	65	61	56	52	47	43	39	34	30	26	21	17	12
7.5	91	86	81	77	72	67	62	58	53	48	44	39	34	30	25	20	16	11	6
8.0	90	85	80	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0

expansion can be measured as long as the shear lips can be accessed without interference from the hinged ligament that has been deformed during testing.

## 27. Interpretation of Test Result

27.1 When the acceptance criterion of any impact test is specified to be a minimum average value at a given temperature, the test result shall be the average (arithmetic mean rounded to the nearest ft-lbf (J)) of the individual test values of three specimens from one test location.

27.1.1 When a minimum average test result is specified:

27.1.1.1 The test result is acceptable when all of the below are met:

(1) The test result equals or exceeds the specified minimum average (given in the specification),

(2) The individual test value for not more than one specimen measures less than the specified minimum average, and

(3) The individual test value for any specimen measures not less than two-thirds of the specified minimum average.

27.1.1.2 If the acceptance requirements of 27.1.1.1 are not met, perform one retest of three additional specimens from the same test location. Each individual test value of the retested

specimens shall be equal to or greater than the specified minimum average value.

### 27.2 Test Specifying a Minimum Transition Temperature:

27.2.1 *Definition of Transition Temperature*—For specification purposes, the transition temperature is the temperature at which the designated material test value equals or exceeds a specified minimum test value.

#### 27.2.2 *Determination of Transition Temperature:*

27.2.2.1 Break one specimen at each of a series of temperatures above and below the anticipated transition temperature using the procedures in Section 26. Record each test temperature to the nearest 1°F (0.5°C).

27.2.2.2 Plot the individual test results (ft-lbf or percent shear) as the ordinate versus the corresponding test temperature as the abscissa and construct a best-fit curve through the plotted data points.

27.2.2.3 If transition temperature is specified as the temperature at which a test value is achieved, determine the temperature at which the plotted curve intersects the specified test value by graphical interpolation (extrapolation is not permitted). Record this transition temperature to the nearest



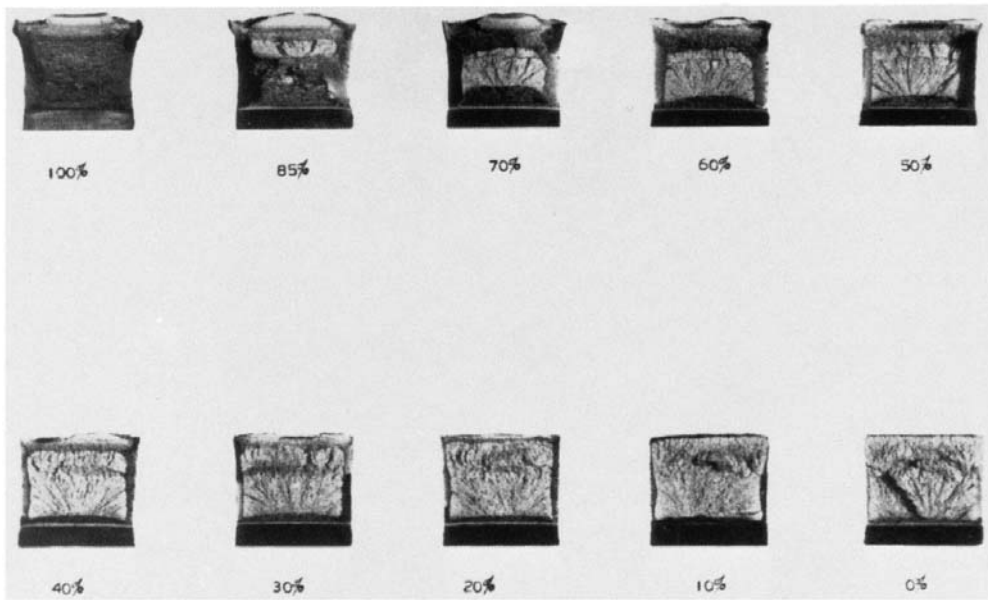


FIG. 14 Fracture Appearance Charts and Percent Shear Fracture Comparator

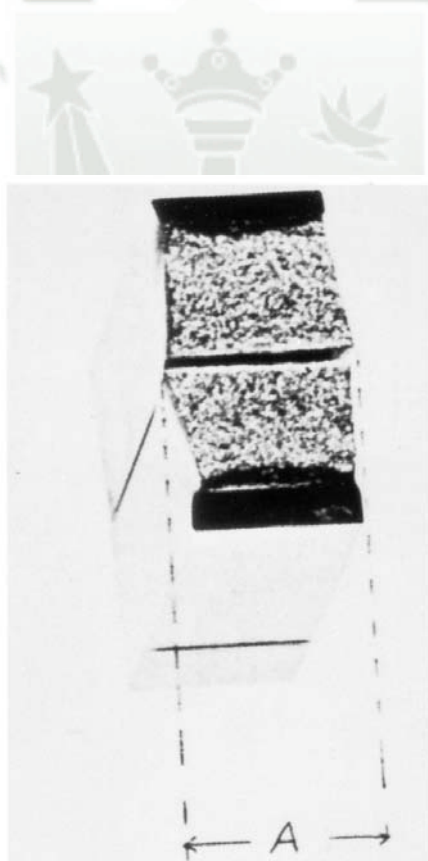


FIG. 15 Halves of Broken Charpy V-Notch Impact Specimen Joined for Measurement of Lateral Expansion, Dimension A

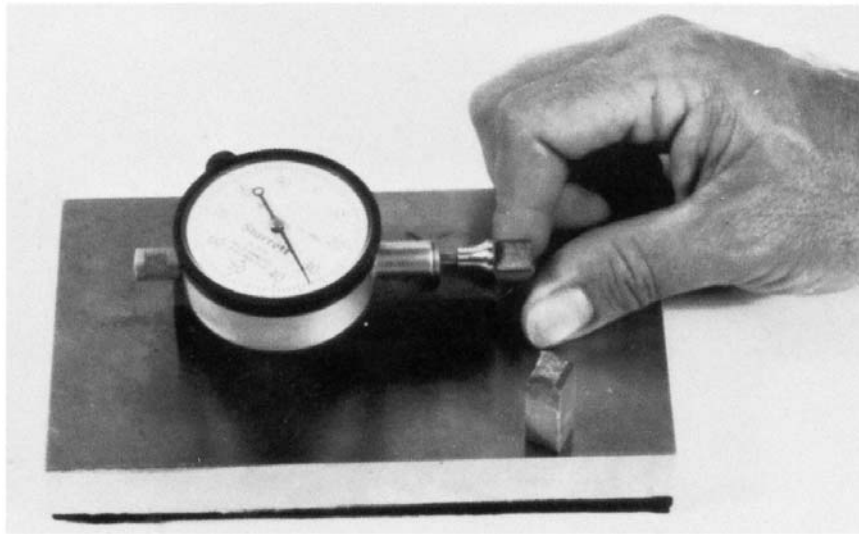


FIG. 16 Lateral Expansion Gauge for Charpy Impact Specimens

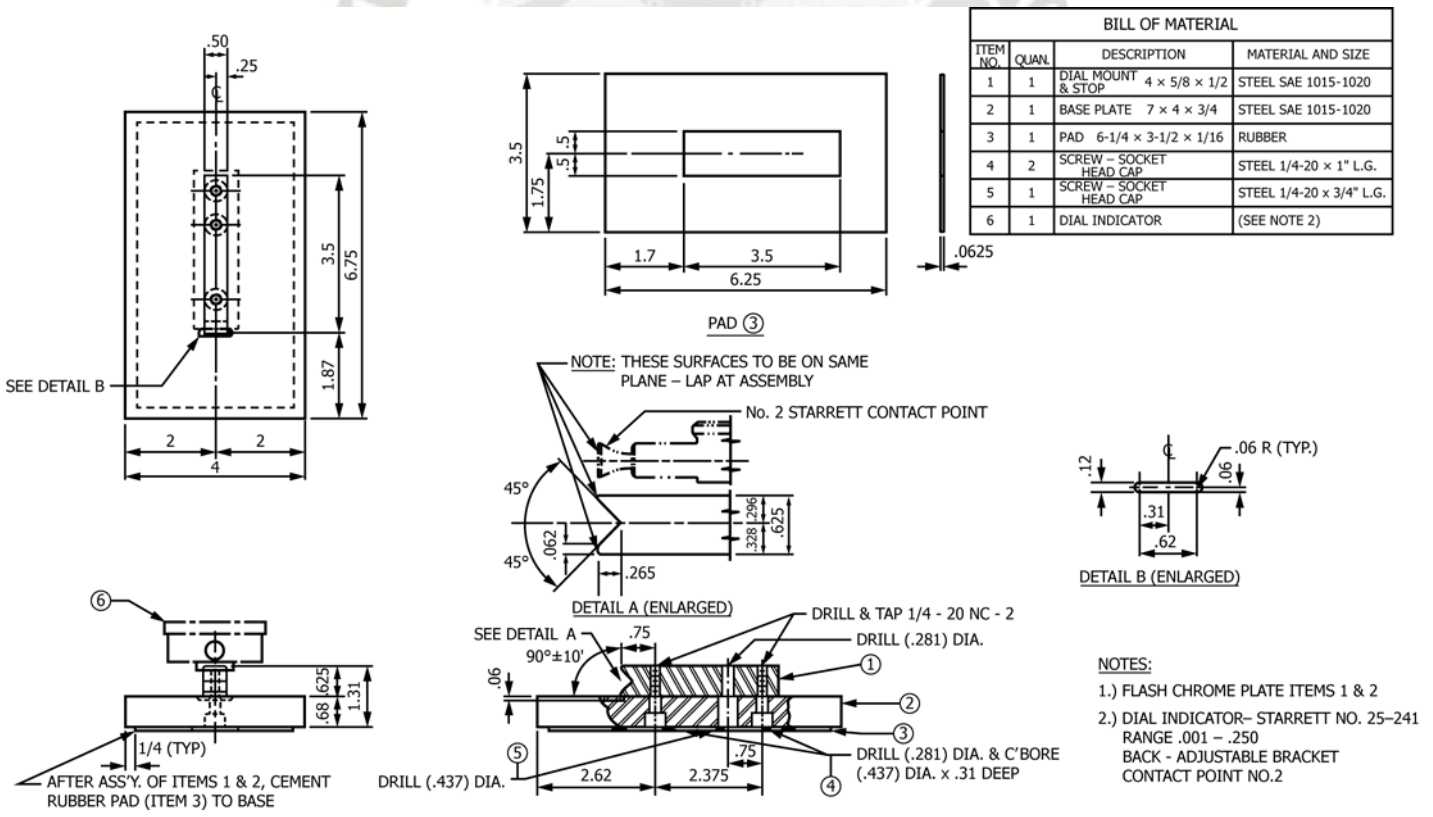


FIG. 17 Assembly and Details for Lateral Expansion Gauge

5°F (3°C). If the tabulated test results clearly indicate a transition temperature lower than specified, it is not necessary to plot the data. Report the lowest test temperature for which test value exceeds the specified value.

27.2.2.4 Accept the test result if the determined transition temperature is equal to or lower than the specified value.

27.2.2.5 If the determined transition temperature is higher than the specified value, but not more than 20°F (12°C) higher than the specified value, test sufficient samples in accordance with Section 26 to plot two additional curves. Accept the test results if the temperatures determined from both additional tests are equal to or lower than the specified value.

27.3 When subsize specimens are permitted or necessary, or both, modify the specified test requirement according to Table

28.1.4 Test temperature and individual test value for each specimen broken, including initial tests and retests.

28.1.5 Test results.

28.1.6 Transition temperature and criterion for its determination, including initial tests and retests.

**29. Report**

29.1 The specification should designate the information to be reported.

**IZOD IMPACT TEST**

**30. Procedure**

**TABLE 9 Charpy V-Notch Test Acceptance Criteria for Various Sub-Size Specimens<sup>A,B,C</sup>**

Full Size, 10 by 10 mm		¾ Size, 10 by 7.5 mm		⅔ Size, 10 by 6.7 mm		½ Size, 10 by 5 mm		⅓ Size, 10 by 3.3 mm		¼ Size, 10 by 2.5 mm	
ft-lbf	[J]	ft-lbf	[J]	ft-lbf	[J]	ft-lbf	[J]	ft-lbf	[J]	ft-lbf	[J]
75	[102]	56	[76]	50	[68]	38	[52]	25	[34]	19	[26]
70	[95]	53	[72]	47	[64]	35	[48]	23	[31]	18	[24]
65	[88]	49	[67]	44	[60]	33	[45]	21	[29]	16	[22]
60	[82]	45	[61]	40	[54]	30	[41]	20	[27]	15	[20]
55	[75]	41	[56]	37	[50]	28	[38]	18	[24]	14	[19]
50	[68]	38	[52]	34	[46]	25	[34]	17	[23]	13	[18]
45	[61]	34	[46]	30	[41]	23	[31]	15	[20]	11	[15]
40	[54]	30	[41]	27	[37]	20	[27]	13	[18]	10	[14]
35	[48]	26	[35]	23	[31]	18	[24]	12	[16]	9	[12]
30	[41]	22	[30]	20	[27]	15	[20]	10	[14]	8	[11]
25	[34]	19	[26]	17	[23]	12	[16]	8	[11]	6	[8]
20	[27]	15	[20]	13	[18]	10	[14]	7	[10]	5	[7]
16	[22]	12	[16]	11	[15]	8	[11]	5	[7]	4	[5]
15	[20]	11	[15]	10	[14]	8	[11]	5	[7]	4	[5]
13	[18]	10	[14]	9	[12]	6	[8]	4	[5]	3	[4]
12	[16]	9	[12]	8	[11]	6	[8]	4	[5]	3	[4]
10	[14]	8	[11]	7	[10]	5	[7]	3	[4]	2	[3]
7	[10]	5	[7]	5	[7]	4	[5]	2	[3]	2	[3]

<sup>A</sup> Care must be taken when using Table 9 for the conversion of subsize specimen absorbed energy results to those values that may be expected from full size Charpy specimens. The use of conversion values should only be applied when both specimens types (full-size and sub-size) are in the same fracture regime (in other words, a lower shelf, transition, or upper shelf) at the test temperature for the material under investigation. In particular test specimens <5 mm can exhibit variable absorbed energy values (NIST Technical Note 1858). (1)

<sup>B</sup> Limit based upon presentation by Kim Wallin, VTT, "Sub-sized CVN Specimen Conversion Methodology 4, Slide #10," which shows a common relationship for sub-sized specimens up to 75 ft-lbf (102J). (2)

<sup>C</sup> Analysis of Data from NIST Note 1858 by J. A. Griffin, UAB, ASTM A01.13 Task Group meeting, San Antonio, TX 5.4.16. (1)

9 or test temperature according to ASME Boiler and Pressure Vessel Code, Table UG-84.2, or both. Greater energies or lower test temperatures may be agreed upon by purchaser and supplier.

**28. Records**

28.1 The test record should contain the following information as appropriate:

28.1.1 Full description of material tested (that is, specification number, grade, class or type, size, heat number).

28.1.2 Specimen orientation with respect to the material axis.

28.1.3 Specimen size.

30.1 Testing equipment and methods are given in Test Methods E23.

**31. Precision and Bias**

31.1 The precision and bias of these test methods for measuring mechanical properties are essentially as specified in Test Methods E8/E8M, E10, E18, and E23.

**32. Keywords**

32.1 bend test; Brinell hardness; Charpy impact test; elongation; FATT (Fracture Appearance Transition Temperature); hardness test; Izod impact test; portable hardness; reduction of area; Rockwell hardness; tensile strength; tension test; yield strength

**ANNEXES****(Mandatory Information)****A1. STEEL BAR PRODUCTS****A1.1 Scope**

A1.1.1 This annex contains testing requirements for Steel Bar Products that are specific to the product. The requirements contained in this annex are supplementary to those found in the general section of this specification. In the case of conflict between requirements provided in this annex and those found in the general section of this specification, the requirements of this annex shall prevail. In the case of conflict between requirements provided in this annex and requirements found in product specifications, the requirements found in the product specification shall prevail.

**A1.2 Orientation of Test Specimens**

A1.2.1 Carbon and alloy steel bars and bar-size shapes, due to their relatively small cross-sectional dimensions, are customarily tested in the longitudinal direction. In special cases where size permits and the fabrication or service of a part justifies testing in a transverse direction, the selection and location of test or tests are a matter of agreement between the manufacturer and the purchaser.

**A1.3 Tension Test**

A1.3.1 *Carbon Steel Bars*—Carbon steel bars are not commonly specified to tensile requirements in the as-rolled condi-

tion for sizes of rounds, squares, hexagons, and octagons under ½ in. (13 mm) in diameter or distance between parallel faces nor for other bar-size sections, other than flats, less than 1 in.<sup>2</sup> (645 mm<sup>2</sup>) in cross-sectional area.

A1.3.2 *Alloy Steel Bars*—Alloy steel bars are usually not tested in the as-rolled condition.

A1.3.3 When tension tests are specified, the practice for selecting test specimens for hot-rolled and cold-finished steel bars of various sizes shall be in accordance with [Table A1.1](#), unless otherwise specified in the product specification.

**A1.4 Bend Test**

A1.4.1 When bend tests are specified, the recommended practice for hot-rolled and cold-finished steel bars shall be in accordance with [Table A1.2](#).

**A1.5 Hardness Test**

A1.5.1 *Hardness Tests on Bar Products*—flats, rounds, squares, hexagons and octagons—is conducted on the surface after a minimum removal of 0.015 in. to provide for accurate hardness penetration.

**TABLE A1.1 Practices for Selecting Tension Test Specimens for Steel Bar Products**

NOTE 1—For bar sections where it is difficult to determine the cross-sectional area by simple measurement, the area in square inches may be calculated by dividing the weight per linear inch of specimen in pounds by 0.2833 (weight of 1 in.<sup>3</sup> of steel) or by dividing the weight per linear foot of specimen by 3.4 (weight of steel 1 in. square and 1 ft long).

Thickness, in. (mm)	Width, in. (mm)	Hot-Rolled Bars	Cold-Finished Bars
Flats			
Under 5/8 (16)	Up to 1½ (38), incl	Full section by 8-in. (200-mm) gauge length (Fig. 3).	Mill reduced section to 2-in. (50-mm) gauge length and approximately 25% less than test specimen width.
	Over 1½ (38)	Full section, or mill to 1½ in. (38 mm) wide by 8-in. (200-mm) gauge length (Fig. 3).	Mill reduced section to 2-in. gauge length and 1½ in. wide.
5/8 to 1½ (16 to 38), excl	Up to 1½ (38), incl	Full section by 8-in. gauge length or machine standard ½ by 2-in. (13 by 50-mm) gauge length specimen from center of section (Fig. 4).	Mill reduced section to 2-in. (50-mm) gauge length and approximately 25% less than test specimen width or machine standard ½ by 2-in. (13 by 50-mm) gauge length specimen from center of section (Fig. 4).
	Over 1½ (38)	Full section, or mill 1½ in. (38 mm) width by 8-in. (200-mm) gauge length (Fig. 3) or machine standard ½ by 2-in. gauge (13 by 50-mm) gauge length specimen from midway between edge and center of section (Fig. 4).	Mill reduced section to 2-in. gauge length and 1½ in. wide or machine standard ½ by 2-in. gauge length specimen from midway between edge and center of section (Fig. 4).
1½ (38) and over		Full section by 8-in. (200-mm) gauge length, or machine standard ½ by 2-in. (13 by 50-mm) gauge length specimen from midway between surface and center (Fig. 4).	Machine standard ½ by 2-in. (13 by 50-mm) gauge length specimen from midway between surface and center (Fig. 4).
Rounds, Squares, Hexagons, and Octagons			
Diameter or Distance Between Parallel Faces, in. (mm)	Hot-Rolled Bars		Cold-Finished Bars
Under 5/8	Full section by 8-in. (200-mm) gauge length or machine to subsize specimen (Fig. 4).		Machine to sub-size specimen (Fig. 4).
5/8 to 1½ (16 to 38), excl	Full section by 8-in. (200-mm) gauge length or machine standard ½ in. by 2-in. (13 by 50-mm) gauge length specimen from center of section (Fig. 4).		Machine standard ½ in. by 2-in. gauge length specimen from center of section (Fig. 4).
1½ (38) and over	Full section by 8-in. (200-mm) gauge length or machine standard ½ in. by 2-in. (13 by 50-mm) gauge length specimen from midway between surface and center of section (Fig. 4).		Machine standard ½ in. by 2-in. (13 by 50-mm gauge length specimen from midway between surface and center of section (Fig. 4)).
Other Bar-Size Sections			
All sizes	Full section by 8-in. (200-mm) gauge length or prepare test specimen 1½ in. (38 mm) wide (if possible) by 8-in. (200-mm) gauge length.		Mill reduced section to 2-in. (50-mm) gauge length and approximately 25% less than test specimen width.

**TABLE A1.2 Recommended Practice for Selecting Bend Test Specimens for Steel Bar Products**

NOTE 1—The length of all specimens is to be not less than 6 in. (150 mm).

NOTE 2—The edges of the specimen may be rounded to a radius not exceeding 1/16 in. (1.6 mm).

Flats		
Thickness, in. (mm)	Width, in. (mm)	Recommended Size
Up to ½ (13), incl	Up to ¾ (19), incl	Full section.
	Over ¾ (19)	Full section or machine to not less than or less than ¾ in. (19 mm) in width by thickness of specimen.
Over ½ (13)	All	Full section or machine to 1 by ½ in. (25 by 13 mm) specimen from midway between center and surface.
Rounds, Squares, Hexagons, and Octagons		
Diameter or Distance Between Parallel Faces, in. (mm)	Recommended Size	
Up to 1½ (38), incl	Full section.	
Over 1½ (38)	Machine to 1 by ½-in. (25 by 13-mm) specimen from midway between center and surface.	

A2. STEEL TUBULAR PRODUCTS

A2.1 Scope

A2.1.1 This annex contains testing requirements for Steel Tubular Products that are specific to the product. The requirements contained in this annex are supplementary to those found in the general section of this specification. In the case of conflict between requirements provided in this annex and those found in the general section of this specification, the requirements of this annex shall prevail. In the case of conflict between requirements provided in this annex and requirements found in product specifications, the requirements found in the product specification shall prevail.

A2.1.2 Tubular shapes covered by this specification include, round, square, rectangular, and special shapes.

A2.2 Tension Test

A2.2.1 Full-Size Longitudinal Test Specimens:

A2.2.1.1 As an alternative to the use of longitudinal strip test specimens or longitudinal round test specimens, tension test specimens of full-size tubular sections are used, provided that the testing equipment has sufficient capacity. Snug-fitting metal plugs should be inserted far enough in the end of such tubular specimens to permit the testing machine jaws to grip the specimens properly without crushing. A design that may be used for such plugs is shown in Fig. A2.1. The plugs shall not extend into that part of the specimen on which the elongation is measured (Fig. A2.1). Care should be exercised to see that insofar as practicable, the load in such cases is applied axially. The length of the full-section specimen depends on the gauge length prescribed for measuring the elongation.

A2.2.1.2 Unless otherwise required by the product specification, the gauge length is 2 in. or 50 mm, except that for tubing having an outside diameter of 3/8 in. (9.5 mm) or less, it is customary for a gauge length equal to four times the outside

diameter to be used when elongation comparable to that obtainable with larger test specimens is required.

A2.2.1.3 To determine the cross-sectional area of the full-section specimen, measurements shall be recorded as the average or mean between the greatest and least measurements of the outside diameter and the average or mean wall thickness, to the nearest 0.001 in. (0.025 mm) and the cross-sectional area is determined by the following equation:

$$A = 3.1416t(D - t) \tag{A2.1}$$

where:

A = sectional area, in.<sup>2</sup>

D = outside diameter, in., and

t = thickness of tube wall, in.

NOTE A2.1—There exist other methods of cross-sectional area determination, such as by weighing of the specimens, which are equally accurate or appropriate for the purpose.

A2.2.2 Longitudinal Strip Test Specimens:

A2.2.2.1 As an alternative to the use of full-size longitudinal test specimens or longitudinal round test specimens, longitudinal strip test specimens, obtained from strips cut from the tubular product as shown in Fig. A2.2 and machined to the dimensions shown in Fig. A2.3 are used. For welded structural tubing, such test specimens shall be from a location at least 90° from the weld; for other welded tubular products, such test specimens shall be from a location approximately 90° from the weld. Unless otherwise required by the product specification, the gauge length shall conform to dimension C in Fig. A2.3. The test specimens shall be tested using grips that are flat or have a surface contour corresponding to the curvature of the tubular product, or the ends of the test specimens shall be flattened without heating prior to the test specimens being tested using flat grips. The test specimen shown as specimen no. 4 in Fig. 3 shall be used, unless the capacity of the testing equipment or the dimensions and nature of the tubular product to be tested makes the use of specimen nos. 1, 2, or 3 necessary.

NOTE A2.2—An exact formula for calculating the cross-sectional area of specimens of the type shown in Fig. A2.3 taken from a circular tube is

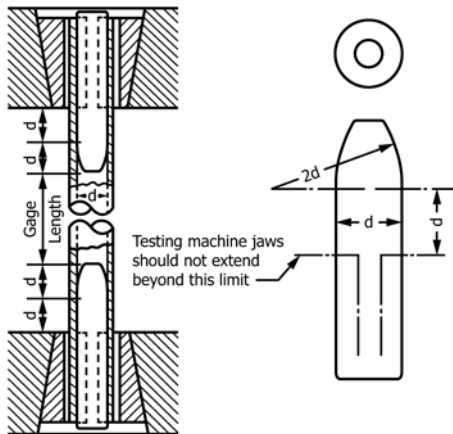
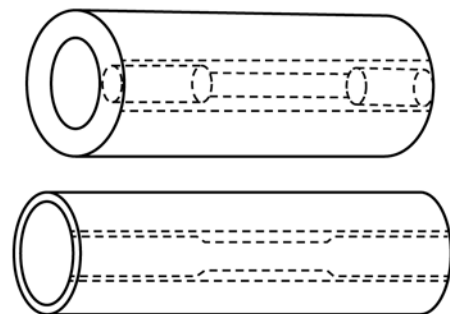
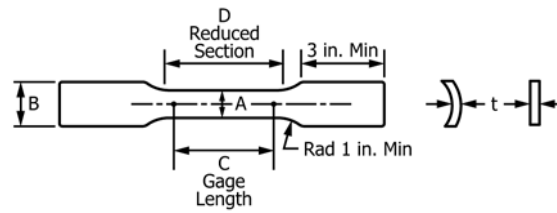


FIG. A2.1 Metal Plugs for Testing Tubular Specimens, Proper Location of Plugs in Specimen and of Specimen in Heads of Testing Machine



NOTE 1—The edges of the blank for the specimen shall be cut parallel to each other.

FIG. A2.2 Location of Longitudinal Tension-Test Specimens in Rings Cut from Tubular Products



DIMENSIONS

Specimen No.	Dimensions, in.			
	A	B	C	D
1	$\frac{1}{2} \pm 0.015$	$1\frac{1}{16}$ approximately	$2 \pm 0.005$	2¼ min
2	$\frac{3}{4} \pm 0.031$	1 approximately	$2 \pm 0.005$	2¼ min
3	$1 \pm 0.062$	1½ approximately	$4 \pm 0.005$	4½ min
4	$1\frac{1}{2} \pm .125$	2 approximately	$2 \pm 0.010$	2¼ min
			$4 \pm 0.015$	4½ min
5	$\frac{1}{4} \pm .002$	$\frac{3}{8}$ approximately	$8 \pm 0.020$	9 min
			$1 \pm 0.003$	1 ¼ min

NOTE 1—Cross-sectional area may be calculated by multiplying A and t.

NOTE 2—The dimension t is the thickness of the test specimen as provided in the applicable material specifications.

NOTE 3—The reduced section shall be parallel within 0.010 in. and may have a gradual taper in width from the ends toward the center, with the ends not more than 0.010 in. wider than the center.

NOTE 4—The ends of the specimen shall be symmetrical with the center line of the reduced section within 0.10 in.

NOTE 5—Metric equivalent: 1 in. = 25.4 mm.

NOTE 6—Specimens with sides parallel throughout their length are permitted, except for referee testing, provided: (a) the above tolerances are used; (b) an adequate number of marks are provided for determination of elongation; and (c) when yield strength is determined, a suitable extensometer is used. If the fracture occurs at a distance of less than 2A from the edge of the gripping device, the tensile properties determined may not be representative of the material. If the properties meet the minimum requirements specified, no further testing is required, but if they are less than the minimum requirements, discard the test and retest.

NOTE 7—Specimen 5 is intended for testing specimens removed from an in-service product. Specimen 5 shall not be used for conformance testing of new product. Acceptance criteria for elongation values obtained from 1 in. gage length specimens shall be determined by agreement between the responsible parties.

FIG. A2.3 Dimensions and Tolerances for Longitudinal Strip Tension Test Specimens for Tubular Products

given in Test Methods E8/E8M.

A2.2.2.2 The width should be measured at each end of the gauge length to determine parallelism and also at the center. The thickness should be measured at the center and used with the center measurement of the width to determine the cross-sectional area. The center width dimension should be recorded to the nearest 0.005 in. (0.127 mm), and the thickness measurement to the nearest 0.001 in.

A2.2.3 Transverse Strip Test Specimens:

A2.2.3.1 In general, transverse tension tests are not recommended for tubular products, in sizes smaller than 8 in. in nominal diameter. When required, transverse tension test specimens may be taken from rings cut from ends of tubes or pipe as shown in Fig. A2.4. Flattening of the specimen may be done either after separating it from the tube as in Fig. A2.4 (a),

or before separating it as in Fig. A2.4 (b), and may be done hot or cold; but if the flattening is done cold, the specimen may subsequently be normalized. Specimens from tubes or pipe for which heat treatment is specified, after being flattened either hot or cold, shall be given the same treatment as the tubes or pipe. For tubes or pipe having a wall thickness of less than ¾ in. (19 mm), the transverse test specimen shall be of the form and dimensions shown in Fig. A2.5 and either or both surfaces may be machined to secure uniform thickness. Specimens for transverse tension tests on welded steel tubes or pipe to determine strength of welds, shall be located perpendicular to the welded seams with the weld at about the middle of their length.

A2.2.3.2 The width should be measured at each end of the gauge length to determine parallelism and also at the center. The thickness should be measured at the center and used with the center measurement of the width to determine the cross-sectional area. The center width dimension should be recorded to the nearest 0.005 in. (0.127 mm), and the thickness measurement to the nearest 0.001 in. (0.025 mm).

A2.2.4 Round Test Specimens:

A2.2.4.1 When provided for in the product specification, the round test specimen shown in Fig. 4 may be used.

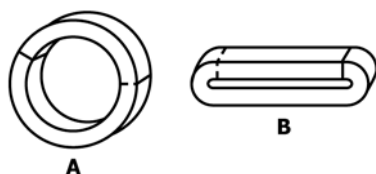
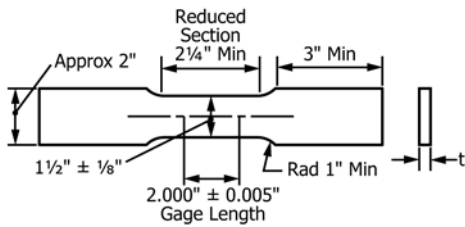


FIG. A2.4 Location of Transverse Tension Test Specimens in Ring Cut from Tubular Products.



NOTE 1—The dimension  $t$  is the thickness of the test specimen as provided for in the applicable material specifications.

NOTE 2—The reduced section shall be parallel within 0.010 in. and may have a gradual taper in width from the ends toward the center, with the ends not more than 0.010 in. wider than the center.

NOTE 3—The ends of the specimen shall be symmetrical with the center line of the reduced section within 0.10 in.

NOTE 4—Metric equivalent: 1 in. = 25.6 mm.

FIG. A2.5 Transverse Tension Test Specimen Machined from Ring Cut from Tubular Products

A2.2.4.2 The diameter of the round test specimen is measured at the center of the specimen to the nearest 0.001 in. (0.025 mm).

A2.2.4.3 Small-size specimens proportional to standard, as shown in Fig. 4, may be used when it is necessary to test material from which the standard specimen cannot be prepared. Other sizes of small-size specimens may be used. In any such small-size specimen, it is important that the gauge length for measurement of elongation be four times the diameter of the specimen (see Note 5, Fig. 4). The elongation requirements for the round specimen 2-in. gauge length in the product specification shall apply to the small-size specimens.

A2.2.4.4 For transverse specimens, the section from which the specimen is taken shall not be flattened or otherwise deformed.

A2.2.4.5 Longitudinal test specimens are obtained from strips cut from the tubular product as shown in Fig. A2.2.

### A2.3 Determination of Transverse Yield Strength, Hydraulic Ring-Expansion Method

A2.3.1 Hardness tests are made on the outside surface, inside surface, or wall cross-section depending upon product-specification limitation. Surface preparation may be necessary to obtain accurate hardness values.

A2.3.2 A testing machine and method for determining the transverse yield strength from an annular ring specimen, have been developed and described in A2.3.3 – 9.1.2.

A2.3.3 A diagrammatic vertical cross-sectional sketch of the testing machine is shown in Fig. A2.6.

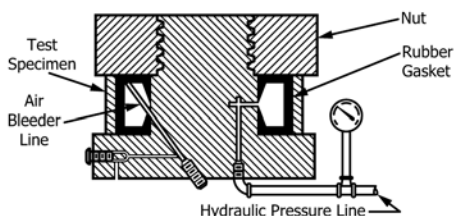


FIG. A2.6 Testing Machine for Determination of Transverse Yield Strength from Annular Ring Specimens

A2.3.4 In determining the transverse yield strength on this machine, a short ring (commonly 3 in. (76 mm) in length) test specimen is used. After the large circular nut is removed from the machine, the wall thickness of the ring specimen is determined and the specimen is telescoped over the oil resistant rubber gasket. The nut is then replaced, but is not turned down tight against the specimen. A slight clearance is left between the nut and specimen for the purpose of permitting free radial movement of the specimen as it is being tested. Oil under pressure is then admitted to the interior of the rubber gasket through the pressure line under the control of a suitable valve. An accurately calibrated pressure gauge serves to measure oil pressure. Any air in the system is removed through the bleeder line. As the oil pressure is increased, the rubber gasket expands which in turn stresses the specimen circumferentially. As the pressure builds up, the lips of the rubber gasket act as a seal to prevent oil leakage. With continued increase in pressure, the ring specimen is subjected to a tension stress and elongates accordingly. The entire outside circumference of the ring specimen is considered as the gauge length and the strain is measured with a suitable extensometer which will be described later. When the desired total strain or extension under load is reached on the extensometer, the oil pressure in pounds per square inch is read and by employing Barlow's formula, the unit yield strength is calculated. The yield strength, thus determined, is a true result since the test specimen has not been cold worked by flattening and closely approximates the same condition as the tubular section from which it is cut. Further, the test closely simulates service conditions in pipe lines. One testing machine unit may be used for several different sizes of pipe by the use of suitable rubber gaskets and adapters.

NOTE A2.3—Barlow's formula may be stated two ways:

$$(1) P = 2St/D \tag{A2.2}$$

$$(2) S = PD/2t \tag{A2.3}$$

where:

- $P$  = internal hydrostatic pressure, psi,
- $S$  = unit circumferential stress in the wall of the tube produced by the internal hydrostatic pressure, psi,
- $t$  = thickness of the tube wall, in., and
- $D$  = outside diameter of the tube, in.

A2.3.5 A roller chain type extensometer which has been found satisfactory for measuring the elongation of the ring specimen is shown in Figs. A2.7 and A2.8. Fig. A2.7 shows the extensometer in position, but unclamped, on a ring specimen. A small pin, through which the strain is transmitted to and measured by the dial gauge, extends through the hollow threaded stud. When the extensometer is clamped, as shown in Fig. A2.8, the desired tension which is necessary to hold the instrument in place and to remove any slack, is exerted on the roller chain by the spring. Tension on the spring may be regulated as desired by the knurled thumb screw. By removing or adding rollers, the roller chain may be adapted for different sizes of tubular sections.

### A2.4 Hardness Tests

A2.4.1 Hardness tests are made either on the outside or the inside surfaces on the end of the tube as appropriate.



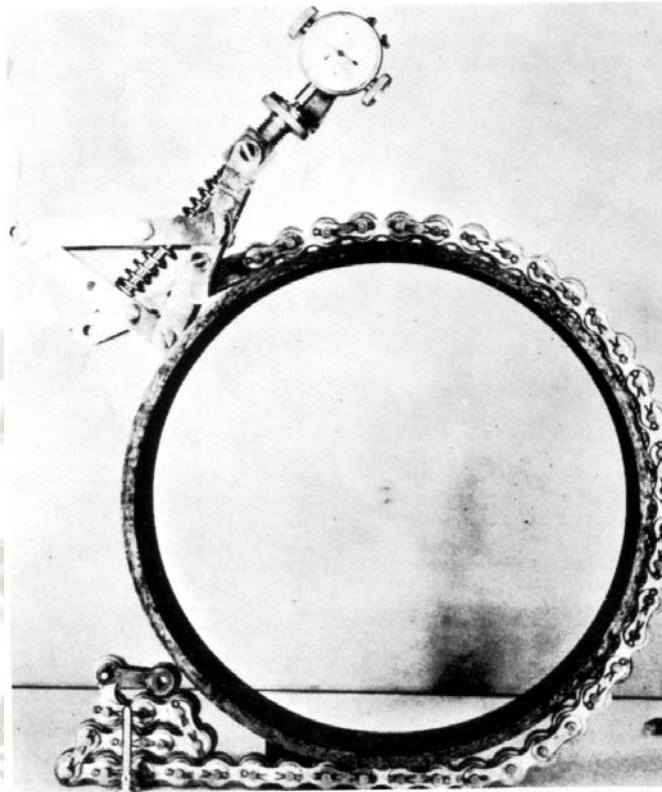


FIG. A2.7 Roller Chain Type Extensometer, Unclamped

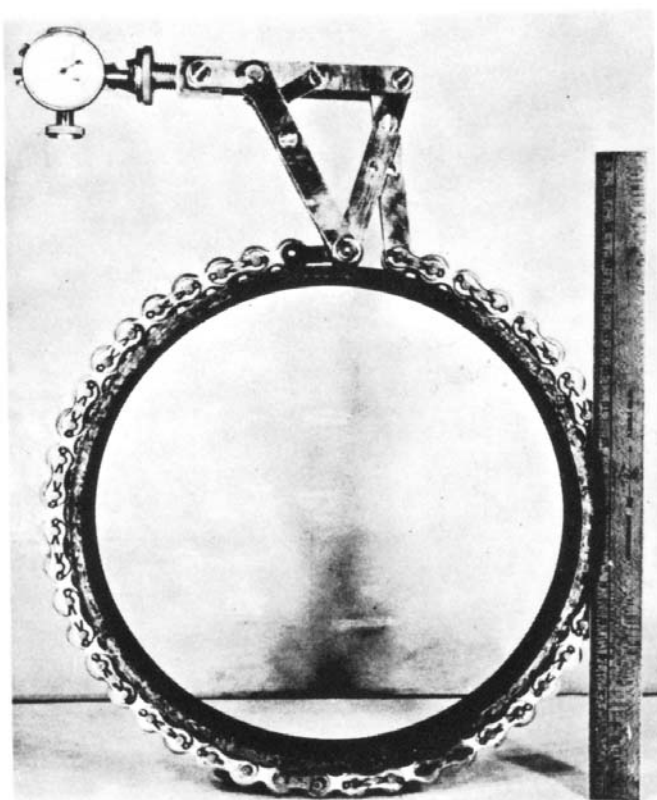


FIG. A2.8 Roller Chain Type Extensometer, Clamped

A2.4.2 The standard 3000-kgf Brinell load may cause too much deformation in a thin-walled tubular specimen. In this case the 500-kgf load shall be applied, or inside stiffening by means of an internal anvil should be used. Brinell testing shall not be applicable to tubular products less than 2 in. (51 mm) in outside diameter, or less than 0.200 in. (5.1 mm) in wall thickness.

A2.4.3 The Rockwell hardness tests are normally made on the inside surface, a flat on the outside surface, or on the wall cross-section depending upon the product limitation. Rockwell hardness tests are not performed on tubes smaller than  $\frac{5}{16}$  in. (7.9 mm) in outside diameter, nor are they performed on the inside surface of tubes with less than  $\frac{1}{4}$  in. (6.4 mm) inside diameter. Rockwell hardness tests are not performed on annealed tubes with walls less than 0.065 in. (1.65 mm) thick or cold worked or heat treated tubes with walls less than 0.049 in. (1.24 mm) thick. For tubes with wall thicknesses less than those permitting the regular Rockwell hardness test, the Superficial Rockwell test is sometimes substituted. Transverse Rockwell hardness readings can be made on tubes with a wall thickness of 0.187 in. (4.75 mm) or greater. The curvature and the wall thickness of the specimen impose limitations on the Rockwell hardness test. When a comparison is made between Rockwell determinations made on the outside surface and determinations made on the inside surface, adjustment of the readings will be required to compensate for the effect of curvature. The Rockwell B scale is used on all materials having an expected hardness range of B0 to B100. The Rockwell C scale is used on material having an expected hardness range of C20 to C68.

A2.4.4 Superficial Rockwell hardness tests are normally performed on the outside surface whenever possible and whenever excessive spring back is not encountered. Otherwise, the tests may be performed on the inside. Superficial Rockwell hardness tests shall not be performed on tubes with an inside diameter of less than  $\frac{1}{4}$  in. (6.4 mm). The wall thickness limitations for the Superficial Rockwell hardness test are given in [Tables A2.1 and A2.2](#).

A2.4.5 When the outside diameter, inside diameter, or wall thickness precludes the obtaining of accurate hardness values, tubular products shall be specified to tensile properties and so tested.

## A2.5 Manipulating Tests

A2.5.1 The following tests are made to prove ductility of certain tubular products:

A2.5.1.1 *Flattening Test*—The flattening test as commonly made on specimens cut from tubular products is conducted by

subjecting rings from the tube or pipe to a prescribed degree of flattening between parallel plates ([Fig. A2.4](#)). The severity of the flattening test is measured by the distance between the parallel plates and is varied according to the dimensions of the tube or pipe. The flattening test specimen should not be less than  $2\frac{1}{2}$  in. (63.5 mm) in length and should be flattened cold to the extent required by the applicable material specifications.

A2.5.1.2 *Reverse Flattening Test*—The reverse flattening test is designed primarily for application to electric-welded tubing for the detection of lack of penetration or overlaps resulting from flash removal in the weld. The specimen consists of a length of tubing approximately 4 in. (102 mm) long which is split longitudinally 90° on each side of the weld. The sample is then opened and flattened with the weld at the point of maximum bend ([Fig. A2.9](#)).

A2.5.1.3 *Crush Test*—The crush test, sometimes referred to as an upsetting test, is usually made on boiler and other pressure tubes, for evaluating ductility ([Fig. A2.10](#)). The specimen is a ring cut from the tube, usually about  $2\frac{1}{2}$  in. (63.5 mm) long. It is placed on end and crushed endwise by hammer or press to the distance prescribed by the applicable material specifications.

A2.5.1.4 *Flange Test*—The flange test is intended to determine the ductility of boiler tubes and their ability to withstand the operation of bending into a tube sheet. The test is made on a ring cut from a tube, usually not less than 4 in. (100 mm) long and consists of having a flange turned over at right angles to the body of the tube to the width required by the applicable material specifications. The flaring tool and die block shown in [Fig. A2.11](#) are recommended for use in making this test.

A2.5.1.5 *Flaring Test*—For certain types of pressure tubes, an alternate to the flange test is made. This test consists of driving a tapered mandrel having a slope of 1 in 10 as shown in [Fig. A2.12 \(a\)](#) or a 60° included angle as shown in [Fig. A2.12 \(b\)](#) into a section cut from the tube, approximately 4 in. (100 mm) in length, and thus expanding the specimen until the inside diameter has been increased to the extent required by the applicable material specifications.

A2.5.1.6 *Bend Test*—For pipe used for coiling in sizes 2 in. and under a bend test is made to determine its ductility and the soundness of weld. In this test a sufficient length of full-size pipe is bent cold through 90° around a cylindrical mandrel having a diameter 12 times the nominal diameter of the pipe. For close coiling, the pipe is bent cold through 180° around a mandrel having a diameter 8 times the nominal diameter of the pipe.

A2.5.1.7 *Transverse Guided Bend Test of Welds*—This bend test is used to determine the ductility of fusion welds. The specimens used are approximately  $1\frac{1}{2}$  in. (38 mm) wide, at

**TABLE A2.1 Wall Thickness Limitations of Superficial Hardness Test on Annealed or Ductile Materials for Steel Tubular Products<sup>A</sup>**  
(“T” Scale (1/16-in. Ball))

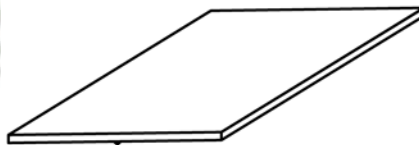
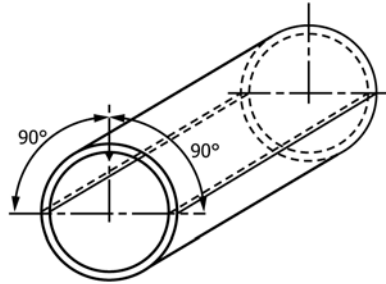
Wall Thickness, in. (mm)	Load, kgf
Over 0.050 (1.27)	45
Over 0.035 (0.89)	30
0.020 and over (0.51)	15

<sup>A</sup> The heaviest load recommended for a given wall thickness is generally used.

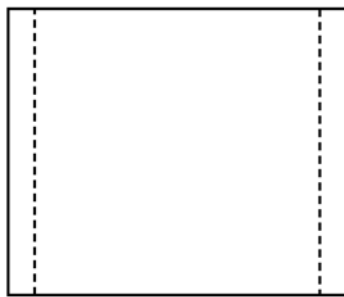
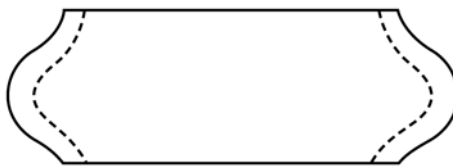
**TABLE A2.2 Wall Thickness Limitations of Superficial Hardness Test on Cold Worked or Heat Treated Material for Steel Tubular Products<sup>A</sup> (“N” Scale (Diamond Penetrator))**

Wall Thickness, in. (mm)	Load, kgf
Over 0.035 (0.89)	45
Over 0.025 (0.51)	30
0.015 and over (0.38)	15

<sup>A</sup> The heaviest load recommended for a given wall thickness is generally used.



**FIG. A2.9 Reverse Flattening Test**

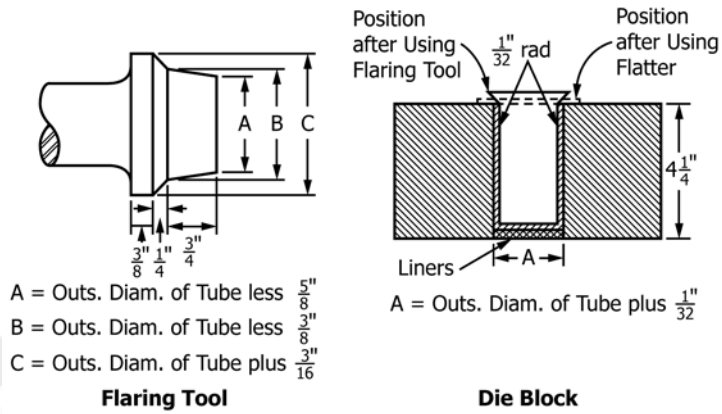


**FIG. A2.10 Crush Test Specimen**

least 6 in. (152 mm) in length with the weld at the center, and are machined in accordance with Fig. A2.13 for face and root bend tests and in accordance with Fig. A2.14 for side bend tests. The dimensions of the plunger shall be as shown in Fig. A2.15 and the other dimensions of the bending jig shall be substantially as given in this same figure. A test shall consist of a face bend specimen and a root bend specimen or two side bend specimens. A face bend test requires bending with the

inside surface of the pipe against the plunger; a root bend test requires bending with the outside surface of the pipe against the plunger; and a side bend test requires bending so that one of the side surfaces becomes the convex surface of the bend specimen.

(a) Failure of the bend test depends upon the appearance of cracks in the area of the bend, of the nature and extent described in the product specifications.



NOTE 1—Metric equivalent: 1 in. = 25.4 mm.

FIG. A2.11 Flaring Tool and Die Block for Flange Test

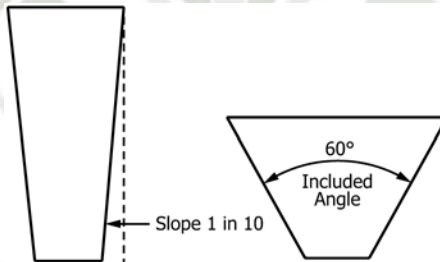
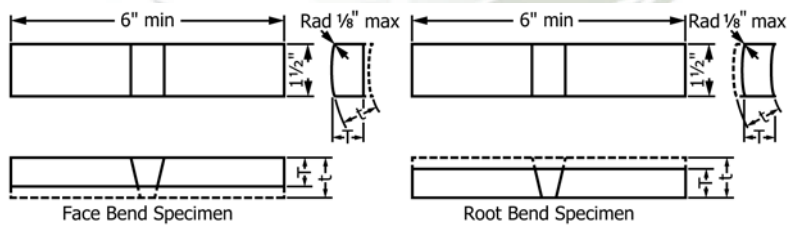


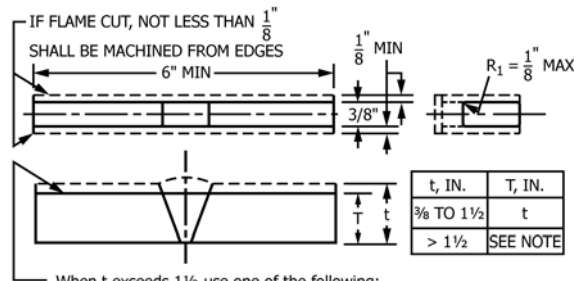
FIG. A2.12 Tapered Mandrels for Flaring Test



NOTE 1—Metric equivalent: 1 in. = 25.4 mm.

Pipe Wall Thickness (t), in.	Test Specimen Thickness, in.
Up to $\frac{3}{8}$ , incl	t
Over $\frac{3}{8}$	$\frac{3}{8}$

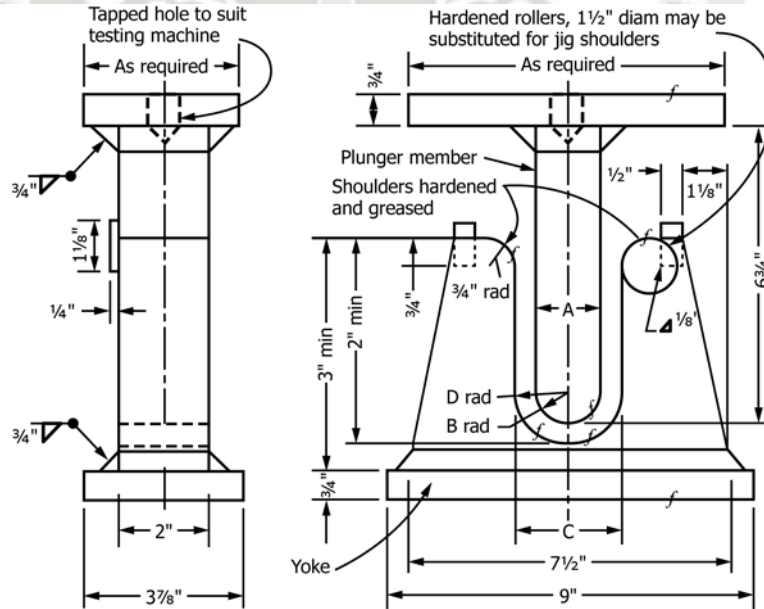
FIG. A2.13 Transverse Face- and Root-Bend Test Specimens



- When  $t$  exceeds  $1/2$  use one of the following:
1. Cut along line indicated by arrow. Edge may be flame cut and may or may not be machined.
  2. Specimens may be cut into approximately equal strips between  $3/4$  in. and  $1/2$  in. wide for testing or the specimens may be bent at full width (see requirements on jig width in Fig. A2.15.)

NOTE 1—Metric equivalent: 1 in. = 25.4 mm.

FIG. A2.14 Side-Bend Specimen for Ferrous Materials



NOTE 1—Metric equivalent: 1 in. = 25.4 mm.

Test Specimen Thickness, in.	A	B	C	D	Material
$3/8$	$1\frac{1}{2}$	$3/4$	$2\frac{3}{8}$	$1\frac{3}{16}$	Materials with a specified minimum tensile strength of 95 ksi or greater.
$t$	$4t$	$2t$	$6t + 1/8$	$3t + 1/16$	
$3/8$	$2\frac{1}{2}$	$1\frac{1}{4}$	$3\frac{3}{8}$	$1\frac{1}{16}$	Materials with a specified minimum tensile strength of 95 ksi or greater.
$t$	$6\frac{2}{3}t$	$3\frac{1}{3}t$	$8\frac{2}{3}t + 1/8$	$4\frac{1}{2}t + 1/16$	

FIG. A2.15 Guided-Bend Test Jig

A3. STEEL FASTENERS

A3.1 Scope

A3.1.1 This annex contains testing requirements for Steel Fasteners that are specific to the product. The requirements contained in this annex are supplementary to those found in the general section of this specification. In the case of conflict between requirements provided in this annex and those found in the general section of this specification, the requirements of this annex shall prevail. In the case of conflict between requirements provided in this annex and requirements found in product specifications, the requirements found in the product specification shall prevail.

A3.1.2 These tests are set up to facilitate production control testing and acceptance testing with certain more precise tests to be used for arbitration in case of disagreement over test results.

A3.2 Tension Tests

A3.2.1 It is preferred that bolts be tested full size, and it is customary, when so testing bolts to specify a minimum ultimate load in pounds, rather than a minimum ultimate strength in pounds per square inch. Three times the bolt nominal diameter has been established as the minimum bolt length subject to the tests described in the remainder of this section. Sections A3.2.1.1 – A3.2.1.6 apply when testing bolts full size. Section A3.2.1.4 shall apply where the individual product specifications permit the use of machined specimens.

A3.2.1.1 *Proof Load*—Due to particular uses of certain classes of bolts it is desirable to be able to stress them, while in use, to a specified value without obtaining any permanent set. To be certain of obtaining this quality the proof load is specified. The proof load test consists of stressing the bolt with a specified load which the bolt must withstand without permanent set. An alternate test which determines yield strength of a full size bolt is also allowed. Either of the following Methods, 1 or 2, may be used but Method 1 shall be the arbitration method in case of any dispute as to acceptance of the bolts.

A3.2.1.2 *Proof Load Testing Long Bolts*—When fasteners are too long to test in the available equipment they may be cut to  $8 \pm 0.125$  in. and tested using Method 1. If there is a dispute over results when testing the same part or lot of parts both full size and cut to 8 in., the 8 in. test results shall be used to determine acceptance.

(a) *Method 1, Length Measurement*—The overall length of a straight bolt shall be measured at its true center line with an instrument capable of measuring changes in length of 0.0001 in. (0.0025 mm) with an accuracy of 0.0001 in. in any 0.001-in. (0.025-mm) range. The preferred method of measuring the length shall be between conical centers machined on the center line of the bolt, with mating centers on the measuring anvils. The head or body of the bolt shall be marked so that it can be placed in the same position for all measurements. The bolt shall be assembled in the testing equipment as outlined in A3.2.1.4, and the proof load specified in the product specification shall be applied. Upon release of this load the length of the bolt shall be again measured and shall show no permanent

elongation. A tolerance of  $\pm 0.0005$  in. (0.0127 mm) shall be allowed between the measurement made before loading and that made after loading. Variables, such as straightness and thread alignment (plus measurement error), may result in apparent elongation of the fasteners when the proof load is initially applied. In such cases, the fastener may be retested using a 3 % greater load, and may be considered satisfactory if the length after this loading is the same as before this loading (within the 0.0005-in. tolerance for measurement error).

A3.2.1.3 *Proof Load-Time of Loading*—The proof load is to be maintained for a period of 10 s before release of load, when using Method 1.

(1) *Method 2, Yield Strength*—The bolt shall be assembled in the testing equipment as outlined in A3.2.1.4. As the load is applied, the total elongation of the bolt or any part of the bolt which includes the exposed six threads shall be measured and recorded to produce a load-strain or a stress-strain diagram. The load or stress at an offset equal to 0.2 % of the length of bolt occupied by six full threads shall be determined by the method described in 14.2.1 of these methods, A370. This load or stress shall not be less than that prescribed in the product specification.

A3.2.1.4 *Axial Tension Testing of Full Size Bolts*—Bolts are to be tested in a holder with the load axially applied between the head and a nut or suitable fixture (Fig. A3.1), either of which shall have sufficient thread engagement to develop the full strength of the bolt. The nut or fixture shall be assembled on the bolt leaving six complete bolt threads unengaged between the grips, except for heavy hexagon structural bolts which shall have four complete threads unengaged between the grips. To meet the requirements of this test, there shall be a tensile failure in the body or threaded section with no failure at the junction of the body and head. When

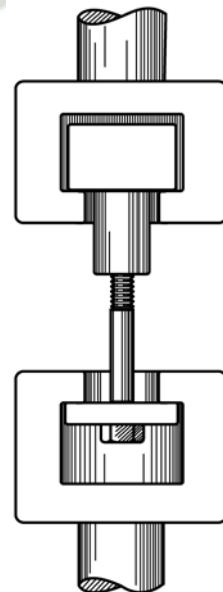


FIG. A3.1 Tension Testing Full-Size Bolt

tensile testing externally threaded fasteners made of austenitic stainless steel and the test fastener's thread pulls out of the internally threaded test fixture after the minimum tensile strength requirement has been reached, the fasteners shall be considered conforming to the tensile strength requirement and, in addition to the tensile strength, the failure mode shall be reported to the purchaser. If it is necessary to record or report the tensile strength of bolts as psi values, the stress area shall be calculated from the mean of the mean root and pitch diameters of Class 3 external threads as follows:

$$A_s = 0.7854 [D - (0.9743/n)]^2 \quad (A3.1)$$

where:

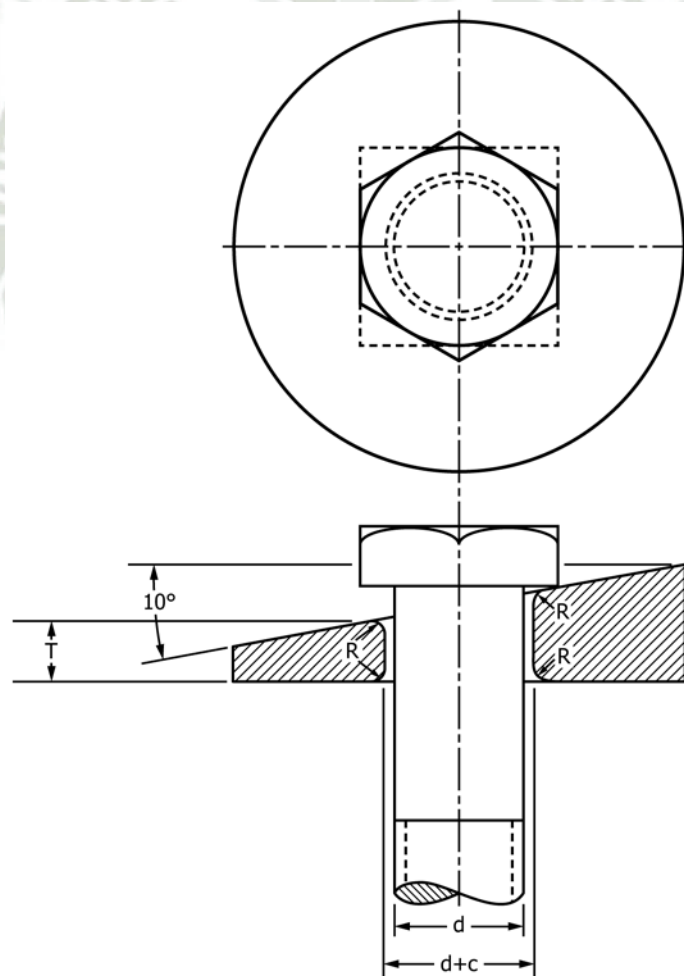
- $A_s$  = stress area, in.<sup>2</sup>,
- $D$  = nominal diameter, in., and
- $n$  = number of threads per inch.

**A3.2.1.5 Tension Testing of Full-Size Bolts with a Wedge—**

The purpose of this test is to obtain the tensile strength and demonstrate the “head quality” and ductility of a bolt with a

standard head by subjecting it to eccentric loading. The ultimate load on the bolt shall be determined as described in A3.2.1.4, except that a 10° wedge shall be placed under the same bolt previously tested for the proof load (see A3.2.1.1). The bolt head shall be so placed that no corner of the hexagon or square takes a bearing load, that is, a flat of the head shall be aligned with the direction of uniform thickness of the wedge (Fig. A3.2). The wedge shall have an included angle between its faces as shown in Table A3.1 and shall have a thickness of one-half of the nominal bolt diameter at the short side of the hole. The hole in the wedge shall have the following clearance over the nominal size of the bolt, and its edges, top and bottom, shall be rounded to the following radius:

Nominal Bolt Size, in.	Clearance in Hole, in. (mm)	Radius on Corners of Hole, in. (mm)
¼ to ½	0.030 (0.76)	0.030 (0.76)
⅝ to ¾	0.050 (1.3)	0.060 (1.5)
7/8 to 1	0.063 (1.5)	0.060 (1.5)
1 ⅛ to 1 ¼	0.063 (1.5)	0.125 (3.2)
1 ½ to 1 ½	0.094 (2.4)	0.125 (3.2)



- $c$  = Clearance of wedge hole
- $d$  = Diameter of bolt
- $R$  = Radius
- $T$  = Thickness of wedge at short side of hole equal to one-half diameter of bolt

**FIG. A3.2 Wedge Test Detail**

TABLE A3.1 Tension Test Wedge Angles

Nominal Product Size, in.	Degrees	
	Bolts	Studs and Flange Bolts
1/4 – 1	10	6
Over 1	6	4

A3.2.1.6 *Wedge Testing of HT Bolts Threaded to Head*—For heat-treated bolts that are threaded 1 diameter and closer to the underside of the head, the wedge angle shall be 6° for sizes 1/4 through 3/4 in. (6.35 to 19.0 mm) and 4° for sizes over 3/4 in.

A3.2.1.7 *Tension Testing of Bolts Machined to Round Test Specimens*:

(1) Bolts under 1 1/2 in. (38 mm) in nominal diameter which require machined tests shall preferably use a standard 1/2-in., (13-mm) round 2-in. (50-mm) gauge length test specimen (Fig. 4); however, bolts of small cross-section that will not permit the taking of this standard test specimen shall use one of the small-size-specimens-proportional-to-standard (Fig. 4) and the specimen shall have a reduced section as large as possible. In all cases, the longitudinal axis of the specimen shall be concentric with the axis of the bolt; the head and threaded section of the bolt may be left intact, as in Fig. A3.3 and Fig. A3.4, or shaped to fit the holders or grips of the testing machine so that the load is applied axially. The gauge length for measuring the elongation shall be four times the diameter of the specimen.

(2) For bolts 1 1/2 in. and over in nominal diameter, a standard 1/2-in. round 2-in. gauge length test specimen shall be turned from the bolt, having its axis midway between the center and outside surface of the body of the bolt as shown in Fig. A3.5.

(3) Machined specimens are to be tested in tension to determine the properties prescribed by the product specifications. The methods of testing and determination of properties shall be in accordance with Section 14 of these test methods.

### A3.3 Hardness Tests for Externally Threaded Fasteners

A3.3.1 When specified, externally threaded fasteners shall be hardness tested. Fasteners with hexagonal or square heads shall be Brinell or Rockwell hardness tested. For hexagonal and square head bolts; test shall be conducted on the wrench flats, top of head, unthreaded shank, end of bolt or at the arbitration location. For studs, products without parallel wrench flats and for head styles other than hexagonal and

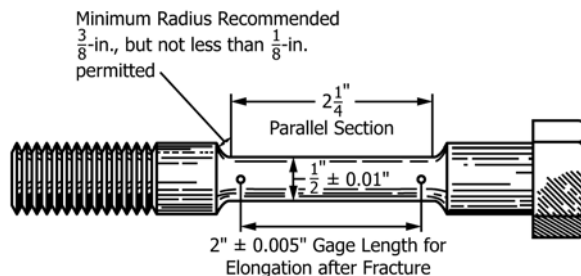
square; tests shall be conducted on the unthreaded shank, end of the bolt or stud or at the arbitration location. Due to possible distortion from the Brinell load, care should be taken that this test meets the requirements of Section 17 of these test methods where the Brinell hardness test is impractical, the Rockwell hardness test shall be substituted. Rockwell hardness test procedures shall conform to Section 18 of these test methods.

A3.3.2 In cases where a dispute exists between buyer and seller as to whether externally threaded fasteners meet or exceed the hardness limit of the product specification, for purposes of arbitration, hardness may be taken on two transverse sections through a representative sample fastener selected at random. Hardness readings shall be taken at the locations shown in Fig. A3.6. All hardness values must conform with the hardness limit of the product specification in order for the fasteners represented by the sample to be considered in compliance. This provision for arbitration of a dispute shall not be used to accept clearly rejectable fasteners.

### A3.4 Testing of Nuts

A3.4.1 *Hardness Test*—Rockwell hardness of nuts shall be determined on the top or bottom face of the nut. Brinell hardness shall be determined on the side of the nuts. Either method may be used at the option of the manufacturer, taking into account the size and grade of the nuts under test. When the standard Brinell hardness test results in deforming the nut it will be necessary to use a minor load or substitute a Rockwell hardness test.

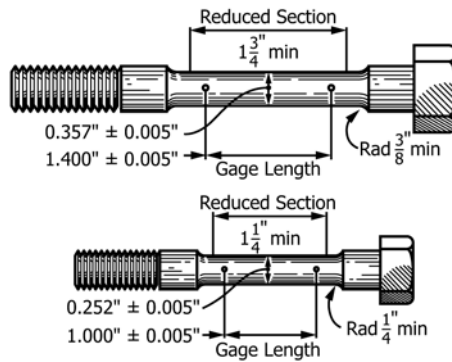
A3.4.2 *Cross Sectional Hardness Test*—Nuts whose proof stress requires a load exceeding 160 000 lb. shall, unless otherwise specified in the purchase order, contract or product specification, be considered too large for full size proof load testing and shall be subjected to a cross sectional hardness test. Sample nuts shall be sectioned laterally at approximately one half (1/2) of the nut height. Such samples need not be threaded, but shall be part of the manufacturing lot, including heat treatment. All tests shall be conducted using Rockwell Hardness test scales. Two sets of three readings shall be taken in locations ~180° apart (See Fig. A3.7). All readings shall be reported when certification is required and shall meet the hardness requirements listed in the product specification. The readings shall be taken across the section of the nut at the following positions:



NOTE 1—Metric equivalent: 1 in. = 25.4 mm.

FIG. A3.3 Tension Test Specimen for Bolt with Turned-Down Shank





NOTE 1—Metric equivalent: 1 in. = 25.4 mm.

FIG. A3.4 Examples of Small Size Specimens Proportional to Standard 2-in. Gauge Length Specimen

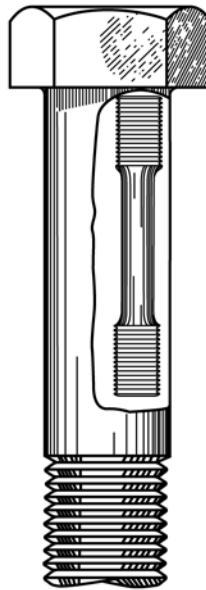
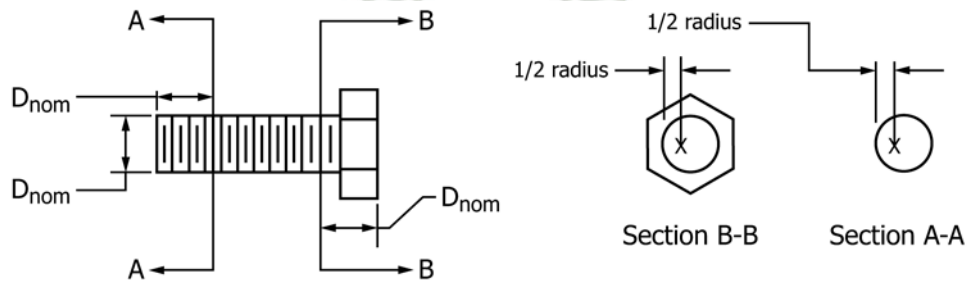


FIG. A3.5 Location of Standard Round 2-in. Gauge Length Tension Test Specimen When Turned from Large Size Bolt



X = Location of Hardness Impressions

FIG. A3.6 Hardness Test Locations for Bolts in a Dispute

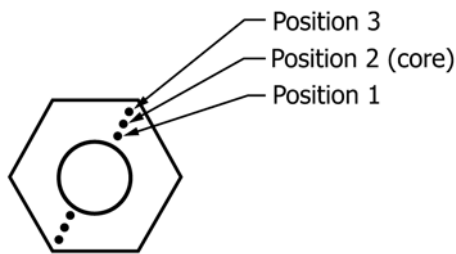


FIG. A3.7 Hardness Test Locations

Position 1—as close as practical to the major diameter (if threaded) or hole side wall (if blank), but no closer than 2-1/2 times the diameter of the indenter.

Position 2—at the core (halfway between the major diameter (if threaded) or hole side wall, if blank) and a corner of the nut.

Position 3—as close as practical to the corner of the nut, but no closer than 2-1/2 times the diameter of the indenter.

## A4. STEEL ROUND WIRE PRODUCTS

### A4.1 Scope

A4.1.1 This annex contains testing requirements for Round Wire Products that are specific to the product. The requirements contained in this annex are supplementary to those found in the general section of this specification. In the case of conflict between requirements provided in this annex and those found in the general section of this specification, the requirements of this annex shall prevail. In the case of conflict between requirements provided in this annex and requirements found in product specifications, the requirements found in the product specification shall prevail.

### A4.2 Apparatus

A4.2.1 *Gripping Devices*—Grips of either the wedge or snubbing types as shown in Figs. A4.1 and A4.2 shall be used (Note A4.1). When using grips of either type, care shall be taken that the axis of the test specimen is located approximately at the center line of the head of the testing machine (Note A4.2). When using wedge grips the liners used behind the grips shall be of the proper thickness.

NOTE A4.1—Testing machines usually are equipped with wedge grips. These wedge grips, irrespective of the type of testing machine, may be referred to as the “usual type” of wedge grips. The use of fine (180 or 240) grit abrasive cloth in the “usual” wedge type grips, with the abrasive contacting the wire specimen, can be helpful in reducing specimen

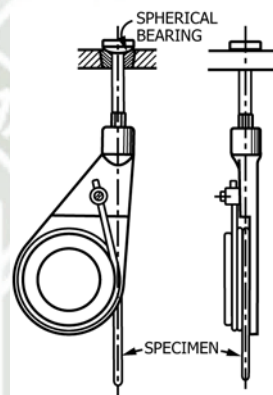


FIG. A4.2 Snubbing-Type Gripping Device

slipping and breakage at the grip edges at tensile loads up to about 1000 pounds. For tests of specimens of wire which are liable to be cut at the edges by the “usual type” of wedge grips, the snubbing type gripping device has proved satisfactory.

For testing round wire, the use of cylindrical seat in the wedge gripping device is optional.

NOTE A4.2—Any defect in a testing machine which may cause nonaxial application of load should be corrected.

A4.2.2 *Pointed Micrometer*—A micrometer with a pointed spindle and anvil suitable for reading the dimensions of the wire specimen at the fractured ends to the nearest 0.001 in. (0.025 mm) after breaking the specimen in the testing machine shall be used.

### A4.3 Test Specimens

A4.3.1 Test specimens having the full cross-sectional area of the wire they represent shall be used. The standard gauge length of the specimens shall be 10 in. (254 mm). However, if the determination of elongation values is not required, any convenient gauge length is permissible. The total length of the specimens shall be at least equal to the gauge length (10 in.) plus twice the length of wire required for the full use of the grip employed. For example, depending upon the type of testing machine and grips used, the minimum total length of specimen may vary from 14 to 24 in. (360 to 610 mm) for a 10-in. gauge length specimen.

A4.3.2 Any specimen breaking in the grips shall be discarded and a new specimen tested.

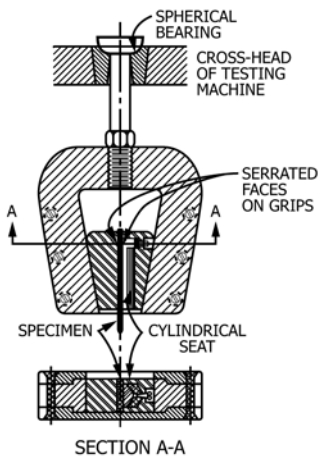


FIG. A4.1 Wedge-Type Gripping Device

#### **A4.4 Elongation**

A4.4.1 In determining permanent elongation, the ends of the fractured specimen shall be carefully fitted together and the distance between the gauge marks measured to the nearest 0.01 in. (0.25 mm) with dividers and scale or other suitable device. The elongation is the increase in length of the gauge length, expressed as a percentage of the original gauge length. In recording elongation values, both the percentage increase and the original gauge length shall be given.

A4.4.2 In determining total elongation (elastic plus plastic extension) autographic or extensometer methods may be employed.

A4.4.3 If fracture takes place outside of the middle third of the gauge length, the elongation value obtained may not be representative of the material.

#### **A4.5 Reduction of Area**

A4.5.1 The ends of the fractured specimen shall be carefully fitted together and the dimensions of the smallest cross section measured to the nearest 0.001 in. (0.025 mm) with a pointed micrometer. The difference between the area thus found and the area of the original cross section, expressed as a percentage of the original area, is the reduction of area.

A4.5.2 The reduction of area test is not recommended in wire diameters less than 0.092 in. (2.34 mm) due to the difficulties of measuring the reduced cross sections.

#### **A4.6 Rockwell Hardness Test**

A4.6.1 On heat-treated wire of diameter 0.100 in. (2.54 mm) and larger, the specimen shall be flattened on two parallel sides by grinding before testing. The hardness test is

not recommended for any diameter of hard drawn wire or heat-treated wire less than 0.100 in. (2.54 mm) in diameter. For round wire, the tensile strength test is greatly preferred over the hardness test.

#### **A4.7 Wrap Test**

A4.7.1 This test is used as a means for testing the ductility of certain kinds of wire.

A4.7.2 The test consists of coiling the wire in a closely spaced helix tightly against a mandrel of a specified diameter for a required number of turns. (Unless other specified, the required number of turns shall be five.) The wrapping may be done by hand or a power device. The wrapping rate may not exceed 15 turns per min. The mandrel diameter shall be specified in the relevant wire product specification.

A4.7.3 The wire tested shall be considered to have failed if the wire fractures or if any longitudinal or transverse cracks develop which can be seen by the unaided eye after the first complete turn. Wire which fails in the first turn shall be retested, as such fractures may be caused by bending the wire to a radius less than specified when the test starts.

#### **A4.8 Coiling Test**

A4.8.1 This test is used to determine if imperfections are present to the extent that they may cause cracking or splitting during spring coiling and spring extension. A coil of specified length is closed wound on an arbor of a specified diameter. The closed coil is then stretched to a specified permanent increase in length and examined for uniformity of pitch with no splits or fractures. The required arbor diameter, closed coil length, and permanent coil extended length increase may vary with wire diameter, properties, and type.

### **A5. NOTES ON SIGNIFICANCE OF NOTCHED-BAR IMPACT TESTING**

#### **A5.1 Notch Behavior**

A5.1.1 The Charpy and Izod type tests bring out notch behavior (brittleness versus ductility) by applying a single overload of stress. The energy values determined are quantitative comparisons on a selected specimen but cannot be converted into energy values that would serve for engineering design calculations. The notch behavior indicated in an individual test applies only to the specimen size, notch geometry, and testing conditions involved and cannot be generalized to other sizes of specimens and conditions.

A5.1.2 The notch behavior of the face-centered cubic metals and alloys, a large group of nonferrous materials and the austenitic steels can be judged from their common tensile properties. If they are brittle in tension they will be brittle when notched, while if they are ductile in tension, they will be ductile when notched, except for unusually sharp or deep notches (much more severe than the standard Charpy or Izod specimens). Even low temperatures do not alter this characteristic of

these materials. In contrast, the behavior of the ferritic steels under notch conditions cannot be predicted from their properties as revealed by the tension test. For the study of these materials the Charpy and Izod type tests are accordingly very useful. Some metals that display normal ductility in the tension test may nevertheless break in brittle fashion when tested or when used in the notched condition. Notched conditions include restraints to deformation in directions perpendicular to the major stress, or multiaxial stresses, and stress concentrations. It is in this field that the Charpy and Izod tests prove useful for determining the susceptibility of a steel to notch-brittle behavior though they cannot be directly used to appraise the serviceability of a structure.

A5.1.3 The testing machine itself must be sufficiently rigid or tests on high-strength low-energy materials will result in excessive elastic energy losses either upward through the pendulum shaft or downward through the base of the machine. If the anvil supports, the pendulum striking edge, or the

machine foundation bolts are not securely fastened, tests on ductile materials in the range of 80 ft-lbf (108 J) may actually indicate values in excess of 90 to 100 ft-lbf (122 to 136 J).

## A5.2 Notch Effect

A5.2.1 The notch results in a combination of multiaxial stresses associated with restraints to deformation in directions perpendicular to the major stress, and a stress concentration at the base of the notch. A severely notched condition is generally not desirable, and it becomes of real concern in those cases in which it initiates a sudden and complete failure of the brittle type. Some metals can be deformed in a ductile manner even down to the low temperatures of liquid air, while others may crack. This difference in behavior can be best understood by considering the cohesive strength of a material (or the property that holds it together) and its relation to the yield point. In cases of brittle fracture, the cohesive strength is exceeded before significant plastic deformation occurs and the fracture appears crystalline. In cases of the ductile or shear type of failure, considerable deformation precedes the final fracture and the broken surface appears fibrous instead of crystalline. In intermediate cases the fracture comes after a moderate amount of deformation and is part crystalline and part fibrous in appearance.

A5.2.2 When a notched bar is loaded, there is a normal stress across the base of the notch which tends to initiate fracture. The property that keeps it from cleaving, or holds it together, is the “cohesive strength.” The bar fractures when the normal stress exceeds the cohesive strength. When this occurs without the bar deforming it is the condition for brittle fracture.

A5.2.3 In testing, though not in service because of side effects, it happens more commonly that plastic deformation precedes fracture. In addition to the normal stress, the applied load also sets up shear stresses which are about 45° to the normal stress. The elastic behavior terminates as soon as the shear stress exceeds the shear strength of the material and deformation or plastic yielding sets in. This is the condition for ductile failure.

A5.2.4 This behavior, whether brittle or ductile, depends on whether the normal stress exceeds the cohesive strength before the shear stress exceeds the shear strength. Several important facts of notch behavior follow from this. If the notch is made sharper or more drastic, the normal stress at the root of the notch will be increased in relation to the shear stress and the bar will be more prone to brittle fracture (see [Table A5.1](#)). Also,

as the speed of deformation increases, the shear strength increases and the likelihood of brittle fracture increases. On the other hand, by raising the temperature, leaving the notch and the speed of deformation the same, the shear strength is lowered and ductile behavior is promoted, leading to shear failure.

A5.2.5 Variations in notch dimensions will seriously affect the results of the tests. Tests on E4340 steel specimens<sup>7</sup> have shown the effect of dimensional variations on Charpy results (see [Table A5.1](#)).

## A5.3 Size Effect

A5.3.1 Increasing either the width or the depth of the specimen tends to increase the volume of metal subject to distortion, and by this factor tends to increase the energy absorption when breaking the specimen. However, any increase in size, particularly in width, also tends to increase the degree of restraint and by tending to induce brittle fracture, may decrease the amount of energy absorbed. Where a standard-size specimen is on the verge of brittle fracture, this is particularly true, and a double-width specimen may actually require less energy for rupture than one of standard width.

A5.3.2 In studies of such effects where the size of the material precludes the use of the standard specimen, as for example when the material is ¼-in. plate, subsize specimens are necessarily used. Such specimens (see [Fig. 6](#) of Test Methods [E23](#)) are based on the Type A specimen of [Fig. 4](#) of Test Methods [E23](#).

A5.3.3 General correlation between the energy values obtained with specimens of different size or shape is not feasible, but limited correlations may be established for specification purposes on the basis of special studies of particular materials and particular specimens. On the other hand, in a study of the relative effect of process variations, evaluation by use of some arbitrarily selected specimen with some chosen notch will in most instances place the methods in their proper order.

## A5.4 Effects of Testing Conditions

A5.4.1 The testing conditions also affect the notch behavior. So pronounced is the effect of temperature on the behavior of steel when notched that comparisons are frequently made by

<sup>7</sup> Fahey, N. H., “Effects of Variables in Charpy Impact Testing,” *Materials Research & Standards*, Vol 1, No. 11, November, 1961, p. 872.

**TABLE A5.1 Effect of Varying Notch Dimensions on Standard Specimens**

	High-Energy Specimens, ft-lbf (J)	Medium-Energy Specimens, ft-lbf (J)	Low-Energy Specimens, ft-lbf (J)
Specimen with standard dimensions	76.0 ± 3.8 (103.0 ± 5.2)	44.5 ± 2.2 (60.3 ± 3.0)	12.5 ± 1.0 (16.9 ± 1.4)
Depth of notch, 0.084 in. (2.13 mm) <sup>A</sup>	72.2 (97.9)	41.3 (56.0)	11.4 (15.5)
Depth of notch, 0.0805 in. (2.04 mm) <sup>A</sup>	75.1 (101.8)	42.2 (57.2)	12.4 (16.8)
Depth of notch, 0.0775 in. (1.77 mm) <sup>A</sup>	76.8 (104.1)	45.3 (61.4)	12.7 (17.2)
Depth of notch, 0.074 in. (1.57 mm) <sup>A</sup>	79.6 (107.9)	46.0 (62.4)	12.8 (17.3)
Radius at base of notch, 0.005 in. (0.127 mm) <sup>B</sup>	72.3 (98.0)	41.7 (56.5)	10.8 (14.6)
Radius at base of notch, 0.015 in. (0.381 mm) <sup>B</sup>	80.0 (108.5)	47.4 (64.3)	15.8 (21.4)

<sup>A</sup> Standard 0.079 ± 0.002 in. (2.00 ± 0.05 mm).

<sup>B</sup> Standard 0.010 ± 0.001 in. (0.25 ± 0.025 mm).

examining specimen fractures and by plotting energy value and fracture appearance versus temperature from tests of notched bars at a series of temperatures. When the test temperature has been carried low enough to start cleavage fracture, there may be an extremely sharp drop in impact value or there may be a relatively gradual falling off toward the lower temperatures. This drop in energy value starts when a specimen begins to exhibit some crystalline appearance in the fracture. The transition temperature at which this embrittling effect takes place varies considerably with the size of the part or test specimen and with the notch geometry.

A5.4.2 Some of the many definitions of transition temperature currently being used are: (1) the lowest temperature at which the specimen exhibits 100 % fibrous fracture, (2) the temperature where the fracture shows a 50 % crystalline and a 50 % fibrous appearance, (3) the temperature corresponding to the energy value 50 % of the difference between values obtained at 100 % and 0 % fibrous fracture, and (4) the temperature corresponding to a specific energy value.

A5.4.3 A problem peculiar to Charpy-type tests occurs when high-strength, low-energy specimens are tested at low temperatures. These specimens may not leave the machine in the direction of the pendulum swing but rather in a sidewise direction. To ensure that the broken halves of the specimens do not rebound off some component of the machine and contact the pendulum before it completes its swing, modifications may be necessary in older model machines. These modifications differ with machine design. Nevertheless the basic problem is the same in that provisions must be made to prevent rebounding of the fractured specimens into any part of the swinging pendulum. Where design permits, the broken specimens may be deflected out of the sides of the machine and yet in other designs it may be necessary to contain the broken specimens within a certain area until the pendulum passes through the anvils. Some low-energy high-strength steel specimens leave impact machines at speeds in excess of 50 ft (15.3 m)/s

although they were struck by a pendulum traveling at speeds approximately 17 ft (5.2 m)/s. If the force exerted on the pendulum by the broken specimens is sufficient, the pendulum will slow down and erroneously high energy values will be recorded. This problem accounts for many of the inconsistencies in Charpy results reported by various investigators within the 10 to 25-ft-lbf (14 to 34 J) range. The Apparatus Section (the paragraph regarding Specimen Clearance) of Test Methods E23 discusses the two basic machine designs and a modification found to be satisfactory in minimizing jamming.

### **A5.5 Velocity of Straining**

A5.5.1 Velocity of straining is likewise a variable that affects the notch behavior of steel. The impact test shows somewhat higher energy absorption values than the static tests above the transition temperature and yet, in some instances, the reverse is true below the transition temperature.

### **A5.6 Correlation with Service**

A5.6.1 While Charpy or Izod tests may not directly predict the ductile or brittle behavior of steel as commonly used in large masses or as components of large structures, these tests can be used as acceptance tests of identity for different lots of the same steel or in choosing between different steels, when correlation with reliable service behavior has been established. It may be necessary to make the tests at properly chosen temperatures other than room temperature. In this, the service temperature or the transition temperature of full-scale specimens does not give the desired transition temperatures for Charpy or Izod tests since the size and notch geometry may be so different. Chemical analysis, tension, and hardness tests may not indicate the influence of some of the important processing factors that affect susceptibility to brittle fracture nor do they comprehend the effect of low temperatures in inducing brittle behavior.

**A6. PROCEDURE FOR CONVERTING PERCENTAGE ELONGATION OF A STANDARD ROUND TENSION TEST SPECIMEN TO EQUIVALENT PERCENTAGE ELONGATION OF A STANDARD FLAT SPECIMEN**

**A6.1 Scope**

A6.1.1 This method specifies a procedure for converting percentage elongation after fracture obtained in a standard 0.500-in. (12.7-mm) diameter by 2-in. (51-mm) gauge length test specimen to standard flat test specimens ½ in. by 2 in. and 1½ in. by 8 in. (38.1 by 203 mm).

**A6.2 Basic Equation**

A6.2.1 The conversion data in this method are based on an equation by Bertella,<sup>8</sup> and used by Oliver<sup>9</sup> and others. The relationship between elongations in the standard 0.500-in. diameter by 2.0-in. test specimen and other standard specimens can be calculated as follows:

$$e = e_o \left[ 4.47 \left( \sqrt{A} \right) / L \right]^a \tag{A6.1}$$

where:

- $e_o$  = percentage elongation after fracture on a standard test specimen having a 2-in. gauge length and 0.500-in. diameter,
- $e$  = percentage elongation after fracture on a standard test specimen having a gauge length L and a cross-sectional area A, and
- $a$  = constant characteristic of the test material.

**A6.3 Application**

A6.3.1 In applying the above equation the constant  $a$  is characteristic of the test material. The value  $a = 0.4$  has been found to give satisfactory conversions for carbon, carbon-manganese, molybdenum, and chromium-molybdenum steels within the tensile strength range of 40 000 to 85 000 psi (275 to 585 MPa) and in the hot-rolled, in the hot-rolled and normalized, or in the annealed condition, with or without tempering. Note that the cold reduced and quenched and tempered states are excluded. For annealed austenitic stainless steels, the value  $a = 0.127$  has been found to give satisfactory conversions.

A6.3.2 **Table A6.1** has been calculated taking  $a = 0.4$ , with the standard 0.500-in. (12.7-mm) diameter by 2-in. (51-mm) gauge length test specimen as the reference specimen. In the case of the subsize specimens 0.350 in. (8.89 mm) in diameter by 1.4-in. (35.6-mm) gauge length, and 0.250-in. (6.35-mm) diameter by 1.0-in. (25.4-mm) gauge length the factor in the equation is 4.51 instead of 4.47. The small error introduced by using **Table A6.1** for the subsize specimens may be neglected. **Table A6.2** for annealed austenitic steels has been calculated taking  $a = 0.127$ , with the standard 0.500-in. diameter by 2-in. gauge length test specimen as the reference specimen.

**TABLE A6.1 Carbon and Alloy Steels—Material Constant  $a = 0.4$ . Multiplication Factors for Converting Percent Elongation from ½-in. Diameter by 2-in. Gauge Length Standard Tension Test Specimen to Standard ½ by 2-in. and 1½ by 8-in. Flat Specimens**

Thickness, in.	½ by 2-in. Specimen	1½ by 8-in. Specimen	Thickness in.	1½ by 8-in. Specimen
0.025	0.574	...	0.800	0.822
0.030	0.596	...	0.850	0.832
0.035	0.614	...	0.900	0.841
0.040	0.631	...	0.950	0.850
0.045	0.646	...	1.000	0.859
0.050	0.660	...	1.125	0.880
0.055	0.672	...	1.250	0.898
0.060	0.684	...	1.375	0.916
0.065	0.695	...	1.500	0.932
0.070	0.706	...	1.625	0.947
0.075	0.715	...	1.750	0.961
0.080	0.725	...	1.875	0.974
0.085	0.733	...	2.000	0.987
0.090	0.742	0.531	2.125	0.999
0.100	0.758	0.542	2.250	1.010
0.110	0.772	0.553	2.375	1.021
0.120	0.786	0.562	2.500	1.032
0.130	0.799	0.571	2.625	1.042
0.140	0.810	0.580	2.750	1.052
0.150	0.821	0.588	2.875	1.061
0.160	0.832	0.596	3.000	1.070
0.170	0.843	0.603	3.125	1.079
0.180	0.852	0.610	3.250	1.088
0.190	0.862	0.616	3.375	1.096
0.200	0.870	0.623	3.500	1.104
0.225	0.891	0.638	3.625	1.112
0.250	0.910	0.651	3.750	1.119
0.275	0.928	0.664	3.875	1.127
0.300	0.944	0.675	4.000	1.134
0.325	0.959	0.686	...	...
0.350	0.973	0.696	...	...
0.375	0.987	0.706	...	...
0.400	1.000	0.715	...	...
0.425	1.012	0.724	...	...
0.450	1.024	0.732	...	...
0.475	1.035	0.740	...	...
0.500	1.045	0.748	...	...
0.525	1.056	0.755	...	...
0.550	1.066	0.762	...	...
0.575	1.075	0.770	...	...
0.600	1.084	0.776	...	...
0.625	1.093	0.782	...	...
0.650	1.101	0.788	...	...
0.675	1.110	...	...	...
0.700	1.118	0.800	...	...
0.725	1.126	...	...	...
0.750	1.134	0.811	...	...

A6.3.3 Elongation given for a standard 0.500-in. diameter by 2-in. gauge length specimen may be converted to elongation for ½ in. by 2 in. or 1½ in. by 8-in. (38.1 by 203-mm) flat specimens by multiplying by the indicated factor in **Table A6.1** and **Table A6.2**.

A6.3.4 These elongation conversions shall not be used where the width to thickness ratio of the test piece exceeds 20, as in sheet specimens under 0.025 in. (0.635 mm) in thickness.

<sup>8</sup> Bertella, C. A., *Giornale del Genio Civile*, Vol 60, 1922, p. 343.  
<sup>9</sup> Oliver, D. A., *Proceedings of the Institution of Mechanical Engineers*, 1928, p. 827.

**TABLE A6.2 Annealed Austenitic Stainless Steels—Material Constant  $a = 0.127$ . Multiplication Factors for Converting Percent Elongation from ½-in. Diameter by 2-in. Gauge Length Standard Tension Test Specimen to Standard ½ by 2-in. and 1½ by 8-in. Flat Specimens**

Thickness, in.	½ by 2-in. Specimen	1½ by 8-in. Specimen	Thickness, in.	1½ by 8-in. Specimen
0.025	0.839	...	0.800	0.940
0.030	0.848	...	0.850	0.943
0.035	0.857	...	0.900	0.947
0.040	0.864	...	0.950	0.950
0.045	0.870	...	1.000	0.953
0.050	0.876	...	1.125	0.960
0.055	0.882	...	1.250	0.966
0.060	0.886	...	1.375	0.972
0.065	0.891	...	1.500	0.978
0.070	0.895	...	1.625	0.983
0.075	0.899	...	1.750	0.987
0.080	0.903	...	1.875	0.992
0.085	0.906	...	2.000	0.996
0.090	0.909	0.818	2.125	1.000
0.095	0.913	0.821	2.250	1.003
0.100	0.916	0.823	2.375	1.007
0.110	0.921	0.828	2.500	1.010
0.120	0.926	0.833	2.625	1.013
0.130	0.931	0.837	2.750	1.016
0.140	0.935	0.841	2.875	1.019
0.150	0.940	0.845	3.000	1.022
0.160	0.943	0.848	3.125	1.024
0.170	0.947	0.852	3.250	1.027
0.180	0.950	0.855	3.375	1.029
0.190	0.954	0.858	3.500	1.032
0.200	0.957	0.860	3.625	1.034
0.225	0.964	0.867	3.750	1.036
0.250	0.970	0.873	3.875	1.038
0.275	0.976	0.878	4.000	1.041
0.300	0.982	0.883	...	...
0.325	0.987	0.887	...	...
0.350	0.991	0.892	...	...
0.375	0.996	0.895	...	...
0.400	1.000	0.899	...	...
0.425	1.004	0.903	...	...
0.450	1.007	0.906	...	...
0.475	1.011	0.909	...	...
0.500	1.014	0.912	...	...
0.525	1.017	0.915	...	...
0.550	1.020	0.917	...	...
0.575	1.023	0.920	...	...
0.600	1.026	0.922	...	...
0.625	1.029	0.925	...	...
0.650	1.031	0.927	...	...
0.675	1.034	...	...	...
0.700	1.036	0.932	...	...
0.725	1.038	...	...	...
0.750	1.041	0.936	...	...

A6.3.5 While the conversions are considered to be reliable within the stated limitations and may generally be used in specification writing where it is desirable to show equivalent elongation requirements for the several standard ASTM tension specimens covered in Test Methods A370, consideration must be given to the metallurgical effects dependent on the thickness of the material as processed.

**A7. TESTING MULTI-WIRE STRAND**

This annex has been replaced by Test Methods **A1061/A1061M**, and procedures for the tension testing of multi-wire strand for prestressed concrete have been integrated into the relevant product specifications.

**A8. ROUNDING OF TEST DATA**
**A8.1 Rounding**

A8.1.1 An observed value or a calculated value shall be rounded off in accordance with the applicable product specification. In the absence of a specified procedure, the rounding-off method of Practice **E29** shall be used.

A8.1.1.1 Values shall be rounded up or rounded down as determined by the rules of Practice **E29**.

A8.1.1.2 In the special case of rounding the number “5” when no additional numbers other than “0” follow the “5,” rounding shall be done in the direction of the specification limits if following Practice **E29** would cause rejection of material.

A8.1.2 Recommended levels for rounding reported values of test data are given in **Table A8.1**. These values are designed to provide uniformity in reporting and data storage, and should be used in all cases except where they conflict with specific requirements of a product specification.

NOTE A8.1—To minimize cumulative errors, whenever possible, values should be carried to at least one figure beyond that of the final (rounded) value during intervening calculations (such as calculation of stress from load and area measurements) with rounding occurring as the final operation. The precision may be less than that implied by the number of significant figures.

**TABLE A8.1 Recommended Values for Rounding Test Data**

Test Quantity	Test Data Range	Rounded Value <sup>A</sup>
Yield Point	up to 50 000 psi, excl (up to 50 ksi)	100 psi (0.1 ksi)
Yield Strength	50 000 to 100 000 psi, excl (50 to 100 ksi)	500 psi (0.5 ksi)
Tensile Strength	100 000 psi and above (100 ksi and above)	1000 psi (1.0 ksi)
	up to 500 MPa, excl	1 MPa
	500 to 1000 MPa, excl	5 MPa
	1000 MPa and above	10 MPa
Elongation	0 to 10 %, excl	0.5 %
	10 % and above	1 %
Reduction of Area	0 to 10 %, excl	0.5 %
	10 % and above	1 %
Impact Energy	0 to 240 ft·lbf (or 0 to 325 J)	1 ft·lbf (or 1 J) <sup>B</sup>
Brinell Hardness	all values	tabular value <sup>C</sup>
Rockwell Hardness	all scales	1 Rockwell Number

<sup>A</sup> Round test data to the nearest integral multiple of the values in this column. If the data value is exactly midway between two rounded values, round in accordance with **A8.1.1.2**.

<sup>B</sup> These units are not equivalent but the rounding occurs in the same numerical ranges for each (1 ft·lbf = 1.356 J).

<sup>C</sup> Round the mean diameter of the Brinell impression to the nearest 0.05 mm and report the corresponding Brinell hardness number read from the table without further rounding.



## A9. METHODS FOR TESTING STEEL REINFORCING BARS

The testing requirements for steel reinforcing bars contained in this annex have been integrated into the relevant product specifications.

### A10. PROCEDURE FOR USE AND CONTROL OF HEAT-CYCLE SIMULATION

#### A10.1 Purpose

A10.1.1 To ensure consistent and reproducible heat treatments of production forgings and the test specimens that represent them when the practice of heat-cycle simulation is used.

#### A10.2 Scope

A10.2.1 Generation and documentation of actual production time—temperature curves (MASTER CHARTS).

A10.2.2 Controls for duplicating the master cycle during heat treatment of production forgings. (Heat treating within the essential variables established during A1.2.1).

A10.2.3 Preparation of program charts for the simulator unit.

A10.2.4 Monitoring and inspection of the simulated cycle within the limits established by the ASME Code.

A10.2.5 Documentation and storage of all controls, inspections, charts, and curves.

#### A10.3 Referenced Documents

A10.3.1 *ASME Standards*:<sup>4</sup>ASME Boiler and Pressure Vessel Code Section III, latest edition.

ASME Boiler and Pressure Vessel Code Section VIII, Division 2, latest edition.

#### A10.4 Terminology

##### A10.4.1 Definitions:

A10.4.1.1 *master chart*—a record of the heat treatment received from a forging essentially identical to the production forgings that it will represent. It is a chart of time and temperature showing the output from thermocouples imbedded in the forging at the designated test immersion and test location or locations.

A10.4.1.2 *program chart*—the metallized sheet used to program the simulator unit. Time-temperature data from the master chart are manually transferred to the program chart.

A10.4.1.3 *simulator chart*—a record of the heat treatment that a test specimen had received in the simulator unit. It is a chart of time and temperature and can be compared directly to the master chart for accuracy of duplication.

A10.4.1.4 *simulator cycle*—one continuous heat treatment of a set of specimens in the simulator unit. The cycle includes heating from ambient, holding at temperature, and cooling. For example, a simulated austenitize and quench of a set of specimens would be one cycle; a simulated temper of the same specimens would be another cycle.

#### A10.5 Procedure

##### A10.5.1 Production Master Charts:

A10.5.1.1 Thermocouples shall be imbedded in each forging from which a master chart is obtained. Temperature shall be monitored by a recorder with resolution sufficient to clearly define all aspects of the heating, holding, and cooling process. All charts are to be clearly identified with all pertinent information and identification required for maintaining permanent records.

A10.5.1.2 Thermocouples shall be imbedded 180° apart if the material specification requires test locations 180° apart.

A10.5.1.3 One master chart (or two if required in accordance with A10.5.3.1) shall be produced to represent essentially identical forgings (same size and shape). Any change in size or geometry (exceeding rough machining tolerances) of a forging will necessitate that a new master cooling curve be developed.

A10.5.1.4 If more than one curve is required per master forging (180° apart) and a difference in cooling rate is achieved, then the most conservative curve shall be used as the master curve.

##### A10.5.2 Reproducibility of Heat Treatment Parameters on Production Forgings:

A10.5.2.1 All information pertaining to the quench and temper of the master forging shall be recorded on an appropriate permanent record, similar to the one shown in Table A10.1.

A10.5.2.2 All information pertaining to the quench and temper of the production forgings shall be appropriately recorded, preferably on a form similar to that used in A10.5.2.1. Quench records of production forgings shall be retained for future reference. The quench and temper record of the master forging shall be retained as a permanent record.

A10.5.2.3 A copy of the master forging record shall be stored with the heat treatment record of the production forging.

A10.5.2.4 The essential variables, as set forth on the heat treat record, shall be controlled within the given parameters on the production forging.

A10.5.2.5 The temperature of the quenching medium prior to quenching each production forging shall be equal to or lower than the temperature of the quenching medium prior to quenching the master forging.

A10.5.2.6 The time elapsed from opening the furnace door to quench for the production forging shall not exceed that elapsed for the master forging.

**TABLE A10.1 Heat-Treat Record-Essential Variables**

	Master Forging	Production Forging 1	Production Forging 2	Production Forging 3	Production Forging 4	Production Forging 5
Program chart number						
Time at temperature and actual temperature of heat treatment						
Method of cooling						
Forging thickness						
Thermocouple immersion						
Beneath buffer (yes/no)						
Forging number						
Product						
Material						
Thermocouple location—0 deg						
Thermocouple location—180 deg						
Quench tank No.						
Date of heat treatment						
Furnace number						
Cycle number						
Heat treater						
Starting quench medium temperature						
Time from furnace to quench						
Heating rate above 1000°F (538°C)						
Temperature upon removal from quench after 5 min						
Orientation of forging in quench						

A10.5.2.7 If the time parameter is exceeded in opening the furnace door to beginning of quench, the forging shall be placed back into the furnace and brought back up to equalization temperature.

A10.5.2.8 All forgings represented by the same master forging shall be quenched with like orientation to the surface of the quench bath.

A10.5.2.9 All production forgings shall be quenched in the same quench tank, with the same agitation as the master forging.

A10.5.2.10 *Uniformity of Heat Treat Parameters*—(1) The difference in actual heat treating temperature between production forgings and the master forging used to establish the simulator cycle for them shall not exceed  $\pm 25^\circ\text{F}$  ( $\pm 14^\circ\text{C}$ ) for the quench cycle. (2) The tempering temperature of the production forgings shall not fall below the actual tempering temperature of the master forging. (3) At least one contact surface thermocouple shall be placed on each forging in a production load. Temperature shall be recorded for all surface thermocouples on a Time Temperature Recorder and such records shall be retained as permanent documentation.

#### A10.5.3 Heat-Cycle Simulation:

A10.5.3.1 Program charts shall be made from the data recorded on the master chart. All test specimens shall be given the same heating rate above, the AC1, the same holding time and the same cooling rate as the production forgings.

A10.5.3.2 The heating cycle above the AC1, a portion of the holding cycle, and the cooling portion of the master chart shall be duplicated and the allowable limits on temperature and time, as specified in (a)–(c), shall be established for verification of the adequacy of the simulated heat treatment.

(a) *Heat Cycle Simulation of Test Coupon Heat Treatment for Quenched and Tempered Forgings and Bars*—If cooling rate data for the forgings and bars and cooling rate control devices for the test specimens are available, the test specimens may be heat-treated in the device.

(b) The test coupons shall be heated to substantially the same maximum temperature as the forgings or bars. The test

coupons shall be cooled at a rate similar to and no faster than the cooling rate representative of the test locations and shall be within  $25^\circ\text{F}$  ( $14^\circ\text{C}$ ) and 20 s at all temperatures after cooling begins. The test coupons shall be subsequently heat treated in accordance with the thermal treatments below the critical temperature including tempering and simulated post weld heat treatment.

(c) *Simulated Post Weld Heat Treatment of Test Specimens* (for ferritic steel forgings and bars)—Except for carbon steel (P Number 1, Section IX of the Code) forgings and bars with a nominal thickness or diameter of 2 in. (51 mm) or less, the test specimens shall be given a heat treatment to simulate any thermal treatments below the critical temperature that the forgings and bars may receive during fabrication. The simulated heat treatment shall utilize temperatures, times, and cooling rates as specified on the order. The total time at temperature(s) for the test material shall be at least 80 % of the total time at temperature(s) to which the forgings and bars are subjected during postweld heat treatment. The total time at temperature(s) for the test specimens may be performed in a single cycle.

A10.5.3.3 Prior to heat treatment in the simulator unit, test specimens shall be machined to standard sizes that have been determined to allow adequately for subsequent removal of decarb and oxidation.

A10.5.3.4 At least one thermocouple per specimen shall be used for continuous recording of temperature on an independent external temperature-monitoring source. Due to the sensitivity and design peculiarities of the heating chamber of certain equipment, it is mandatory that the hot junctions of control and monitoring thermocouples always be placed in the same relative position with respect to the heating source (generally infrared lamps).

A10.5.3.5 Each individual specimen shall be identified, and such identification shall be clearly shown on the simulator chart and simulator cycle record.

A10.5.3.6 The simulator chart shall be compared to the master chart for accurate reproduction of simulated quench in

accordance with **A10.5.3.2(a)**. If any one specimen is not heat treated within the acceptable limits of temperature and time, such specimen shall be discarded and replaced by a newly machined specimen. Documentation of such action and reasons for deviation from the master chart shall be shown on the simulator chart, and on the corresponding nonconformance report.

#### A10.5.4 Reheat Treatment and Retesting:

A10.5.4.1 In the event of a test failure, retesting shall be handled in accordance with rules set forth by the material specification.

A10.5.4.2 If retesting is permissible, a new test specimen shall be heat treated the same as previously. The production forging that it represents will have received the same heat treatment. If the test passes, the forging shall be acceptable. If it fails, the forging shall be rejected or shall be subject to reheat treatment if permissible.

A10.5.4.3 If reheat treatment is permissible, proceed as follows: (1) Reheat treatment same as original heat treatment

(time, temperature, cooling rate): Using new test specimens from an area as close as possible to the original specimens, repeat the austenitize and quench cycles twice, followed by the tempering cycle (double quench and temper). The production forging shall be given the identical double quench and temper as its test specimens above. (2) Reheat treatment using a new heat treatment practice. Any change in time, temperature, or cooling rate shall constitute a new heat treatment practice. A new master curve shall be produced and the simulation and testing shall proceed as originally set forth.

A10.5.4.4 In summation, each test specimen and its corresponding forging shall receive identical heat treatment or heat treatment; otherwise the testing shall be invalid.

A10.5.5 *Storage, Recall, and Documentation of Heat-Cycle Simulation Data*—All records pertaining to heat-cycle simulation shall be maintained and held for a period of ten years or as designed by the customer. Information shall be so organized that all practices can be verified by adequate documented records.

## REFERENCES

- (1) Griffin J.A., “Analysis of Data From Nist Technical Note 1858, ASTM A01.13,” Task Group meeting, San Antonio, TX, 5.4.16. [https://www.sfsa.org/misc/A370refs/1\\_Griffin\\_Analysis%20of%20Data%20from%20NIST%20TEchnical%20Note%201858.pdf](https://www.sfsa.org/misc/A370refs/1_Griffin_Analysis%20of%20Data%20from%20NIST%20TEchnical%20Note%201858.pdf)
- (2) Wallin K., Powerpoint presentation “Sub-sized Cvn Specimen Conversion Methodology, ASTM A01.13,” Task Group meeting, Tampa, FL, 11.18.15. [https://www.sfsa.org/misc/A370refs/2\\_Wallin%20Powerpoint%20Sub-size%20CVN%20Specimen%20Conversion%20Methodology.pdf](https://www.sfsa.org/misc/A370refs/2_Wallin%20Powerpoint%20Sub-size%20CVN%20Specimen%20Conversion%20Methodology.pdf)
- (3) Griffin, J.A., “A Literature Review to Assess the Reliability of the Conversion Factors for Sub-Size Specimens Shown in ASTM A370 Table 9.” <https://www.sfsa.org/publications/misc/Report%20to%20ASTM%20Table%209%20TG%20Table%209%20only%20version%202.pdf>
- (4) Lucon E., McCowan C.N., and Santoyo R.L. “Impact Characterization of 4340 and T200 Steels by Means of Standard, Sub-size and Miniaturized Charpy Specimens,” *NIST Technical Note 1858*. <http://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.1858.pdf>.
- (5) Lucon E., McCowan C.N., Santoyo R.L. “Impact Characterization of Line Pipe Steels by Means of Standard, Sub-size and Miniaturized Charpy Specimens,” *NIST Technical Note 1865*. <http://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.1865.pdf>.

## SUMMARY OF CHANGES

Committee A01 has identified the location of selected changes to this standard since the last issue (A370 – 17a) that may impact the use of this standard. (Approved Dec. 1, 2018.)

- (1) Added “nominal” to better define diameter in **Annex A3**.
- (2) Deleted statement in 19.1 that Test Method **A833** lacks a precision and bias statement.

Committee A01 has identified the location of selected changes to this standard since the last issue (A370 – 17) that may impact the use of this standard. (Approved Nov. 15, 2017.)

- (1) Increased range of values in Table 9 to 75 ft.lbf [102 J].
- (2) Replaced previous footnote A in Table 9 with new footnote A.
- (3) Added footnotes B and C to Table 9.
- (4) Added references (1) and (2) to References section.

Committee A01 has identified the location of selected changes to this standard since the last issue (A370 – 16) that may impact the use of this standard. (Approved Jan. 1, 2017.)

- (1) Added Section **30**.
- (2) Revised Section **32**.

Committee **A01** has identified the location of selected changes to this standard since the last issue (A370 – 15) that may impact the use of this standard. (Approved May 1, 2016.)

- (1) Removed previous Annex A7 and A9.
- (2) Added Precision and Bias statement (Section **31**).
- (3) Revised **Annex A3** to permit testing of parts greater than 8 inches in length using Method 1.

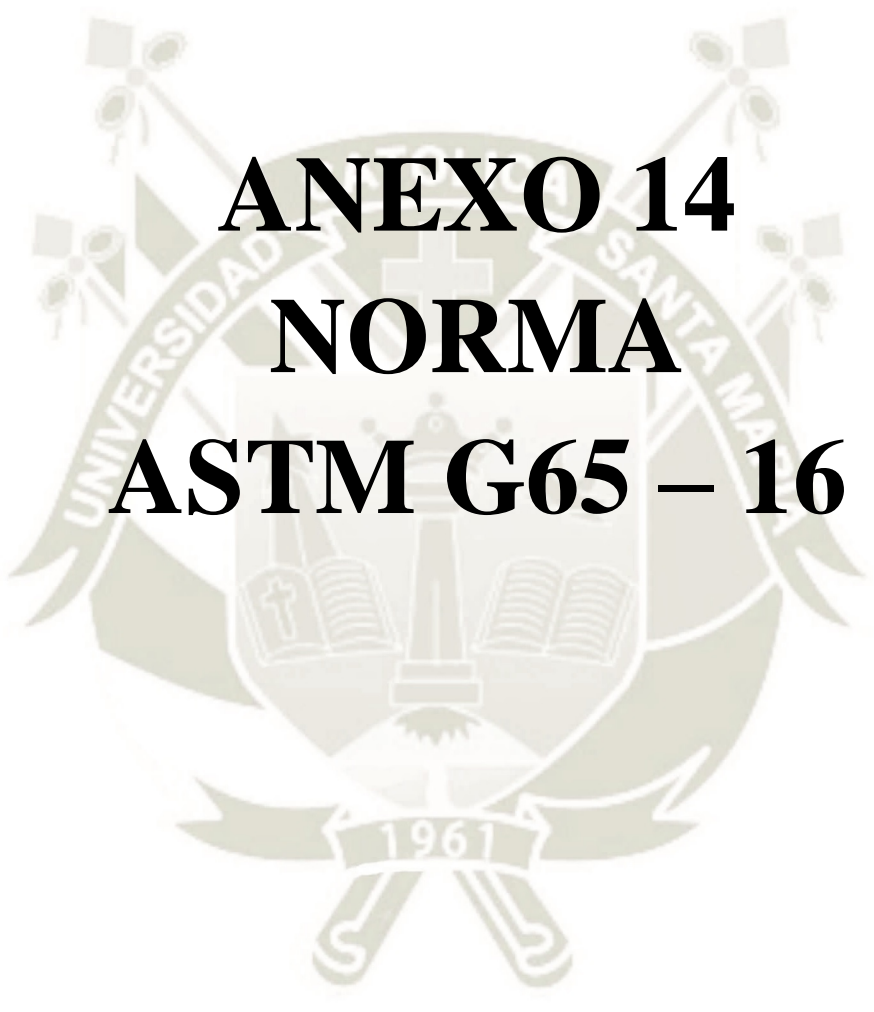
Committee **A01** has identified the location of selected changes to this standard since the last issue (A370 – 14) that may impact the use of this standard. (Approved Nov. 1, 2015.)

- (1) Revised **27.1, 14.3**.
- (2) Revised Footnote A of **Table 9**.
- (3) Added References section.
- (4) Added **A1058** to Section **2**.
- (5) Added **1.5.1**.

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**ANEXO 14**  
**NORMA**  
**ASTM G65 – 16**



Designation: G65 – 16<sup>ε1</sup>

# Standard Test Method for Measuring Abrasion Using the Dry Sand/Rubber Wheel Apparatus<sup>1</sup>

This standard is issued under the fixed designation G65; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

<sup>ε1</sup> NOTE—Editorially corrected [Table X1.3](#) in November 2017.

## 1. Scope

1.1 This test method covers laboratory procedures for determining the resistance of metallic materials to scratching abrasion by means of the dry sand/rubber wheel test. It is the intent of this test method to produce data that will reproducibly rank materials in their resistance to scratching abrasion under a specified set of conditions.

1.2 Abrasion test results are reported as volume loss in cubic millimetres for the particular test procedure specified. Materials of higher abrasion resistance will have a lower volume loss.

NOTE 1—In order to attain uniformity among laboratories, it is the intent of this test method to require that volume loss due to abrasion be reported only in the metric system as cubic millimetres.  $1 \text{ mm}^3 = 6.102 \times 10^{-5} \text{ in}^3$ .

1.3 This test method covers five recommended procedures which are appropriate for specific degrees of wear resistance or thicknesses of the test material.

1.3.1 *Procedure A*—This is a relatively severe test which will rank metallic materials on a wide volume loss scale from low to extreme abrasion resistance. It is particularly useful in ranking materials of medium to extreme abrasion resistance.

1.3.2 *Procedure B*—A short-term variation of Procedure A. It may be used for highly abrasive resistant materials but is particularly useful in the ranking of medium- and low-abrasive-resistant materials. Procedure B should be used when the volume-loss values developed by Procedure A exceeds  $100 \text{ mm}^3$ .

1.3.3 *Procedure C*—A short-term variation of Procedure A for use on thin coatings.

1.3.4 *Procedure D*—This is a lighter load variation of Procedure A which is particularly useful in ranking materials of low-abrasion resistance. It is also used in ranking materials of

a specific generic type or materials which would be very close in the volume loss rates as developed by Procedure A.

1.3.5 *Procedure E*—A short-term variation of Procedure B that is useful in the ranking of materials with medium- or low-abrasion resistance.

1.4 *This standard does not purport to address the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

## 2. Referenced Documents

2.1 *ASTM Standards:*<sup>2</sup>

- D2000 Classification System for Rubber Products in Automotive Applications
- D2240 Test Method for Rubber Property—Durometer Hardness
- E11 Specification for Woven Wire Test Sieve Cloth and Test Sieves
- E122 Practice for Calculating Sample Size to Estimate, With Specified Precision, the Average for a Characteristic of a Lot or Process
- E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods
- E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method
- G40 Terminology Relating to Wear and Erosion
- G105 Test Method for Conducting Wet Sand/Rubber Wheel Abrasion Tests

<sup>1</sup> This test method is under the jurisdiction of ASTM Committee G02 on Wear and Erosion and is the direct responsibility of Subcommittee G02.30 on Abrasive Wear.

Current edition approved March 1, 2016. Published March 2016. Originally approved in 1980. Last previous edition approved in 2015 as G65 – 15. DOI: 10.1520/G0065-16E01.

<sup>2</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

2.2 American Foundrymen's Society Standards:  
AFS Foundry Sand Handbook, 7th Edition<sup>3</sup>

### 3. Terminology

#### 3.1 Definitions:

3.1.1 *abrasive wear*—wear due to hard particles or hard protuberances forced against and moving along a solid surface (Terminology G40).

NOTE 2—This definition covers several different wear modes or mechanisms that fall under the abrasive wear category. These modes may degrade a surface by scratching, cutting, deformation, or gouging (1 and 2).<sup>4</sup>

### 4. Summary of Test Method

4.1 The dry sand/rubber wheel abrasion test (Fig. 1) involves the abrading of a standard test specimen with a grit of controlled size and composition. The abrasive is introduced between the test specimen and a rotating wheel with a chlorobutyl or neoprene rubber rim of a specified hardness. This test specimen is pressed against the rotating wheel at a specified force by means of a lever arm while a controlled flow of grit abrades the test surface. The rotation of the wheel is such that its contact face moves in the direction of the sand flow. Note that the pivot axis of the lever arm lies within a plane that is approximately tangent to the rubber wheel surface, and normal to the horizontal diameter along which the load is applied. The test duration and force applied by the lever arm is varied as noted in Procedure A through E. Specimens are weighed before and after the test and the loss in mass recorded. It is necessary to convert the mass loss to volume loss in cubic

<sup>3</sup> Available from American Foundrymen's Society, Golf and Wolf Roads, Des Plaines, IL 60016.

<sup>4</sup> The boldface numbers in parentheses refer to a list of references at the end of this standard.

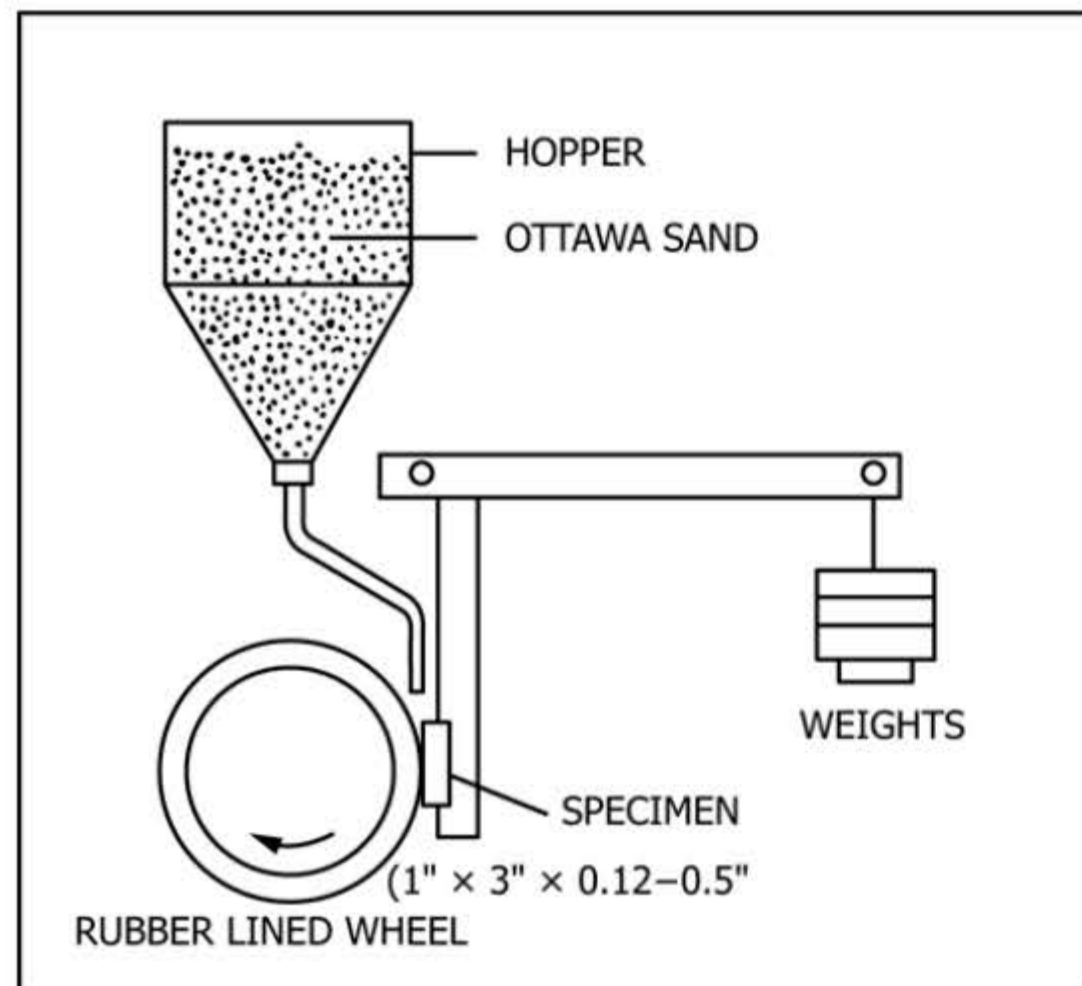


FIG. 1 Schematic Diagram of Test Apparatus

millimetres, due to the wide differences in the density of materials. Abrasion is reported as volume loss per specified procedure.

### 5. Significance and Use (1-7)

5.1 The severity of abrasive wear in any system will depend upon the abrasive particle size, shape, and hardness, the magnitude of the stress imposed by the particle, and the frequency of contact of the abrasive particle. In this practice these conditions are standardized to develop a uniform condition of wear which has been referred to as scratching abrasion (1 and 3). The value of the practice lies in predicting the relative ranking of various materials of construction in an abrasive environment. Since the practice does not attempt to duplicate all of the process conditions (abrasive size, shape, pressure, impact, or corrosive elements), it should not be used to predict the exact resistance of a given material in a specific environment. Its value lies in predicting the ranking of materials in a similar relative order of merit as would occur in an abrasive environment. Volume loss data obtained from test materials whose lives are unknown in a specific abrasive environment may, however, be compared with test data obtained from a material whose life is known in the same environment. The comparison will provide a general indication of the worth of the unknown materials if abrasion is the predominant factor causing deterioration of the materials.

### 6. Apparatus and Material<sup>5</sup>

6.1 Fig. 2 shows a typical design and Fig. 3 and Fig. 4 are photographs of the test apparatus which may be constructed from readily available materials. Also, see Ref (3). Several elements are of critical importance to ensure uniformity in test results among laboratories. These are the type of rubber used on the wheel, the type of abrasive and the shape, positioning and the size opening of the sand nozzle, and a suitable lever arm system to apply the required force.

6.2 *Rubber Wheel*—The wheel shown in Fig. 5 shall consist of a steel disk with an outer layer of chlorobutyl or neoprene rubber molded to its periphery. Uncured rubber shall be bonded to the rim and fully cured in a steel mold. The optimum hardness of the cured rubber is Durometer A-60. A range from A58 to 62 is acceptable. At least four hardness readings shall be taken on the rubber approximately 90° apart around the periphery of the wheel using a Shore A Durometer tester in accordance with Test Method D2240. The gage readings shall be taken after a dwell time of 5 s. The recommended composition of the rubber and a qualified molding source is noted in Table 1 and Table 2. (See 9.9 for preparation and care of the rubber wheel before and after use and see Fig. 2 and Fig. 5.)

6.3 *Abrasive*—The type of abrasive shall be a rounded quartz grain sand as typified by AFS 50/70 Test Sand (Fig. 6).<sup>6</sup>

<sup>5</sup> Original users of this test method fabricated their own apparatus. Machines are available commercially from several manufacturers of abrasion testing equipment.

<sup>6</sup> Available from U.S. Silica Co., P.O. Box 577, Ottawa, IL 61350. Sand from other sources was not used in the development of this test method and may give different results.

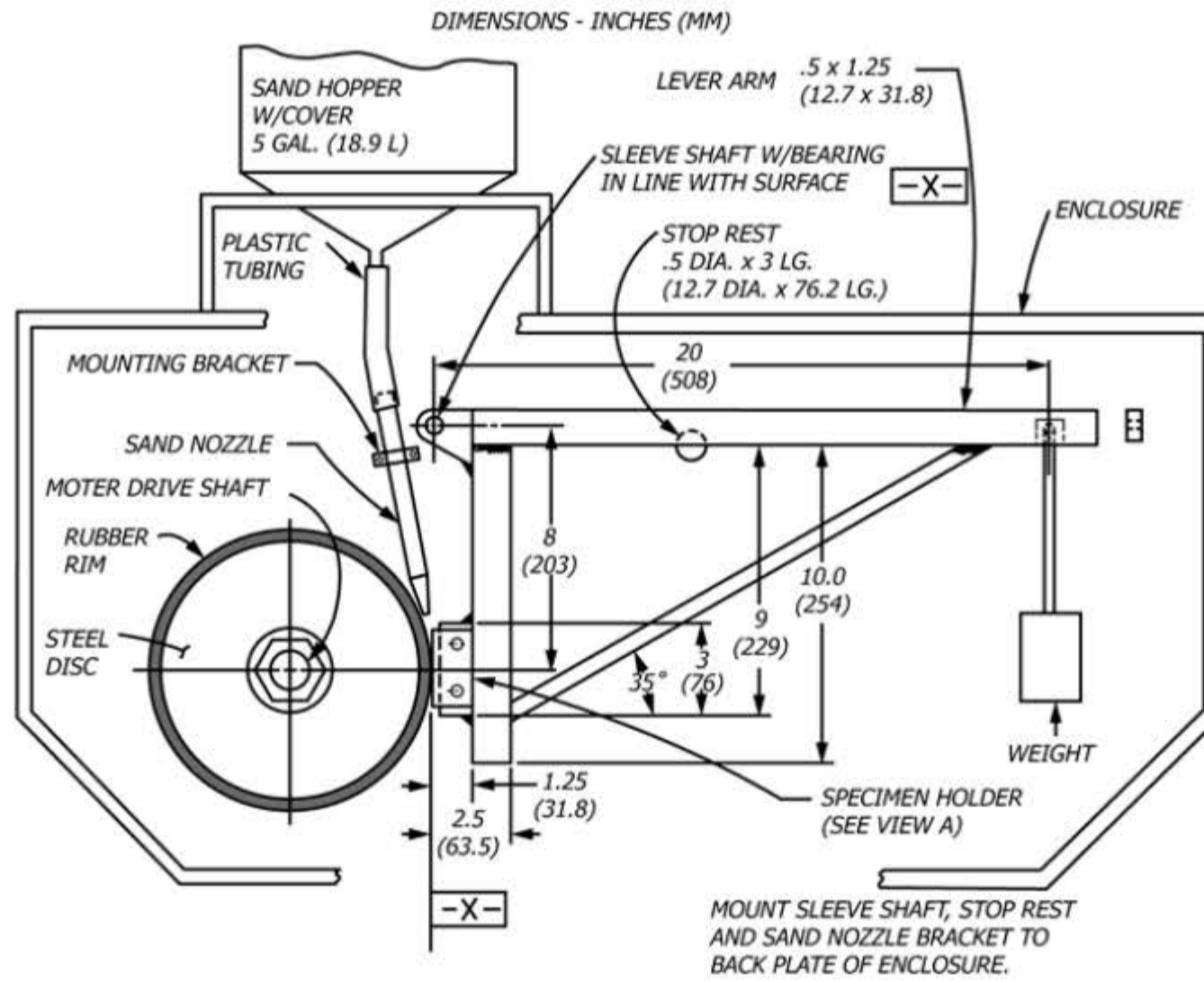
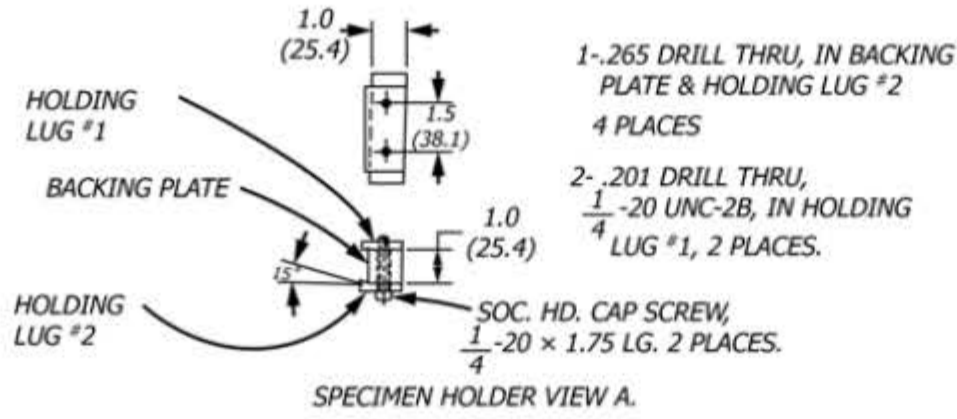


FIG. 2 Dry Sand/Rubber Wheel Abrasion Test Apparatus

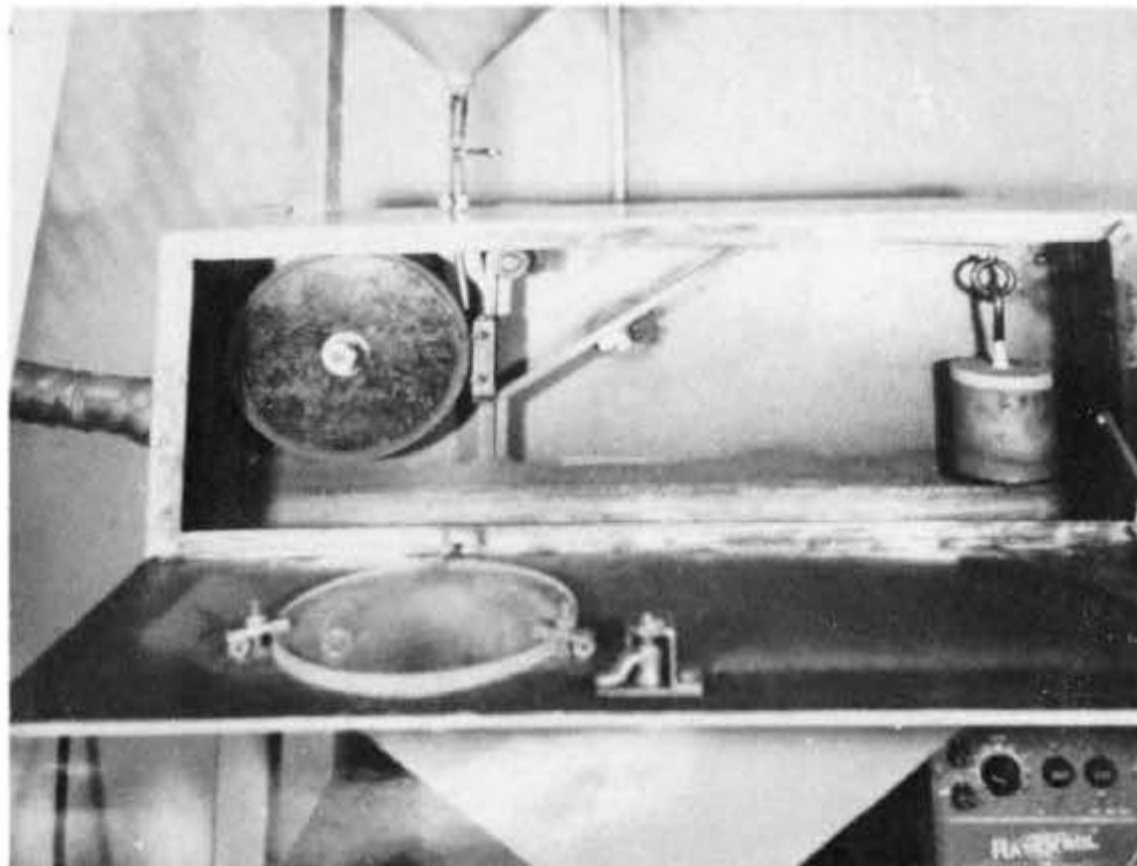


FIG. 3 Wheel and Lever Arm

The moisture content shall not exceed 0.5 weight %. Sand that has been subjected to dampness or to continued high relative

humidity may take on moisture, which will affect test results. Moisture content may be determined by measuring the weight



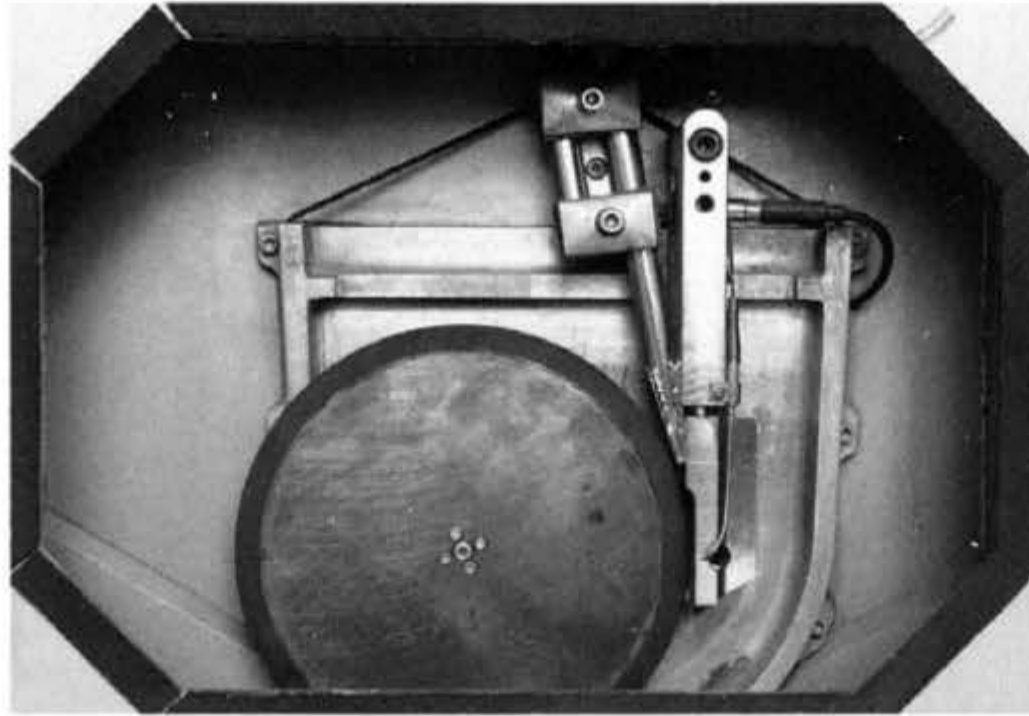


FIG. 4 Enclosure Frame

Dimensions – mm (inches)

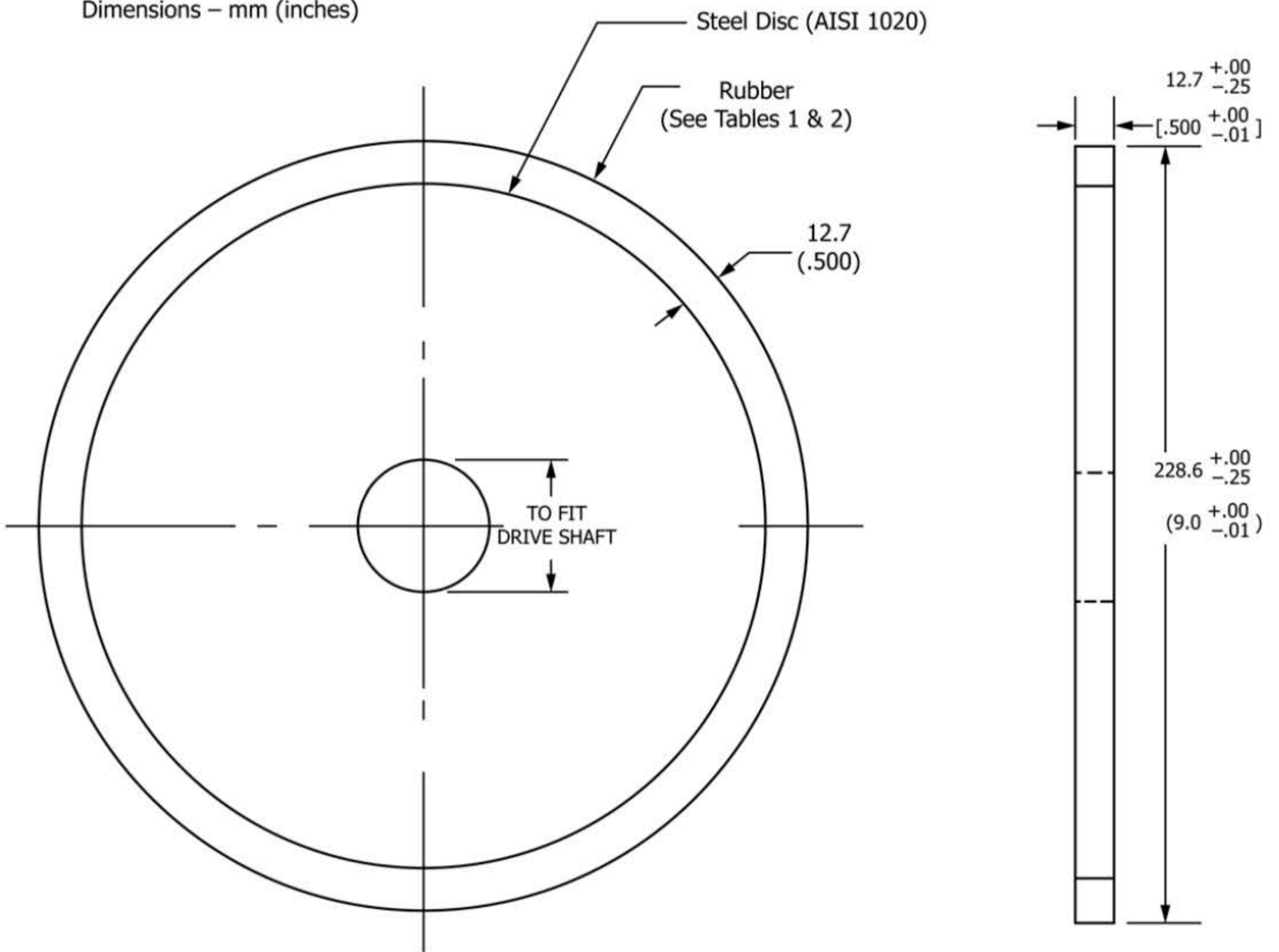


FIG. 5 Rubber Wheel

loss after heating a sample to approximately 120°C (250°F) for 1 h minimum. If test sand contains moisture in excess of 0.5 % it shall be dried by heating to 100°C (212°F) for 1 h minimum and the moisture test repeated. In high-humidity areas sand

may be effectively stored in constant temperature and humidity rooms or in an enclosed steel storage bin equipped with a 100-W electric bulb. Welding electrode drying ovens, available from welding equipment suppliers are also suitable. Multiple

**TABLE 1 A Formula for Chlorobutyl Rubber<sup>A</sup>**

NOTE 1—Specific gravity of mix: 1.15. Pressure cure: 20 min at 160°C (320°F).

Materials	Proportions by Weight
Chlorobutyl No. HT 10-66 (Enjay Chemical)	100
Agerite Staylite-S	1
HAF black	60
Circolight oil	5
Stearic acid	1
Zinc oxide	5
Ledate	2

<sup>A</sup>The sole source of supply known to the committee at this time is Falex Corporation, 1020 Airpark Dr., Sugar Grove, IL 60554. If you are aware of alternative suppliers, please provide this information to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend.

**TABLE 2 Formula for Neoprene Rubber<sup>A</sup>**

NOTE 1—The rubber will conform to Classification **D2000**.

NOTE 2—The 60 Durometer wheel will be in accordance with 2BC615K11Z1Z2Z3Z4, where Z1—Elastomer—Neoprene GW, Z2—Type A Durometer hardness 60 ± 2, Z3—Not less than 50 % rubber hydrocarbon content, and Z4—Medium thermal black reinforcement.

NOTE 3—The wheels are molded under pressure. Cure tiems of 40 to 60 min at 153°C (307°F) are used to minimize “heat-to-heat” variations.

Materials	Proportions by Weight
Neoprene GW	100
Magnesia <sup>B</sup>	2
Zinc Oxide <sup>C</sup>	10
Octamine	2
Stearic Acid	0.5
SRF Carbon Black <sup>D</sup>	37
ASTM #3 Oil	10

<sup>A</sup>The sole source of supply known to the committee at this time is Falex Corporation, 1020 Airpark Dr., Sugar Grove, IL 60554. If you are aware of alternative suppliers, please provide this information to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend.

<sup>B</sup>Maglite D (Merck)

<sup>C</sup>Kadox 16 (Ner Jersey Zinc)

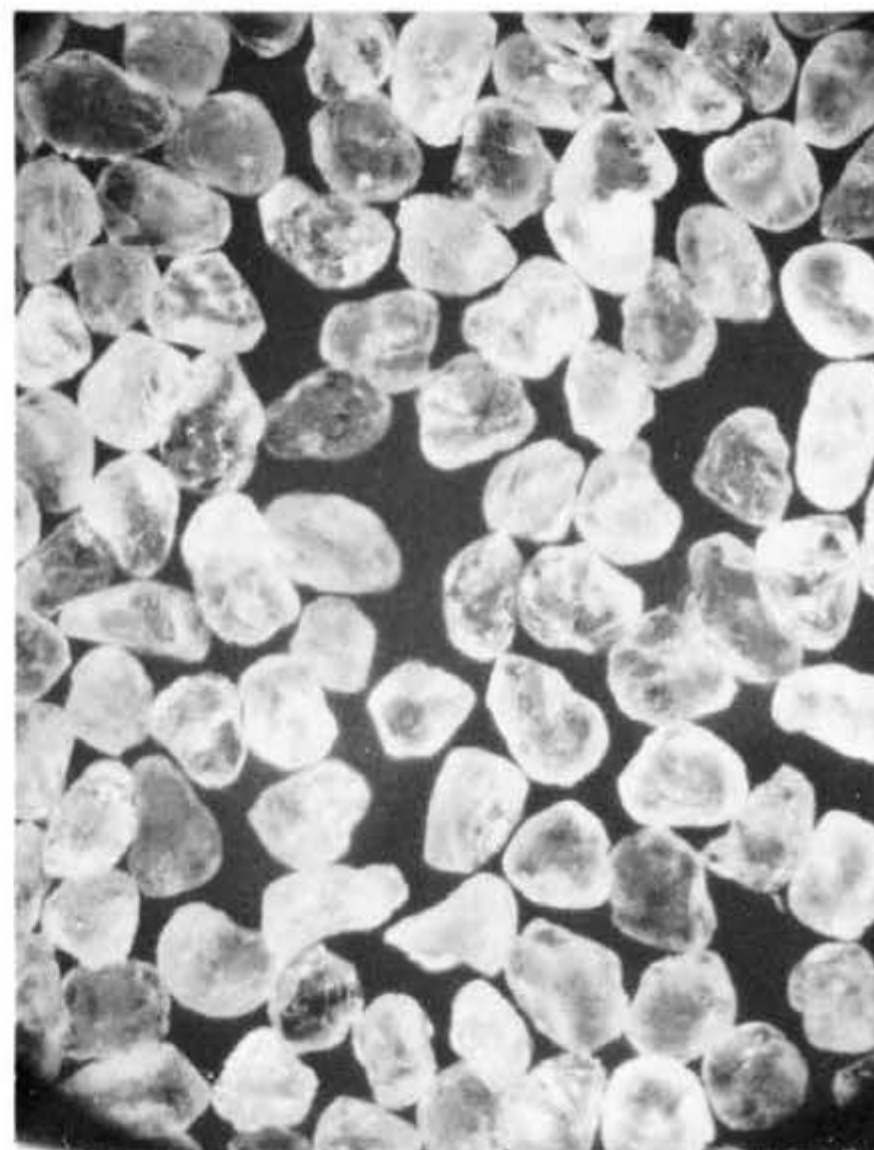
<sup>D</sup>ASTM Grade N762

use of the sand may affect test results and is not recommended. AFS 50/70 Test Sand is controlled to the following size range using U.S. sieves (Specification **E11**).

U.S. Sieve Size	Sieve Opening	% Retained on Sieve
40	425 μm (0.0165 in.)	none
50	300 μm (0.0117 in.)	5 max
70	212 μm (0.0083 in.)	95 min
100	150 μm (0.0059 in.)	none passing

6.4 **Sand Nozzle**—**Fig. 7** shows the fabricated nozzle design which was developed to produce an accurate sand flow rate and proper shape of sand curtain for test procedures. The nozzle may be of any convenient length that will allow for connection to the sand hopper using plastic tubing. In new nozzles, the rate of sand flow is adjusted by grinding the orifice of the nozzle to increase the width of the opening to develop a sand flow rate of 300 to 400 g/min. During use, the nozzle opening must be positioned as close to the junction of the test specimen and the rubber wheel as the design will allow. (See **Fig. 8**.)

6.4.1 Any convenient material of construction that is available as welded or seamless pipe may be used for the construc-



**FIG. 6 25X Magnification AFS 50/70 Test Sand Ottawa Silica Co.**

tion of the fabricated nozzle. Stainless steel is preferred because of its corrosion resistance and ease of welding. Copper and steel are also used successfully.

6.4.2 **Formed Nozzle**—Nozzles formed from tubing may be used only when they duplicate the size and shape (rectangular orifice and taper), and the sand flow characteristics (flow rate and streamlined flow) of the fabricated nozzle. (See **Fig. 7** and **Fig. 9**.)

6.4.3 **Sand Flow**—The nozzle must produce a sand flow rate of 300 to 400 g/min (0.66 to 0.88 lb/min).

6.4.4 **Sand Curtain**—**Fig. 9** shows the proper stream-lined flow and the narrow shape of the sand curtain as it exits from the sand nozzle. A turbulent sand flow as depicted in **Fig. 10** will tend to produce low and inconsistent test results. It is intended that the sand flows in a streamlined manner and passes between the specimen and rubber wheel.

6.5 **Motor Drive**—The wheel is driven by a nominally 0.7-kW (1-hp) dc motor through a 10/1 gear box to ensure that full torque is delivered during the test. The rate of revolution (200 ± 10 rpm) must remain constant under load. Other drives producing 200 rpm under load are suitable.

6.6 **Wheel Revolution Counter**—The machine shall be equipped with a revolution counter that will monitor the number of wheel revolutions as specified in the procedure (Section 9). It is recommended that the incremental counter have the ability to shut off the machine after a preselected number of wheel revolutions or increments up to 12 000 revolutions is attained.

6.7 **Specimen Holder and Lever Arm**—The specimen holder is attached to the lever arm to which weights are added, so that

FABRICATED SAND NOZZLE

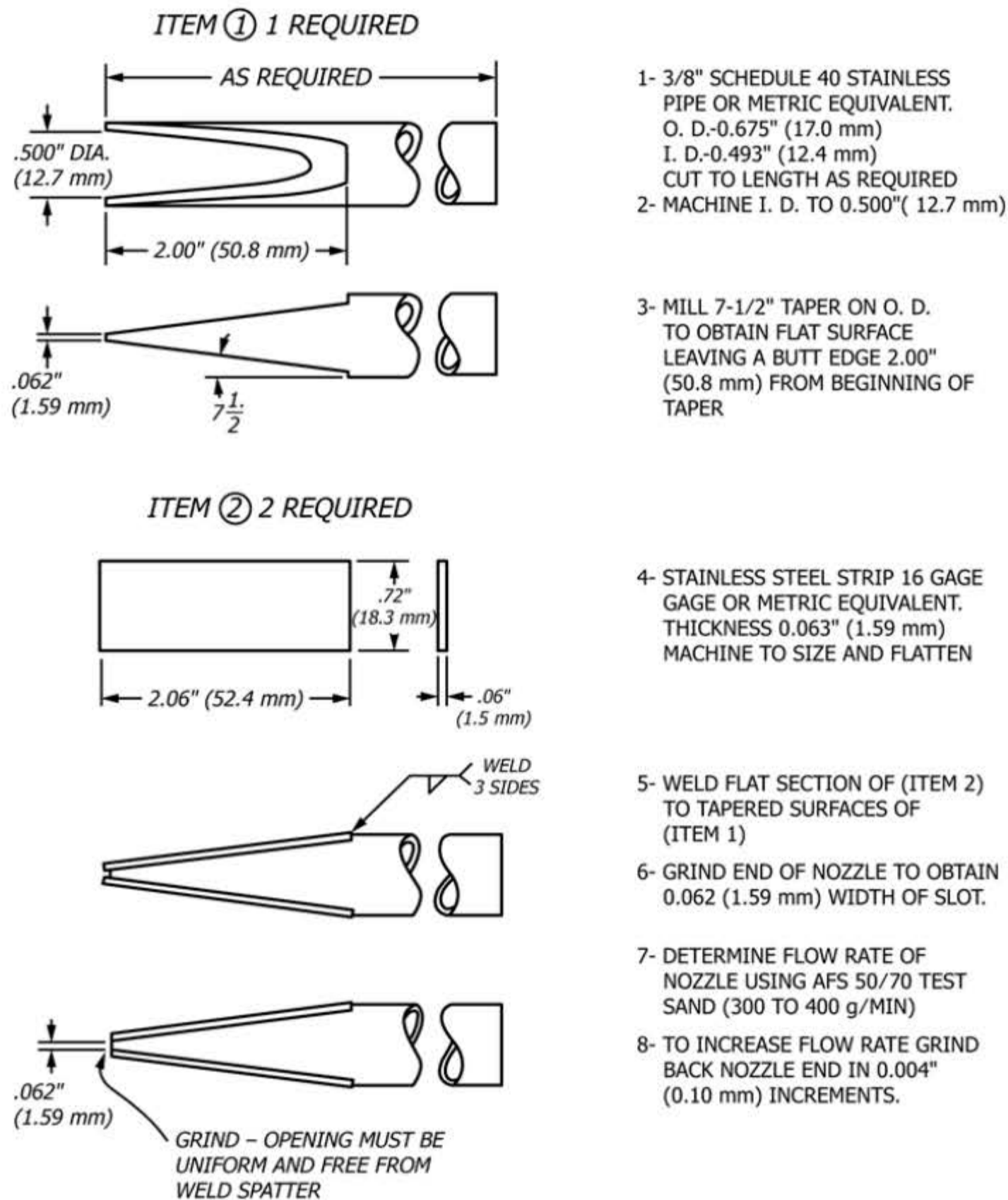


FIG. 7 Sand Nozzle

a force is applied along the horizontal diametral line of the wheel. An appropriate number of weights must be available to apply the appropriate force (Table 3) between the test specimen and the wheel. The actual weight required should not be calculated, but rather should be determined by direct measurement by noting the load required to pull the specimen holder away from the wheel. A convenient weight system is a can filled with sand (see Fig. 2).

6.8 Analytical Balance—The balance used to measure the loss in mass of the test specimen shall have a sensitivity of 0.001 g. Procedure C requires a sensitivity of 0.0001 g.

6.9 Enclosure, Frame, and Abrasive Hopper—Fig. 3 and Fig. 4 are photographs of a typical test apparatus. The size and shape of the support elements, enclosure, and hopper may be varied according to the user's needs.

7. Specimen Preparation and Sampling

7.1 Materials—It is the intent of this test method to allow for the abrasion testing of any material form, including

wrought metals, castings, forgings, gas or electric weld overlays, plasma spray deposits, powder metals, metallizing, electroplates, cermets, ceramics and so forth. The type of material will, to some extent, determine the overall size of the test specimen.

7.2 Typical Specimen, a rectangular shape 25 by 76 mm (1.0 by 3.0 in.) and between 3.2 and 12.7 mm (0.12 and 0.50 in.) thick. The size may be varied according to the user's need with the restriction that the length and width be sufficient to show the full length of the wear scar as developed by the test. The test surface should be flat within 0.125 mm (0.005 in.) maximum.

7.3 Wrought, Cast, and Forged Metal—Specimens may be machined to size directly from the raw material.

7.4 Electric or Gas Weld Deposits are applied to one flat surface of the test piece. Double-weld passes are recommended to prevent weld dilution by the base metal. The heat of welding may distort the test specimen. When this occurs, the specimen may be mechanically straightened or ground, or both. In order



FIG. 8 Position of Sand Nozzle

to develop a suitable wear scar, the surface to be abraded must be ground flat to produce a smooth, level surface at least 63.4 mm (2.50 in.) long and 19.1 mm (0.75 in.) for the test. (See 7.5.) Note that the welder technique, heat input of welds, and the flame adjustment of gas welds will have an effect on the abrasion resistance of a weld deposit.

7.5 *Finish*—Test specimens should be smooth, flat, and free of scale. Surface defects such as porosity and roughness may bias the test results, and such specimens should be avoided unless the surface itself is under investigation. Typical suitable surfaces are mill-rolled surfaces such as are present on cold-rolled steel, electroplated and similar deposits, ground surfaces, and finely machined or milled surfaces. A ground surface finish of approximately 0.8  $\mu\text{m}$  (32  $\mu\text{in.}$ ) or less is acceptable. The type of surface or surface preparation shall be stated in the data sheet.

## 8. Test Parameters

8.1 **Table 3** indicates the force applied against the test specimen and the number of wheel revolutions for test Procedures A through E.

8.2 *Sand Flow*—The rate of sand flow shall be 300 to 400 g/min (0.66 to 0.88 lb/min).

8.3 *Time*—The time of the test will be about 30 min for Procedures A and D, 10 min for Procedure B, 5 min for Procedure E, and 30 s for Procedure C, depending upon the actual wheel speed. In all cases the number of wheel revolutions and not the time shall be the controlling parameter.

8.4 *Lineal Abrasion*—**Table 3** shows the lineal distance of scratching abrasion developed using a 228.6-mm (9-in.) diam-

eter wheel rotating for the specified number of revolutions. As the rubber wheel reduces in diameter the number of wheel revolutions shall be adjusted to equal the sliding distance of a new wheel (**Table 3**) or the reduced abrasion rate shall be taken into account by adjusting the volume loss produced by the worn wheel to the normalized volume loss of a new wheel. (See 10.2.)

## 9. Procedure

9.1 *Cleaning*—Immediately prior to weighing, clean the specimen with a solvent or cleaner and dry. Take care to remove all dirt or foreign matter or both from the specimen. Dry materials with open grains (some powder metals or ceramics) to remove all traces of the cleaning solvent, which may have been entrapped in the material. Steel specimens having residual magnetism should be demagnetized or not used.

9.2 Weigh the specimen to the nearest 0.001 g (0.0001 g for Procedure C).

9.3 Seat the specimen securely in the holder and add the proper weights to the lever arm to develop the proper force pressing the specimen against the wheel. This may be measured accurately by means of a spring scale which is hooked around the specimen and pulled back to lift the specimen away from the wheel. A wedge should be placed under the lever arm so that the specimen is held away from the wheel prior to start of test. (See **Fig. 2**.)

9.4 Set the revolution counter to the prescribed number of wheel revolutions.

9.5 *Sand Flow and Sand Curtain*—The rate of sand flow through the nozzles shall be between 300 g (0.66 lb)/min and 400 g (0.88 lb)/min. Do not start the wheel rotation until the proper uniform curtain of sand has been established (see **Fig. 9** and Note 3).

9.5.1 The dwell time between tests shall be the time required for the temperature of the rubber wheel to return to room temperature. For Procedure B the dwell time shall be at least 30 min.

9.6 Start the wheel rotation and immediately lower the lever arm carefully to allow the specimen to contact the wheel.

9.7 When the test has run the desired number of wheel revolutions, lift the specimen away from the wheel and stop the sand flow and wheel rotation. The sand flow rate should be measured before and after a test, unless a consistent flow rate has been established.

9.8 Remove the specimen and reweigh to the nearest 0.001 g (0.0001 g for Procedure C).

9.8.1 *Wear Scar*—Observe the wear scar and compare it to the photographs of uniform and nonuniform wear scars in **Fig. 11**. A nonuniform pattern indicates improper alignment of the rubber rim to the test specimen or an unevenly worn rubber wheel. This condition may reduce the accuracy of the test.

9.9 *Preparation and Care of Rubber Wheels*—Dress the periphery of all new rubber wheels and make concentric to the bore of the steel disk upon which the rubber is mounted. The concentricity of the rim shall be within 0.05 mm (0.002 in.)

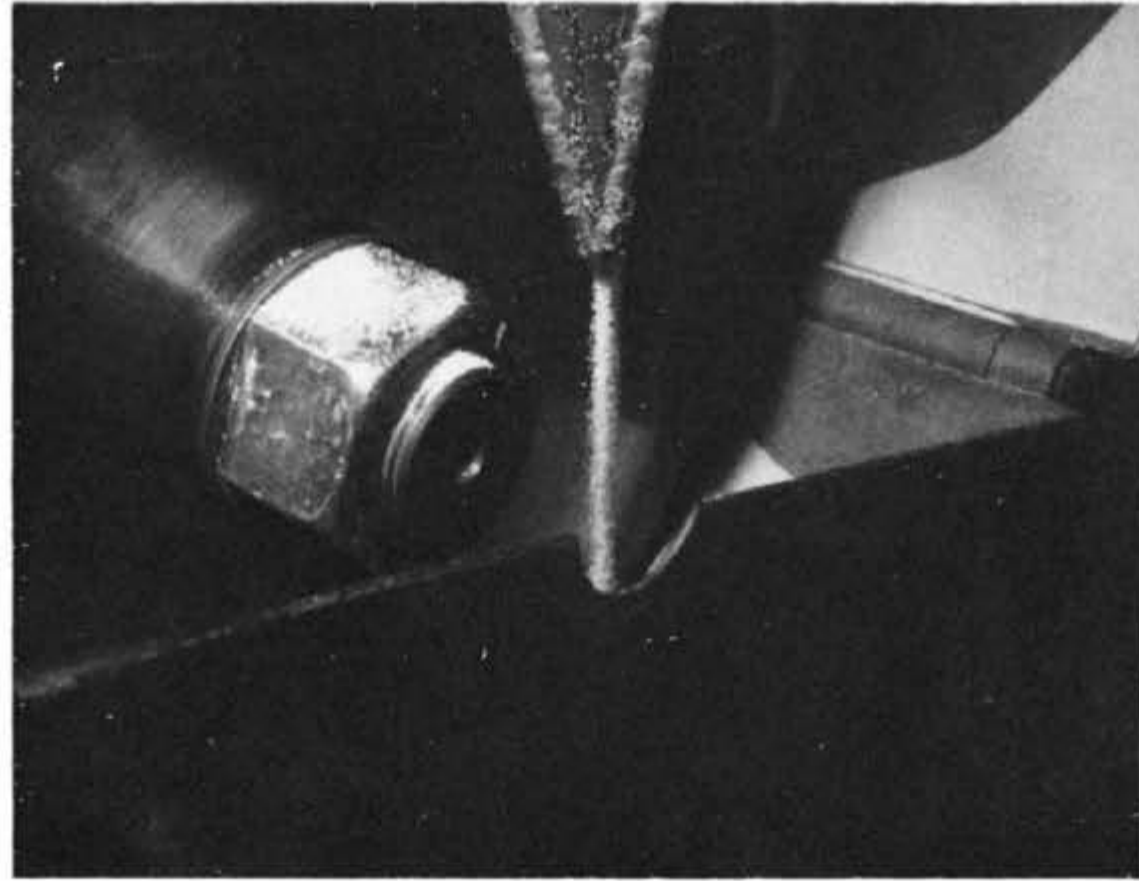


FIG. 9 Sand Flow—Streamlined

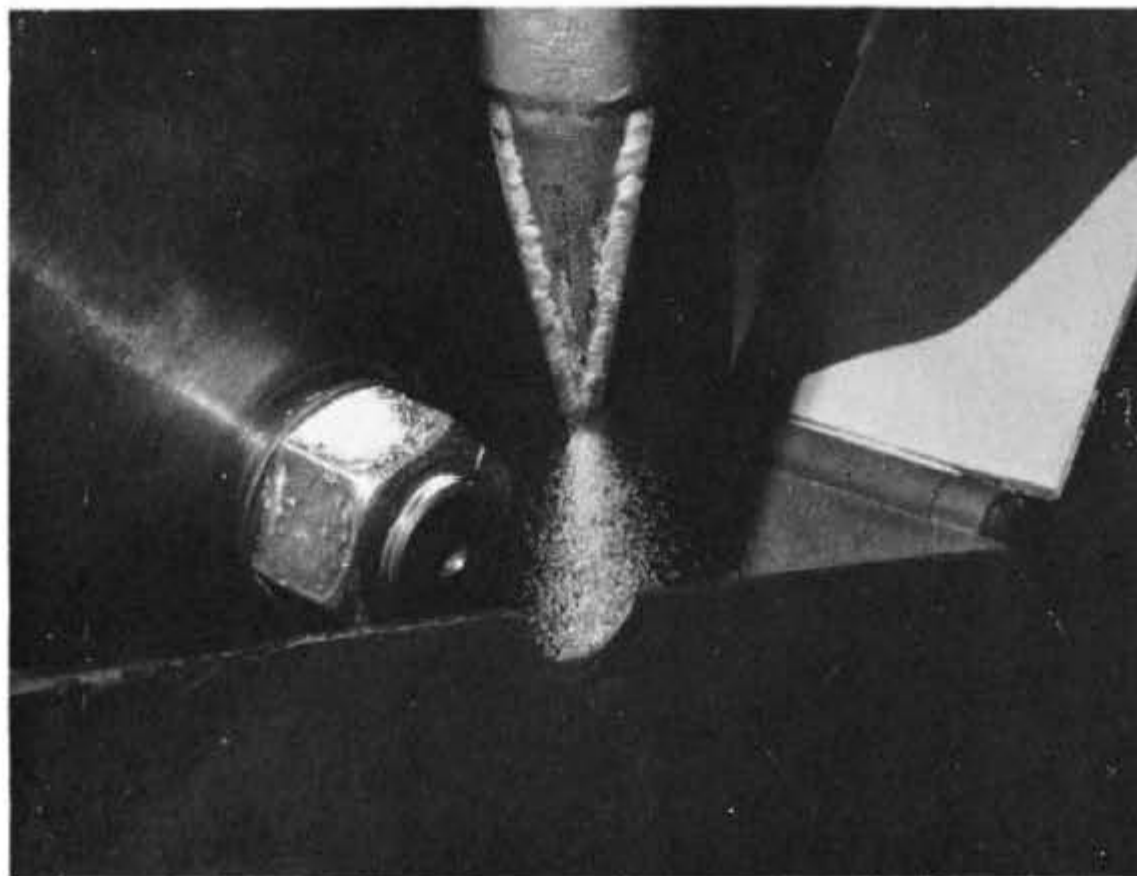


FIG. 10 Sand Flow—Turbulence

total indicator reading on the diameter. Follow the same dressing procedure on used wheels that develop grooves or that wear unevenly so as to develop trapezoidal or uneven wear scars on the test specimen (Fig. 11). The intent is to produce a uniform surface that will run tangent to the test specimen without causing vibration or hopping of the lever arm. The wear scars shall be rectangular in shape and of uniform depth at any section across the width. The rubber wheel may be used until the diameter wears to 215.9 mm (8.50 in.). New rubber rims may be mounted on steel disks by the qualified source (6.2).

TABLE 3 Test Parameters

Specified Procedure	Force Against Specimen, <sup>B</sup> N (lb)	Wheel Revolutions	Lineal Abrasion <sup>A</sup> m	(ft)
A	130 (30)	6000	4309	(14 138)
B	130 (30)	2000	1436	(4 711)
C	130 (30)	100	71.8	(236)
D	45 (10.1)	6000	4309	(14 138)
E	130 (30)	1000	718	(2 360)

<sup>A</sup> See 8.4.

N = Newton (SI metric term for force)

1 lbf = 4.44822 N

1 Kgf = 9.806650 N

<sup>B</sup> Force tolerance is ±3 %.

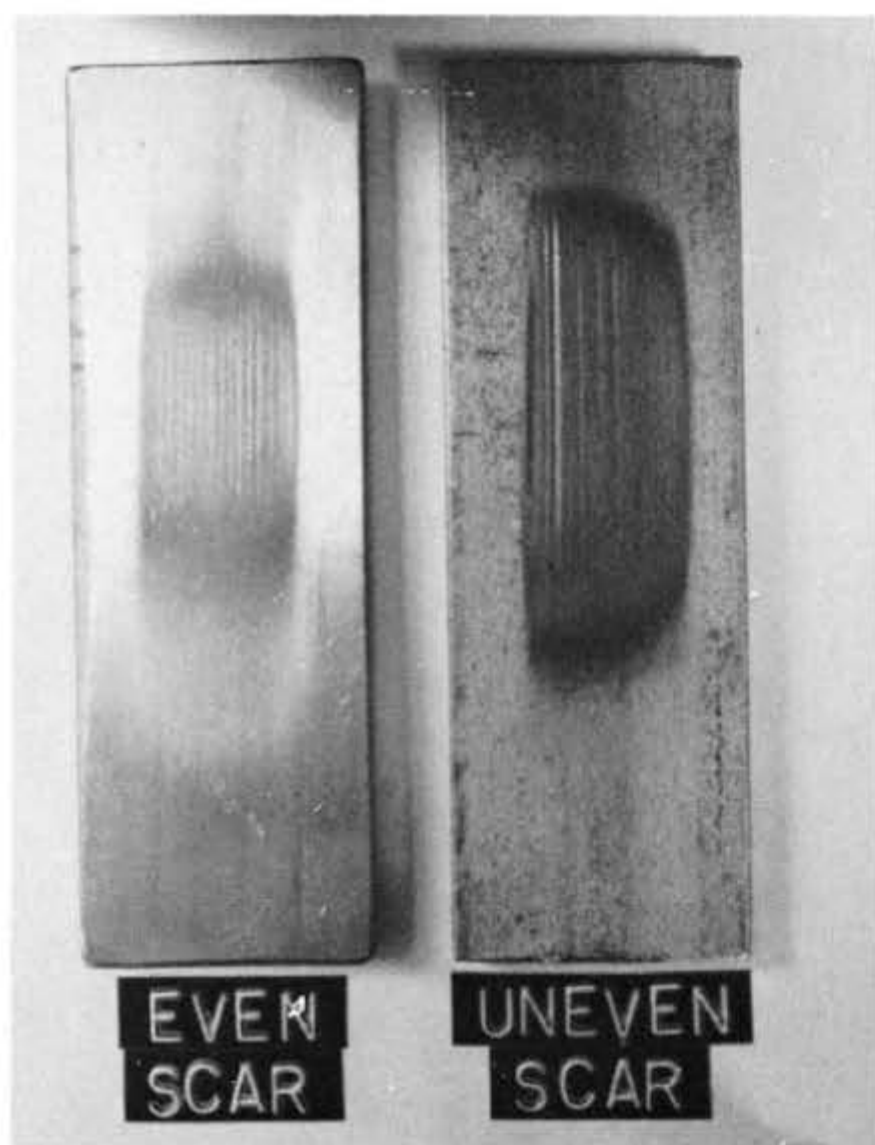


FIG. 11 Typical Wear Scars Uneven and Nonuniform Wear Scars Indicate Improper Alignment or Wear of Rubber Wheel

9.10 *Wheel Dressing Procedure*—The preferred dressing procedure for the periphery of the rubber rim is to mount a diamond-cut file<sup>7</sup>, stone or soft metal in place of the specimen in the holder and run the machine with load until the wheel is clean. Another dressing procedure for the periphery of the rubber rim is to mount the wheel on a lathe, and machine the surface with a tool bit especially ground for rubber applica-

<sup>7</sup> The sole source of supply known to the committee at this time is Falex Corp., 1020 Airpark Dr., Sugar Grove, IL 60554. If you are aware of alternative suppliers, please provide this information to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend.

tions. Grind a carbide or high-speed steel tool bit to very deep rake angles (Fig. 12). Feed the tool across the rubber surface in the opposite direction from that normally used for machining steel. This allows the angular surface of the tool bit to shear away thin layers of rubber without tearing or forming grooves in the rubber as would occur when using the pointed edges of the tool. The recommended machining parameters are: *Feed*—25 mm/min (1.0 in./min); *Speed*—200 rpm; *Depth of Cut*—0.254 mm (0.010 in.) to 0.762 mm (0.030 in.). The dressed wheel should be first used on a soft carbon steel test specimen (AISI 1020 or equivalent) using Procedure A. This results in a smooth, uniform, non-sticky surface. An alternative dressing method involves the use of a high-speed grinder on the tool post of a lathe. Take great care since grinding often tends to overheat and smear the chlorobutyl rubber, leaving a sticky surface. Such a surface will pick up and hold sand particles during testing. If the grinding method is used, not more than 0.05 mm (0.002 in.) may be ground from the surface at one time so as to prevent overheating on the chlorobutyl rubber wheel.

### 10. Calculating and Reporting Results

10.1 The abrasion test results should be reported as volume loss in cubic millimetres in accordance with the specified procedure used in the test. For example, \_\_\_mm<sup>3</sup> per ASTM\_\_\_ Procedure \_\_\_. While mass loss results may be used internally in test laboratories to compare materials of equivalent densities, it is essential that all users of this test procedure report their results uniformly as volume loss in publications or reports so that there is no confusion caused by variations in density. Convert mass loss to volume loss as follows:

$$\text{Volume loss, mm}^3 = \frac{\text{mass loss (g)}}{\text{density (g/cm}^3\text{)}} \times 1000 \quad (1)$$

10.2 *Adjusting the Volume Loss*—As the rubber wheel decreases in diameter the amount of scratching abrasion developed in a given practice will be reduced accordingly. The actual volume loss produced by these slightly smaller wheels will, therefore, be inaccurate. The “adjusted volume loss” value takes this into account and indicates the actual abrasion

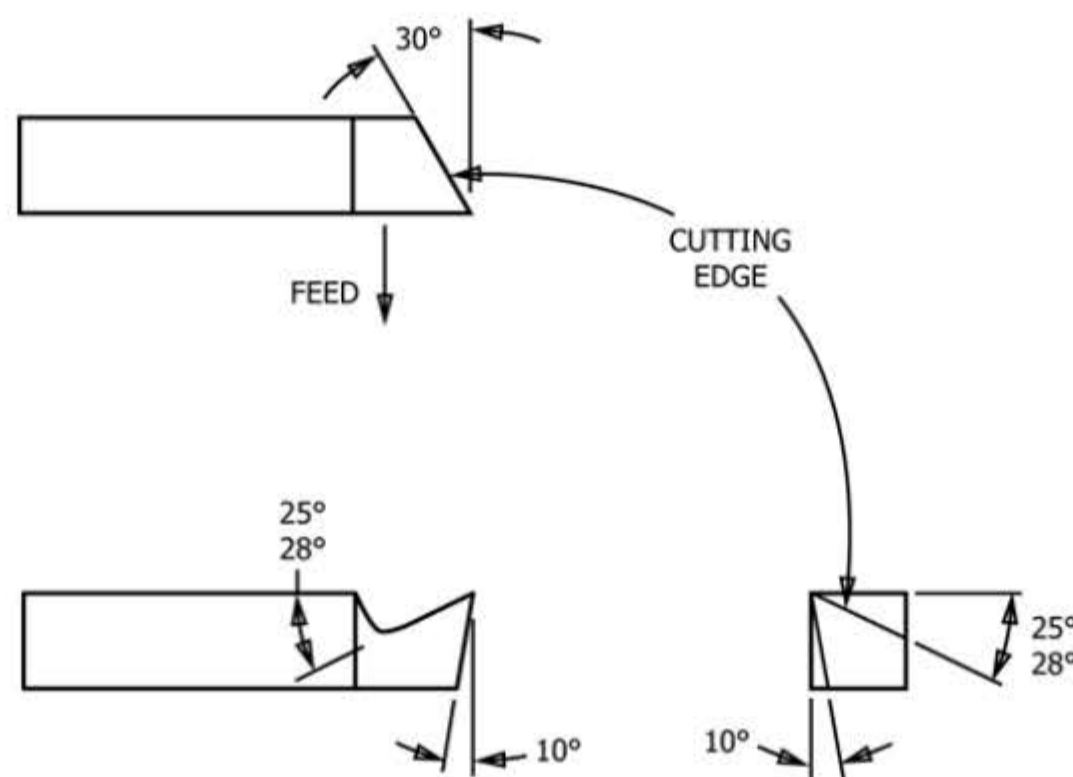


FIG. 12 Typical Wheel Dressing Tool

rate that would be produced by a 228.6-mm (9.00-in.) diameter wheel. Calculate the adjusted volume loss (AVL) as follows:

$$AVL = \text{measured volume loss} \times \frac{228.6 \text{ mm (9.00 in.)}}{\text{wheel diameter after use}} \quad (2)$$

**10.3 Reporting Test Results**—All significant test parameters and test data as noted in **Tables 3 and 4** shall be reported, including wheel rubber type. Any variation from the recommended procedure must be noted in the comments. The report shall include a statement of the current precision and accuracy of the test apparatus as qualified by the testing of Reference Materials. The volume loss data developed by the initial qualification tests or the volume loss data developed by the periodic re-qualification tests should be listed on the data sheet (**Table 4**).

**11. Precision and Bias<sup>8</sup>**

11.1 The precision of this test method is based on an interlaboratory study of ASTM G65, Test Method for Measuring Abrasion Using the Dry Sand/Rubber Wheel Apparatus, as conducted in 2013. Six laboratories participated in this study, each testing three different materials. Every “test result” represents an individual determination. The laboratories were asked to report replicate test results for each material. Practice

<sup>8</sup> Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:G02-1016. Contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org).

**E691** was followed for the basic design and analysis of the data; the details are given in ASTM Research Report No. RR:G02-1016.

11.1.1 *Repeatability Limit (r)*—Two test results obtained within one laboratory shall be judged not equivalent if they differ by more than the “r” value for that material; “r” is the interval representing the critical difference between two test results for the same material, obtained by the same operator using the same equipment on the same day in the same laboratory.

11.1.1.1 Repeatability limits are listed in **Tables 5 and 6** below.

11.1.2 *Reproducibility Limit (R)*—Two test results shall be judged not equivalent if they differ by more than the “R” value for that material; “R” is the interval representing the critical difference between two test results for the same material, obtained by different operators using different equipment in different laboratories.

11.1.2.1 Reproducibility limits are listed in **Tables 5 and 6** below.

11.1.3 The above terms (repeatability limit and reproducibility limit) are used as specified in Practice **E177**.

11.1.4 Any judgment in accordance with **11.1.1** would normally have an approximate 95 % probability of being correct; however, the precision statistics obtained in this ILS must not be treated as exact mathematical quantities which are applicable to all circumstances and uses. The limited number

**TABLE 4 Data Sheet**

Dry Sand/Rubber Wheel Test ASTM G-65 Procedure _____						
Qualification of Apparatus (11.4):					Date _____	
Reference Materials _____					Quantity _____	
Adjusted Volume Loss (avg) _____ mm <sup>3</sup> Coefficient of Variation _____					%	
Test Data						
Material Description: _____					Wheel diameter: _____	
Heat Treatment: _____					Wheel width: _____	
Hardness: _____					Wheel hardness: _____	
Surface Preparation _____						
Test No.						
Rubber Type						
Test load						
Wheel revolutions						
Sand flow, g/min						
Initial mass, g						
Final mass, g						
Mass loss, g						
Density, g/cm <sup>3A</sup>						
Volume loss, mm <sup>3</sup> (mass loss/density) x 1000						
Adjusted volume loss, mm <sup>3</sup>						
Comments: _____						
_____						
_____						
_____						
Company Name _____ Tested by _____ Date _____						

<sup>A</sup> Density of materials may be obtained from *ASM Metals Handbook*, Vol 1, 8th ed. or suppliers of materials.

**TABLE 5 Procedure A (Volume Loss mm<sup>3</sup>)**

Material	Average	Repeatability Standard Deviation	Reproducibility Standard Deviation	Repeatability Limit	Reproducibility Limit
	$\bar{x}$	$S_r$	$S_R$	$r$	$R$
D2	42.70	1.10	2.61	3.09	7.31
Carbide	9.28	0.86	1.04	2.40	2.92

**TABLE 6 Procedure B (Volume Loss mm<sup>3</sup>)**

Material	Average	Repeatability Standard Deviation	Reproducibility Standard Deviation	Repeatability Limit	Reproducibility Limit
	$\bar{x}$	$S_r$	$S_R$	$r$	$R$
H13	54.16	3.66	6.80	10.26	19.04

of laboratories reporting usable results for Procedure A indicates that there will be times when differences greater than predicted by the ILS results will arise, sometimes with considerably greater or smaller frequency than the 95 % probability limit would imply. Consider the precision limits listed for those abrasives with fewer than six reporting laboratories as a general guide, and the associated probability of 95 % as only an indicator of what can be expected.

11.2 The precision statement was determined through statistical examination of 30 test results, from a total of six laboratories, on three different materials labeled as:

- D2: High carbon-chromium tool steel
- Carbide: Nickel matrix hardfacing containing spherical carbide with a 60/40 carbide/matrix density percentage
- H13: Low carbon medium chromium tool steel

It is recommended to choose the listed material closest in characteristics to your test material when considering precision.

## APPENDIX

### (Nonmandatory Information)

#### X1. SOME STATISTICAL CONSIDERATIONS IN ABRASION TESTING

##### X1.1 Background

X1.1.1 The Dry Sand/Rubber and Wheel Abrasion Test as developed and described by Haworth, Avery, and others (1-7) has been in various stages of evolution and use since 1960. A number of variations of this test procedure have been used by several research and industrial laboratories in the United States who were faced with the problem of evaluating hard surfacing alloys, castings, and wrought products for their resistance to abrasive wear. Individual laboratories set their own test parameters with the goal being the generation of reproducible test data within the laboratory. As the need for standardization became apparent, Subcommittee G02.30 formed a task group to study the effect of each test parameter on the overall results within individual laboratories and among all laboratories as a group. While standardization of test parameters was attained, it became evident that the variability or experimental error inherent in each laboratory was a factor that must be considered. Not only must the test method, apparatus, and individual operator generate repeatable results, but the test results must be consistently reproducible within an acceptable range. Another important consideration in establishing repeatable and reproducible test results was the selection of an adequate sample

size. More specifically this was the need for laboratories to agree on the number of times a test should be repeated on a given homogeneous material in order to obtain a meaningful average result. While single test results and simple arithmetic averaging may in some few cases be useful in individual laboratories, it is essential that statistical techniques and multiple testing of specimens be utilized for the qualification of each test apparatus, and for the comparison of materials. Further information on statistical methods may be found in Practice E122, MNL 7, and in the references.

##### X1.2 Statistical Equations

X1.2.1 Several equations for the calculation of standard deviation and coefficient of variation are used in the statistical analysis of data shown in Table X1.1. To ensure uniformity among laboratories using the dry sand/rubber wheel test, the standard deviation and coefficient of variation of results produced from a series of tests should be calculated by the following equations:

$$S_r = \sqrt{\frac{1}{p} (\sum S_j^2)} \quad (X1.1)$$



**TABLE X1.1 Statistical Analyses of Interlaboratory Test Results**

Round-Robin Test Conditions	Specified Procedure	Number of Samples	Average, mm <sup>3</sup>	Standard Deviation Within, mm <sup>3</sup>	Standard Deviation Between, mm <sup>3</sup>	Coefficient of Variation Within, %	Coefficient of Variation Between, %	Coefficient of Variation Total, %	Standard Deviation Total, mm <sup>3</sup>
RR No. 15 4340 steel	E	3	51.63	1.67	0.75	3.2	1.5	3.5	1.83
RR No. 14A and 14B 4340 steel	E	3	47.74	1.84	2.46	3.9	5.2	6.04	3.07
RR No. 14A and 14B 4340 steel	B	3	91.08	2.18	4.98	2.4	3.5	6	5.44
RR No. 12 WC-14 weight % CO 0.010 in. thick	A	4	2.18	0.14	0.42	6.4	19.3	20.4	0.44
RR No. 14 hard-chrome plating 0.010 in. thick	C	3	1.33	0.1	0.25	7.4	19.1	20.5	0.27

- $d$  = deviations from average,  $(\bar{x}_j - \bar{x})$   
 $S_{\bar{x}}$  =  $\sqrt{\sum(d^2)/p-1}$   
 $S_L$  =  $\sqrt{(S_{\bar{x}}^2) - (S_r^2)}$   
 $S_L$  = 0 if the quantity under the root sign is negative.  
 $S_R$  =  $\sqrt{(S_r^2) + (S_L^2)}$  is the reproducibility standard deviation of the test method for the parameter measured.  
 $V_r(\%)$  =  $100(S_r)/(\bar{x})$ , the estimated relative standard deviation or coefficient of variation within a laboratory for the parameter measured (repeatability).  
 $V_L(\%)$  =  $100(S_L)/(\bar{x})$ , the estimated relative standard deviation or coefficient of variation between laboratories for the parameter measured (reproducibility).

where:

- $p$  = number of laboratories,  
 $n$  = number of replicate tests,  
 $\bar{x}_j$  = average of  $n$  number of replicate tests of each, laboratory of parameter  $j$ ,  
 $S_j$  = standard deviation,  
 $\bar{x}$  = average of  $\bar{x}_j$  's for all laboratories of each parameter,  
 $S_r$  = estimated repeatability standard deviation within, and a laboratory for each parameter measured.

### X1.3 Typical Volume Loss Values

X1.3.1 Procedure A of the Dry Sand/Rubber Wheel Test will produce volume losses in metallic materials ranging from 0.25 to 250 mm<sup>3</sup>. The more abrasion-resistant materials will develop the least volume loss. Table X1.2 shows typical volume loss ranges that may be expected in the metals listed. They are offered as guidelines only and not as purchasing specifications or as standard reference specimens. Any material specifications involving this test method must be by agreement between the seller and the purchaser. When volume losses exceed 100 mm<sup>3</sup>, greater accuracy in material ranking is obtained by using Procedure D (see Table 3). Procedure A should be used for the more abrasion-resistant materials. Procedure E or B can be used for materials with volume losses in the range from 50 to 100 mm.

### X1.4 ILS for Alternate Rubber Wheel

X1.4.1 Due to supply issues of the original chlorobutyl rubber wheel formulation, an alternate rubber was selected that is both previously accepted (G105) for tribological abrasion testing and readily available. G105 neoprene rubber, formulation for 60 durometer hardness was selected for prototype and Inter-Laboratory Study. The results show consistency of the neoprene rubber between laboratories (Table X1.3).

**TABLE X1.2 Volume Loss Range**

	Standard Values (Mean ± Standard Deviation) <sup>A</sup>				
	Practice A, mm <sup>3</sup>	Practice B, mm <sup>3</sup>	Practice C, mm <sup>3</sup>	Practice D, mm <sup>3</sup>	Practice E, mm <sup>3</sup>
AISI Tool Steel D-2 Reference Material No. 1 <sup>B</sup>	35.6 ± 5.2	...	...	...	...
AISI Tool Steel H-13 Reference Material No. 2 <sup>B</sup>	...	55.6 ± 4.2	...	...	...
AISI 4340 Steel Reference Material No. 3 <sup>B</sup>	...	...	...	91.1 ± 5.4	49.2 ± 2.9
	Nonstandard Values				
316 stainless bar annealed RB-80	260 ± 20	...	...	58.5 ± 26.6	...
AISI 1090 plate-normalized 900°C (1600°F) air-cooled 24-26 HRc	80.7 ± 8.0	...	...	33.0 ± 6.0	...
17-4PH stainless-aged 500°C (925°F)-4 h at temperature, air-cooled-43 HRc	220 ± 20	122.1 ± 15.3	...	70.9 ± 6.1	...
Stellite 1016 hard surfacing overlay 57-58 HRc applied by oxyacetylene welding process (35 flame)	17 ± 4	...	...	...	...
Sintered tungsten carbide (Kennametal K-714, Valenite 2889)	1.9 ± 0.3	...	...	...	...
WC-Co flame spray coatings	2.2 ± 0.4	...	...	...	...
Hard-chrome plating	...	...	1.3 ± 0.3	...	...

<sup>A</sup>The mean values and standard deviation for volume loss reported were calculated from the values in Research Report RR: RR:G02-1006.

<sup>B</sup>See 11.6.2 for heat treat.

**TABLE X1.3 ILS Round Robin Data—Neoprene Rubber Wheel on D2, H13, and Composite Carbide Coupons**

<b>D2</b>										
Test Lab	A	A	B	B	C	C	D	D	E	E
Mass Loss (g)	0.2220	0.2260	0.2207	0.2207	0.2154	0.2228	0.2070	0.2060	0.2644	0.3519
Volume Loss (mm <sup>3</sup> )										45.70
D2 Avg Mass Loss										
D2 Std Dev										
<b>H13</b>										
Test Lab										E
Mass Loss (g)										0.4568
Volume Loss (mm <sup>3</sup> )										58.87
H13 Avg Mass Loss										
H13 Std Dev										
<b>Carbide</b>										
Test Lab										E
Mass Loss (g)	0.1140	0.1032	0.1205	0.1050	0.1028	0.1065	0.0858	0.1071	0.1205	0.1226
Volume Loss (mm <sup>3</sup> )	9.60	8.69	10.65	9.18	8.65	8.96	7.05	9.02	10.18	10.32
Carbide Avg Mass Loss	0.1096					Variance	0.000152			
Carbide Std Dev	0.012341					Variance Population	0.000137			

†Editorially corrected.

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# **ANEXO 15**

# **NORMA**

# **ASTM G99 – 17**



Designation: G99 – 17

# Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus<sup>1</sup>

This standard is issued under the fixed designation G99; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This test method covers a laboratory procedure for determining the wear of materials during sliding using a pin-on-disk apparatus. Materials are tested in pairs under nominally non-abrasive conditions. The principal areas of experimental attention in using this type of apparatus to measure wear are described. The coefficient of friction may also be determined.

1.2 This test method standard uses a specific set of test parameters (load, sliding speed, materials, etc.) that were then used in an interlaboratory study (ILS), the results of which are given here (Tables 1 and 2). (This satisfies the ASTM form in that “The directions for performing the test should include all of the essential details as to apparatus, test specimen, procedure, and calculations needed to achieve satisfactory precision and bias.”) Any user should report that they “followed the requirements of ASTM G99,” where that is true.

1.3 Now it is often found in practice that users may follow all instructions given here, but choose other test parameters, such as load, speed, materials, environment, etc., and thereby obtain different test results. Such a use of this standard is encouraged as a means to improve wear testing methodology. However, it must be clearly stated in any report that, while the directions and protocol in Test Method G99 were followed (if true), the choices of test parameters were different from Test Method G99 values, and the test results were therefore also different from the Test Method G99 results. This use should be described as having “followed the procedure of ASTM G99.” All test parameters that were used in such case must be stated.

1.4 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate*

*safety and health practices and determine the applicability of regulatory limitations prior to use.*

## 2. Referenced Documents

2.1 *ASTM Standards:*<sup>2</sup>

[E178 Practice for Dealing With Outlying Observations](#)

[G40 Terminology Relating to Wear and Erosion](#)

[G117 Guide for Calculating and Reporting Measures of Precision Using Data from Interlaboratory Wear or Erosion Tests](#) (Withdrawn 2016)<sup>3</sup>

2.2 *DIN Standard:*<sup>4</sup>

[DIN 50324 Testing of Friction and Wear](#)

## 3. Summary of Test Method

3.1 For the pin-on-disk wear test, two specimens are required. One, a pin with a radiused tip, is positioned perpendicular to the other, usually a flat circular disk. A ball, rigidly held, is often used as the pin specimen. The test machine causes either the disk specimen or the pin specimen to revolve about the disk center. In either case, the sliding path is a circle on the disk surface. The plane of the disk may be oriented either horizontally or vertically.

NOTE 1—Wear results may differ for different orientations.

3.1.1 The pin specimen is pressed against the disk at a specified load usually by means of an arm or lever and attached weights. Other loading methods have been used, such as hydraulic or pneumatic.

NOTE 2—Wear results may differ for different loading methods.

3.2 Wear results are reported as volume loss in cubic millimetres for the pin and the disk separately. When two different materials are tested, it is recommended that each material be tested in both the pin and disk positions.

3.3 The amount of wear is determined by measuring appropriate linear dimensions of both specimens before and after the

<sup>2</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For Annual Book of ASTM Standards volume information, refer to the standard's Document Summary page on the ASTM website.

<sup>3</sup> The last approved version of this historical standard is referenced on [www.astm.org](http://www.astm.org).

<sup>4</sup> Available from Beuth Verlag GmbH (DIN-- DIN Deutsches Institut für Normung e.V.), Burggrafenstrasse 6, 10787, Berlin, Germany, <http://www.en.din.de>.

<sup>1</sup> This test method is under the jurisdiction of ASTM Committee G02 on Wear and Erosion and is the direct responsibility of Subcommittee G02.40 on Non-Abrasive Wear.

Current edition approved Jan. 1, 2017. Published January 2017. Originally approved in 1990. Last previous edition approved in 2016 as G99 – 05 (2016). DOI: 10.1520/G0099-17.

TABLE 1 Characteristics of the Interlaboratory Wear Test Specimens

NOTE 1—See Note 4 for information.

	Composition (weight%)	Microstructure	Hardness (HV 10)	Roughness <sup>A</sup>	
				R <sub>z</sub> (mean) (μm)	R <sub>a</sub> (mean) (μm)
Steel ball (100 Cr6) (AISI 52 100) <sup>B</sup> Diameter 10 mm	1.35 to 1.65 Cr ← 0.95 to 1.10 C 0.15 to 0.35 Si 0.25 to 0.45 Mn	martensitic with minor carbides and austenite	838 ± 21	0.100	0.010
Steel disc (100 Cr6) (AISI 52 100) <sup>C</sup> Diameter 40 mm	← <0.030 P <0.030 S	martensitic with minor carbides and austenite	852 ± 14	0.952	0.113
Alumina ball, diameter = 10 mm <sup>D</sup>	← 95 % Al <sub>2</sub> O <sub>3</sub> (with additives of TiO <sub>2</sub> , MgO, and ZnO)	equi-granular alpha alumina with very minor secondary phases	1610 ± 101 (HV 0.2)	1.369	0.123
Alumina disc, diameter = 40.6 mm <sup>D</sup>	←		1599 ± 144 (HV 0.2)	0.968	0.041

<sup>A</sup> Measured by stylus profilometry. R<sub>z</sub> is maximum peak-to-valley roughness. R<sub>a</sub> is arithmetic average roughness.

<sup>B</sup> Standard ball-bearing balls (SKF).

<sup>C</sup> Standard spacers for thrust bearings (INA).

<sup>D</sup> Manufactured by Compagnie Industrielle des Ceramiques Electroniques, France.

TABLE 2 Results of the Interlaboratory Tests<sup>A</sup>

NOTE 1—See Note A for test conditions.

NOTE 2—Numbers in parentheses refer to all data received in the tests. In accordance with Practice E178, outlier data values were identified in some cases and discarded, resulting in the numbers without parentheses. The differences are seen to be small.

NOTE 3—Values preceded by ± are one standard deviation.

NOTE 4—Data were provided by 28 laboratories.

NOTE 5—Calculated quantities (for example, wear volume) are given as mean values only.

NOTE 6—Values labeled “NM” were found to be smaller than the reproducible limit of measurement.

NOTE 7—A similar compilation of test data is given in DIN 50324.

Results (ball) (disk)	Specimen Pairs			
	Steel-steel	Alumina-steel	Steel-alumina	Alumina-alumina
Ball wear scar diameter (mm)	2.11 ± 0.27 (2.11 ± 0.27)	NM	2.08 ± 0.35 (2.03 ± 0.41)	0.3 ± 0.06 (0.3 ± 0.06)
Ball wear volume (10 <sup>-3</sup> mm <sup>3</sup> )	198 (198)	...	186 (169)	0.08 (0.08)
Number of values	102 (102)	...	60 (64)	56 (59)
Disk wear scar width (mm)	NM	0.64 ± 0.12 (0.64 ± 0.12)	NM	NM
Disk wear volume (10 <sup>-3</sup> mm <sup>3</sup> )	...	480 (480)	...	...
Number of values	...	60 (60)	...	...
Friction coefficient	0.60 ± 0.11	0.76 ± 0.14	0.60 ± 0.12	0.41 ± 0.08
Number of values	109	75	64	76

<sup>A</sup> Test conditions: F = 10 N; v = 0.1 ms<sup>-1</sup>, T = 23°C; relative humidity range 12 to 78 %; laboratory air; sliding distance 1000 m; wear track (nominal) diameter = 32 mm; materials: steel = AISI 52 100; and alumina = α-Al<sub>2</sub>O<sub>3</sub>.

test, or by weighing both specimens before and after the test. If linear measures of wear are used, the length change or shape change of the pin, and the depth or shape change of the disk wear track (in millimetres) are determined by any suitable metrological technique, such as electronic distance gaging or stylus profiling. Linear measures of wear are converted to wear volume (in cubic millimetres) by using appropriate geometric relations. Linear measures of wear are used frequently in practice since mass loss is often too small to measure precisely. If loss of mass is measured, the mass loss value is converted to volume loss (in cubic millimetres) using an appropriate value for the specimen density.

3.4 Wear results are usually obtained by conducting a test for a selected sliding distance and for selected values of load and speed. One set of test conditions that was used in an interlaboratory measurement series is given in Tables 1-3. Other test conditions may be selected depending on the purpose of the test. In such cases, the user should report their results as “following the procedure of ASTM G99.”

3.5 Wear results may in some cases be reported as plots of wear volume versus sliding distance using different specimens for different distances. Such plots may display non-linear relationships between wear volume and distance over certain

TABLE 3 Test Parameters Used for Interlaboratory Tests

Normal Force (N)	10
Sliding Speed (m/s)	0.1
Sliding Distance (m)	1000
Pin-end Diameter, spherical (mm)	10
Environment	air
Temperature, nominal (°C)	23
Humidity, (%RH)	12–78
Track Diameter (mm)	25–35

portions of the total sliding distance, and linear relationships over other portions. Causes for such differing relationships include initial “break-in” processes, transitions between regions of different dominant wear mechanisms, and so forth. The extent of such non-linear periods depends on the details of the test system, materials, and test conditions.

3.6 It is not recommended that continuous wear depth data obtained from position-sensing gages be used because of the complicated effects of wear debris and transfer films present in the contact gap, and interferences from thermal expansion or contraction.

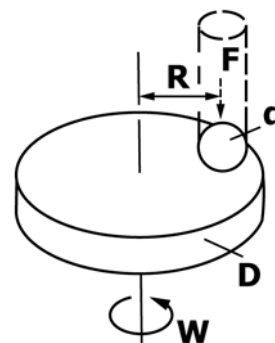
#### 4. Significance and Use

4.1 The amount of wear in any system will, in general, depend upon the number of system factors such as the applied load, machine characteristics, sliding speed, sliding distance, the environment, and the material properties. The value of any wear test method lies in predicting the relative ranking of material combinations. Since the pin-on-disk test method does not attempt to duplicate all the conditions that may be experienced in service (for example; lubrication, load, pressure, contact geometry, removal of wear debris, and presence of corrosive environment), there is no insurance that the test will predict the wear rate of a given material under conditions differing from those in the test.

4.2 The use of this test method will fall in one of two categories: (1) the test(s) will follow all particulars of the standard, and the results will have been compared to the ILS data (Table 2), or (2) the test(s) will have followed the procedures/methodology of Test Method G99 but applied to other materials or using other parameters such as load, speed, materials, etc., or both. In this latter case, the results cannot be compared to the ILS data (Table 2). Further, it must be clearly stated what choices of test parameters/materials were chosen.

#### 5. Apparatus

5.1 *General Description*—Fig. 1 shows a schematic drawing of a typical pin-on-disk wear test system.<sup>5</sup> One type of typical system consists of a driven spindle and chuck for holding the revolving disk, a lever-arm device to hold the pin, and attachments to allow the pin specimen to be forced against the revolving disk specimen with a controlled load. Another



NOTE 1— $F$  is the normal force on the pin,  $d$  is the pin or ball diameter,  $D$  is the disk diameter,  $R$  is the wear track radius, and  $w$  is the rotation velocity of the disk.

FIG. 1 Schematic of Pin-on-Disk Wear Test System

type of system loads a pin revolving about the disk center against a stationary disk. In any case the wear track on the disk is a circle, involving multiple wear passes on the same track. The system may have a friction force measuring system, for example, a load cell, that allows the coefficient of friction to be determined.

5.2 *Motor Drive*—A variable speed motor, capable of maintaining constant speed ( $\pm 1\%$  of rated full load motor speed) under load is required. The motor should be mounted in such a manner that its vibration does not affect the test. Rotating speeds are typically in the range 0.3 to 3 rad/s (60 to 600 r/min).

5.3 *Revolution Counter*—The machine shall be equipped with a revolution counter or its equivalent that will record the number of disk revolutions, and preferably have the ability to shut off the machine after a pre-selected number of revolutions.

5.4 *Pin Specimen Holder and Lever Arm*—In one typical system, the stationary specimen holder is attached to a lever arm that has a pivot. Adding weights, as one option of loading, produces a test force proportional to the mass of the weights applied. Ideally, the pivot of the arm should be located in the plane of the wearing contact to avoid extraneous loading forces due to the sliding friction. The pin holder and arm must be of substantial construction to reduce vibrational motion during the test.

5.5 *Wear Measuring Systems*—Instruments to obtain linear measures of wear should have a sensitivity of 2.5  $\mu\text{m}$  or better. Any balance used to measure the mass loss of the test specimen shall have a sensitivity of 0.1 mg or better; in low wear situations greater sensitivity may be needed.

#### 6. Test Specimens and Sample Preparation

6.1 *Materials*—This test method may be applied to a variety of materials. The only requirement is that specimens having the specified dimensions can be prepared and that they will withstand the stresses imposed during the test without failure or excessive flexure. The materials being tested shall be described by dimensions, surface finish, material type, form, composition, microstructure, processing treatments, and indentation hardness (if appropriate).

<sup>5</sup> A number of other reported designs for pin-on-disk systems are given in “A Catalog of Friction and Wear Devices,” American Society of Lubrication Engineers (1973). Three commercially-built pin-on-disk machines were either involved in the interlaboratory testing for this standard or submitted test data that compared adequately to the interlaboratory test data. Further information on these machines can be found in Research Report RR:G02-1008.

6.2 *Test Specimens*—The typical pin specimen is cylindrical or spherical in shape. Typical cylindrical or spherical pin specimen diameters range from 2 to 10 mm. The typical disk specimen diameters range from 30 to 100 mm and have a thickness in the range of 2 to 10 mm. Specimen dimensions used in an interlaboratory test with pin-on-disk systems are given in [Table 1](#).

6.3 *Surface Finish*—A ground surface roughness of 0.8 μm (32 μin.) arithmetic average or less is usually recommended.

NOTE 3—Rough surfaces make wear scar measurement difficult.

6.3.1 Care must be taken in surface preparation to avoid subsurface damage that alters the material significantly. Special surface preparation may be appropriate for some test programs. State the type of surface and surface preparation in the report.

## 7. Test Parameters

7.1 *Load*—Values of the force in Newtons at the wearing contact.

7.2 *Speed*—The relative sliding speed between the contacting surfaces in metres per second.

7.3 *Distance*—The accumulated sliding distance in meters.

7.4 *Temperature*—The temperature of one or both specimens at locations close to the wearing contact.

7.5 *Atmosphere*—The atmosphere (laboratory air, relative humidity, argon, lubricant, and so forth.) surrounding the wearing contact.

## 8. Procedure

8.1 Immediately prior to testing, and prior to measuring or weighing, clean and dry the specimens. Take care to remove all dirt and foreign matter from the specimens. Use non-chlorinated, non-film-forming cleaning agents and solvents. Dry materials with open grains to remove all traces of the cleaning fluids that may be entrapped in the material. Steel (ferromagnetic) specimens having residual magnetism should be demagnetized. Report the methods used for cleaning.

8.2 Measure appropriate specimen dimensions to the nearest 2.5 μm or weigh the specimens to the nearest 0.0001 g.

8.3 Insert the disk securely in the holding device so that the disk is fixed perpendicular ( $\pm 1^\circ$ ) to the axis of the resolution.

8.4 Insert the pin specimen securely in its holder and, if necessary, adjust so that the specimen is perpendicular ( $\pm 1^\circ$ ) to the disk surface when in contact, in order to maintain the necessary contact conditions.

8.5 Add the proper mass to the system lever or bale to develop the selected force pressing the pin against the disk.

8.6 Start the motor and adjust the speed to the desired value while holding the pin specimen out of contact with the disk. Stop the motor.

8.7 Set the revolution counter (or equivalent) to the desired number of revolutions.

8.8 Begin the test with the specimens in contact under load. The test is stopped when the desired number of revolutions is achieved. Tests should not be interrupted or restarted.

8.9 Remove the specimens and clean off any loose wear debris. Note the existence of features on or near the wear scar such as: protrusions, displaced metal, discoloration, microcracking, or spotting.

8.10 Remeasure the specimen dimensions to the nearest 2.5 μm or reweigh the specimens to the nearest 0.0001 g, as appropriate.

8.11 Repeat the test with additional specimens to obtain sufficient data for statistically significant results.

## 9. Calculation and Reporting

9.1 The wear measurements should be reported as the volume loss in cubic millimetres for the pin and disk, separately.

9.1.1 Use the following equations for calculating volume losses when the pin has initially a spherical end shape of radius  $R$  and the disk is initially flat, under the conditions that only one of the two members wears significantly:

$$\begin{aligned} \text{pin (spherical end) volume loss, mm}^3 & \quad (1) \\ &= \frac{\pi (\text{wear scar diameter, mm})^4}{64 (\text{sphere radius, mm})} \end{aligned}$$

assuming that there is *no significant disk wear*. This is an approximate geometric relation that is correct to 1 % for (wear scar diameter/sphere radius) <0.3, and is correct to 5 % for (wear scar diameter/sphere radius) <0.7. The exact equation is given in [Appendix X1](#).

$$\text{disk volume loss, mm}^3 \quad (2)$$

$$= \frac{\pi (\text{wear track radius, mm})(\text{track width, mm})^3}{6 (\text{sphere radius, mm})}$$

assuming that there is *no significant pin wear*. This is an approximate geometric relation that is correct to 1 % for (wear track width/sphere radius) <0.3, and is correct to 5 % for (wear track width/sphere radius) <0.8. The exact equation is given in [Appendix X1](#).

9.1.2 Calculation of wear volumes for pin shapes of other geometries use the appropriate geometric relations, recognizing that assumptions regarding wear of each member may be required to justify the assumed final geometry.

9.1.3 Wear scar measurements should be done at least at two representative locations on the pin surfaces and disk surfaces, and the final results averaged.

9.1.4 In situations where both the pin and the disk wear significantly, it will be necessary to measure the wear depth profile on both members. A suitable method uses stylus profiling. Profiling is the only approach to determine the exact final shape of the wear surfaces and thereby to calculate the volume of material lost due to wear. In the case of disk wear, the average wear track profile can be integrated to obtain the track cross-section area, and multiplied by the average track length to obtain disk wear volume. In the case of pin wear, the wear scar profile can be measured in two orthogonal directions, the profile results averaged, and used in a figure-of-revolution calculated for pin wear volume.

9.1.4.1 If little wear has occurred as evidenced by very small wear scars, or if the wear scars are covered by any solid film formed during wear, it is best practice to use surface profilometry to determine wear volume. Further, if the amount



of pin wear is small and the pin wear scar is not flat, profilometry must be used.

9.1.5 While mass loss results may be used internally in laboratories to compare materials of equivalent densities, this test method reports wear as volume loss so that there is no confusion caused by variations in density. Take care to use and report the best available density value for the materials tested when calculating volume loss from measured mass loss.

9.1.6 Use the following equation for conversion of mass loss to volume loss.

$$\text{volume loss, mm}^3 = \frac{\text{mass loss, g}}{\text{density, g/cm}^3} \times 1000. \quad (3)$$

9.2 If the materials being tested exhibit considerable transfer between specimens without loss from the system, volume loss may not adequately reflect the actual amount or severity of wear. In these cases, this test method for reporting wear should not be used.

9.3 Friction coefficient (defined in Terminology G40) should be reported when available. Describe the conditions associated with the friction measurements, for example, initial, steady-state, and so forth.

9.4 Adequate specification of the materials tested is important. As a minimum, the report should specify material type, form, processing treatments, surface finish, and specimen preparation procedures. If appropriate, indentation hardness should be reported.

## 10. Precision and Bias<sup>6</sup>

### 10.1 Statement of Precision:

10.1.1 The precision of the measurements obtained with this test method will depend upon the test parameters chosen. The reproducibility of repeated tests on the same material will depend upon material homogeneity, machine and material interaction, and careful adherence to the specified procedure by

<sup>6</sup> Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:G02-1008.

the machine operator. Normal variations in the wear test procedure will tend to reduce the precision of the test method as compared to the precision of such material property tests as hardness or density.

10.1.2 Table 2 contains wear data obtained from interlaboratory tests. Mean and standard deviation values are given for all measured quantities.

10.1.3 Statistical analysis (using Guide G117) of the steel vs. steel ball wear scar diameter results for 24 laboratories leads to a mean and standard deviation of 2.14 and 0.29 mm, respectively. The 95 % repeatability limit (within-lab) was 0.37 mm, and the 95 % reproducibility limit (between-labs) was 0.81 mm. Statistical analysis of the steel vs. steel ball friction results for 25 laboratories leads to a mean and standard deviation of 0.60 and 0.11, respectively. The 95 % repeatability limit (within-lab) was 0.19, and the 95 % reproducibility limit (between-labs) was 0.32.

10.2 Statement of Bias—No bias can be assigned to these results since there are no absolute accepted values for wear.

10.3 General Considerations—Participants in the interlaboratory testing that led to the statements of precision and bias given above involved 28 laboratories, 2 different materials (4 material pairs), 1 test condition, and 3 to 5 replicate measurements each (see Note 4). Subsequent to this testing, data were received from another laboratory that utilized a commercial test machine. These data were found consistent with the results in the interlaboratory study.

NOTE 4—The interlaboratory data given in Table 1 and Table 2 resulted through the cooperation of thirty one institutions in seven countries with the help of national representatives within the Versailles Advanced Materials and Standards (VAMAS) working party on wear test methods.<sup>7</sup>

## 11. Keywords

11.1 ceramic wear; friction; metal wear; non-abrasive; pin-on-disk; wear

<sup>7</sup> Czichos, H., Becker, S., and Lexow, J., *Wear*, Vol 114, 1987, pp. 109–130 and *Wear*, Vol 118, 1987, pp. 379–380.

## APPENDIX

### (Nonmandatory Information)

## X1. EQUATIONS

X1.1 Exact equations for determining wear volume loss are as follows for:

X1.1.1 A spherical ended pin:

$$\text{pin volume loss} = (\pi h/6)[3d^2/4 + h^2] \quad (X1.1)$$

where:

$h$  =  $r - [r^2 - d^2/4]^{1/2}$   
 $d$  = wear scar diameter, and  
 $r$  = pin end radius.

Assuming no significant disk wear.

X1.1.2 A disk:

$$\text{disk volume loss} = 2\pi R [r^2 \sin^{-1}(d/2r) - (d/4)(4r^2 - d^2)^{1/2}] \quad (X1.2)$$

where:

$R$  = wear track radius, and  
 $d$  = wear track width.

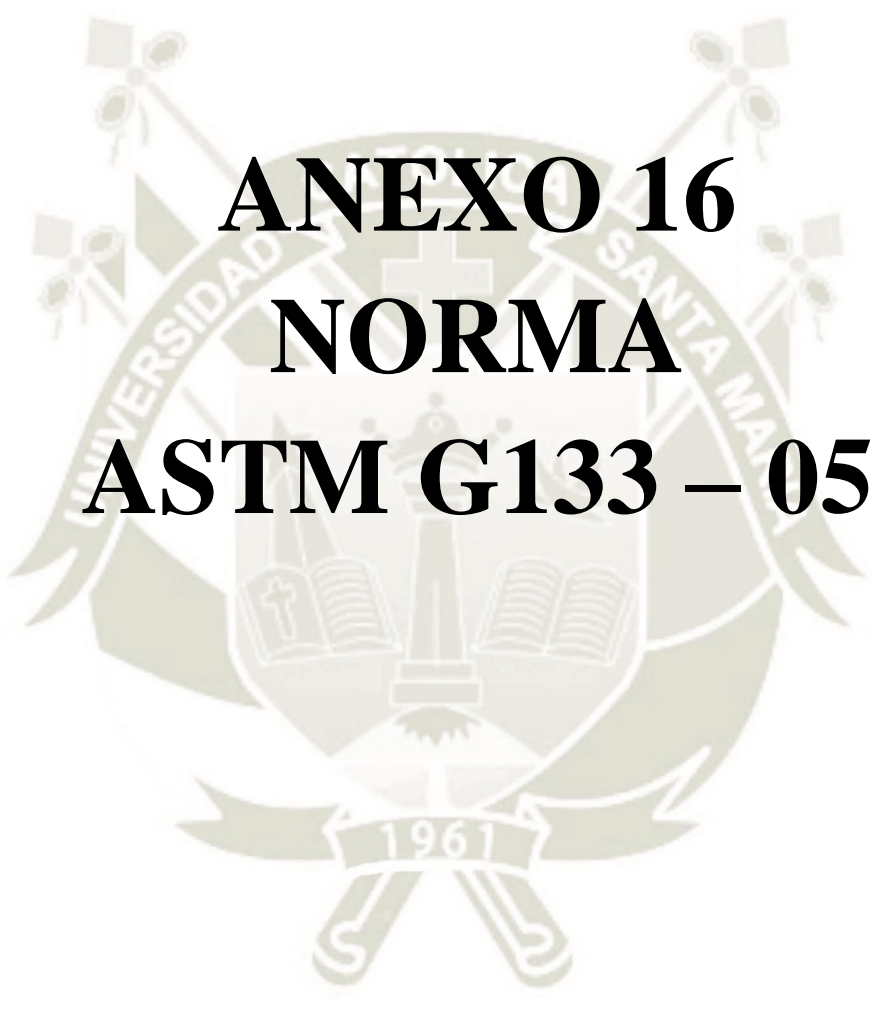
Assuming no significant pin wear.

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**ANEXO 16**  
**NORMA**  
**ASTM G133 – 05**



# Standard Test Method for Linearly Reciprocating Ball-on-Flat Sliding Wear<sup>1</sup>

This standard is issued under the fixed designation G133; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This test method covers laboratory procedures for determining the sliding wear of ceramics, metals, and other candidate wear-resistant materials using a linear, reciprocating ball-on-flat plane geometry. The direction of the relative motion between sliding surfaces reverses in a periodic fashion such that the sliding occurs back and forth and in a straight line. The principal quantities of interest are the wear volumes of the contacting ball and flat specimen materials; however, the coefficient of kinetic friction may also be measured using the method described. This test method encompasses both unlubricated and lubricated testing procedures. The scope of this test method does not include testing in corrosive or chemically aggressive environments.

1.2 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

## 2. Referenced Documents

### 2.1 ASTM Standards:<sup>2</sup>

- E112 Test Methods for Determining Average Grain Size
- E1181 Test Methods for Characterizing Duplex Grain Sizes
- G40 Terminology Relating to Wear and Erosion
- G99 Test Method for Wear Testing with a Pin-on-Disk Apparatus
- G115 Guide for Measuring and Reporting Friction Coefficients
- G117 Guide for Calculating and Reporting Measures of

<sup>1</sup> This test method is under the jurisdiction of ASTM Committee G02 on Wear and Erosion and is the direct responsibility of Subcommittee G02.40 on Non-Abrasive Wear.

Current edition approved June 1, 2016. Published June 2016. Originally approved in 1995. Last previous edition approved in 2010 as G133 – 05 (2010). DOI: 10.1520/G0133-05R16.

<sup>2</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[Precision Using Data from Interlaboratory Wear or Erosion Tests](#)

[G118 Guide for Recommended Format of Wear Test Data Suitable for Databases](#)

## 3. Terminology

### 3.1 Definitions:

3.1.1 Definitions used in this test method are given in Terminology G40. The following definitions of important terms used in this test method are cited from Terminology G40.

3.1.2 *friction force*—the resisting force tangential to the interface between two bodies when, under the action of an external force, one body moves or tends to move relative to the other.

3.1.3 *Hertzian contact pressure*—the magnitude of the pressure at any specified location in a Hertzian contact area, as calculated from Hertz's equations of elastic deformation.

3.1.4 *wear*—damage to a solid surface, generally involving the progressive loss of material due to relative motion between that surface and a contacting surface or surfaces.

3.1.5 *wear rate*—the rate of material removal or dimensional change due to wear per unit of exposure parameter, for example, quantity removed (mass, volume, thickness) in unit distance of sliding or unit time.

## 4. Summary of Test Method

4.1 This test method involves two specimens—a flat specimen and a spherically ended specimen (herein called the “ball” specimen) which slides against the flat specimen. These specimens move relative to one another in a linear, back and forth sliding motion, under a prescribed set of conditions.

4.2 In this test method, the load is applied vertically downward through the ball specimen against the horizontally mounted flat specimen. The normal load, stroke length, frequency and type of oscillation, test temperature, lubricant (if any), test duration, and atmospheric environment (including relative humidity range) are selected from one of two procedures.

4.3 Since this test method involves reciprocating sliding where changes in the sliding velocity and direction of motion occur during the test, constant velocity conditions are not maintained. The manner in which the velocity varies with time

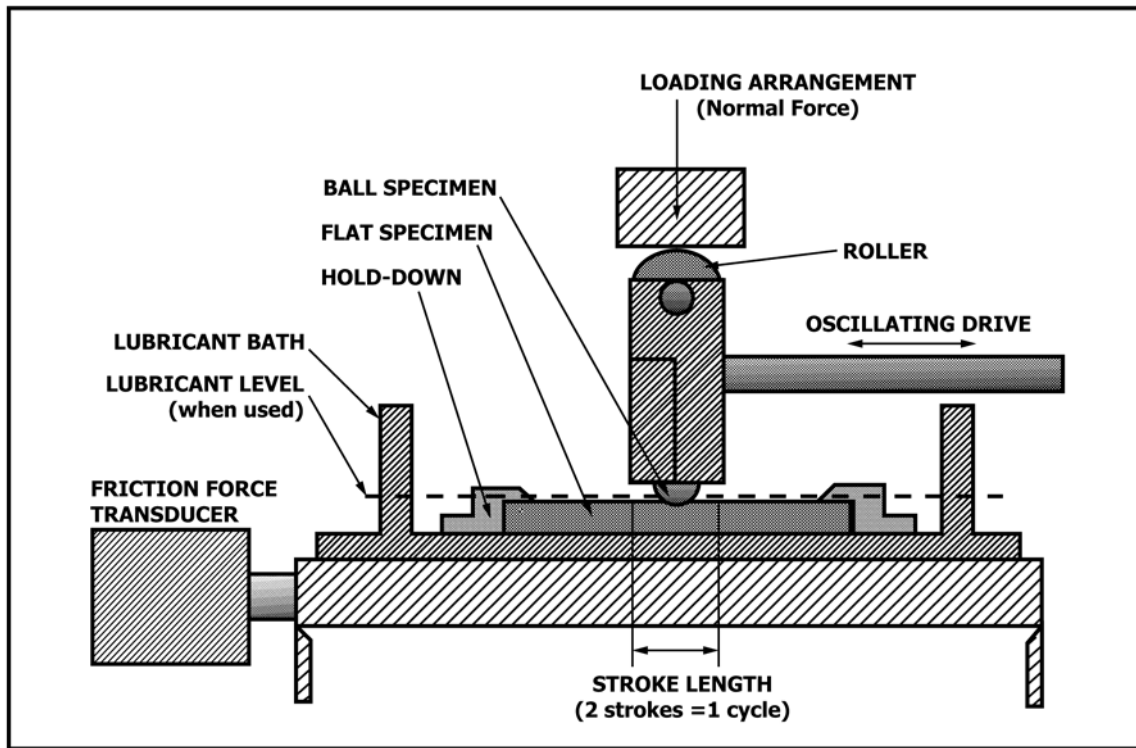


FIG. 1 Reciprocating Test—Schematic Diagram

is determined by the design of the mechanism which drives the ball or flat specimen back and forth.

4.4 Dimensional changes for both ball and flat specimens are used to calculate wear volumes and wear rates.

4.5 Friction forces are measured during the test and may be used to assess changes in the contact conditions or the kinetic friction coefficient as a function of time.

## 5. Significance and Use

5.1 This test method is designed to simulate the geometry and motions that are experienced in many types of rubbing components whose normal operation results in periodic reversals in the direction of relative sliding. The wear resulting from this mode of movement may differ from that experienced by the same materials sliding continuously in only one direction (unidirectional sliding) even for comparable durations of contact. Test loads and speeds are to be determined by the severity of the proposed application or purpose of the testing. Either of two sets of testing conditions (designated Procedures A and B) may be used.

## 6. Apparatus

6.1 *General Description*—Fig. 1 shows the arrangement for the reciprocating ball-on-flat wear test available on a commercial machine. The ball is rigidly mounted and has a spherical tip which moves back and forth across the surface of a polished flat specimen. Use of a spherical tip alleviates the alignment problems associated with flat-ended balls sliding on flat surfaces. Alternate configurations in which the flat moves and the ball specimen is fixed may be used. A provision is made for applying a uniform normal force (load) to the contact between

the ball and the flat. Temperature measurement and control capability is provided to heat and monitor the flat specimen which may either be immersed in a lubricant bath or tested without lubricant. The tangential force can be measured continuously during oscillating contact and used to obtain friction coefficient data.<sup>3</sup>

6.2 *Specimen Drive*—A drive train, capable of providing smooth, reciprocating motion to the ball and overcoming the frictional resistance of the specimens at maximum load, is required. For example, a Scotch yoke drive mechanism can provide a smooth, sinusoidal velocity profile for the ball specimen relative to the flat specimen without the need for the motor to stop and reverse direction periodically. Stepper-type motors may also be used provided that the motion is smooth and uniform.

6.3 *Ball and Ball Specimen Holder*—The ball specimen may be a fixed bearing ball or any spherically tipped specimen as long as the sliding contact is equivalent to a ball on a flat plane. If a bearing ball is used, it shall be clamped tightly enough to prevent slippage during the test. The ball holder should be rigid enough so that the periodic reversal in the sliding direction does not result in tilting or other misalignment of the contact.

6.4 *Flat Specimen Holder*—The flat specimen is secured to the base of the machine to prevent slippage or buckling during the test. A variety of shapes and configurations for the flat specimen are possible. The primary criterion is that the coupon present a flat, horizontal surface to the ball specimen.

<sup>3</sup> Machines of this type are described in *A Catalogue of Friction and Wear Devices*, American Society of Lubrication Engineers (now STLE) 838 Busse Highway, Park Ridge, IL, 1973, pp. 50–72.

### 6.5 Instrumentation:

6.5.1 *Friction Force*—A tension-compression load cell or similar force-sensing device may be used to measure the friction forces generated during sliding. Calibration of the friction force (see subsection 7.1.3) in both forward and reverse sliding directions is required. Since the direction of the friction force changes rapidly during the test, traditional strip-chart-type recorders may be too slow to follow these changes at high frequencies of reciprocation. A commercial version of this machine is available with a signal conditioner to rectify, and output the root-mean-square friction force to a strip-chart-recorder or to a computerized data acquisition system. The method of sensing and recording friction force during the test shall be described in the testing report.

6.5.2 *Test Duration*—In this test method, test duration is specified in seconds. To compute the sliding distance in metres or number of cycles, use the following:

$$X = 0.002 \times t \times f \times L \quad (1)$$

or

$$N = t \times f \quad (2)$$

where:

- $X$  = total sliding distance of the ball, m,
- $N$  = number of cycles in the test,
- $t$  = test time, s,
- $f$  = oscillating frequency, Hz (cycles/s), and
- $L$  = length of stroke, mm.

A cycle is defined as two stroke lengths (up and back). Electronic timers can be used to terminate the test. If a cycle-counter is available, this may be used instead of the timer, in which case Eq 2 will be used.

6.5.3 *Humidity*—The wear and friction of many materials is significantly affected by the moisture in the air. It is therefore required that the relative humidity (to an accuracy of  $\pm 3\%$ ) be measured before and during the test. Humidity can vary with air flow and in different parts of the same room, so the humidity sensor should be located as close to the test specimens as reasonably possible, in such a way that the air movement conditions are the same for humidity sensor as for the test specimens.

6.5.4 *Temperature*—The ambient temperature, in degrees Celsius, shall be measured and reported during room temperature tests. In full immersion, liquid-lubricated tests, the bath temperature shall be measured and reported.

## 7. Calibration

7.1 The parts of the apparatus that require calibration are (1) the loading system, (2) the motion drive (speed and stroke length), and (3) the friction force sensor.

7.1.1 *Loading System*—The load (normal force) applied to the specimen shall be checked periodically. In machines which apply the load by a spring/lever arrangement and indicate the load on a dial gage, this can be done by substituting a previously calibrated compression load cell for the specimen and checking the applied load indicated on the loading dial against the calibrated load cell output. Statically applied loads shall be kept constant within a maximum deviation of  $\pm 2.0\%$  of the test load. For example, permitted static error of a 25.0-N

normal force would be  $\pm 0.5$  N. During oscillating tests, the normal force may vary slightly about the mean value due to the dynamics of the machine. This variation is to be expected.

7.1.2 *Motion Drive*—The oscillating frequency of the moving specimen shall be checked periodically against the drive motor setting to ensure that the rate of oscillation is known. (**Warning**—Due to inertial effects, differences in the loading and fixturing method become more significant as the oscillating frequency of the test is increased, and harmonic frequencies characteristic of the test machine must be avoided when selecting the oscillating frequency.)

7.1.3 *Friction Force Sensor*—The friction force sensor shall be calibrated periodically in both directions of load application. Depending on the machine, a fixture which applies a calibrating load in line with the normal point of contact between the ball and flat should be used.

## 8. Procedure

8.1 *Specimen Preparation*—The ball specimen and flat specimen shall be used either in a polished condition, or in a specified condition consistent with the application of interest. In a polished condition, the surface should be as free as possible from preparation artifacts such as grinding-induced cracks, gross grinding marks, and grain pull-out. Surface roughnesses of 0.02 to 0.05- $\mu\text{m}$   $R_a$  (arithmetic roughness) are typical.

8.2 Clean the specimens using the following procedure:

- 8.2.1 Wash with a mild liquid laboratory glassware cleaner,
- 8.2.2 Hot air dry,
- 8.2.3 Ultrasonically clean in acetone (2 min),
- 8.2.4 Hot air dry,
- 8.2.5 Ultrasonically clean in methanol (2 min), and
- 8.2.6 Hot air dry.

8.2.7 If there is considerable porosity in the specimens, it is necessary that they be baked dry for 4 h at a temperature greater than 150°C in a clean oven.

NOTE 1—Certain materials could be adversely affected by cleaning in solvents. Deviations from the prescribed cleaning procedure are permitted, but they shall be described in the report.

8.3 Clean the specimens after they are secured in place in the test fixture by wiping with acetone and then with methanol-moistened cotton swabs. It is possible that during mounting, some contamination was inadvertently placed on them, and this final cleaning will help alleviate the problem. Inspect the ball tip with a hand lens after it is mounted to ensure that there are no defects in the contact area.

8.4 Gently lower the ball specimen upon the flat specimen, and ensure that the reciprocating drive shaft motion is horizontal and parallel to the surface of the flat specimen. The height of the specimen or mount may require adjustment to ensure that this condition is fulfilled. Apply the prescribed test load. Confirm that the desired oscillating speed has been set before turning on the motor.

8.5 Two possible testing procedures, one for unlubricated tests (Procedure A), and one for high-contact stress-lubricated tests at elevated temperature (Procedure B), are given in 8.5.1. The procedure appropriate for the given materials and test

severity should be selected. If neither procedure in 8.5.1 is determined to be suitable, other conditions may be used, but testing will not be in compliance with this test method. See the reporting requirements in Section 10 for reporting exceptions to Procedures A and B.

8.5.1 The two testing procedures are as follows.

8.5.1.1 *Procedure A*—Unlubricated wear testing at room temperature.

- (1) Pin tip radius, 4.76 mm ( $\frac{3}{16}$  in.),
- (2) Normal force, 25.0 N,
- (3) Stroke length, 10.0 mm,
- (4) Oscillating frequency, 5.0 Hz,
- (5) Test duration, 16 min 40 s (sliding distance 100 m),
- (6) Ambient temperature,  $22 \pm 3^\circ\text{C}$ ,
- (7) Relative humidity, 40 to 60 %, and
- (8) Lubrication, none applied.

8.5.1.2 *Procedure B*—Lubricated wear testing at elevated temperature.

- (1) Pin tip radius, 4.76 mm ( $\frac{3}{16}$  in.),
- (2) Normal force, 200.0 N,
- (3) Stroke length, 10.0 mm,
- (4) Oscillating frequency, 10.0 Hz,
- (5) Test duration, 33 min 20 s (sliding distance 400 m),
- (6) Temperature,  $150 \pm 2^\circ\text{C}$ ,
- (7) Relative humidity, 40 to 60 %, and
- (8) Lubrication, full immersion under the selected lubricant (see Note 2).

NOTE 2—This procedure requires full-immersion lubrication. If other methods, such as a controlled drip feeding system, are used to simulate certain applications, the provisions of 8.6 will apply.

8.5.2 When heated, liquid-lubricated tests are being conducted, as in Procedure B, apply the lubricant and heat the specimens to the selected temperature allowing them to equilibrate for not less than 5 min before applying the load and starting the test. Bath temperature shall be controlled to within a maximum deviation of  $\pm 2.0^\circ\text{C}$  from the desired temperature. A fresh supply of lubricant shall be used for each test unless the objective is to evaluate the effects of used lubricants on friction and wear.

8.5.3 Set the timer (or cycle counter), if available, for the selected test duration.

8.5.4 Start the friction (and temperature) recording equipment and initiate the test.

8.5.5 After the prescribed duration, stop the motor. Remove the normal force to recheck the zero point on the friction force recording system.

8.5.6 Allow specimens to cool, if heated, then remove the test specimens. To measure the wear, it is necessary to clean the specimens in such a way that the surface features are not altered. For unlubricated tests, a concentrated jet of air may be used to dispel the debris from the worn area of the specimens. For liquid-lubricated specimens, ultrasonic cleaning in a suitable solvent may be used. Specimens shall be thoroughly dried.

8.5.7 Examine the tip of the ball specimen to ensure that no rolling or other slippage has taken place. Any ball movement within the holder during the test invalidates the test results. Similarly, any slippage of the flat specimen in its fixture invalidates the test results.

8.6 *Alternative Testing Procedures*—To achieve certain simulation conditions, or for other technical reasons, Procedures A and B may not be suitable for a given reciprocating wear testing project. Modifications to the specific test conditions prescribed in Procedures A and B may be used for conducting such tests; however, in reporting the results, the specific parameters which are not in compliance with one of the standard testing procedures shall be specifically noted. A statement such as the following may then be used: “These tests are not in full compliance with the provisions of Test Method G133, Procedure A, because the normal force in these tests was 50.0 N, instead of 25.0 N as prescribed by the standard, and the stroke length was 5.0 mm, instead of 10.0 mm as prescribed by the standard. All other provisions of Test Method G133 have been followed.”

## 9. Measurement and Calculation of Wear

9.1 Depending upon the relative wear of ball and flat specimens, various assumptions about the geometric irregularity of the wear scars can be made. Fig. 2 shows several possible wear conditions. In Fig. 2(a), the flat material is much more wear-resistant than the ball material. In Fig. 2(b), the ball material is much more wear-resistant than the flat material. In Fig. 2(c), measurable wear occurs on both ball and flat materials.

9.2 *Wear of the Ball Specimen*—Owing to the nature of this type of test, the wear scar on the ball specimen may not always be circular or flat. Refer to the following which applies.

9.2.1 If the end of the ball appears flat, but not circular, the average of the maximum and minimum dimensions of the scar shall be computed and this value used as the effective ball scar diameter ( $D$ ). Pin scar measurements may be made by removing the ball specimen holder and placing the wear scar portion under a reflecting microscope. A calibrated ocular or a photomicrograph of known magnification may be used to measure scar dimensions.

9.2.1.1 The wear volume ( $V_p$ ) for a flat ball wear scar of effective diameter  $D$  (the case in Fig. 2(a)), is found from the same relationship given in Test Method G99, Appendix X1.1.1:

$$V_p = (\pi h/6)[3D^2/4 + h^2] \quad (3)$$

where:

$h$  = height of material removed, mm.

Assuming a spherical wear volume, the height of material removed can be calculated from  $D$  as follows:

$$h = R - [R^2 - (D^2/4)]^{1/2} \quad (4)$$

where:

$R$  = original ball radius, mm.

(Warning—For lubricated tests in which there is minimal wear, it is possible to be misled in reading the apparent wear scar diameter of the ball tip optically because of elastic recovery. A small, shallow annulus surrounding the elastically deformed area may give the impression of wear, whereas little or no appreciable wear has actually occurred. Profilometry may be used to determine whether the wear scar is flat and consequently whether (Eq 3) and (Eq 4) can be used.)

View along the sliding direction (in and out of the plane of the figure) for three conditions of wear.

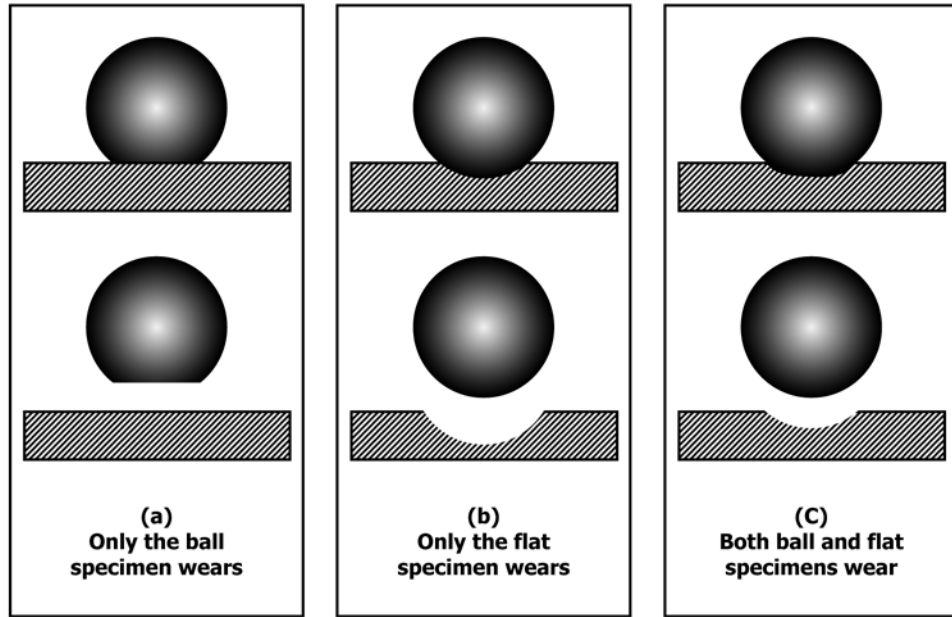


FIG. 2 Possible Situations for Differing Wear Resistance of Ball and Flat Specimens

9.2.2 If the ball tip is obviously worn, but the wear track profile on the flat specimen indicates that the ball is not entirely flat, as in Fig. 2(c), note those facts and either measure volume by an alternate method, fully describing the method used, or do not report wear volume.

NOTE 3—Various methods have been used to measure the wear volumes of non-flat ball tips.<sup>4</sup> These methods may be used and the results reported; however, a statement such as that given in 8.6 should be used to indicate that the calculation method is not in accordance with the provisions of this test method.

9.2.3 If there is only light abrasion or a few scratches on the ball specimen, the term “no measurable wear” may be used.

9.2.4 If the tip of the ball is obscured by an adherent deposit of wear debris, no measure of wear shall be reported, but the reason why the measurement cannot be made shall be reported.

9.3 *Wear of the Flat Specimen*—The wear volume of the flat specimen is computed from the length of the stroke and the average cross-sectional area of the wear track, as measured at locations equally spaced along its length. In most cases, the width and depth of the wear scar on the flat specimen will be relatively uniform throughout its length. If the areas of the three initial profiles differ by less than 25 %, three profiles will be sufficient. If wear is nonuniform, six cross-sectional profiles shall be obtained to compute the average track cross-sectional area. Generally, in calculating wear volume of the flat specimen, the minor geometric errors associated with the direction-reversal points at each end of the track can be neglected. (**Warning**—It is not recommended that continuous wear depth data obtained from position-sensing gages be used because of the possible complications arising from entrapped debris, thermal expansion due to frictional heating, hydrody-

namic lift, and tribochemical films which can form in the wear interface under certain conditions.)

9.3.1 A cross section of the wear track is the area of the material removed from the original flat surface as viewed on a plane normal to the original surface and to the direction of sliding motion. Cross-sectional profiles may be obtained using a stylus-type instrument or its functional equivalent. On the printed profile made across the wear track, a straight line is drawn between the unworn areas on both sides of the wear scar and the cross-sectional area of the wear groove, below that reference line, is used to compute the wear volume. The cross-sectional area may be determined by planimetry, through the use of computerized digitizing tablet, or by importing the surface trace data directly into a computer program which permits the measurement of areas under profiles. Wear volume of the flat,  $V_f$  in  $\text{mm}^3$ , is calculated from:

$$V_f = A \times L \quad (5)$$

where:

$A$  = average cross-sectional area of the track,  $\text{mm}^2$ , and  
 $L$  = length of the stroke, mm.

## 10. Report

10.1 Report any unusual event such as noise, chattering, or excessive vibration which occurs during the test. Also, report any unusual frictional behavior, as indicated in 10.3.3. Test parameters to be reported should conform with either Procedure A or B. If procedures other than A or B are used, the report should explicitly state so, listing the conditions which are different than those described in 8.5.1.

10.2 Report the following:

10.2.1 Characterization of the ball and flat specimen materials. Information shall be sufficient to establish their source, chemical composition, processing history, surface treatment,

<sup>4</sup> Whitenton, E. P., and Blau, P. J., “A Comparison of Methods for Determining Wear Volumes and Surface Parameters of Spherically-Tipped Sliders,” *Wear*, Vol 124, 1988, pp. 291–309.



and root-mean-square surface roughness. Commercial designations for materials should be given, if applicable. If a lubricant is used, provide its commercial name or other description, and any other properties needed to identify the source and traceability of the lubricant. Grain size and percent porosity of specimens may be reported, if applicable. If reporting grain size, indicate whether the grain size is nonuniform or duplex. See Test Methods E112 and E1181. Additional guidelines for reporting data are found in Guide G118.

NOTE 4—Quantities which have been measured on the same lot used for fabricating wear test specimens should be distinguished from those obtained on other lots of material (or handbook values) and assumed to apply to the given test specimens. Tests involving proprietary materials are specifically excluded from reporting compositions or processes; however, material lot numbers and as many specific identifiers as possible shall otherwise be provided.

### 10.2.2 Test Parameters:

10.2.2.1 Applied normal force,  $N$ , and ball tip radius, mm.

10.2.2.2 Stroke length, mm.

10.2.2.3 Test duration, s or min:s.

10.2.2.4 Frequency of oscillation,  $s^{-1}$ , and type of motion produced by the oscillating drive system; for example, sinusoidal velocity profile, triangular velocity profile, and so forth.

10.2.2.5 Ambient relative humidity, %.

10.2.2.6 Ambient temperature, °C.

10.2.2.7 Whether lubricated or unlubricated.

### 10.2.3 Results:

10.2.3.1 Wear volume only, not wear rate, is reported because there is no reason to assume that wear occurs at a constant rate throughout the testing period.

10.2.3.2 Wear volume of the ball specimen, if the scar is flat, in  $mm^3$ . See 9.2 for a more detailed discussion of this measurement.

10.2.3.3 Wear volume of the flat specimen,  $mm^3$ . See 9.3 for a more detailed discussion of this measurement.

10.2.3.4 A concise description of the appearance of the wear scars, including the presence of debris deposits or films which form during sliding. Photomicrographs of the scars should be included, if available.

10.2.3.5 When reporting the results of multiple tests, indicate the number of replicates per material and condition and the average wear volumes for ball and flat specimens. Report the standard deviation.

### 10.3 Reporting Optional:

10.3.1 Report the computed value of the maximum elastic contact stress ( $S_c$ ), as calculated by the method developed by Hertz. The following equation may be used:

$$S_c = 0.918[P/(D^2 E_o^2)]^{1/3} \quad (6)$$

where:

$P$  = applied load, N, and

$D$  = diameter of the sphere m.

$E_o$  is obtained from:

$$E_o = [(1 - \nu_1^2)/E_1] + [(1 - \nu_2^2)/E_2] \quad (7)$$

where:

$E_{1,2}$  = elastic moduli (Young's moduli) of the two solids in contact,  $P_a$ , and

$\nu_{1,2}$  = Poisson's ratios (dimensionless) of the two materials, respectively.

If the calculated contact stress exceeds the hardness of either material, there will be permanent plastic deformation and elastic conditions do not apply.

10.3.2 Photomicrographs or surface analysis data for the wear scars on the ball and flat specimens.

10.3.3 A description of the frictional behavior observed during the test. Kinetic friction coefficient can be calculated from:

$$\mu_k = F/P \quad (8)$$

where:

$\mu_k$  = kinetic friction coefficient,

$F$  = nominal, measured friction force during sliding, N, and

$P$  = applied load (normal force), N.

10.3.4 On some machines, root-mean-square friction force is available as an instrumentation output. The test report should clearly indicate the manner in which friction force was obtained. Further guidance in measuring and reporting friction data may be found in Guide G115.

NOTE 5—Friction force may vary during an experiment due to run-in and other factors. For example, it may start high then experience a transition to a lower value during the test. It is often useful in analyzing test results to note the magnitudes and durations of any observed friction transitions. If friction force remains steady throughout the test or quickly reaches a steady state, one nominal value may be sufficient, otherwise, the type of frictional data reported will depend on the overall trends observed during the test. If friction never reaches a steady value, its range of values may be reported with appropriate notations as to its behavior.

## 11. Precision and Bias<sup>5</sup>

11.1 *Precision*—The precision of wear determinations is dependent on the wear characteristics of the material under the imposed testing conditions. Some materials wear evenly so as to produce clearly defined wear scars, and wear dimensions can be measured with a higher degree of precision than for certain other materials which wear in an uneven manner and whose wear scars cannot be delineated as clearly.

11.2 *Repeatability and Reproducibility*—Procedure A was used in the same laboratory to conduct eight tests of silicon nitride sliding on silicon nitride. The coefficient of variation of the wear volume of the flat specimens was 34.7 %. The coefficient of variation for the friction coefficient in the same tests was 1.8 %. The same specimen materials were tested in five laboratories using Procedure B with mineral oil lubrication. The coefficient of variation for the wear volume of the flat specimens within-laboratory was  $\pm 23.7$  %. Reproducibility was reflected in a between-laboratory coefficient of variation of  $\pm 48.6$  %. For the friction coefficient, the within-laboratory coefficient of variation was  $\pm 2.64$  % and the between-laboratory coefficient of variation was  $\pm 5.29$  %. Appendix X1 provides examples of the repeatability and reproducibility of Procedures A and B when applied to tests of silicon nitride ceramics. These numerical values for repeatability and reproducibility do not necessarily represent those quantities which

<sup>5</sup> Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:G02-1010.

would be obtained if other material combinations were tested under Procedures A and B. Since the repeatability and reproducibility of wear and friction data are material-dependent, a general statement for Procedures A or B cannot be made.

11.3 *Bias*—Since there is no accepted reference material for determining the bias of the procedures in this wear testing method, there is no basis upon which to determine the bias.

## 12. Discussion

12.1 Wear testing involves careful attention to specimen preparation, characterization, cleaning, and test procedures. Contact geometry, normal force, type of motion, temperature, surface finish, and ambient environment should be as close as possible to that of a chosen application if wear screening is to provide meaningful results.

12.2 Wear rate can change during the course of a test or during the course of the life of a wear part. Run-in wear rates can exceed steady-state wear rates, and catastrophic transitions in wear rate can occur to end the useful life of a component. In this test method, wear is reported only as the total volume lost after a set period of sliding. This avoids making the assumption that the wear rate was constant during the test. One indirect indication that wear rate may be changing is a significant change in the nominal level of the friction force during a test. To determine the change in wear rate with test duration, interrupted tests with periodic wear volume assessments may be made. However, the replacement of the specimens in the

machine to continue testing may not produce identical contact conditions to those when the test was interrupted.

12.3 Moisture in the air (humidity) has been shown to affect both friction and wear of ceramics, metals, and polymers. The range of relative humidities over which pronounced changes in tribological behavior occur may be relatively short and it may vary between materials. Therefore, restricting testing to a  $50 \pm 10\%$  band of relative humidity does not necessarily ensure that the friction or wear at each end of the band will be the same. It is better to hold the humidity variation for a series of tests to  $\pm 5\%$  or less, if possible. Construction of a controlled-humidity enclosure around the testing fixtures is the best approach but is not required to meet the requirements of this test method. Testing on days with similar humidity readings is a less-desirable alternative.

12.4 Unlike material combinations may wear at different rates depending on which material is the ball specimen and which is the flat specimen. The ball specimen experiences nominally constant contact, whereas the flat specimen surface experiences a changing state of stress as the slider passes and may wear by a different set of mechanisms. It should therefore not be assumed that the same relative wear volumes would be obtained if materials for ball and flat specimens were reversed.

## 13. Keywords

13.1 friction testing; lubricated wear; reciprocating wear test; wear of ceramics; wear of metals; wear testing

## APPENDIX

### (Nonmandatory Information)

#### X1. RESULTS OF WITHIN-LABORATORY TESTS USING PROCEDURE A WITH SILICON NITRIDE TEST SPECIMENS

X1.1 *Procedure A*—The repeatability of test results for Procedure A was determined by two participating laboratories, designated “A” and “B,” each using a different make of commercial wear testing machine. Silicon nitride ceramic material was used for both the ball and flat specimens (see [Table X1.1](#)). Flat specimens materials were similar in bulk composition although there was a slight difference in the sintering aids. The ball specimens were provided from the same lot of material. Friction coefficients and wear volumes for the flat specimens, for eight replicate runs at laboratories “A” and “B,” are compared in [Table X1.2](#) and [Table X1.3](#).

#### X1.2 Results of Interlaboratory Tests Using Procedure B with Silicon Nitride Specimens

X1.2.1 Five laboratories participated. All laboratories used the same make and model of commercial testing machine with a Scotch yoke drive mechanism providing a sinusoidal velocity profile. The specimen materials were the same as those described in [Table X1.1](#). Mineral oil (J. T. Baker Company, U.S.P. grade, with Vitamin E added as a stabilizer, viscosity by Brookfield viscometer was 140 cP, and the flash point was 215°C) was used as the lubricant. Two flat specimens and one ball specimen were supplied to each laboratory. Two wear tests

were performed on each flat specimen using a fresh area of the ball specimen for each test; therefore, four tests were conducted. Nominal friction coefficient values were obtained from chart recordings of the root-mean-square friction force. A spread sheet computer software package designed for Guide [G117](#) was used to process test data on steady-state friction coefficient and the computed wear volumes flat specimens from stylus traces of the wear grooves (see [9.3](#)). The ball wear volume was not reported because the scars on the balls were not flat.

X1.2.2 Results are summarized in [Table X1.4](#) and [Table X1.5](#). As is often the case for wear tests, the within-laboratory repeatability is better than the between-laboratory reproducibility. The friction coefficient data ([Table X1.4](#)) exhibited less variation than the wear volume data ([Table X1.5](#)). The latter quantity requires more steps in order to obtain a final numerical value so that the potential for compounding measurement uncertainties, rounding errors, and calculation errors is greater.

X1.2.3 These data illustrate the variability of Procedure B with a given set of ceramic materials and a single lubricant, and should not be used to estimate the variability to be expected for other materials or lubricants.

**TABLE X1.1 Material Descriptors for Pin and Flat Wear Specimens**

Specimen	Laboratory A	Flat Specimen
Ball (pin)	Noralide <sup>A</sup> NBD 200 silicon nitride ball (9.525-mm diameter, AFBMA Grade 5)	Noralide NBD 200 silicon nitride ball (9.525-mm diameter, AFBMA Grade 5)
Flat specimen	Sintered, reaction bonded silicon nitride prepared by Eaton Corporation; surface ground and polished to an arithmetic average surface roughness of 0.05 $\mu\text{m}$ .	Fine-grained silicon nitride ceramic, grade GS-44, produced by Allied Signal Ceramic Components; surface ground and polished to an arithmetic average surface roughness of 0.05 $\mu\text{m}$ .

<sup>A</sup>The term “Noralide” and the Noralide logo are trademarks of Saint-Gobain Ceramics, Structural Ceramics, Hexoloy Products, 23 Acheson Drive, Niagara Falls, New York 14303, USA.

**TABLE X1.2 Friction Coefficient Results for Silicon Nitride Specimens Using Procedure A**

NOTE 1—Coefficient of variation =  $\pm 1.8\%$ ; 95 % confidence limits = 0.04.

Test Number	Laboratory A		Laboratory B	
	Friction Coefficient, $\mu$	Deviation from Average, $\mu$	Friction Coefficient, $\mu$	Deviation from Average, $\mu$
1	0.800	-0.005	0.715	-0.075
2	0.800	-0.005	0.854	0.064
3	0.803	-0.002	0.800	0.010
4	0.808	0.003	0.817	0.027
5	0.800	-0.005	0.742	-0.048
6	0.781	-0.024	0.811	0.021
7	0.820	0.015	0.716	-0.074
8	0.828	0.023	0.862	0.072
Average	0.81		0.79	
Standard deviation	0.014		0.058	
Coefficient of variation	$\pm 1.8\%$		$\pm 7.4\%$	
95% confidence limit	0.04		0.16	

**TABLE X1.3 Wear Volume Results for Silicon Nitride Specimens Using Procedure A**

NOTE 1—Coefficient of variation =  $\pm 34.7\%$ ; 95 % confidence limits = 0.53.

Test Number	Laboratory A		Laboratory B	
	Wear Volume, mm <sup>3</sup>	Deviation from Average, mm <sup>3</sup>	Wear Volume, mm <sup>3</sup>	Deviation from Average, mm <sup>3</sup>
1	0.746	0.203	0.394	0.020
2	0.611	0.068	0.513	0.139
3	0.507	-0.036	0.276	-0.098
4	0.635	0.092	0.325	-0.049
5	0.293	-0.250	0.427	0.053
6	0.229	-0.314	0.388	0.014
7	0.619	0.076	0.379	0.005
8	0.707	0.164	0.287	-0.087
Average	0.543		0.374	
Standard deviation	0.189		0.078	
Coefficient of variation	$\pm 34.7\%$		$\pm 20.8\%$	
95% confidence limit	0.53		0.22	

**TABLE X1.4 Friction Coefficients for Silicon Nitride Specimens Using Procedure B**

NOTE 1—Coefficient of variation (%): within laboratory—2.635; between laboratory—5.285. 95 % limit: within laboratory—0.011; between laboratory—0.023.

Laboratory Number	Number of Replicates	Average, $\mu$	Standard Deviation, $\mu$	Deviation from Average
1	4	0.163	0.002	0.008
2	4	0.155	0.002	0.000
3	4	0.158	0.005	0.003
4	4	0.154	0.005	-0.001
5	4	0.143	0.005	-0.012
Average = 4		Average = 0.155	Within-Laboratory Standard Deviation = 0.004	Between-Laboratory Standard Deviation = 0.008

**TABLE X1.5 Flat Specimen Wear Volumes for Silicon Nitride Specimens Using Procedure B**

NOTE 1—Coefficient of variation (%): within laboratory— $\pm 23.708$ ; between laboratory— $\pm 48.632$ . 95 % limit: within laboratory—0.00266; between laboratory—0.00546.

Laboratory Number	Number of Replicates	Average, mm <sup>3</sup>	Standard Deviation, mm <sup>3</sup>	Deviation from Average, mm <sup>3</sup>
1	4	0.00338	0.00049	-0.00063
2	4	0.00390	0.00090	-0.00092
3	4	0.00710	0.00132	0.00309
4	4	0.00377	0.00124	-0.00024
5	4	0.00272	0.00044	-0.00129
Average = 4		Average = 0.00401	Within-Laboratory Standard Deviation = 0.00095	Between-Laboratory Standard Deviation = 0.00195

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# **ANEXO 17**

# **RESULTADOS DE**

# **ENSAYO DE DUREZA**

**CENTRO DE PRODUCCIÓN DE BIENES Y SERVICIOS DE ENSAYOS DE  
MATERIALES DE LA EPIMMEM – UCSM**

**REPORTE DE ANÁLISIS**

**Código:** DP-009 al 045

**Fecha de ejecución de ensayo:** 17/01/2019

**DATOS DEL CLIENTE**

**CLIENTE:** Sr. Rubén Purca Justo

**MATERIAL A ENSAYAR:** ACERO DIN 32MnCrMo6-4-3

**RESUMEN DE RESULTADOS**

A continuación se detalla los resultados de acuerdo al código designado por el cliente:

Cód. Muestra	Ensayo/Propiedad	Zona Examinada	Resultados	Observaciones
DP-009	BASE 1 Dureza Rockwell C	BASE	58.77 HRC	T° de trabajo 21°C
DP-010	C1000 1 Dureza Rockwell C	BASE	57.40 HRC	T° de trabajo 21°C
DP-011	C1000 1 Dureza Rockwell C	ZAC	61.20 HRC	T° de trabajo 21°C
DP-012	C1000 1 Dureza Rockwell C	RECUBRIMIENTO	71.20 HRC	T° de trabajo 21°C
DP-013	C1000 2 Dureza Rockwell C	BASE	52.10 HRC	T° de trabajo 21°C
DP-014	C1000 2 Dureza Rockwell C	ZAC	62.00 HRC	T° de trabajo 21°C
DP-015	C1000 2 Dureza Rockwell C	RECUBRIMIENTO	67.80 HRC	T° de trabajo 21°C
DP-016	C1000 3 Dureza Rockwell C	BASE	49.10 HRC	T° de trabajo 21°C
DP-017	C1000 3 Dureza Rockwell C	ZAC	63.00 HRC	T° de trabajo 21°C
DP-018	C1000 3 Dureza Rockwell C	RECUBRIMIENTO	71.20 HRC	T° de trabajo 21°C
DP-019	C1000 4 Dureza Rockwell C	BASE	55.00 HRC	T° de trabajo 21°C
DP-020	C1000 4 Dureza Rockwell C	ZAC	60.30 HRC	T° de trabajo 21°C
DP-021	C1000 4 Dureza Rockwell C	RECUBRIMIENTO	70.00 HRC	T° de trabajo 21°C
DP-022	CTMG 1 Dureza Rockwell C	BASE	51.40 HRC	T° de trabajo 21°C
DP-023	CTMG 1 Dureza Rockwell C	ZAC	58.50 HRC	T° de trabajo 21°C
DP-024	CTMG 1 Dureza Rockwell C	RECUBRIMIENTO	63.90 HRC	T° de trabajo 21°C
DP-025	CTMG 2 Dureza Rockwell C	BASE	55.90 HRC	T° de trabajo 21°C
DP-026	CTMG 2 Dureza Rockwell C	ZAC	54.20 HRC	T° de trabajo 21°C
DP-027	CTMG 2 Dureza Rockwell C	RECUBRIMIENTO	64.00 HRC	T° de trabajo 21°C
DP-028	CTMG 3 Dureza Rockwell C	BASE	51.30 HRC	T° de trabajo 21°C
DP-029	CTMG 3 Dureza Rockwell C	ZAC	54.30 HRC	T° de trabajo 21°C
DP-030	CTMG 3 Dureza Rockwell C	RECUBRIMIENTO	63.50 HRC	T° de trabajo 21°C
DP-031	CTMG 4 Dureza Rockwell C	BASE	52.70 HRC	T° de trabajo 21°C

DP-032	CTMG 4 Dureza Rockwell C	ZAC	56.10 HRC	T° de trabajo 21°C
DP-033	CTMG 4 Dureza Rockwell C	RECUBRIMIENTO	63.00 HRC	T° de trabajo 21°C
DP-034	E43 1 Dureza Rockwell C	BASE	58.40 HRC	T° de trabajo 21°C
DP-035	E43 1 Dureza Rockwell C	ZAC	61.70 HRC	T° de trabajo 21°C
DP-036	E43 1 Dureza Rockwell C	RECUBRIMIENTO	70.10 HRC	T° de trabajo 21°C
DP-037	E43 2 Dureza Rockwell C	BASE	56.20 HRC	T° de trabajo 21°C
DP-038	E43 2 Dureza Rockwell C	ZAC	61.50 HRC	T° de trabajo 21°C
DP-039	E43 2 Dureza Rockwell C	RECUBRIMIENTO	67.30 HRC	T° de trabajo 21°C
DP-040	E43 3 Dureza Rockwell C	BASE	58.40 HRC	T° de trabajo 21°C
DP-041	E43 3 Dureza Rockwell C	ZAC	60.30 HRC	T° de trabajo 21°C
DP-042	E43 3 Dureza Rockwell C	RECUBRIMIENTO	72.80 HRC	T° de trabajo 21°C
DP-043	E43 4 Dureza Rockwell C	BASE	56.80 HRC	T° de trabajo 21°C
DP-044	E43 4 Dureza Rockwell C	ZAC	57.90 HRC	T° de trabajo 21°C
DP-045	E43 4 Dureza Rockwell C	RECUBRIMIENTO	71.50 HRC	T° de trabajo 21°C

**NOTA:**

- Las probetas fueron preparadas por el cliente.
- Las probetas evaluadas fueron: Acero DIN 32MnCrMo6-4-3, Acero DIN 32MnCrMo 6-4-3 sometido a soldadura por proceso SMAW con electrodo CITODUR 1000 (C1000), Acero DIN 32MnCrMo6-4-3 sometido a soldadura por proceso SMAW con electrodo CITOMANGAN(CTMG) y Acero DIN 32MnCrMo6-4-3 sometido a soldadura por proceso SMAW con electrodo EXADUR 43 (E43).
- La superficie evaluada fue la transversal respecto al cordón de soldadura.

Arequipa, 17 de enero del 2019

FACTURA N°

Ensayo ejecutado por: Ing. Emilio Chire R.



*Universidad Católica de Santa María*

☎ (51 54) 382038 Fax: (51 54) 251213 ✉ [ucsm@ucsm.edu.pe](mailto:ucsm@ucsm.edu.pe) 🌐 <http://www.ucsm.edu.pe> Apartado:

AREQUIPA - PERÚ

**CENTRO DE PRODUCCION DE BIENES Y SERVICIOS DE ENSAYOS DE  
MATERIALES DE LA EPIMMEM – UCSM**

**CONSTANCIA**

El suscrito, Ing. Emilio Chire Ramirez, Coordinador del Laboratorio de Ensayo de Materiales de la EPIMMEM, hace constar que:

El señor **PURCA JUSTO, Rubén**; ha efectuado 15 ensayos de dureza, 15 ensayos metalográficos y 15 preparaciones de probetas para metalografía de acero DIN 32MnCrMo 6-4-3, cuyos resultados fueron entregados en forma digital al interesado.

Se expide la presente solicitud del interesado.

Arequipa, 17 de enero del 2019

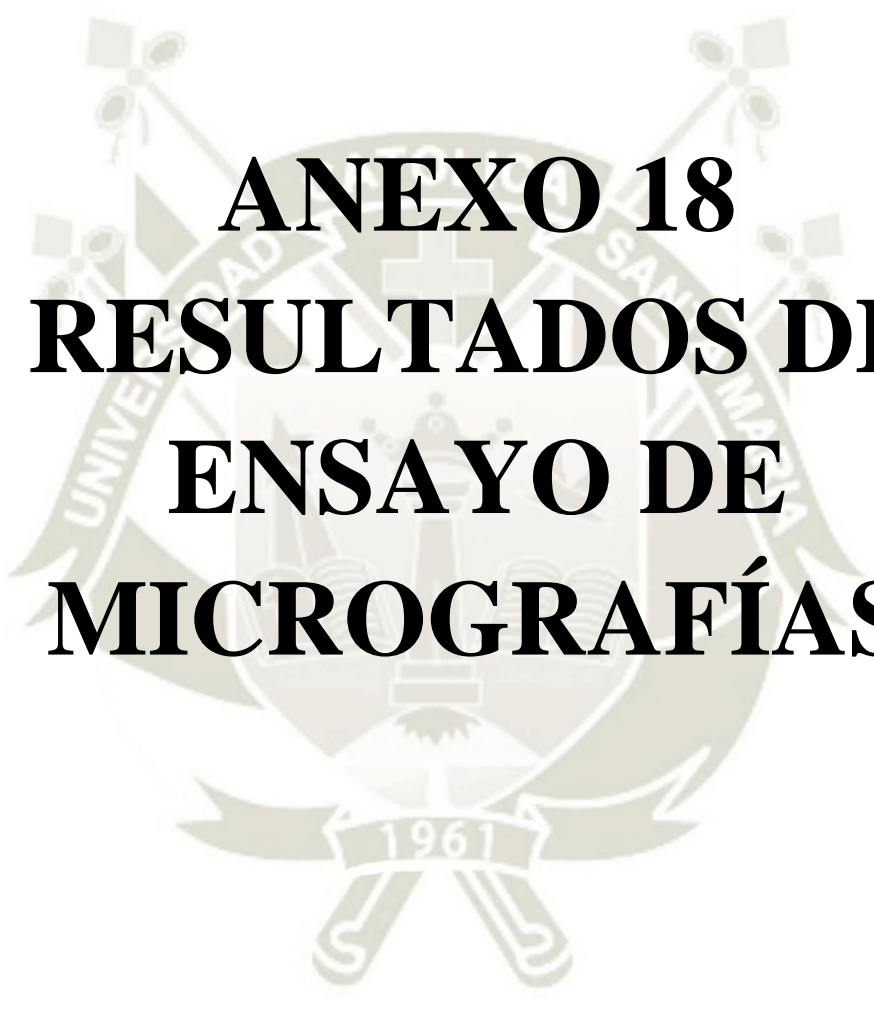
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Ensayo ejecutado por: Ing. Emilio Chire R.



**ING. EMILIO CHIRE RAMIREZ**  
COORDINADOR DEL LABORATORIO  
N° REG. CIP 23235



A large, faint watermark of the Universidad Católica de Santa María seal is centered in the background. The seal features a central figure holding a book and a lamp, with the year 1961 at the bottom and the university's name around the perimeter.

# **ANEXO 18 RESULTADOS DE ENSAYO DE MICROGRAFÍAS**

**CENTRO DE PRODUCCIÓN DE BIENES Y SERVICIOS DE ENSAYOS DE  
MATERIALES DE LA EPIMMEM – UCSM**

**REPORTE DE ANÁLISIS**

**Código:** MP-007 al 026

**Fecha de ejecución de ensayo:** 17/01/2019

**DATOS DEL CLIENTE**

**CLIENTE:**

Sr. Rubén Purca Justo

**MATERIAL A ENSAYAR:**

ACERO DIN 32MnCrMo6-4-3

**RESUMEN DE RESULTADOS**

A continuación, se detalla los resultados de acuerdo al código designado por el cliente:

Cód. Muestra	Ensayo/Propiedad	Zona Examinada	Reactivo Usado	Resultados	Observaciones
MP-007	Metalográfico de Acero DIN 32MnCrMo6-4-3	BASE	Nital	Micrografías 1	T° de trabajo 21°C
MP-008	C1000 Metalográfico de Acero DIN 32MnCrMo6-4-3	BASE	Nital	Micrografías 2	T° de trabajo 21°C
MP-009	C1000 Metalográfico de Acero DIN 32MnCrMo6-4-3	ZAC	Nital	Micrografías 3	T° de trabajo 21°C
MP-010	C1000 Metalográfico de Acero DIN 32MnCrMo6-4-3	RECUBRIMIENTO	Nital	Micrografías 4	T° de trabajo 21°C
MP-011	CTMG Metalográfico de Acero DIN 32MnCrMo6-4-3	BASE	Nital	Micrografías 5	T° de trabajo 21°C
MP-012	CTMG Metalográfico de Acero DIN 32MnCrMo6-4-3	ZAC	Nital	Micrografías 6	T° de trabajo 21°C
MP-013	CTMG Metalográfico de Acero DIN 32MnCrMo6-4-3	RECUBRIMIENTO	Nital	Micrografías 7	T° de trabajo 21°C
MP-014	E43 Metalográfico de Acero DIN 32MnCrMo6-4-3	BASE	Nital	Micrografías 8	T° de trabajo 21°C
MP-015	E43 Metalográfico de Acero DIN 32MnCrMo6-4-3	ZAC	Nital	Micrografías 9	T° de trabajo 21°C
MP-016	E43 Metalográfico de Acero DIN 32MnCrMo6-4-3	RECUBRIMIENTO	Nital	Micrografías 10	T° de trabajo 21°C
MP-017	Metalográfico de Acero DIN 32MnCrMo6-4-3	BASE	Vilella	Micrografías 11	T° de trabajo 21°C

MP-018	C1000 Metalográfico de Acero DIN 32MnCrMo6-4-3	BASE	Vilella	Micrografías 12	T° de trabajo 21°C
MP-019	C1000 Metalográfico de Acero DIN 32MnCrMo6-4-3	ZAC	Vilella	Micrografías 13	T° de trabajo 21°C
MP-020	C1000 Metalográfico de Acero DIN 32MnCrMo6-4-3	RECUBRIMIENTO	Vilella	Micrografías 14	T° de trabajo 21°C
MP-021	CTMG Metalográfico de Acero DIN 32MnCrMo6-4-3	BASE	Vilella	Micrografías 15	T° de trabajo 21°C
MP-022	CTMG Metalográfico de Acero DIN 32MnCrMo6-4-3	ZAC	Vilella	Micrografías 16	T° de trabajo 21°C
MP-023	CTMG Metalográfico de Acero DIN 32MnCrMo6-4-3	RECUBRIMIENTO	Vilella	Micrografías 17	T° de trabajo 21°C
MP-024	E43 Metalográfico de Acero DIN 32MnCrMo6-4-3	BASE	Vilella	Micrografías 18	T° de trabajo 21°C
MP-025	E43 Metalográfico de Acero DIN 32MnCrMo6-4-3	ZAC	Vilella	Micrografías 19	T° de trabajo 21°C
MP-026	E43 Metalográfico de Acero DIN 32MnCrMo6-4-3	RECUBRIMIENTO	Vilella	Micrografías 20	T° de trabajo 21°C

**NOTA:**

- Las probetas para cada ensayo fueron preparadas de acuerdo a protocolos para preparación de muestras metalográficas.
- Las probetas evaluadas fueron: Acero DIN 32MnCrMo6-4-3, Acero DIN 32MnCrMo 6-4-3 sometido a soldadura por proceso SMAW con electrodo CITODUR 1000 (C1000), Acero DIN 32MnCrMo6-4-3 sometido a soldadura por proceso SMAW con electrodo CITOMANGAN(CTMG) y Acero DIN 32MnCrMo6-4-3 sometido a soldadura por proceso SMAW con electrodo EXADUR 43 (E43).
- La superficie evaluada fue la transversal respecto al cordón de soldadura.

Arequipa, 17 de enero del 2019

FACTURA N°

Ensayo ejecutado por: Ing. Emilio Chire R.

## ANEXOS

### I.- PREPARACIÓN DE MUESTRAS:

Se realizó de acuerdo a los protocolos de preparación de muestras metalográficas que incluyen las siguientes etapas:

1.1 **Desbaste grueso:** Se trabajó papel lijar al agua, marca ABRALIT:

- Lijar #100
- Lijar #220
- Lijar #400
- Lijar #600

1.2 **Desbaste fino:** Se trabajó con papel lijar al agua:

- Lijar #1000, marca ABRALIT
- Lijar #1200, marca ABRALIT
- Lijar #2000, marca ASALITE

1.3 **Pulido fino:** En una pulidora de disco con paño de pulido, con pasta de alúmina 0,5 micrones.

### II.-Ataque químico:

Se realizó con:

Solución de Nital al 3%, con un tiempo de contacto de 10 segundos

Solución de Vilella preparado de acuerdo a norma con un tiempo de contacto de 10 segundos.

**III.- ANÁLISIS MICROESTRUCTURAL:** Se realizó con un Microscopio Metalúrgico Invertido Óptico, Time Group INC, DX40TV

**Resolución:**

20X/100x

20X

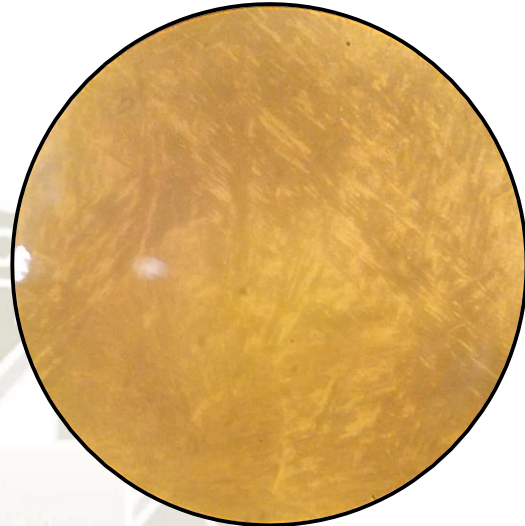
#### IV.- MICROGRAFÍAS:

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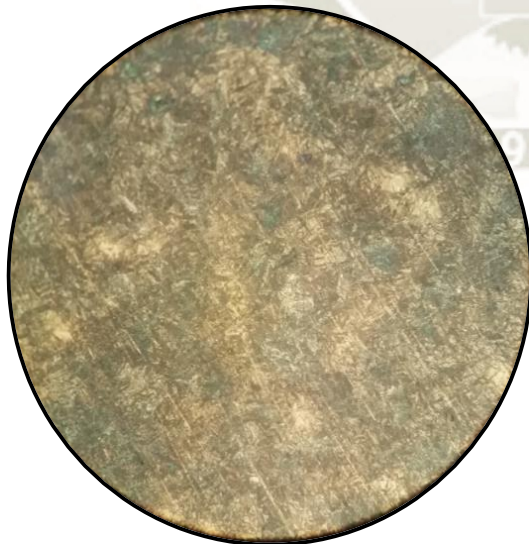


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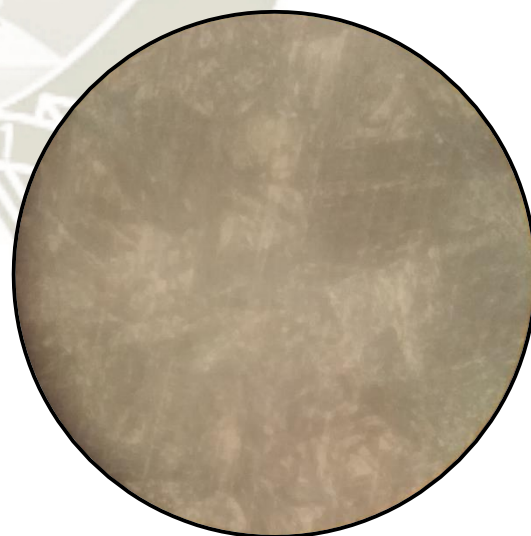


- Micrografías 2

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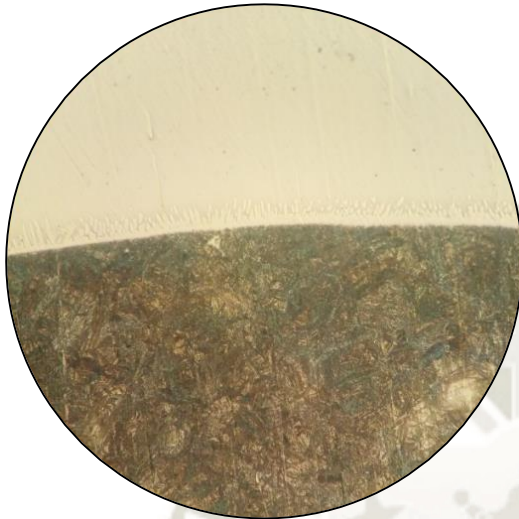


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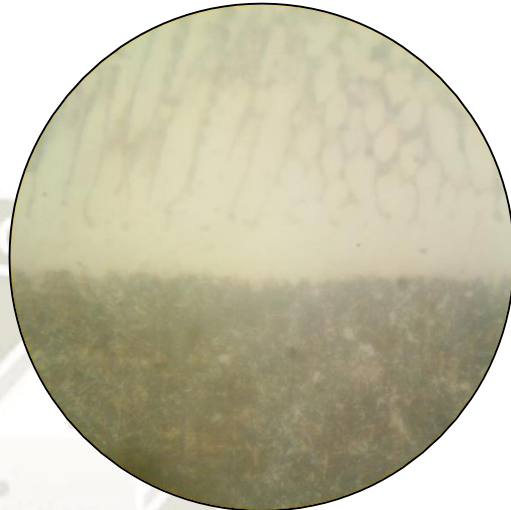


- Micrografías 3

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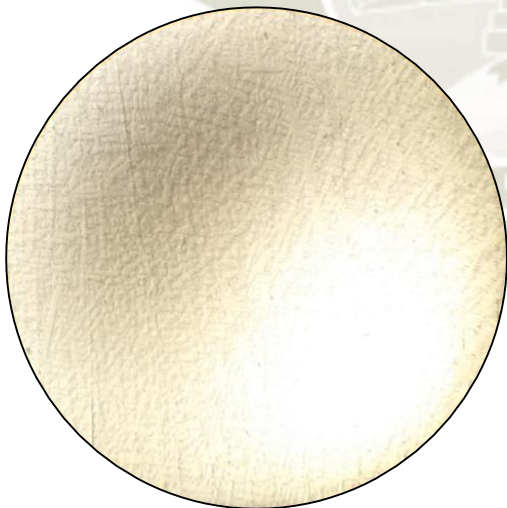


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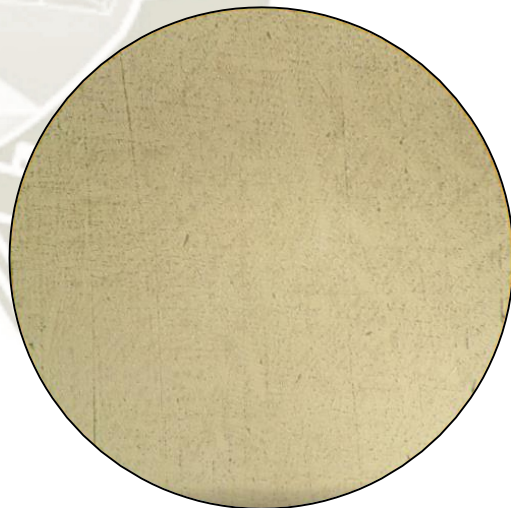


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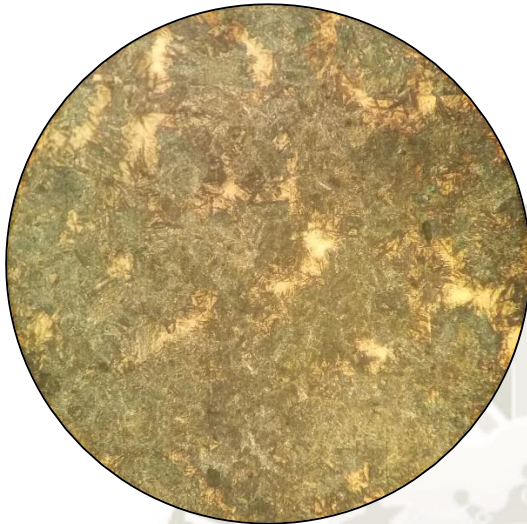


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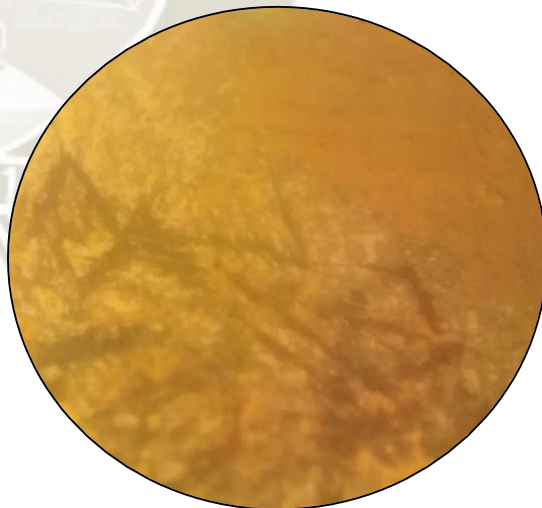


- Micrografías 6

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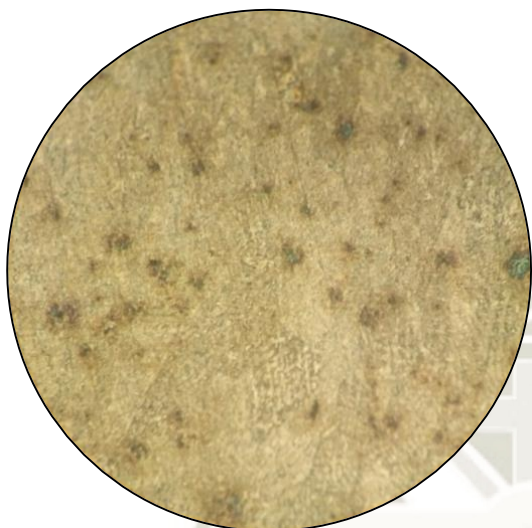


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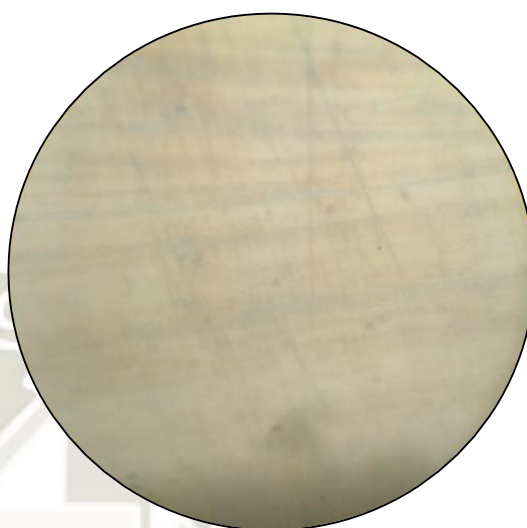


- Micrografías 7

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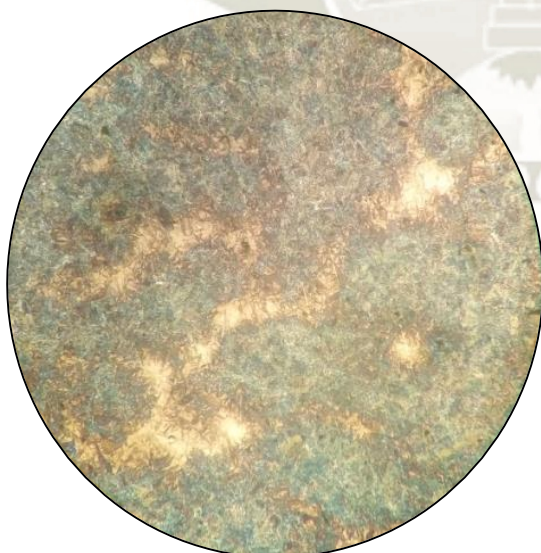


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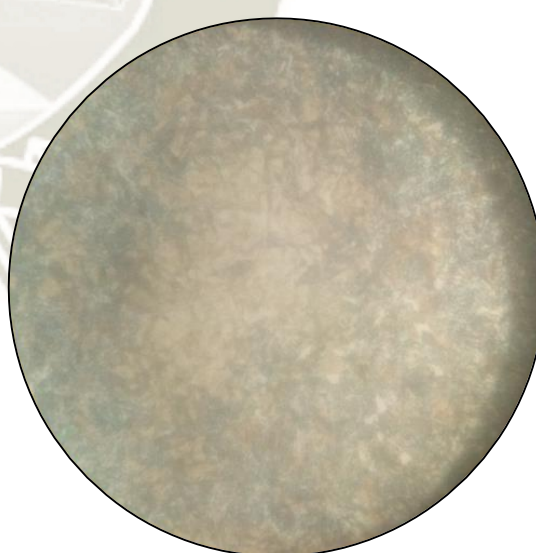


- Micrografías 8

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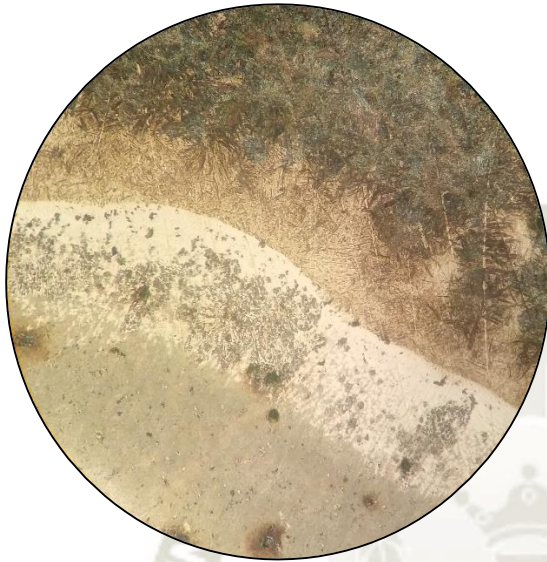
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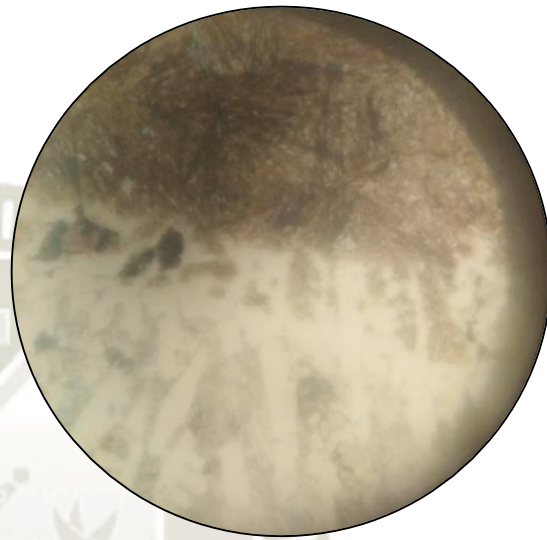


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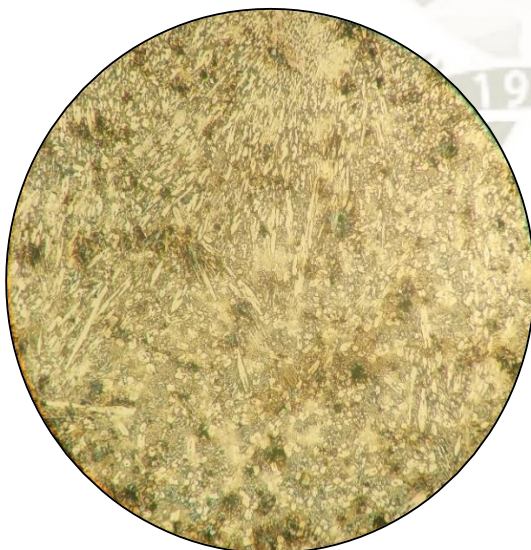


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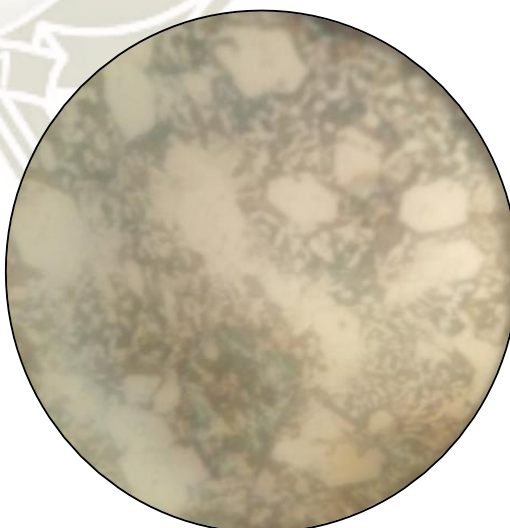


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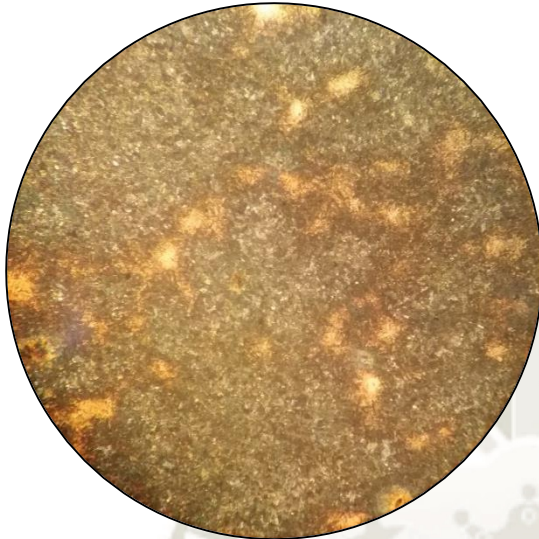


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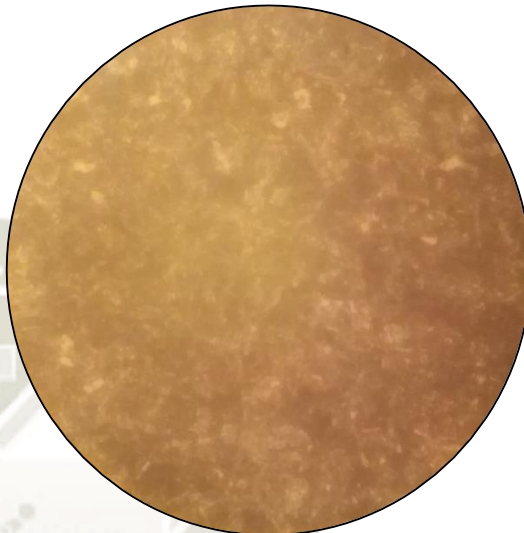


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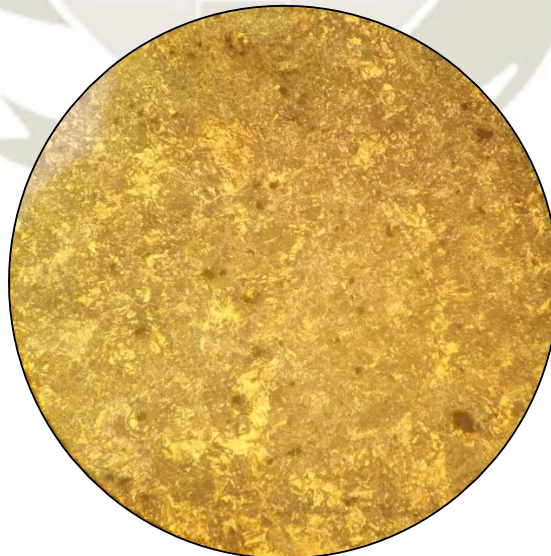


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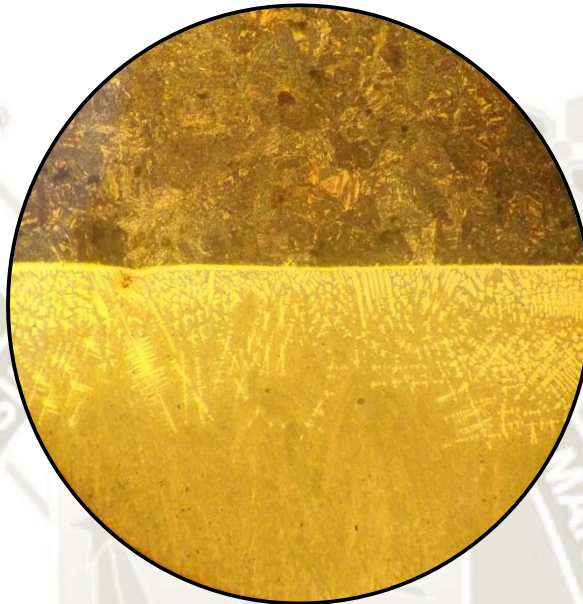
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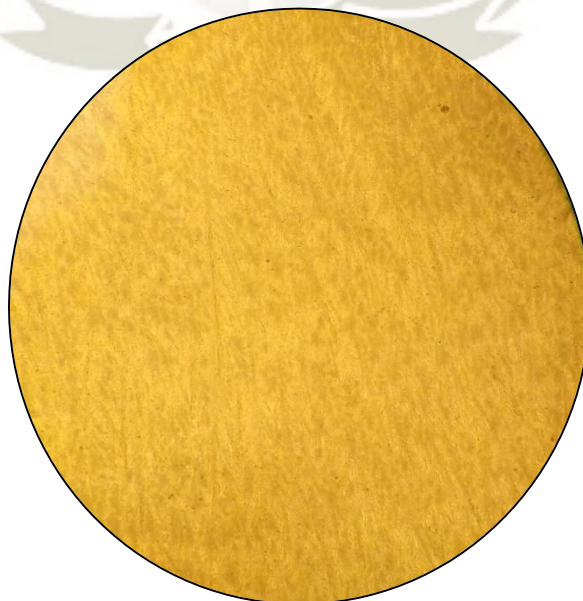
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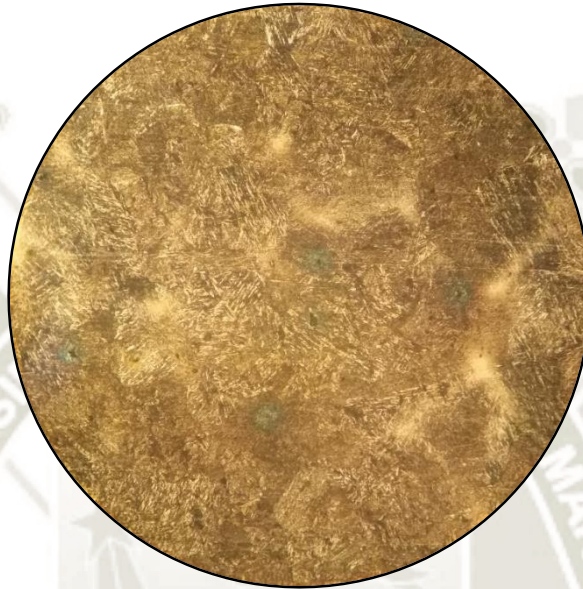
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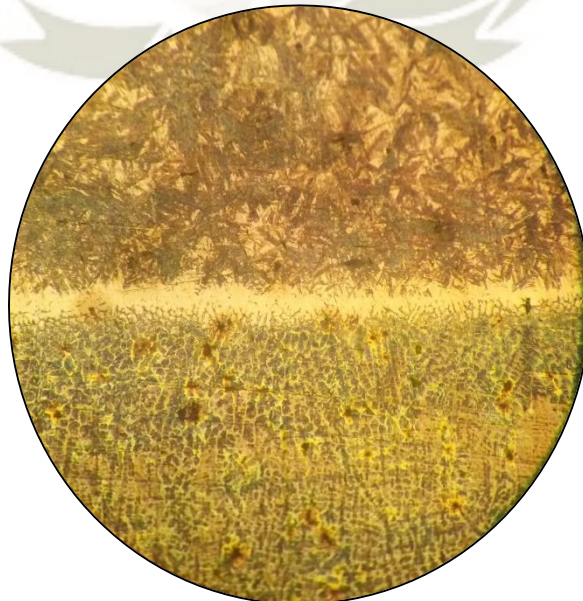
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- Micrografías 16

Aumento 20X



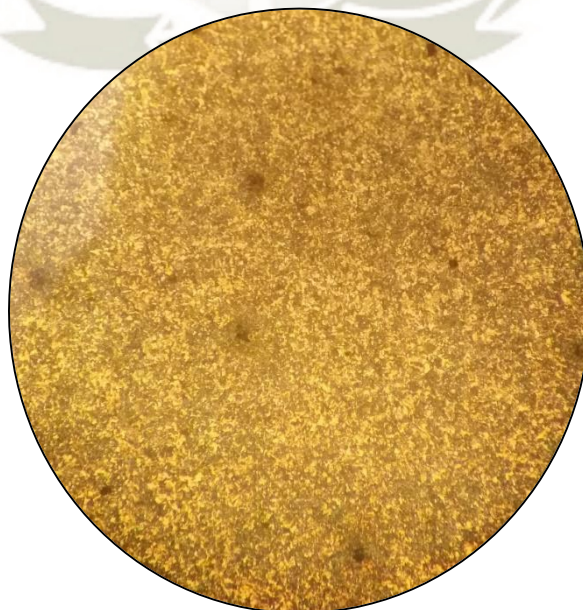
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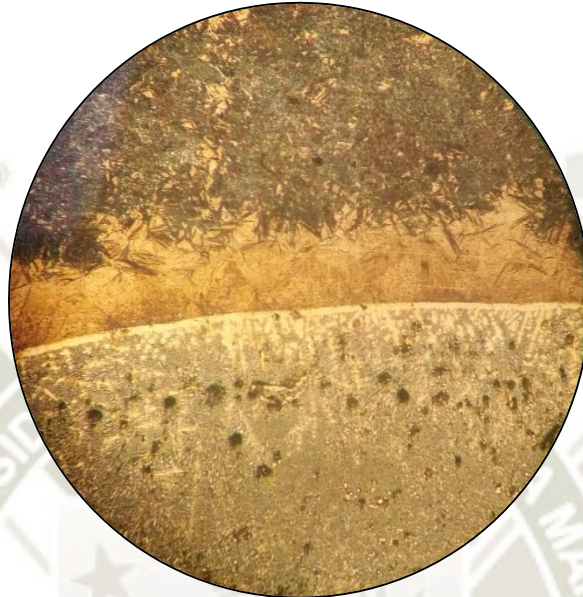
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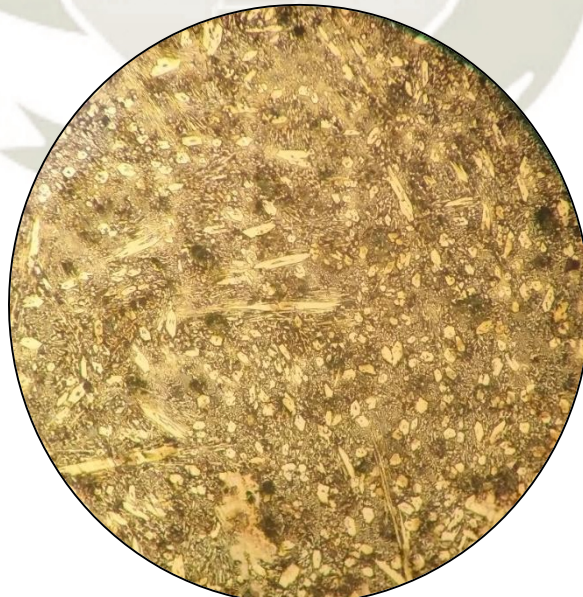
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Aumento 20X



- Micrografías 20

Aumento 20X



**CENTRO DE PRODUCCION DE BIENES Y SERVICIOS DE ENSAYOS DE  
MATERIALES DE LA EPIMMEM – UCSM****CONSTANCIA**

El suscrito, Ing. Emilio Chire Ramirez, Coordinador del Laboratorio de Ensayo de Materiales de la EPIMMEM, hace constar que:

El señor **PURCA JUSTO, Rubén**; ha efectuado 15 ensayos de dureza, 15 ensayos metalográficos y 15 preparaciones de probetas para metalografía de acero DIN 32MnCrMo 6-4-3, cuyos resultados fueron entregados en forma digital al interesado.

Se expide la presente solicitud del interesado.

Arequipa, 17 de enero del 2019

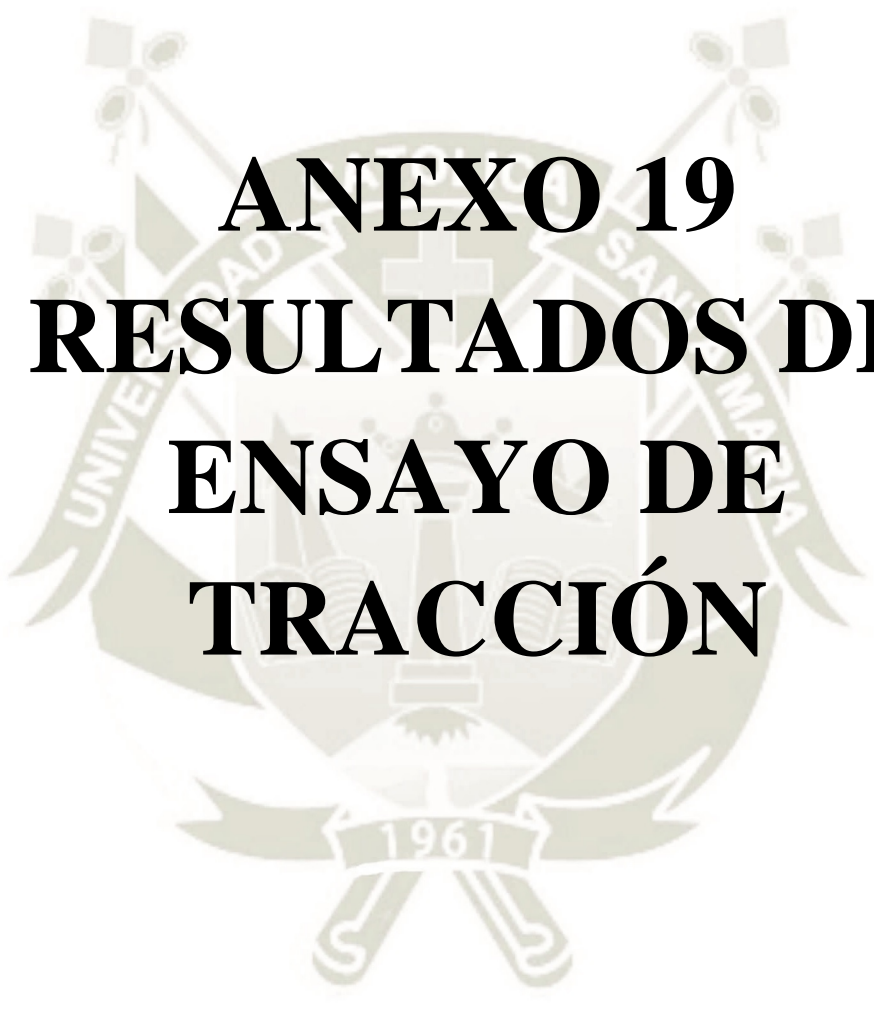
FACTURA N° G-0349244

Ensayo ejecutado por: Ing. Emilio Chire R.

**ING. EMILIO CHIRE RAMIREZ**

COORDINADOR DEL LABORATORIO

N° REG. CIP 23235



# **ANEXO 19 RESULTADOS DE ENSAYO DE TRACCIÓN**



**RESULTADOS DEL ENSAYO DE TRACCIÓN**

**ENSAYO REALIZADO** : ENSAYO DE TRACCIÓN  
**MUESTRAS** : Muestras de uniones soldadas  
**Nº DE MUESTRAS** : 04  
**EQUIPO UTILIZADO** : Marca INSTRON modelo 23-100.  
**NORMA DE ENSAYO** : ASTM – E370 -18  
**SOLICITANTE** : RUBÉN RODRIGO PURCA JUSTO  
**TESIS** : “Análisis Mediante Elementos Discretos (MED) y Evaluación Experimental bajo la norma ASTM G99 del desgaste abrasivo en revestimientos duros aplicados por Procesos de Soldadura en las uñas de acero 32MNCRMO6-4-3 de una Excavadora Hidráulica CAD 336D2L”.

Probeta		Diámetro Inicial	Diámetro Final	Área	Longitud Inicial	Longitud Final	Elongación %	Estricción %
1	Exadur 43	8.89	8.71	62.07	36.7	39.54	7.73	2.02
2	Citomangan	8.86	8.62	61.65	38.42	41.71	8.57	2.71
3	C 1000	8.69	8.47	59.31	37.76	42.10	11.40	2.53
4	Material Base	7.95	7.85	49.64	61.64	64.70	4.96	1.26

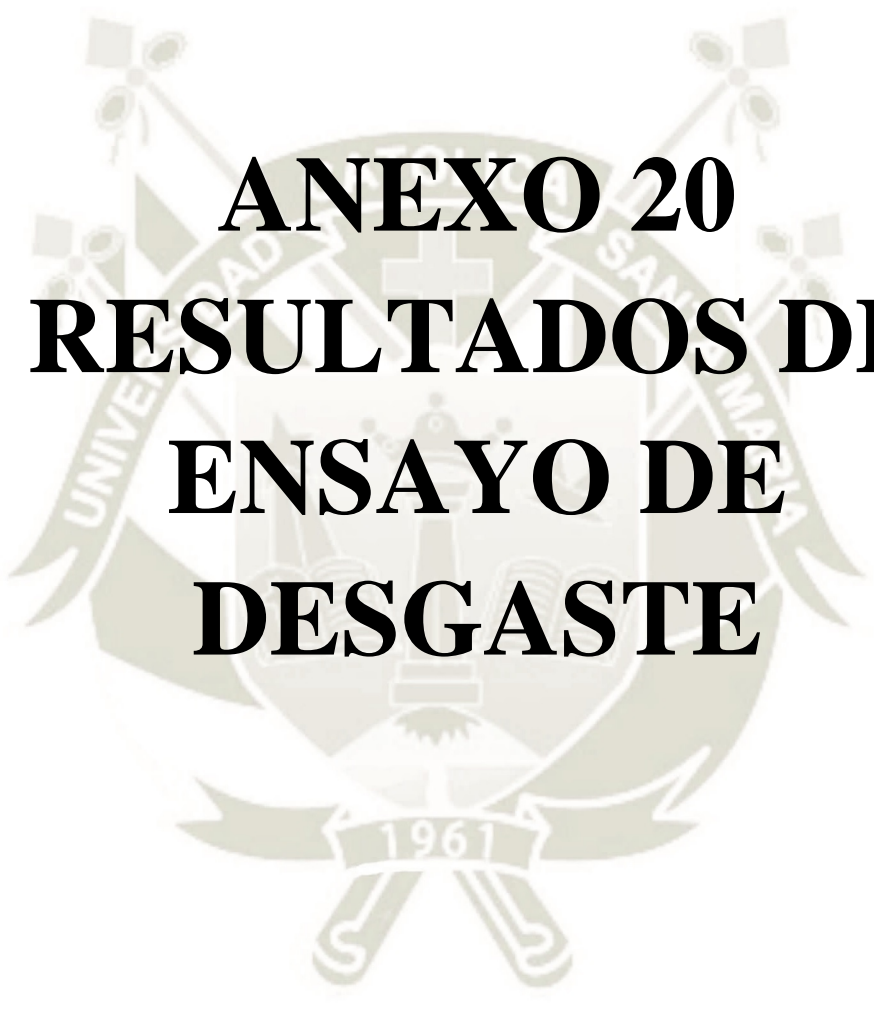
MUESTRAS (pulgadas)		Fuerza Máxima	Resistencia a la Tracción
		N	MPa
Exadur 43	1	21827.94	351.67
Citomangan	2	26140.48	424.01
C 1000	3	27481.82	463.36
Material Base	4	34923.60	703.55

Arequipa, 03 de Julio del 2019



GUIDO F. QUISPE AMPUERO  
 INGENIERO METALURGISTA  
 Reg. del Colegio de Ingenieros N° 103532

Ing. Guido Quispe Ampuero  
 CIP 103532



**ANEXO 20  
RESULTADOS DE  
ENSAYO DE  
DESGASTE**

A large, faint watermark of the Universidad Católica de Santa María seal is centered in the background. The seal features a shield with a cross and an open book, flanked by two figures holding staffs. Below the shield is a banner with the year '1961'.

## **Evaluacion Experimental del desgaste en revestimientos duros**

# Ensayo de desgaste de procesos de soldadura

## Base 1

### Standard parameters

#### Instrument

- Standard tribometer
- Serial number: 1000059319
- Tribometer / Version 7.3.17
- Date of measurement: 7/31/2019 12:43:38 PM

#### Static partner

- Coating: -
- Substrate: WC
- Dimension: 6.00 [mm]
- Geometry: Ball

#### Sample

- Coating: -
- Substrate: Base 1
- Cleaning: -
- Supplier: -

#### Environment

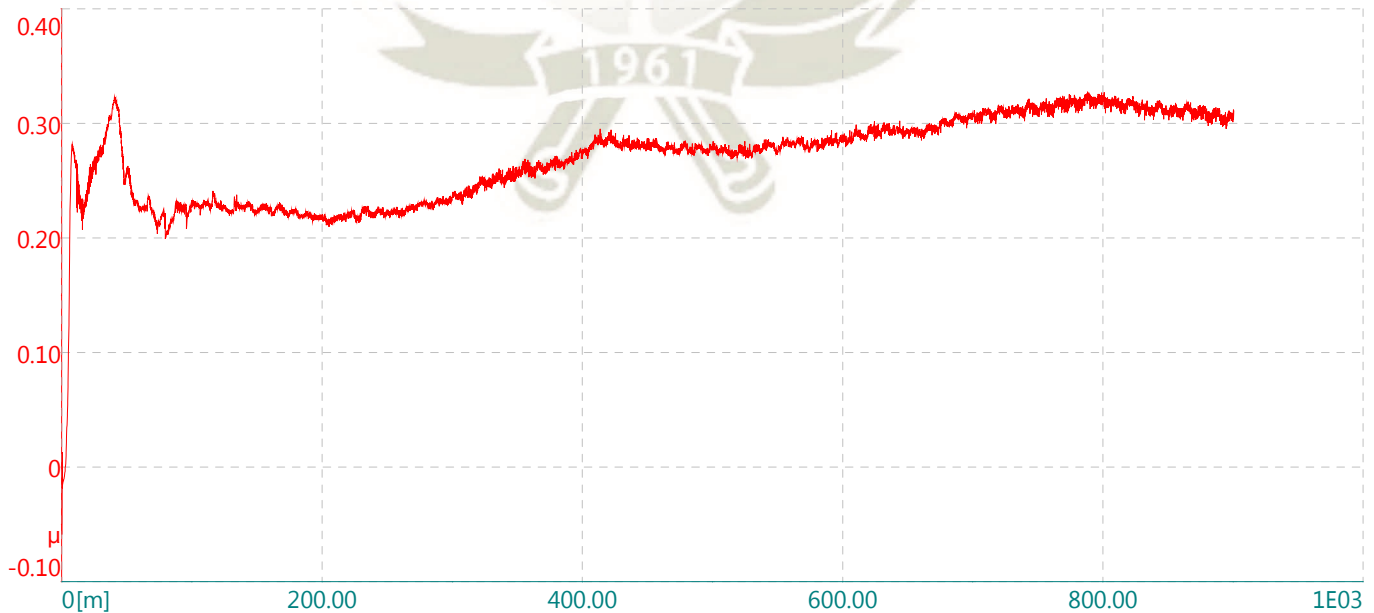
- Temperature: 21.20 [°C]
- Atmosphere: Air
- Humidity: 10.00 [%]

#### Sequence

- Sequence count: 1
- Single-way mode
- Radius: 8.00 [mm]
- Lin. Speed: 25.00 [cm/s]
- Acquisition rate: 5.0 [Hz]
- Cycles sampled: 1/1
- Pause: 0 [s]
- Homing at begin: Yes
- Normal load: 10.00 [N]
- Unload at end: No
- Stop condit.: 905.00 [m]  
Or  $\mu > 0.80$
- Effective Stop: Meters

Sample	Static partner	Calculations
Worn track section: 129117.4 [ $\mu\text{m}^2$ ]	Worn cap diameter: 674.4 [ $\mu\text{m}$ ]	Sample Wear Rate: 0.0007172 [ $\text{mm}^3/\text{N}/\text{m}$ ]
Young's Modulus: 14.2 [GPa]	Young's Modulus: 600.0 [GPa]	Partner Wear Rate: 3.755E-007 [ $\text{mm}^3/\text{N}/\text{m}$ ]
Poisson ratio: 0.250	Poisson ratio: 0.300	Max Herzian Stress: 0.3607 [GPa]

Start : 0.013    min : -0.059    max : 0.328    mean : 0.269    std. dev. : 0.040



Friction coef.

## Modelization Base 1

Analysis : "oz"  
plane : XZ - y=0.00  $\mu\text{m}$

Radius of contact(a) : 144.8642  $\mu\text{m}$   
Maximal stress(pmax) : 0.228 gpa

### Indenter : WC

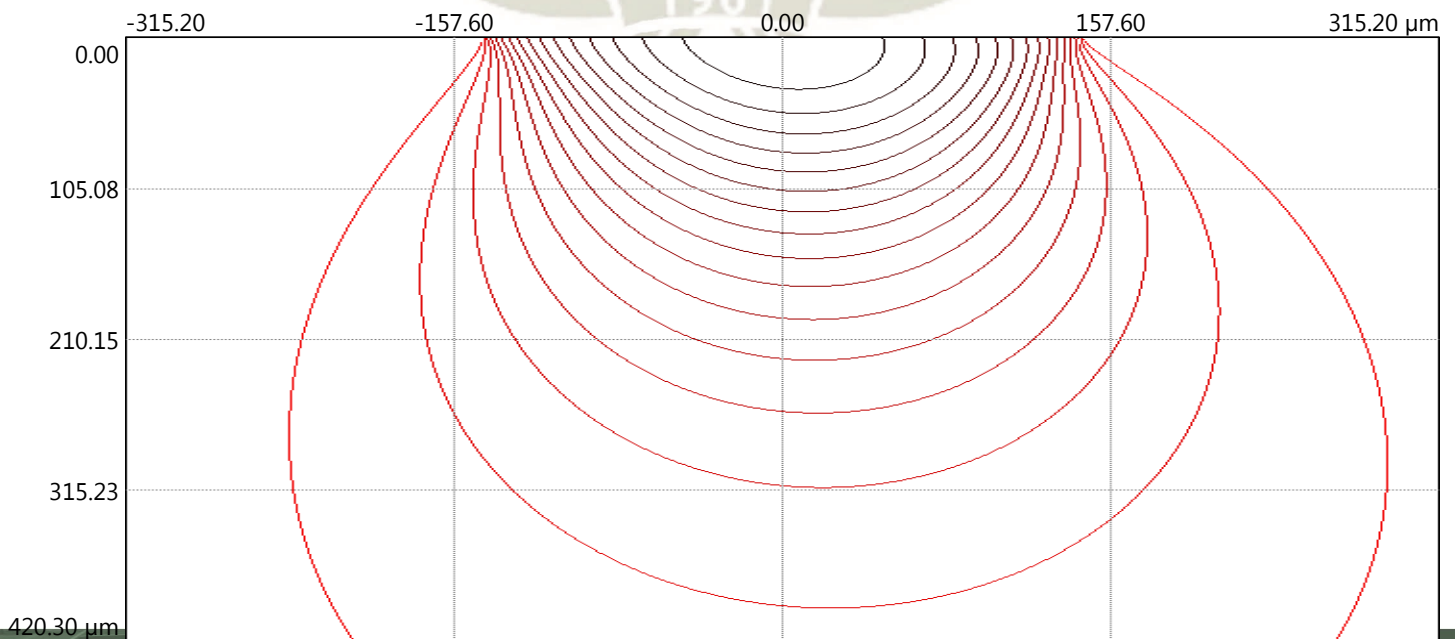
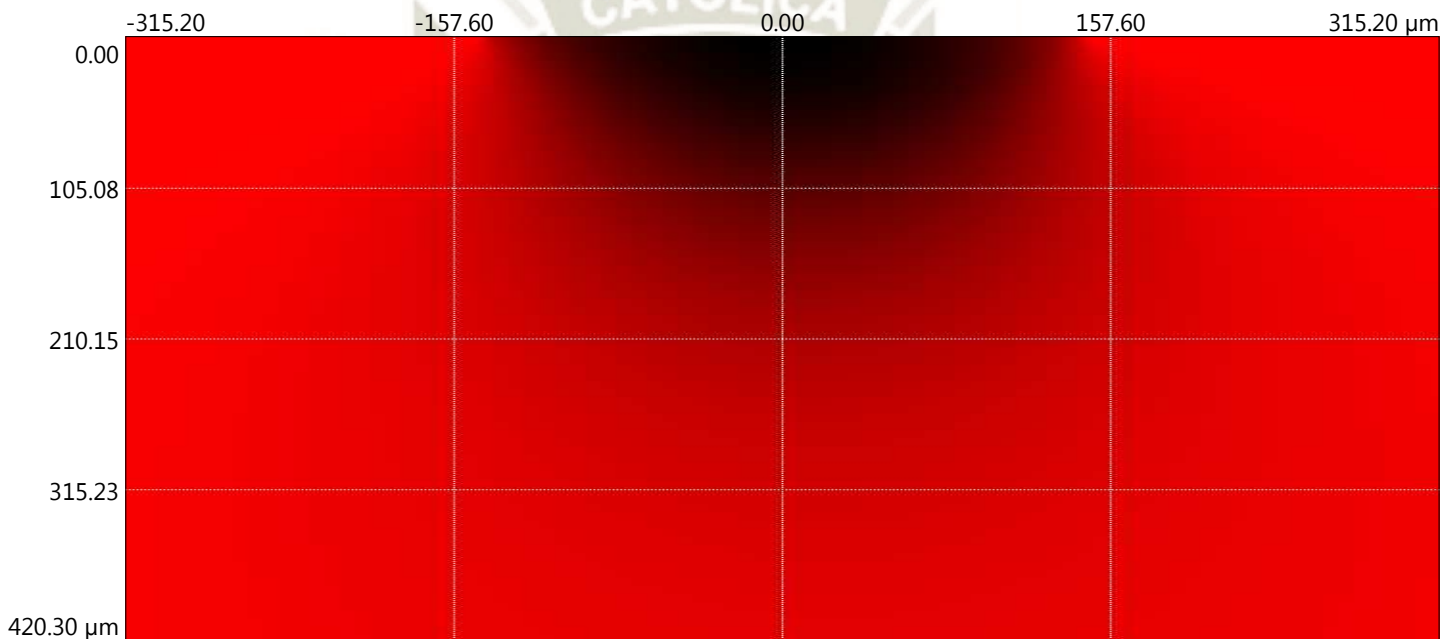
Radius (r) : 6000.00  $\mu\text{m}$   
Young modulus (e) : 600.000 gpa  
Poisson ratio (v) : 0.30

### Sample : 32MnCrMo6-4-3

Radius (r) : 100000.00  $\mu\text{m}$   
Young modulus (e) : 14.173 gpa  
Poisson ratio (v) : 0.25

Load : 10000.0 mn friction coefficient ( $\mu$ ) : 0.268

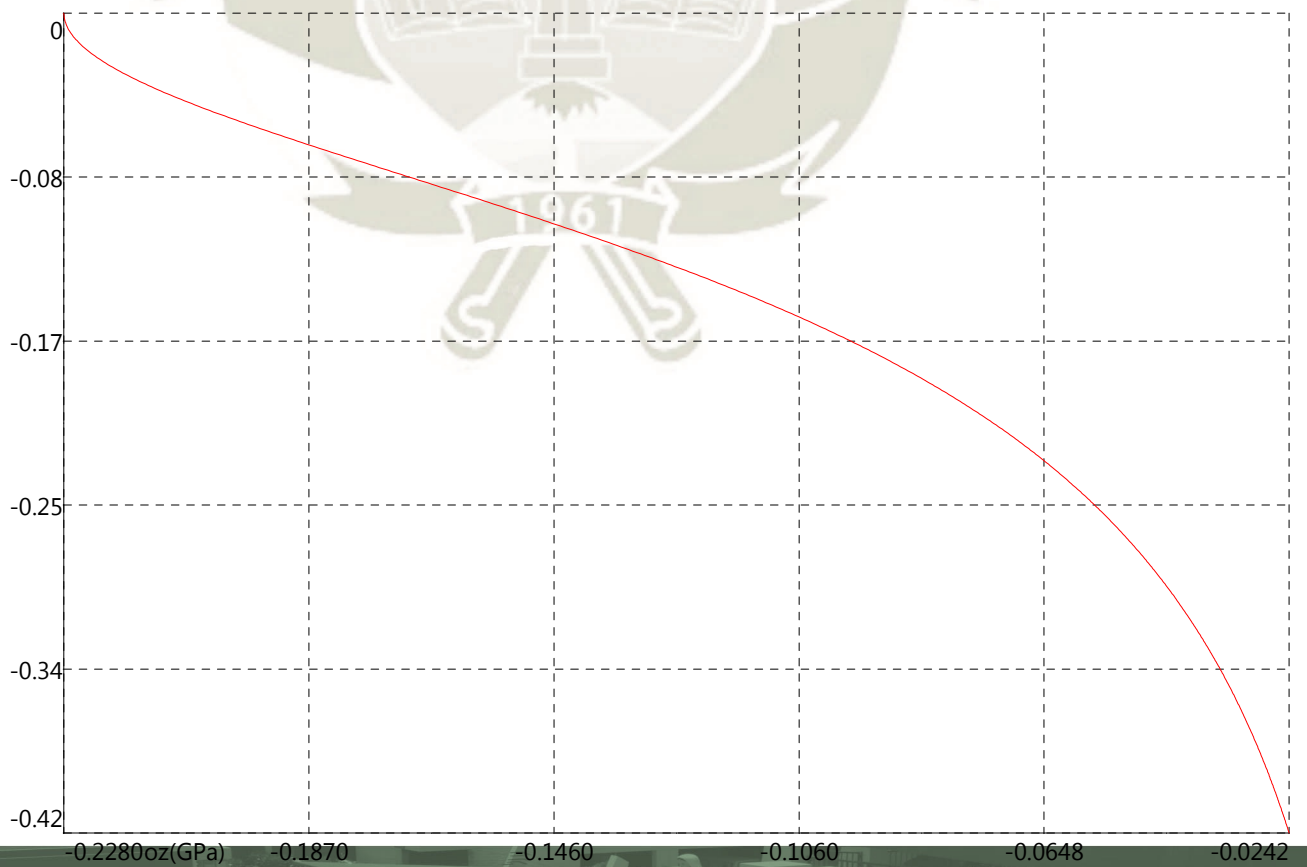
■ -0.228 gpa ■ 0.000241 GPa



oz as a function of x for z=0.000



oz as a function of z for x=0.000

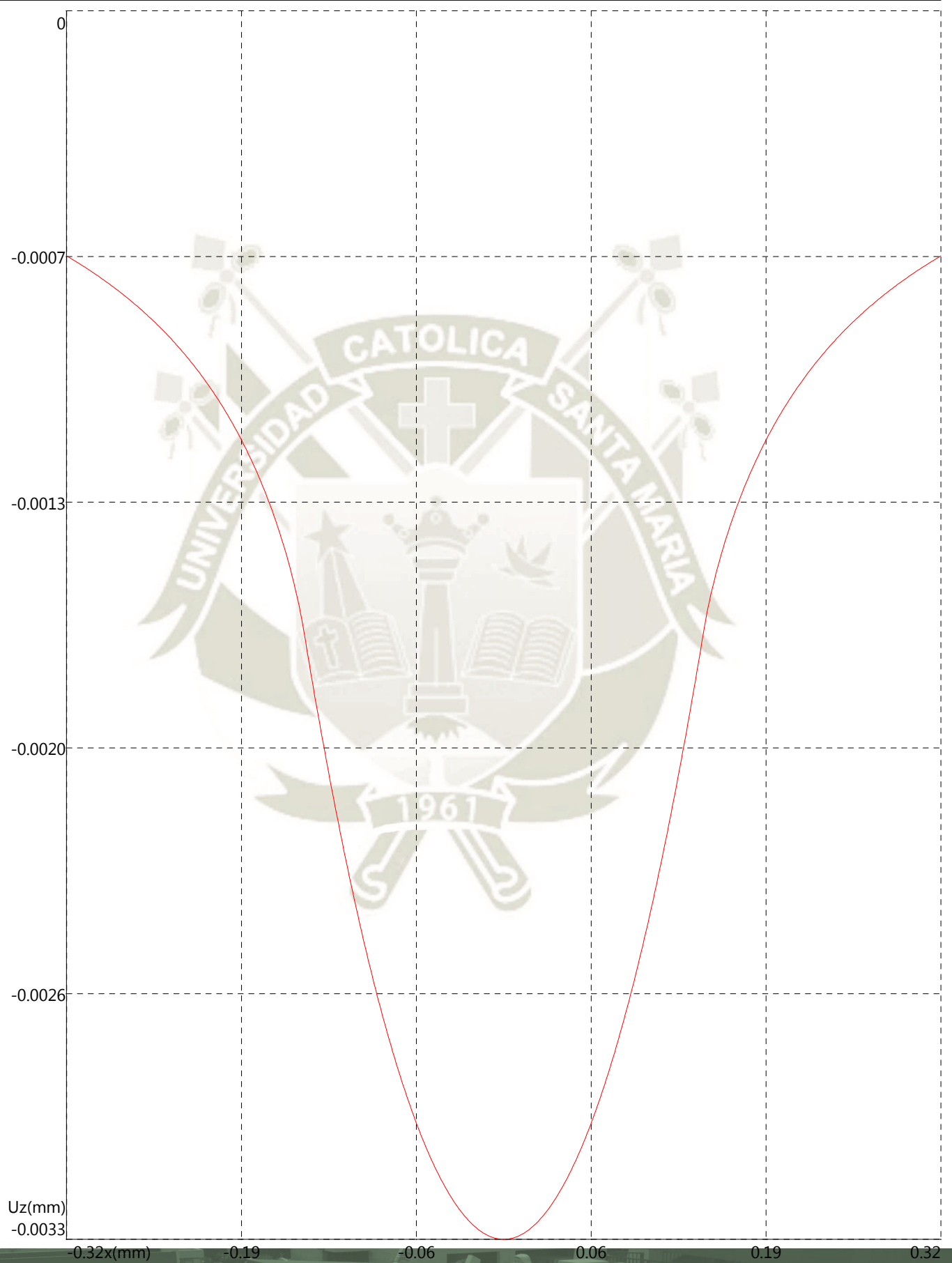


oz as a function of x and z

- oz
- X
- Z



Strain as a function of x





**Base 2**

Standard parameters

**Instrument**

- Standard tribometer
- Serial number: 1000059319
- Tribometer / Version 7.3.17
- Date of measurement: 8/1/2019 1:43:48 PM

**Static partner**

- Coating: -
- Substrate: WC
- Dimension: 6.00 [mm]
- Geometry: Ball

**Sample**

- Coating: -
- Substrate: Base 2
- Cleaning: -
- Supplier: -

**Environment**

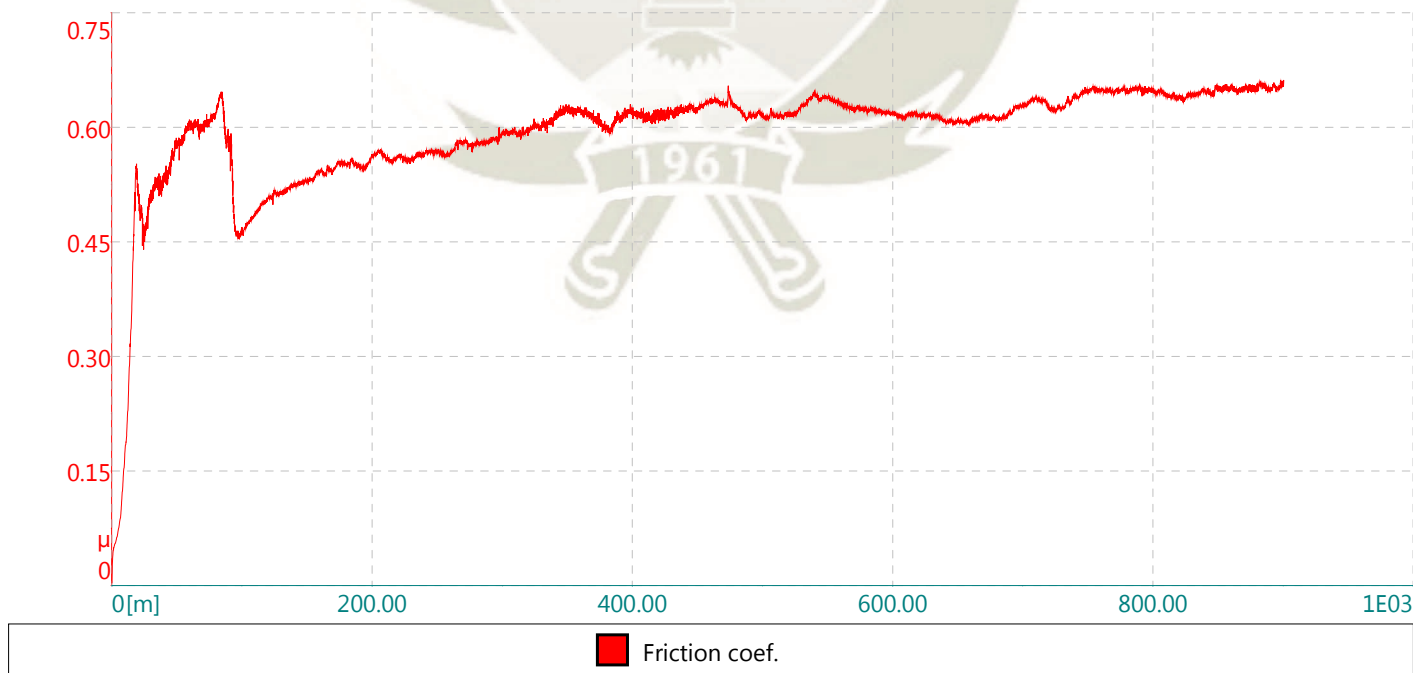
- Temperature: 20.50 [°C]
- Atmosphere: Air
- Humidity: 10.00 [%]

**Sequence**

- Sequence count: 1
- Single-way mode
- Radius: 8.00 [mm]
- Lin. Speed: 25.00 [cm/s]
- Acquisition rate: 5.0 [Hz]
- Cycles sampled: 1/1
- Pause: 0 [s]
- Homing at begin: Yes
- Normal load: 10.00 [N]
- Unload at end: No
- Stop condit.: 905.00 [m]  
Or  $\mu > 0.80$
- Effective Stop: Meters

Sample	Static partner	Calculations
Worn track section: 76997.1 [ $\mu\text{m}^2$ ]	Worn cap diameter: 897.4 [ $\mu\text{m}$ ]	Sample Wear Rate: 0.0004277 [ $\text{mm}^3/\text{N/m}$ ]
Young's Modulus: 14.2 [GPa]	Young's Modulus: 600.0 [GPa]	Partner Wear Rate: 1.182E-006 [ $\text{mm}^3/\text{N/m}$ ]
Poisson ratio: 0.250	Poisson ratio: 0.300	Max Herzian Stress: 0.3607 [GPa]

Start : 0.003    min : 0.003    max : 0.662    mean : 0.594    std. dev. : 0.075



## Modelization Base 2

Analysis : "oz"  
plane : XZ - y=0.00  $\mu\text{m}$

Radius of contact(a) : 144.8642  $\mu\text{m}$   
Maximal stress(pmax) : 0.228 gpa

### Indenter : WC

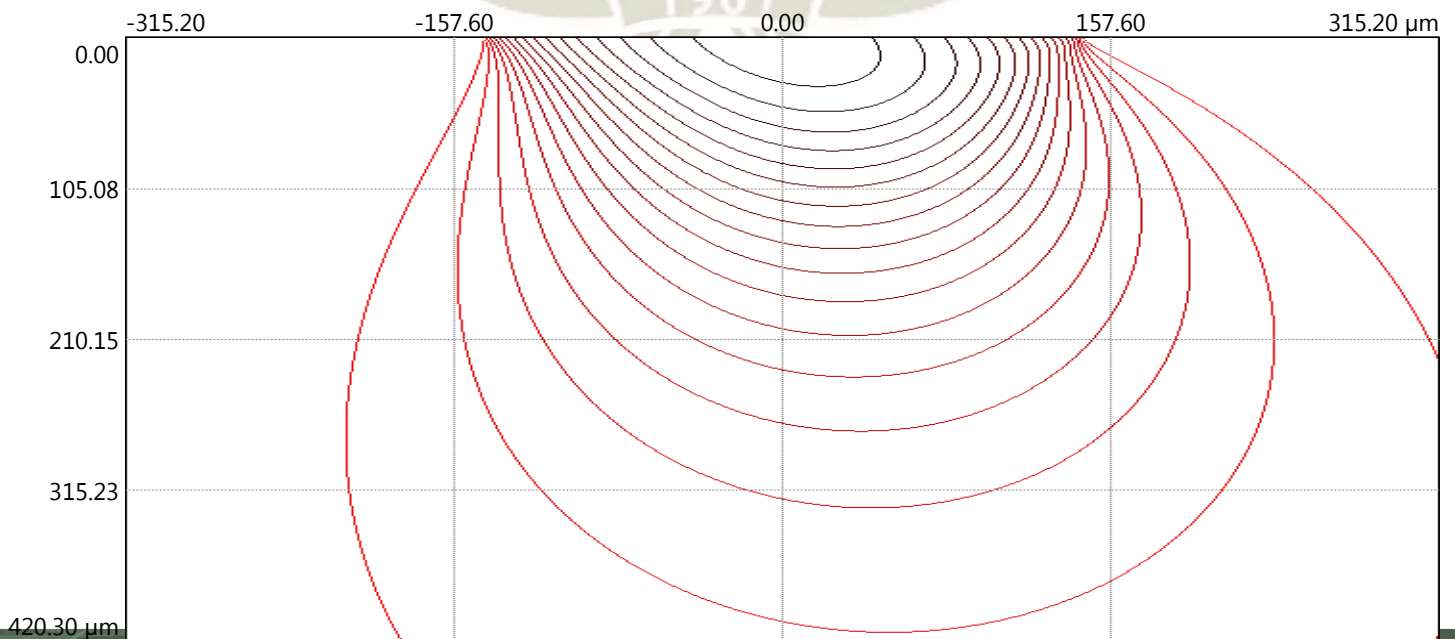
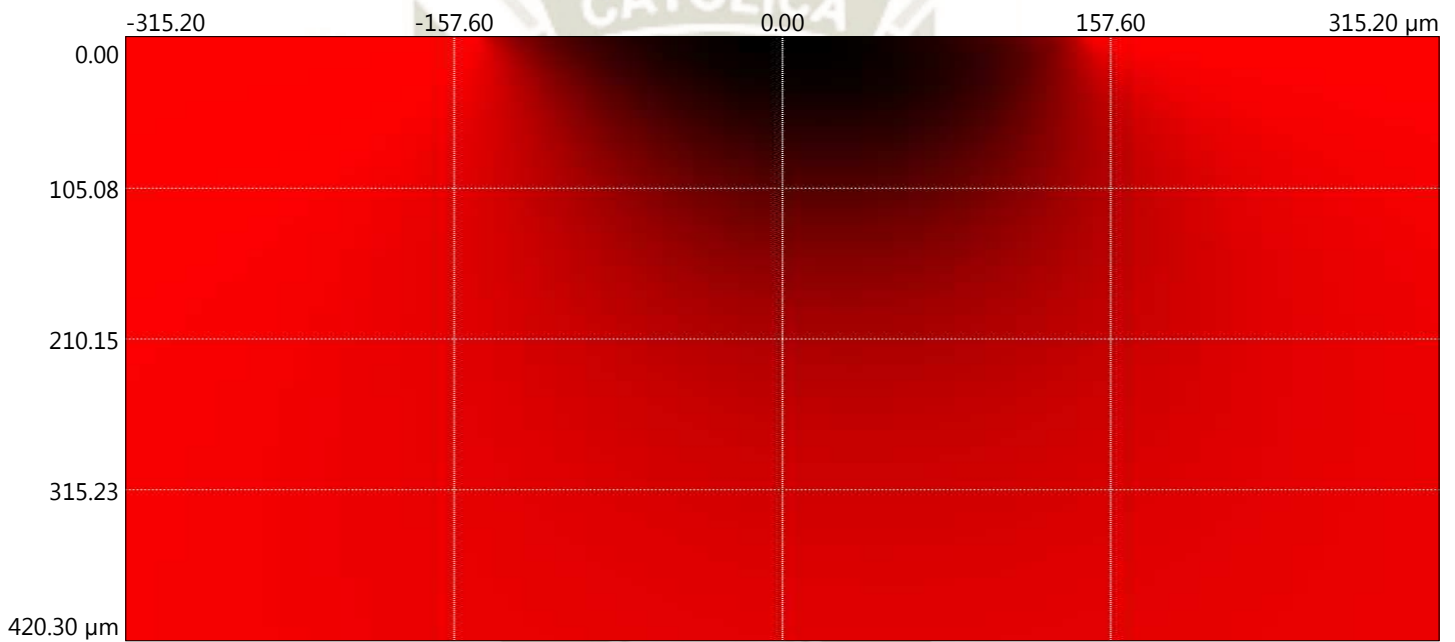
Radius (r) : 6000.00  $\mu\text{m}$   
Young modulus (e) : 600.000 gpa  
Poisson ratio (v) : 0.30

### Sample : 32MnCrMo6-4-3

Radius (r) : 100000.00  $\mu\text{m}$   
Young modulus (e) : 14.173 gpa  
Poisson ratio (v) : 0.25

Load : 10000.0 mn friction coefficient ( $\mu$ ) : 0.593

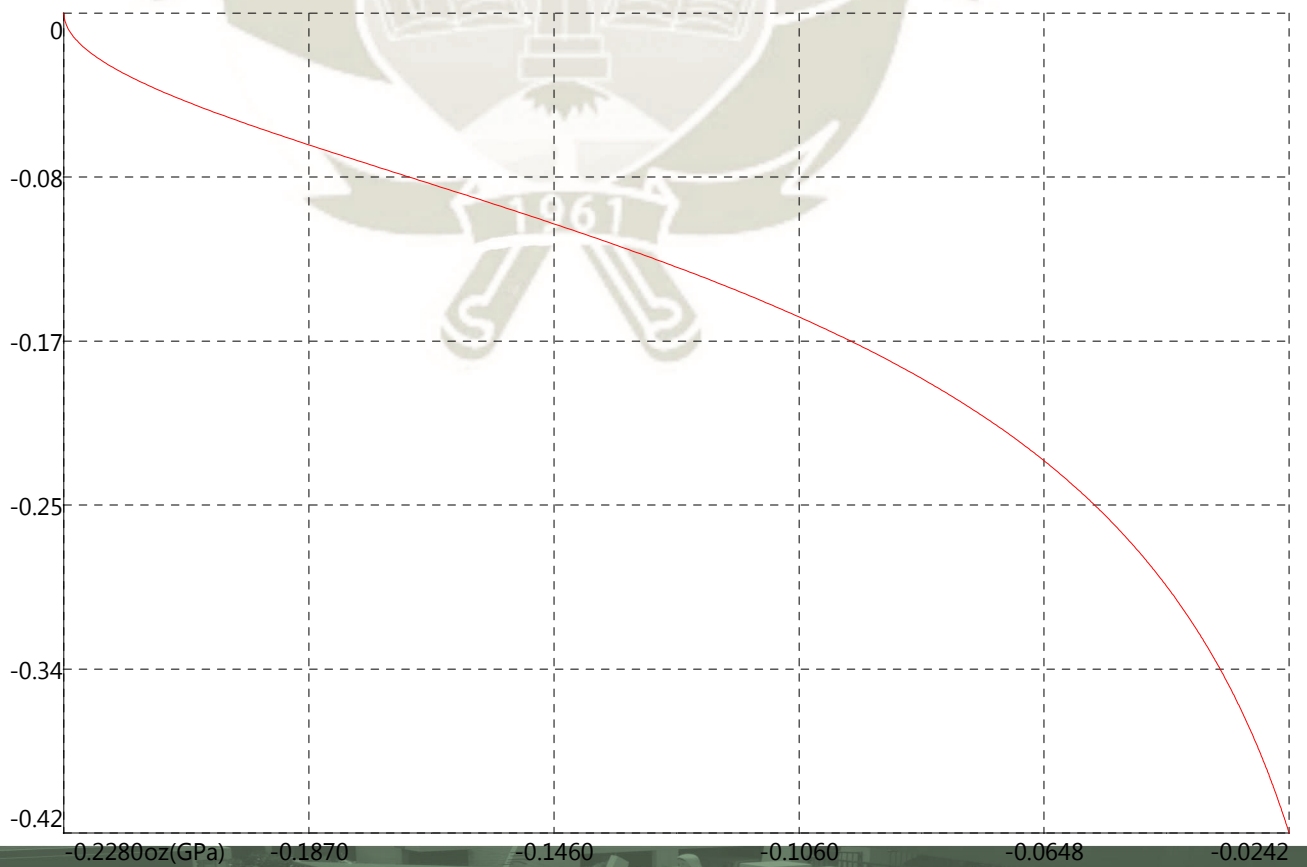
■ -0.228 gpa ■ 0.0023 GPa



oz as a function of x for z=0.000



oz as a function of z for x=0.000

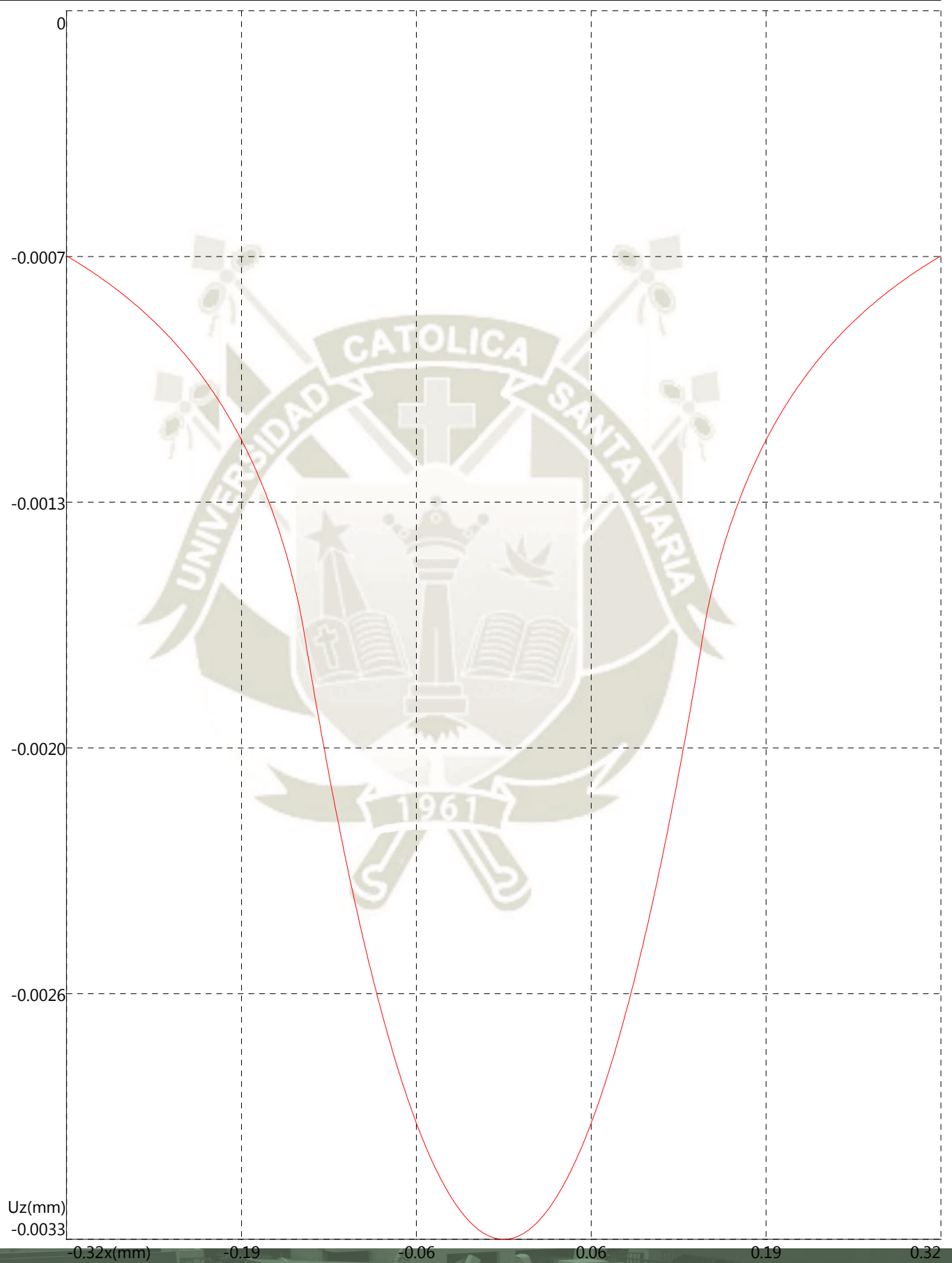


oz as a function of x and z

- oz
- X
- Z



Strain as a function of x



## Muestra A

### Standard parameters

#### Instrument

- Standard tribometer
- Serial number: 1000059319
- Tribometer / Version 7.3.17
- Date of measurement: 7/31/2019 4:34:40 PM

#### Static partner

- Coating: -
- Substrate: WC
- Dimension: 6.00 [mm]
- Geometry: Ball

#### Sample

- Coating: -
- Substrate: Muestra A
- Cleaning: -
- Supplier: -

#### Environment

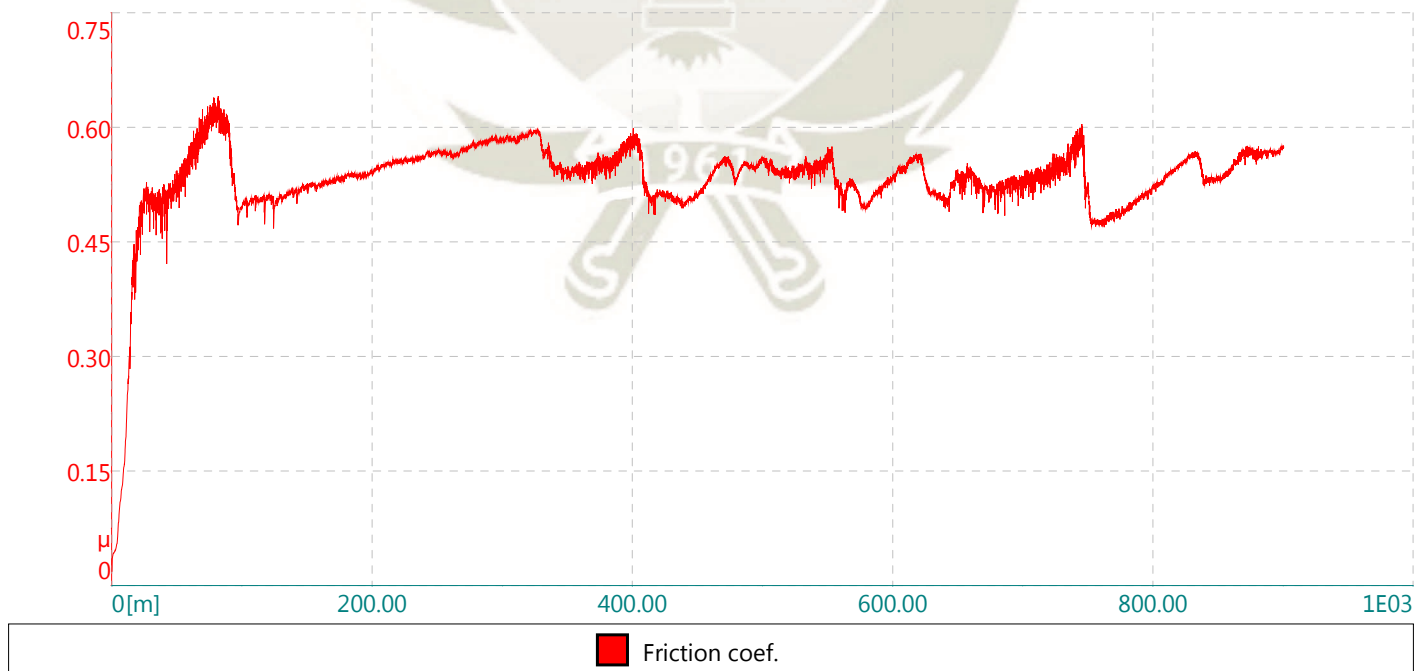
- Temperature: 21.20 [°C]
- Atmosphere: Air
- Humidity: 10.00 [%]

#### Sequence

- Sequence count: 1
- Single-way mode
- Radius: 8.01 [mm]
- Lin. Speed: 25.00 [cm/s]
- Acquisition rate: 5.0 [Hz]
- Cycles sampled: 1/1
- Pause: 0 [s]
- Homing at begin: Yes
- Normal load: 10.00 [N]
- Unload at end: No
- Stop condit.: 905.00 [m]  
Or  $\mu > 0.80$
- Effective Stop: Meters

Sample	Static partner	Calculations
Worn track section: 72936.0 [ $\mu\text{m}^2$ ]	Worn cap diameter: 747.0 [ $\mu\text{m}$ ]	Sample Wear Rate: 0.0004056 [ $\text{mm}^3/\text{N}/\text{m}$ ]
Young's Modulus: 5.0 [GPa]	Young's Modulus: 600.0 [GPa]	Partner Wear Rate: 5.661E-007 [ $\text{mm}^3/\text{N}/\text{m}$ ]
Poisson ratio: 0.320	Poisson ratio: 0.300	Max Hertzian Stress: 0.186 [GPa]

Start : 0.034    min : 0.018    max : 0.641    mean : 0.533    std. dev. : 0.060



### Modelization A

Analysis : "oz"  
plane : XZ - y=0.00  $\mu\text{m}$

Radius of contact(a) : 202.1002  $\mu\text{m}$   
Maximal stress(pmax) : 0.117 gpa

#### Indenter : WC

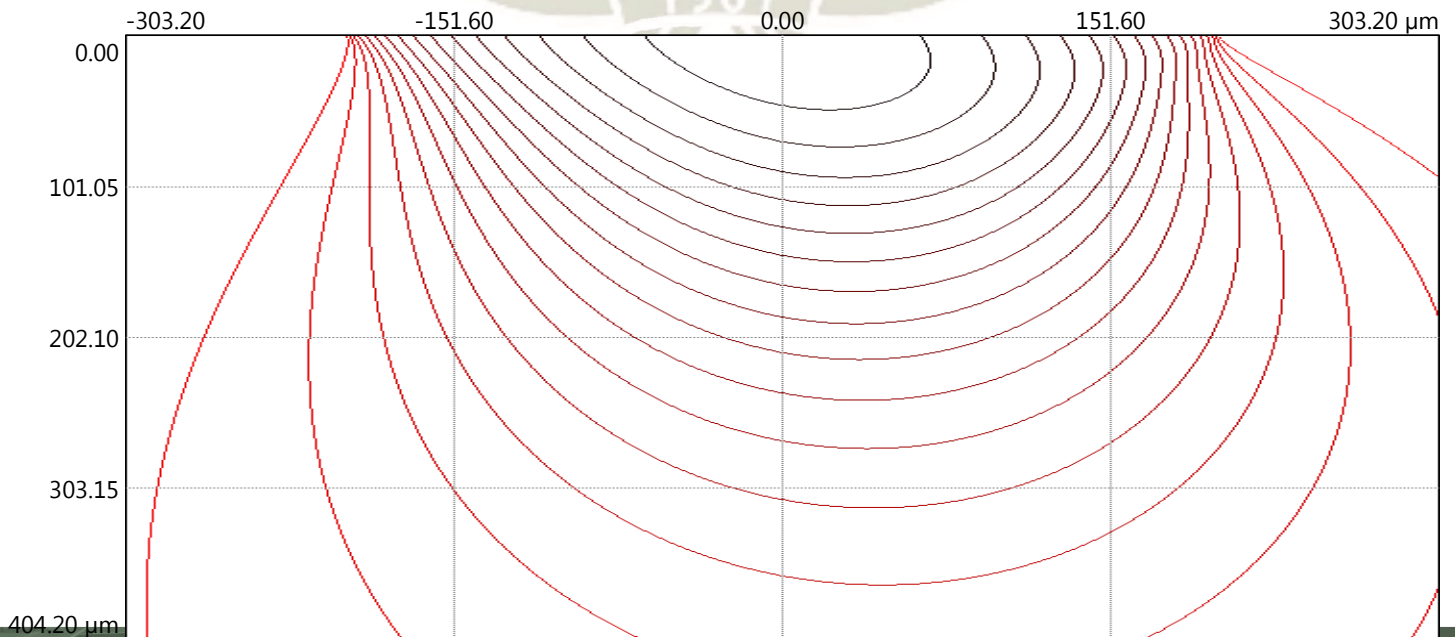
Radius (r) : 6000.00  $\mu\text{m}$   
Young modulus (e) : 600.000 gpa  
Poisson ratio ( $\nu$ ) : 0.30

#### Sample : Sold. Citomangan

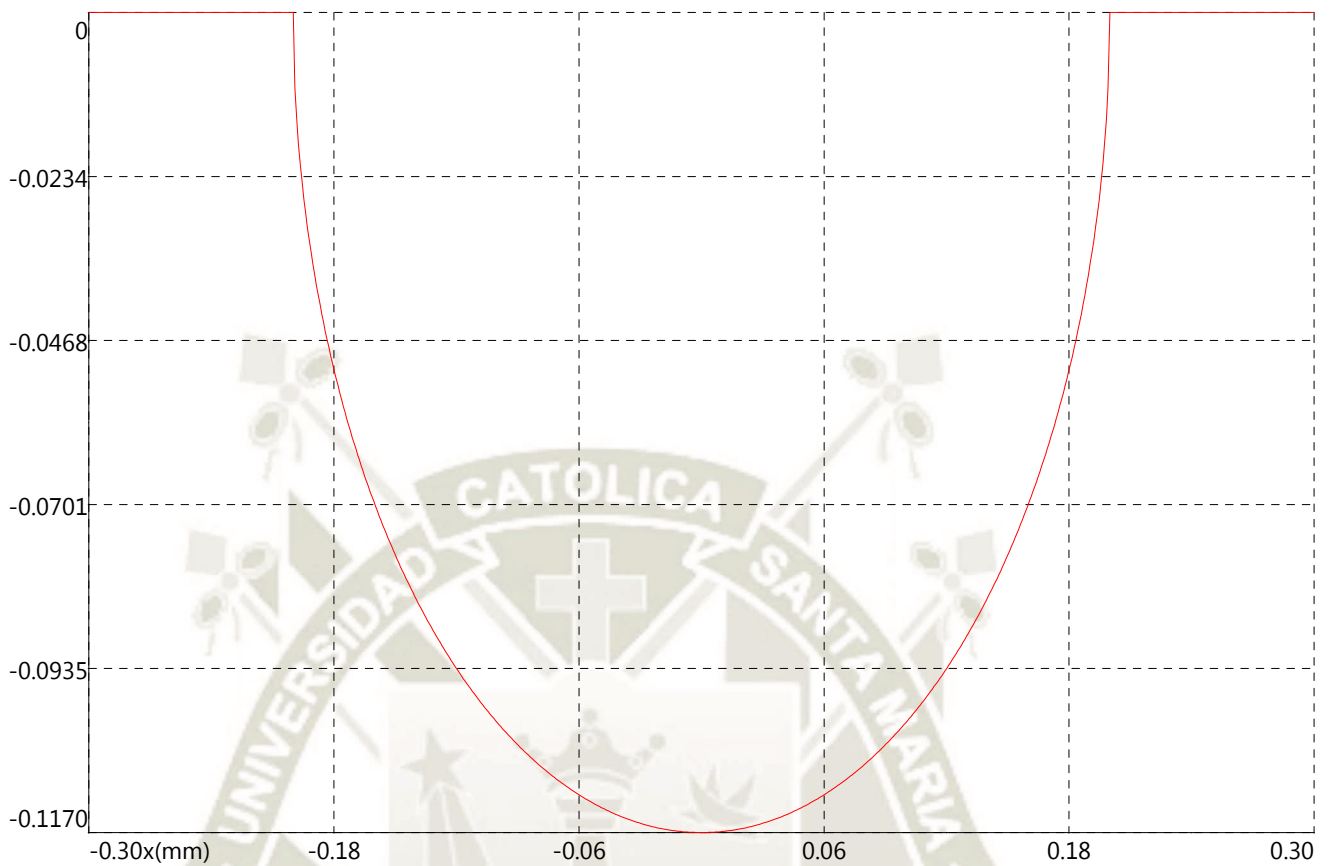
Radius (r) : 100000.00  $\mu\text{m}$   
Young modulus (e) : 4.948 gpa  
Poisson ratio ( $\nu$ ) : 0.32

Load : 10000.0 mn friction coefficient ( $\mu$ ) : 0.531

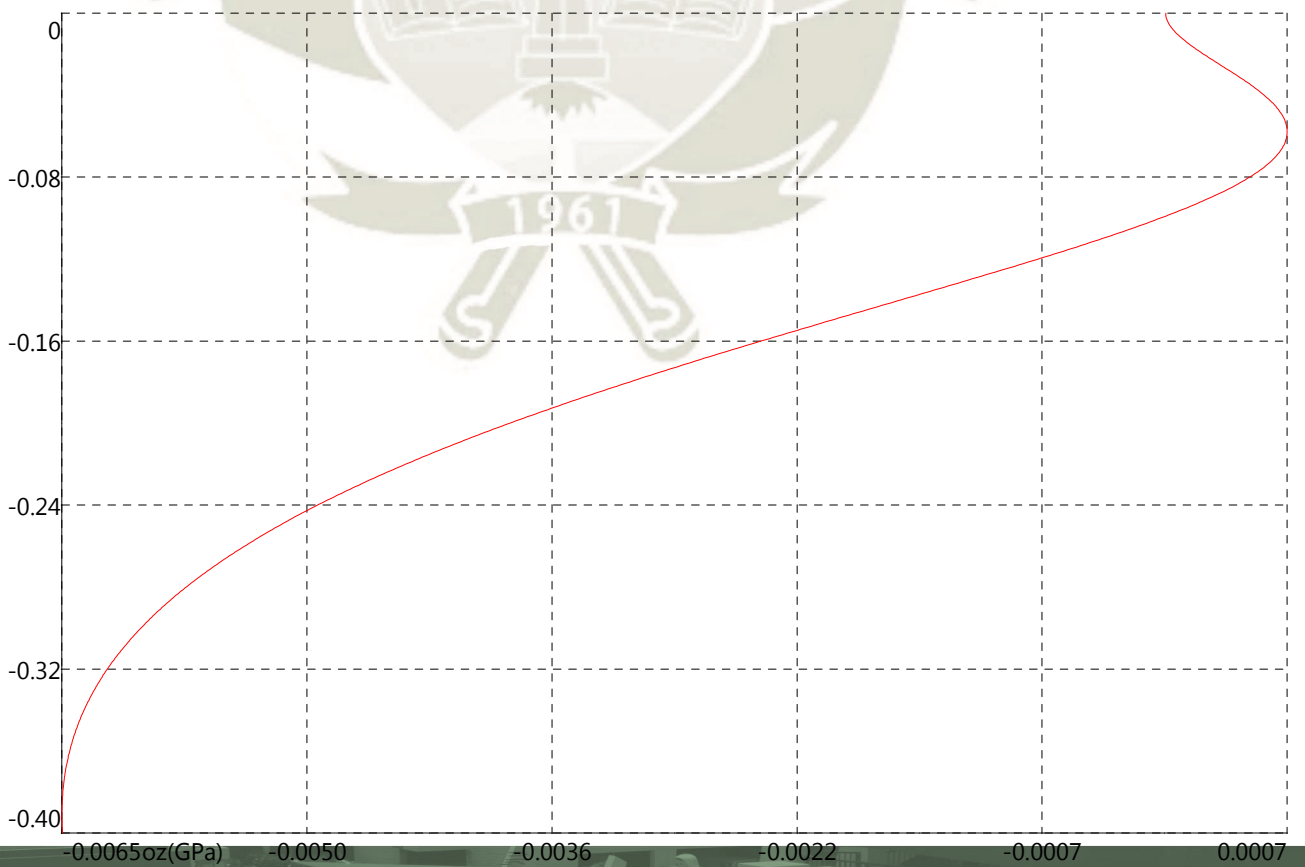
■ -0.117 gpa ■ 0.000874 GPa



oz as a function of x for z=0.000



oz as a function of z for x=-0.303



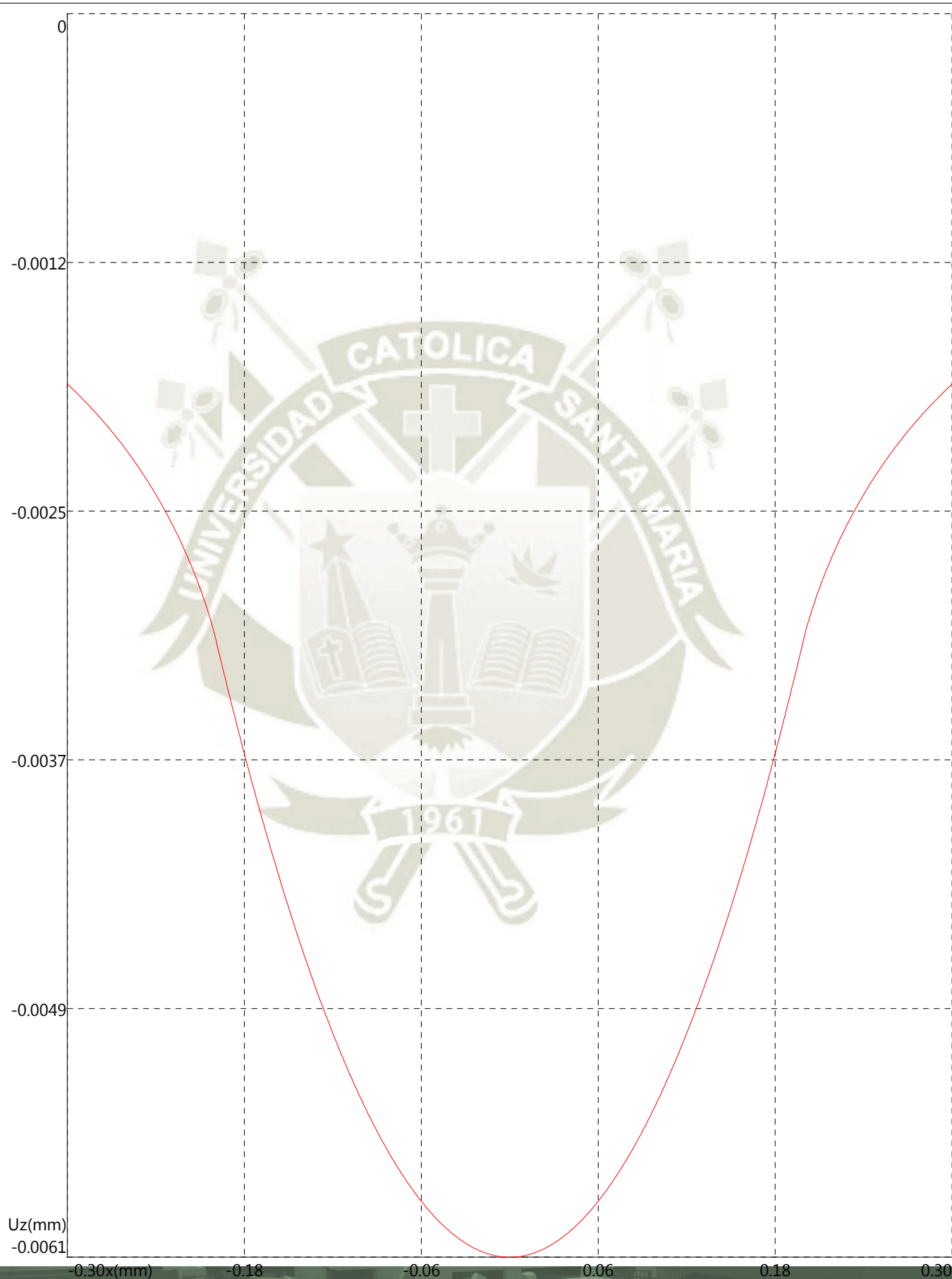


oz as a function of x and z

- oz
- X
- Z



Strain as a function of x



## Muestra A2

### Standard parameters

#### Instrument

- Standard tribometer
- Serial number: 1000059319
- Tribometer / Version 7.3.17
- Date of measurement: 8/12/2019 3:29:13 PM

#### Static partner

- Coating: -
- Substrate: WC
- Dimension: 6.00 [mm]
- Geometry: Ball

#### Sample

- Coating: -
- Substrate: Muestra A2
- Cleaning: -
- Supplier: -

#### Environment

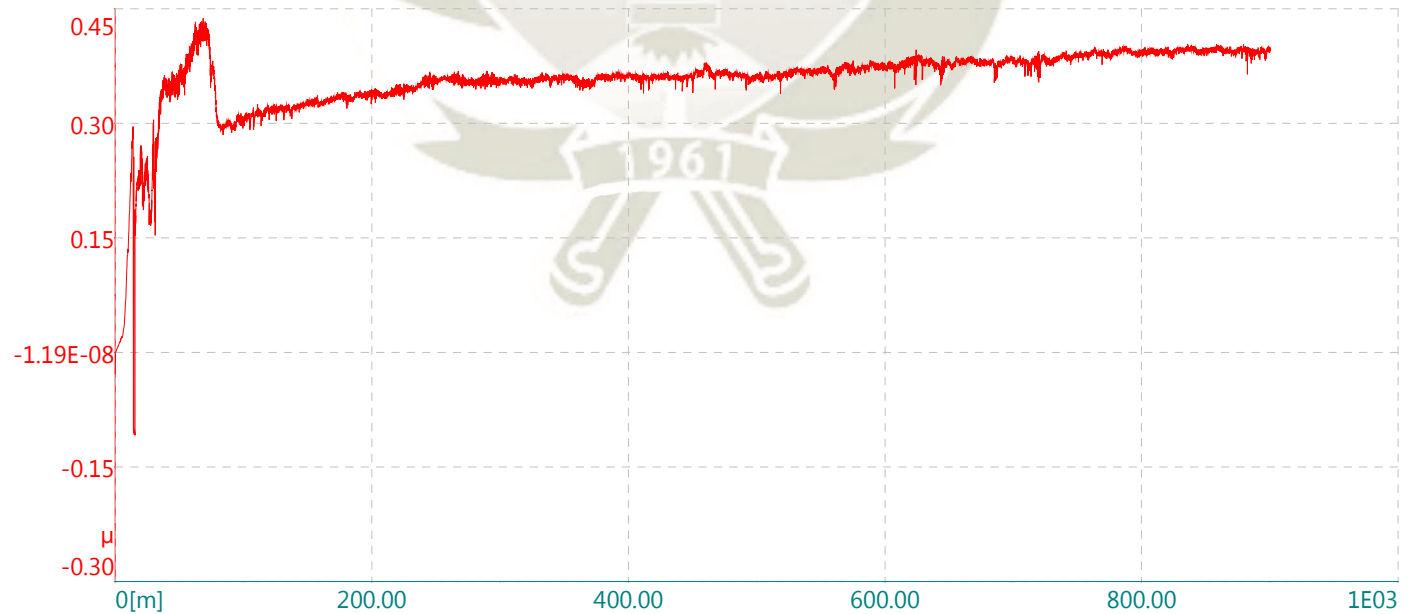
- Temperature: 20.00 [°C]
- Atmosphere: Air
- Humidity: 10.00 [%]

#### Sequence

- Sequence count: 1
- Single-way mode
- Radius: 7.98 [mm]
- Lin. Speed: 25.00 [cm/s]
- Acquisition rate: 5.0 [Hz]
- Cycles sampled: 1/1
- Pause: 0 [s]
- Homing at begin: Yes
- Normal load: 10.00 [N]
- Unload at end: No
- Stop condit.: 905.00 [m]  
Or  $\mu > 0.80$
- Effective Stop: Meters

Sample	Static partner	Calculations
Worn track section: 67212.0 [ $\mu\text{m}^2$ ]	Worn cap diameter: 770.7 [ $\mu\text{m}$ ]	Sample Wear Rate: 0.0003724 [ $\text{mm}^3/\text{N/m}$ ]
Young's Modulus: 5.0 [GPa]	Young's Modulus: 600.0 [GPa]	Partner Wear Rate: 6.414E-007 [ $\text{mm}^3/\text{N/m}$ ]
Poisson ratio: 0.320	Poisson ratio: 0.300	Max Herzian Stress: 0.186 [GPa]

Start : -0.028    min : -0.108    max : 0.438    mean : 0.357    std. dev. : 0.051



## Modelization A2

Analysis : "oz"  
plane : XZ - y=0.00  $\mu\text{m}$

Radius of contact(a) : 202.1002  $\mu\text{m}$   
Maximal stress(pmax) : 0.117 gpa

### Indenter : WC

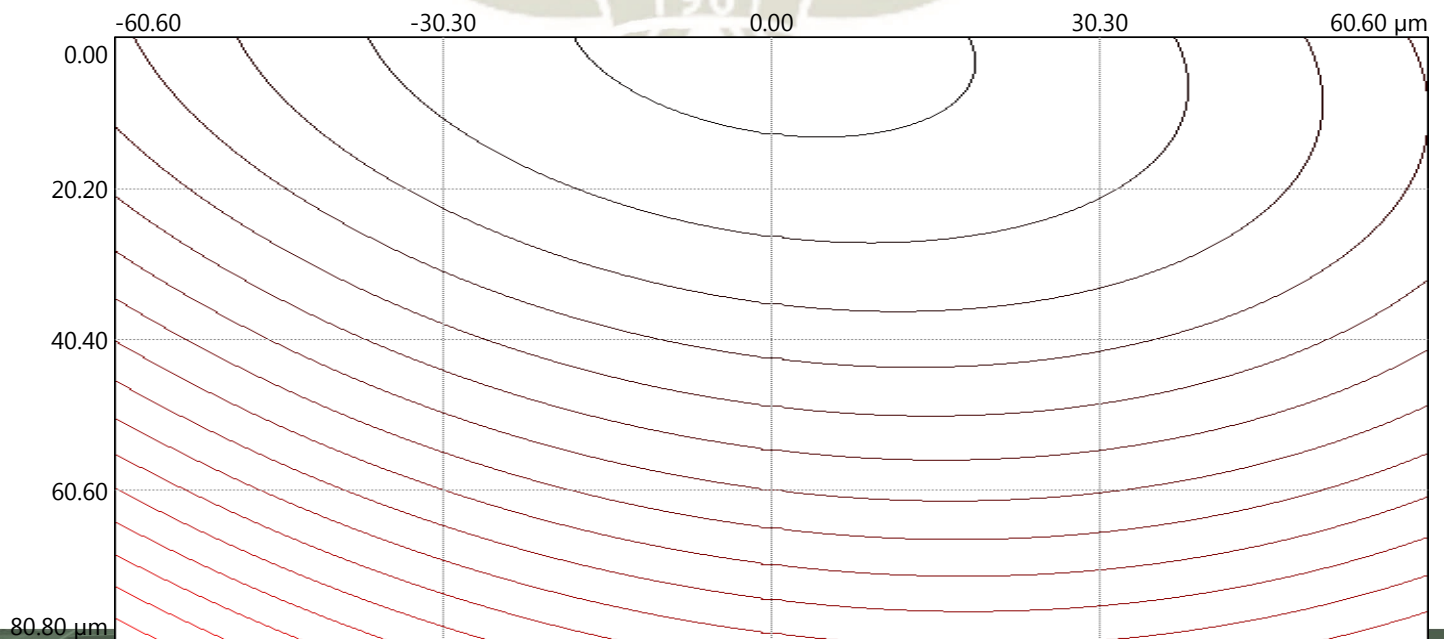
Radius (r) : 6000.00  $\mu\text{m}$   
Young modulus (e) : 600.000 gpa  
Poisson ratio ( $\nu$ ) : 0.30

### Sample : Sold. Citomangan

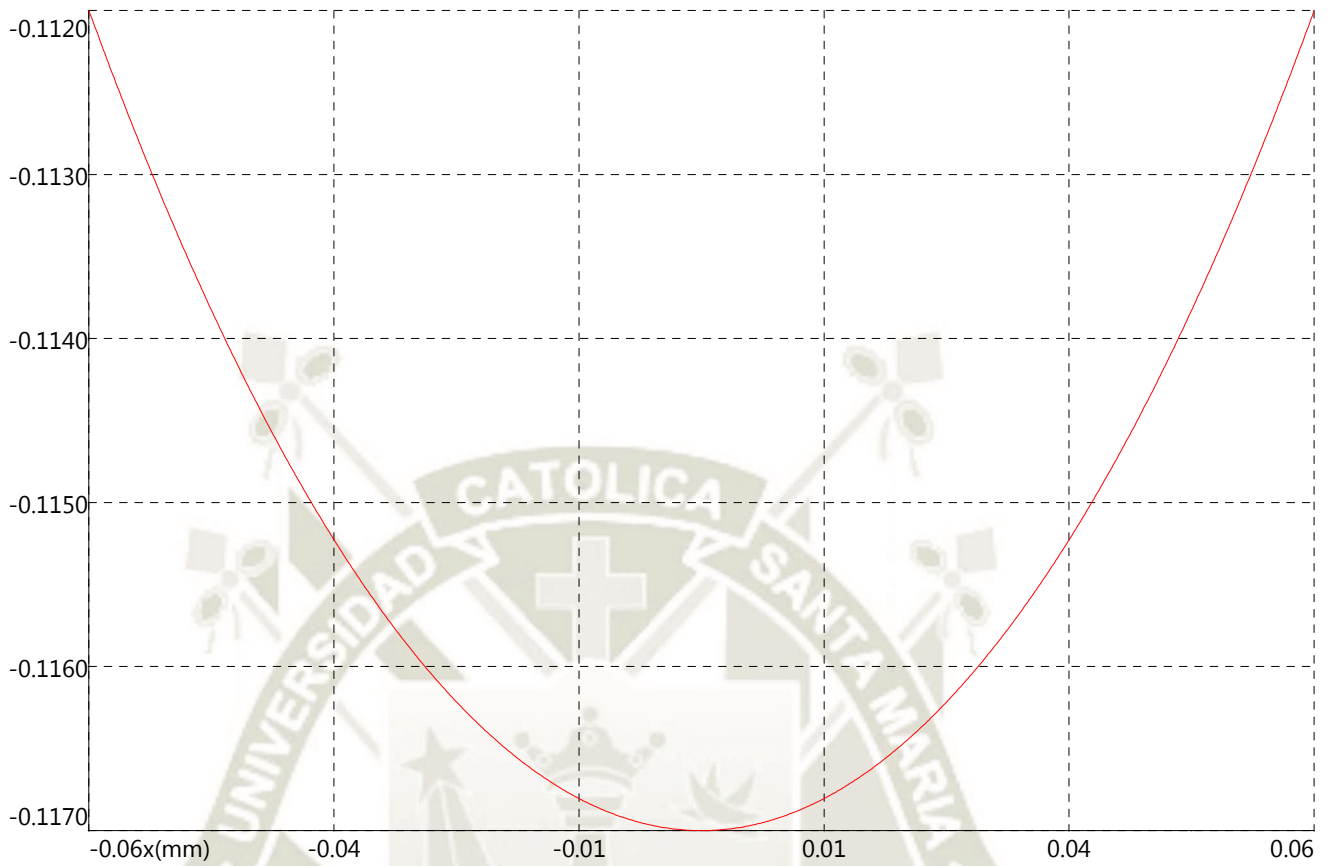
Radius (r) : 100000.00  $\mu\text{m}$   
Young modulus (e) : 4.948 gpa  
Poisson ratio ( $\nu$ ) : 0.32

Load : 10000.0 mn friction coefficient ( $\mu$ ) : 0.357

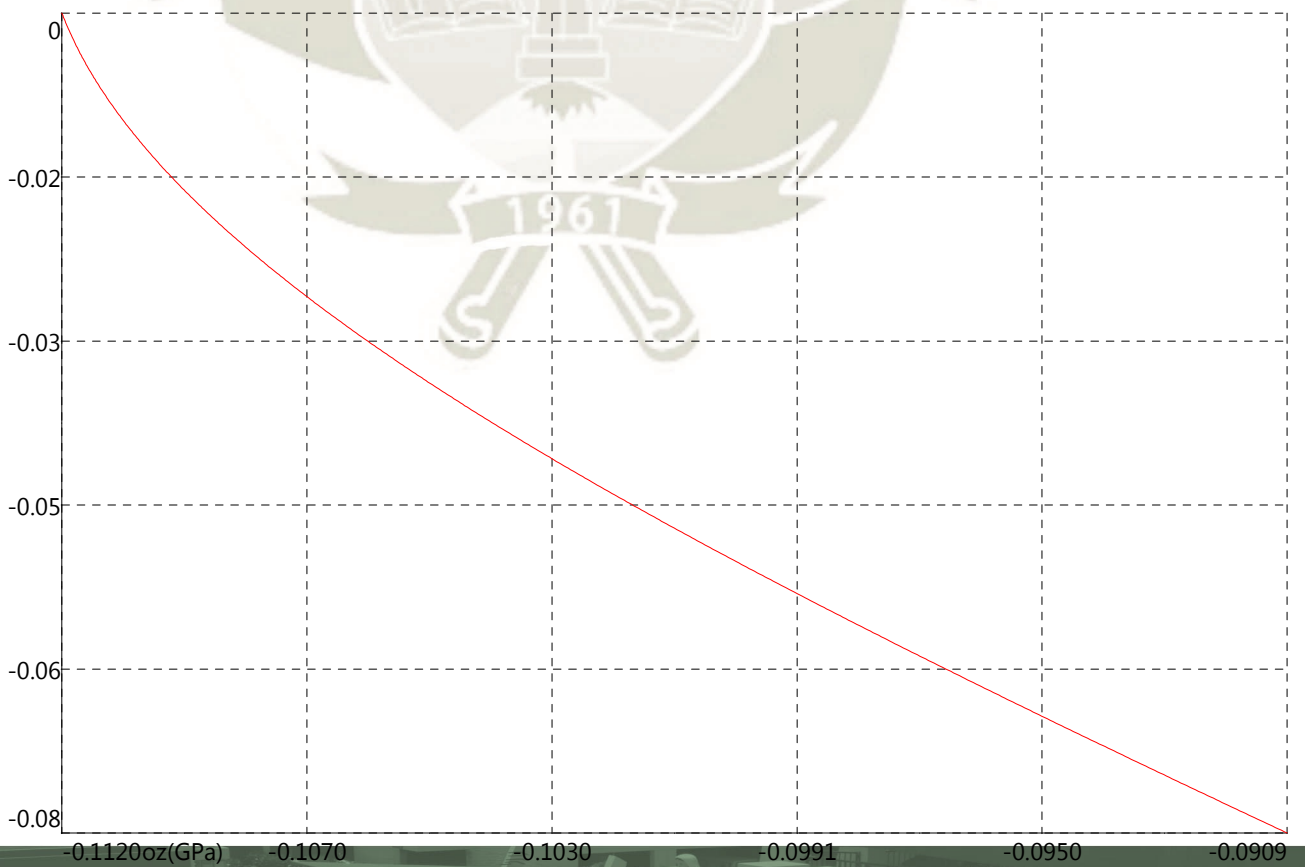
■ -0.117 gpa ■ -0.0909 GPa



oz as a function of x for z=0.000



oz as a function of z for x=-0.061

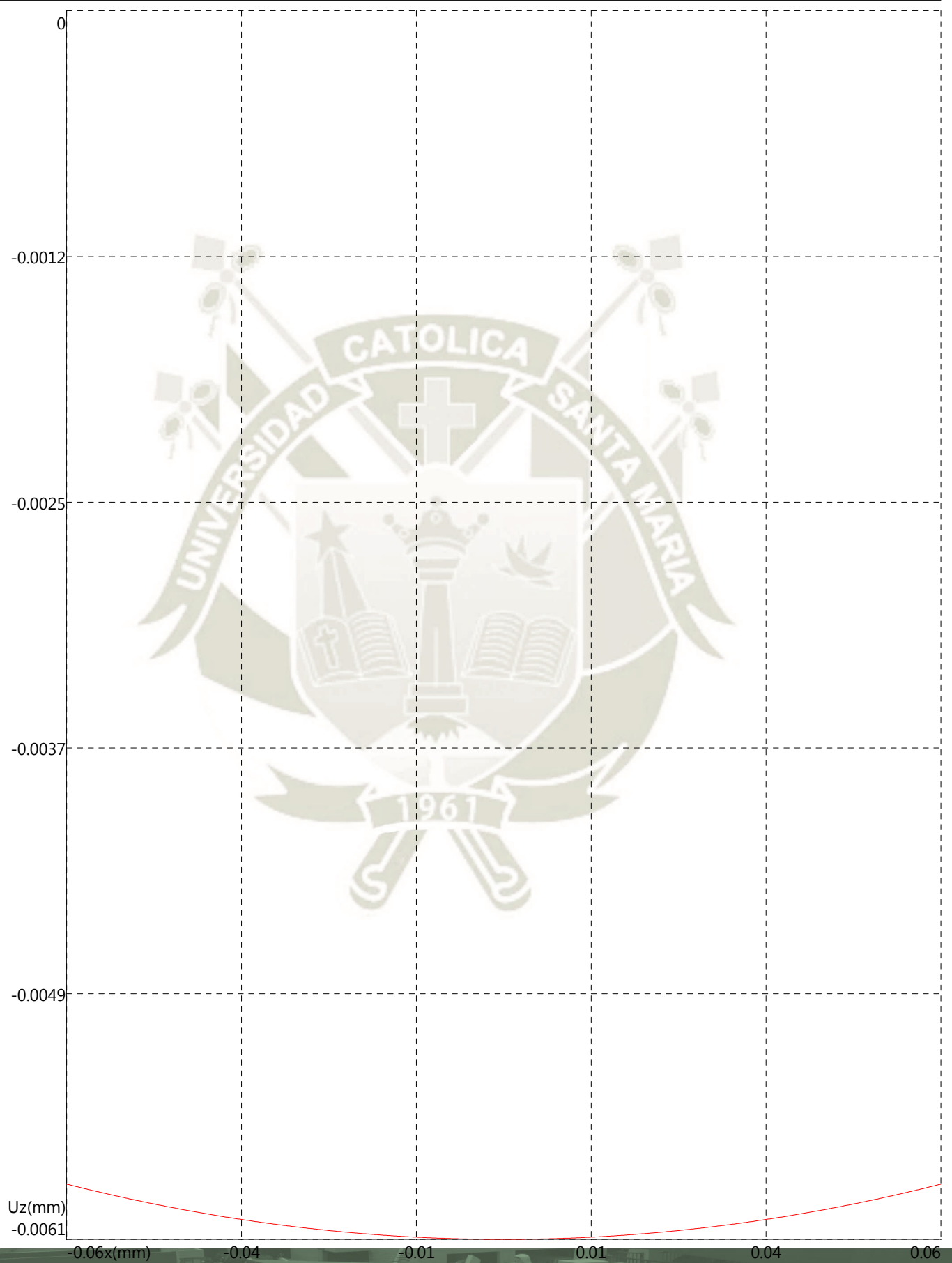


oz as a function of x and z

- oz
- X
- Z



Strain as a function of x



## Muestra B

### Standard parameters

#### Instrument

- Standard tribometer
- Serial number: 1000059319
- Tribometer / Version 7.3.17
- Date of measurement: 7/31/2019 5:49:06 PM

#### Static partner

- Coating: -
- Substrate: WC
- Dimension: 6.00 [mm]
- Geometry: Ball

#### Sample

- Coating: -
- Substrate: Muestra B
- Cleaning: -
- Supplier: -

#### Environment

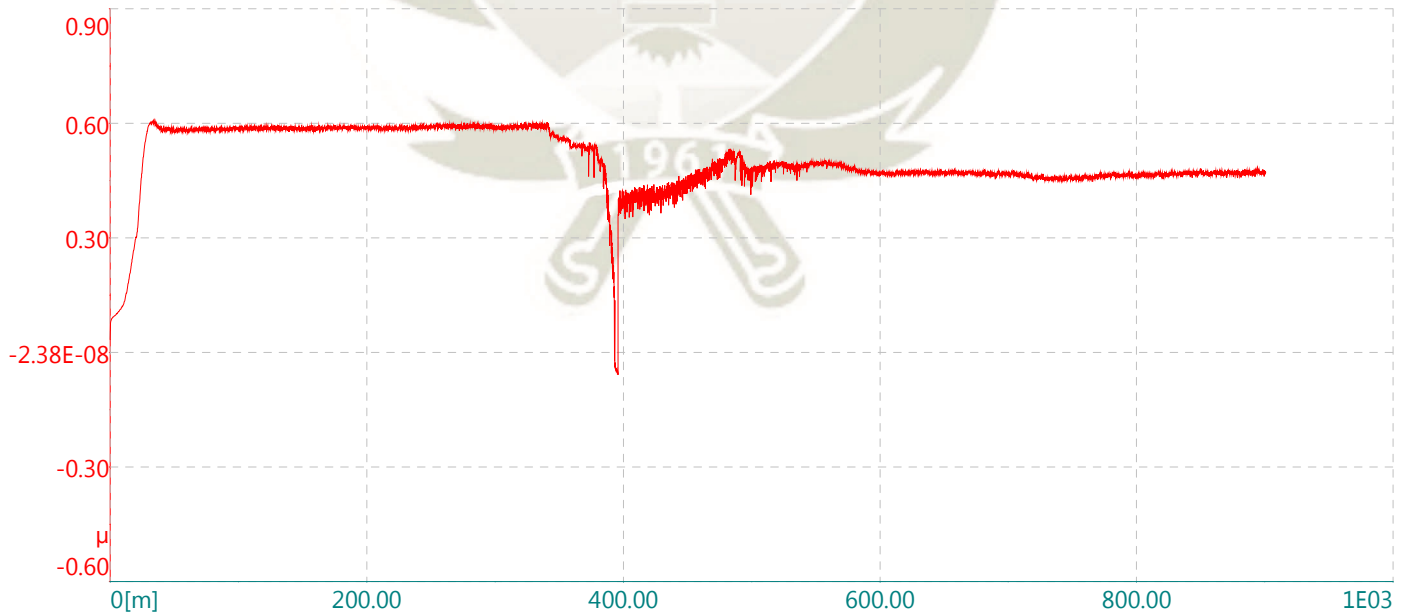
- Temperature: 19.20 [°C]
- Atmosphere: Air
- Humidity: 10.00 [%]

#### Sequence

- Sequence count: 1
- Single-way mode
- Radius: 8.00 [mm]
- Lin. Speed: 25.00 [cm/s]
- Acquisition rate: 5.0 [Hz]
- Cycles sampled: 1/1
- Pause: 0 [s]
- Homing at begin: Yes
- Normal load: 10.00 [N]
- Unload at end: No
- Stop condit.: 905.00 [m]  
Or  $\mu > 0.80$
- Effective Stop: Meters

Sample	Static partner	Calculations
Worn track section: 43630.4 [ $\mu\text{m}^2$ ]	Worn cap diameter: 294.5 [ $\mu\text{m}$ ]	Sample Wear Rate: 0.0002423 [ $\text{mm}^3/\text{N/m}$ ]
Young's Modulus: 4.6 [GPa]	Young's Modulus: 600.0 [GPa]	Partner Wear Rate: 1.361E-008 [ $\text{mm}^3/\text{N/m}$ ]
Poisson ratio: 0.260	Poisson ratio: 0.300	Max Herzian Stress: 0.1715 [GPa]

Start : 0.034    min : -0.059    max : 0.605    mean : 0.502    std. dev. : 0.089



■ Friction coef.



### Modelization B

Analysis : "oz"  
plane : XZ - y=0.00  $\mu\text{m}$

Radius of contact(a) : 210.1395  $\mu\text{m}$   
Maximal stress(pmax) : 0.108 gpa

#### Indenter : WC

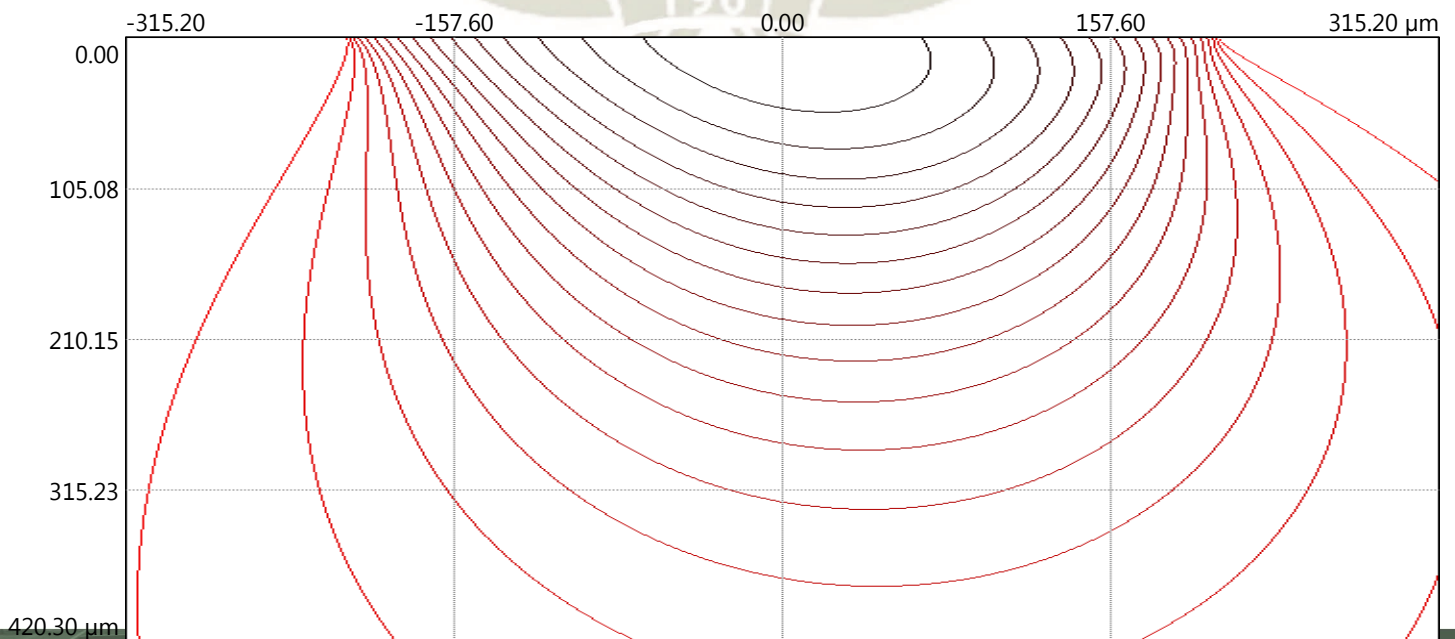
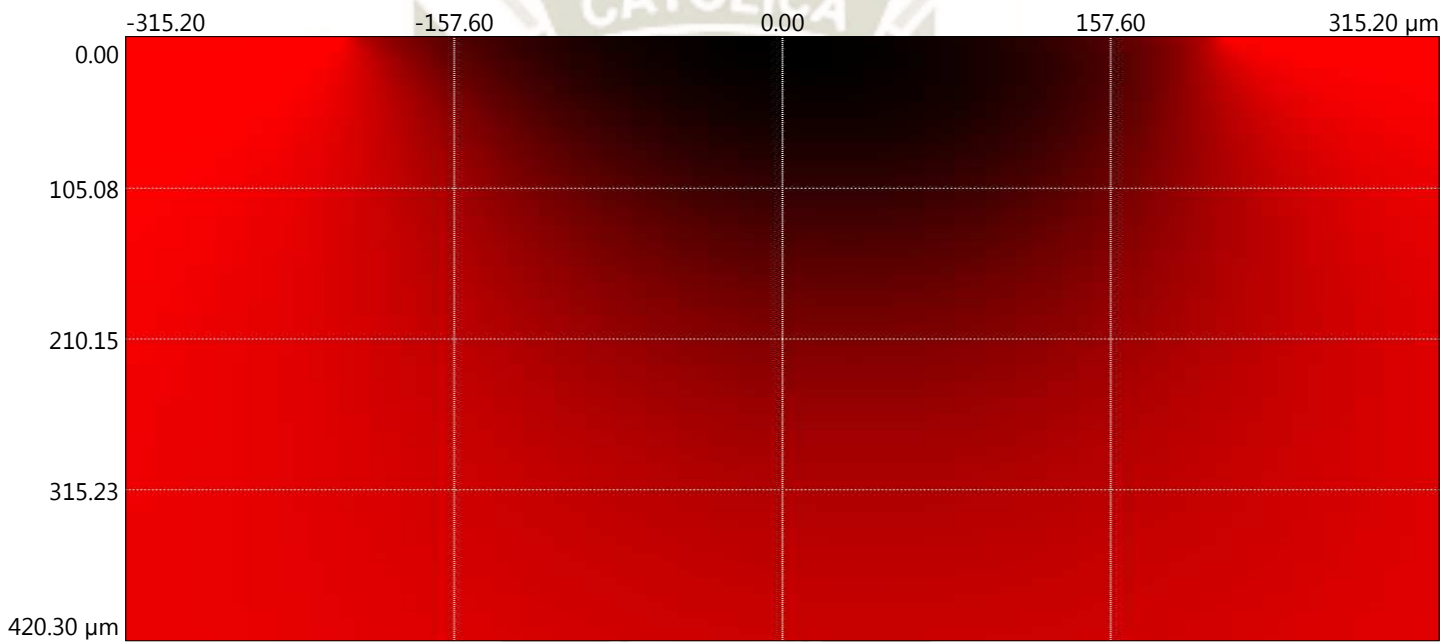
Radius (r) : 6000.00  $\mu\text{m}$   
Young modulus (e) : 600.000 gpa  
Poisson ratio (v) : 0.30

#### Sample : Sold. Exadur-43

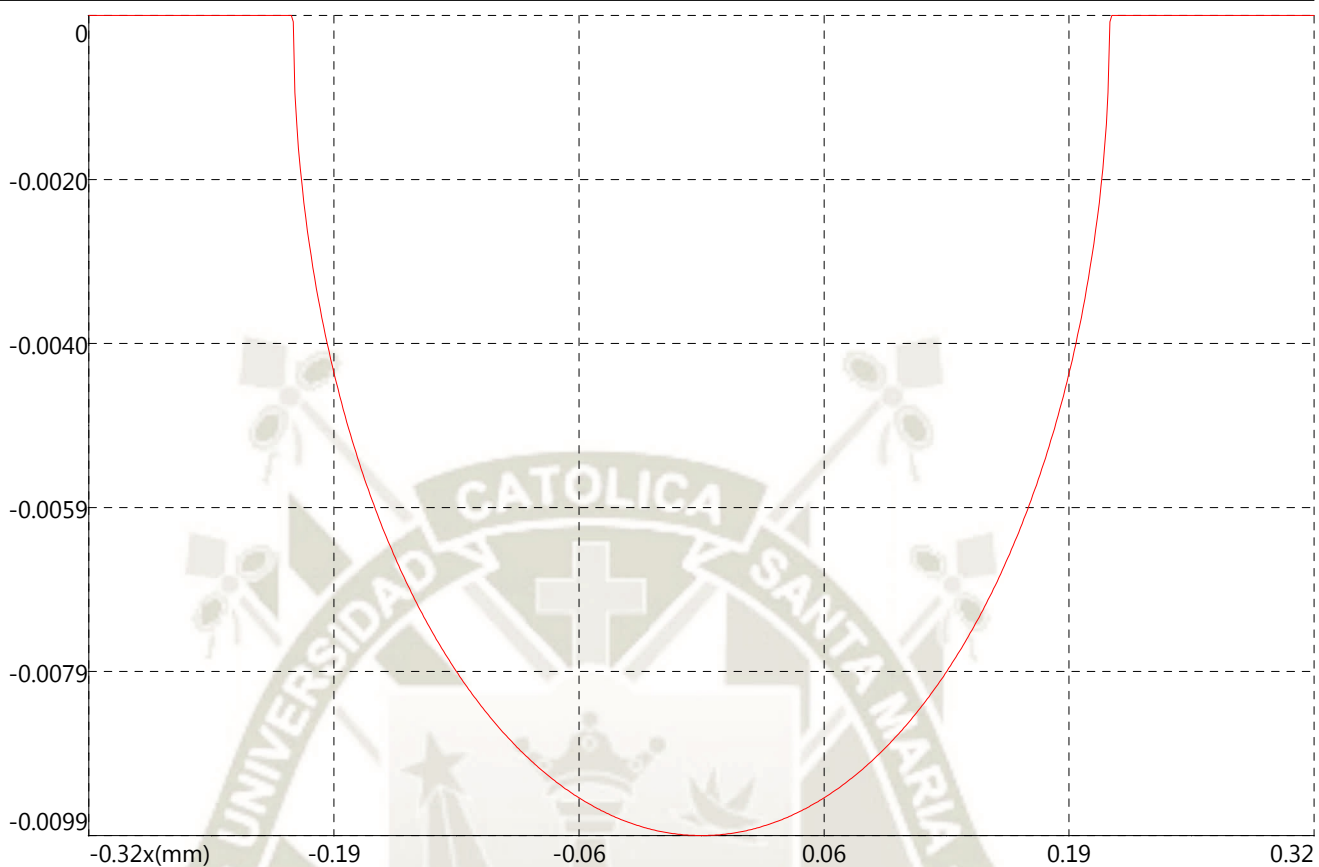
Radius (r) : 100000.00  $\mu\text{m}$   
Young modulus (e) : 4.550 gpa  
Poisson ratio (v) : 0.26

Load : 10000.0 mn friction coefficient ( $\mu$ ) : 0.501

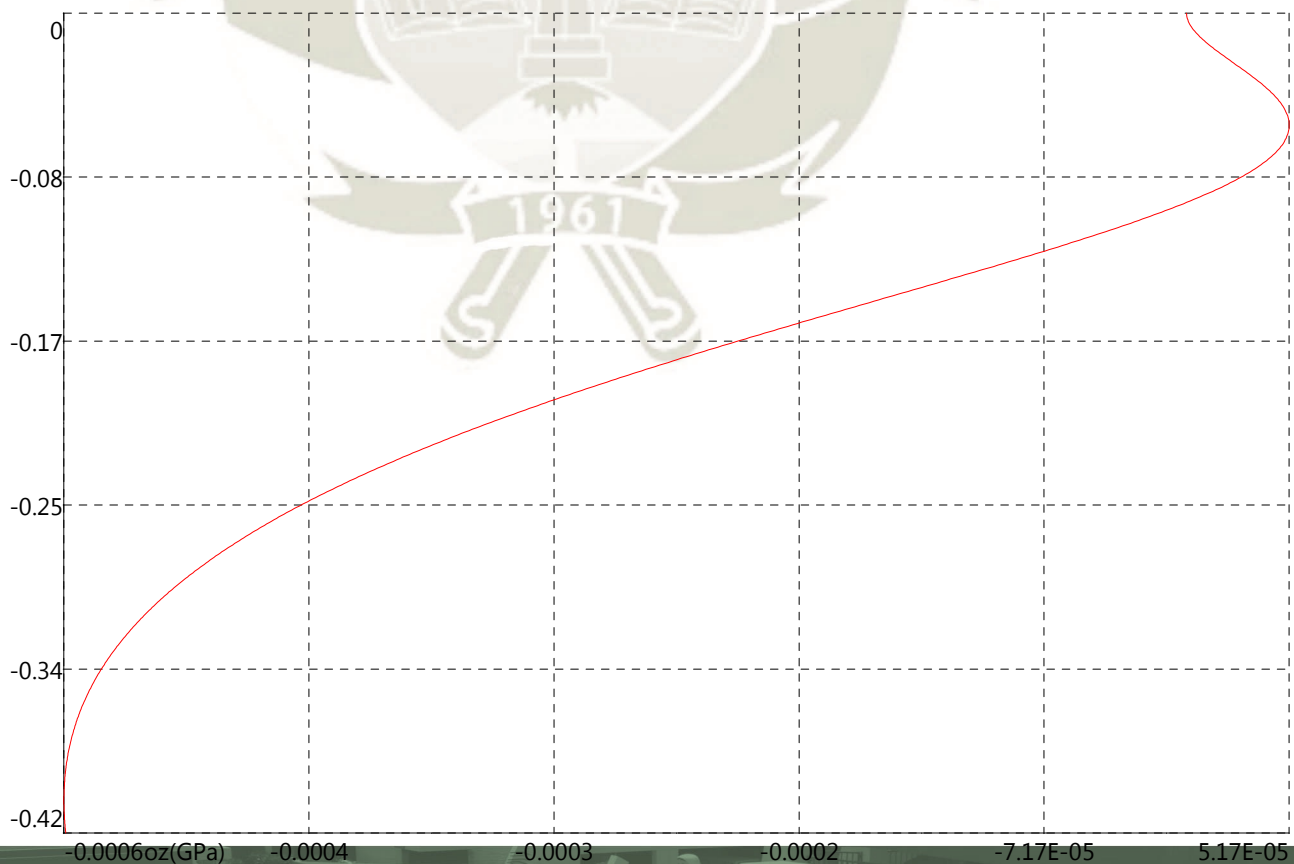
■ -0.0099 gpa ■ 6.3E-005 GPa



oz as a function of x for z=0.000



oz as a function of z for x=-0.315

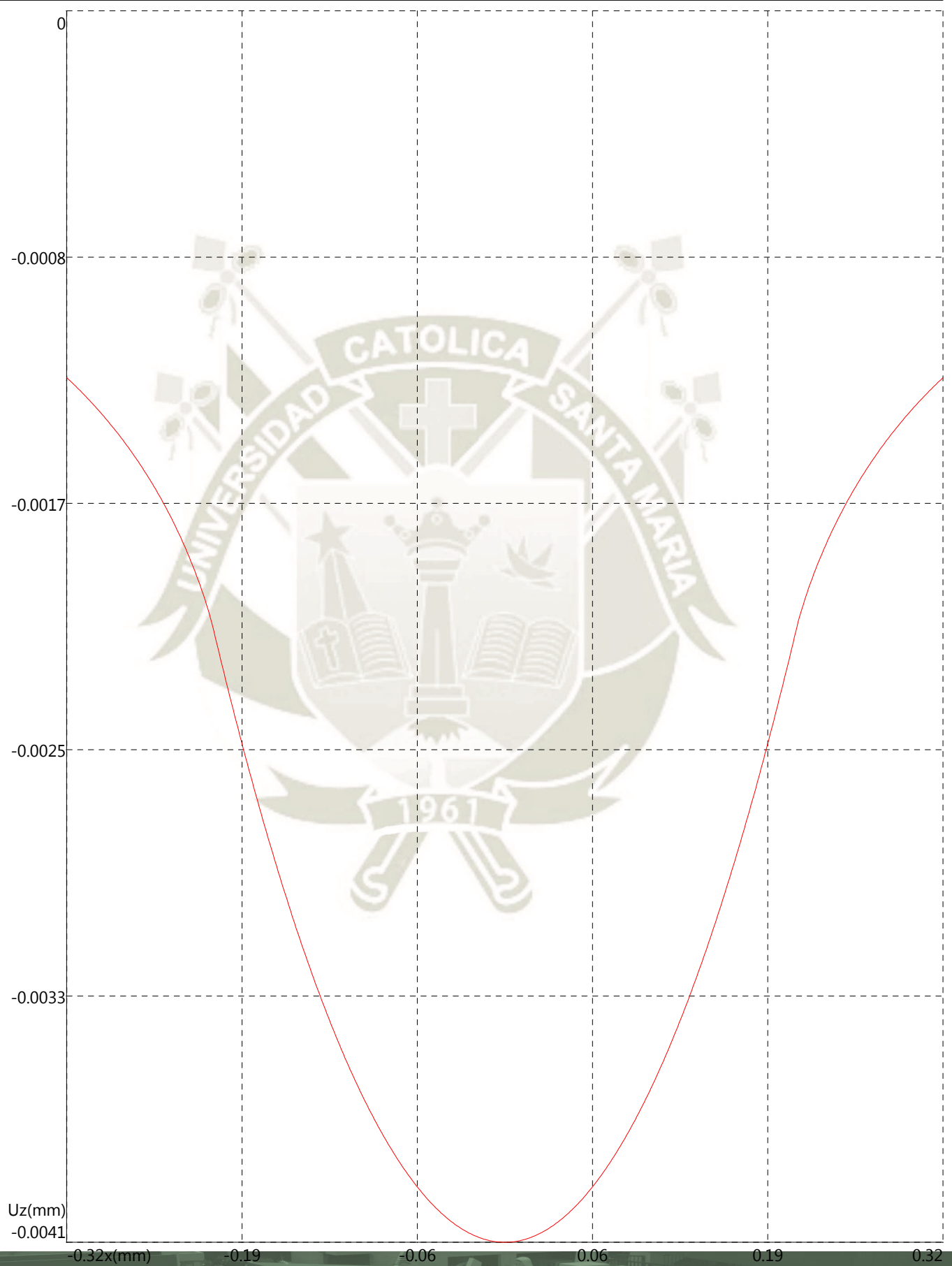


oz as a function of x and z

- oz
- X
- Z



Strain as a function of x



## Muestra B2

### Standard parameters

#### Instrument

- Standard tribometer
- Serial number: 1000059319
- Tribometer / Version 7.3.17
- Date of measurement: 8/1/2019 3:13:30 PM

#### Static partner

- Coating: -
- Substrate: WC
- Dimension: 6.00 [mm]
- Geometry: Ball

#### Sample

- Coating: -
- Substrate: Muestra B2
- Cleaning: -
- Supplier: -

#### Environment

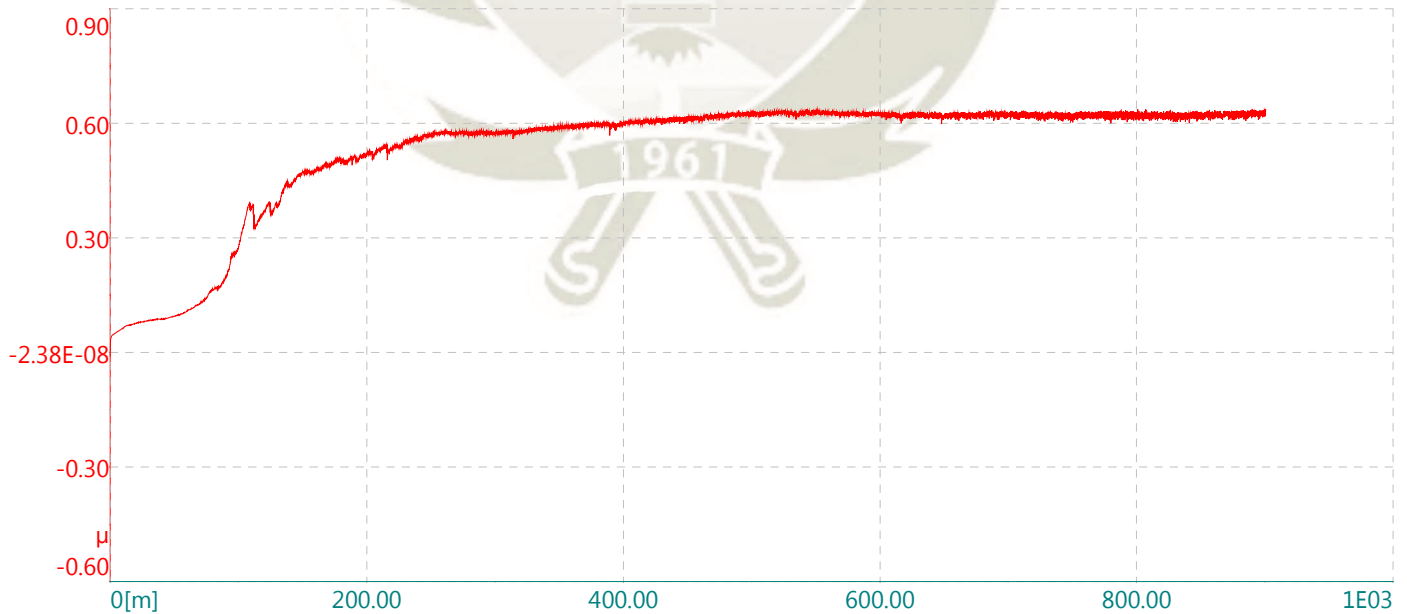
- Temperature: 20.50 [°C]
- Atmosphere: Air
- Humidity: 10.00 [%]

#### Sequence

- Sequence count: 1
- Single-way mode
- Radius: 8.01 [mm]
- Lin. Speed: 25.00 [cm/s]
- Acquisition rate: 5.0 [Hz]
- Cycles sampled: 1/1
- Pause: 0 [s]
- Homing at begin: Yes
- Normal load: 10.00 [N]
- Unload at end: No
- Stop condit.: 905.00 [m]  
Or  $\mu > 0.80$
- Effective Stop: Meters

Sample	Static partner	Calculations
Worn track section: 24821.5 [ $\mu\text{m}^2$ ]	Worn cap diameter: 634.3 [ $\mu\text{m}$ ]	Sample Wear Rate: 0.000138 [ $\text{mm}^3/\text{N}/\text{m}$ ]
Young's Modulus: 4.6 [GPa]	Young's Modulus: 600.0 [GPa]	Partner Wear Rate: 2.937E-007 [ $\text{mm}^3/\text{N}/\text{m}$ ]
Poisson ratio: 0.260	Poisson ratio: 0.300	Max Herzian Stress: 0.1715 [GPa]

Start : -0.010    min : -0.010    max : 0.639    mean : 0.535    std. dev. : 0.160



■ Friction coef.

### Modelization B2

Analysis : "oz"  
plane : XZ - y=0.00  $\mu\text{m}$

Radius of contact(a) : 210.1395  $\mu\text{m}$   
Maximal stress(pmax) : 0.108 gpa

#### Indenter : WC

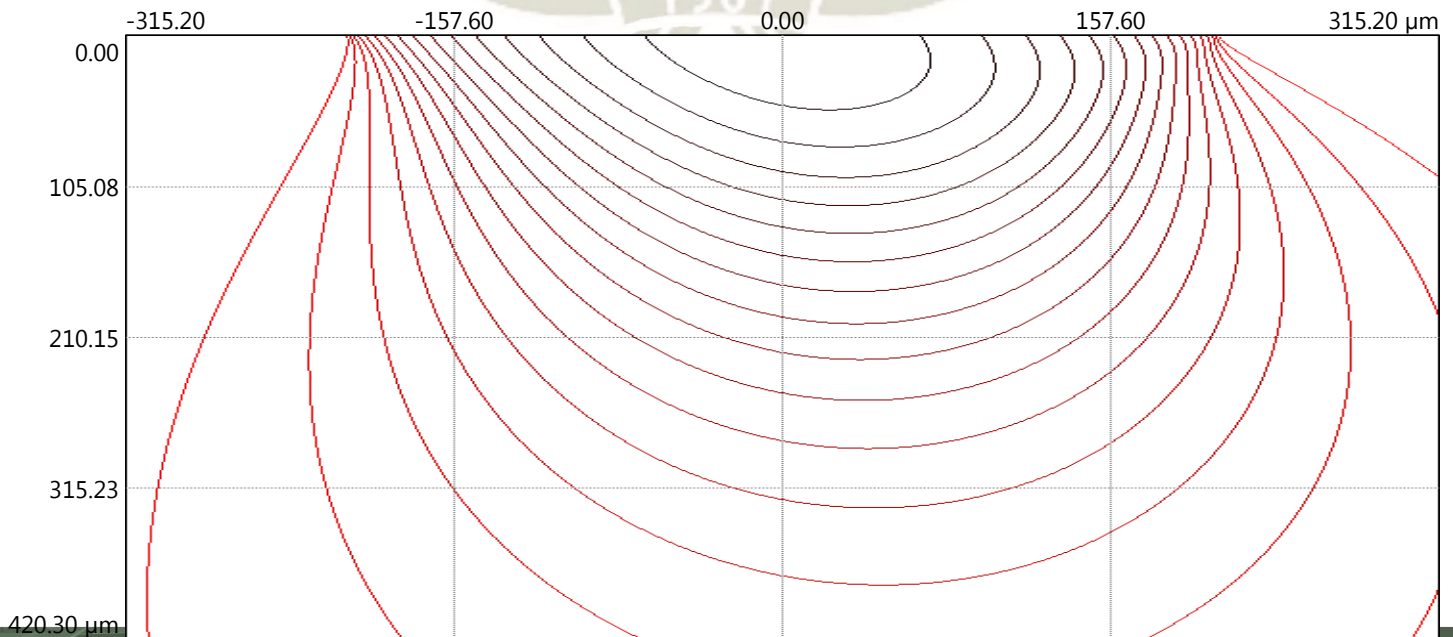
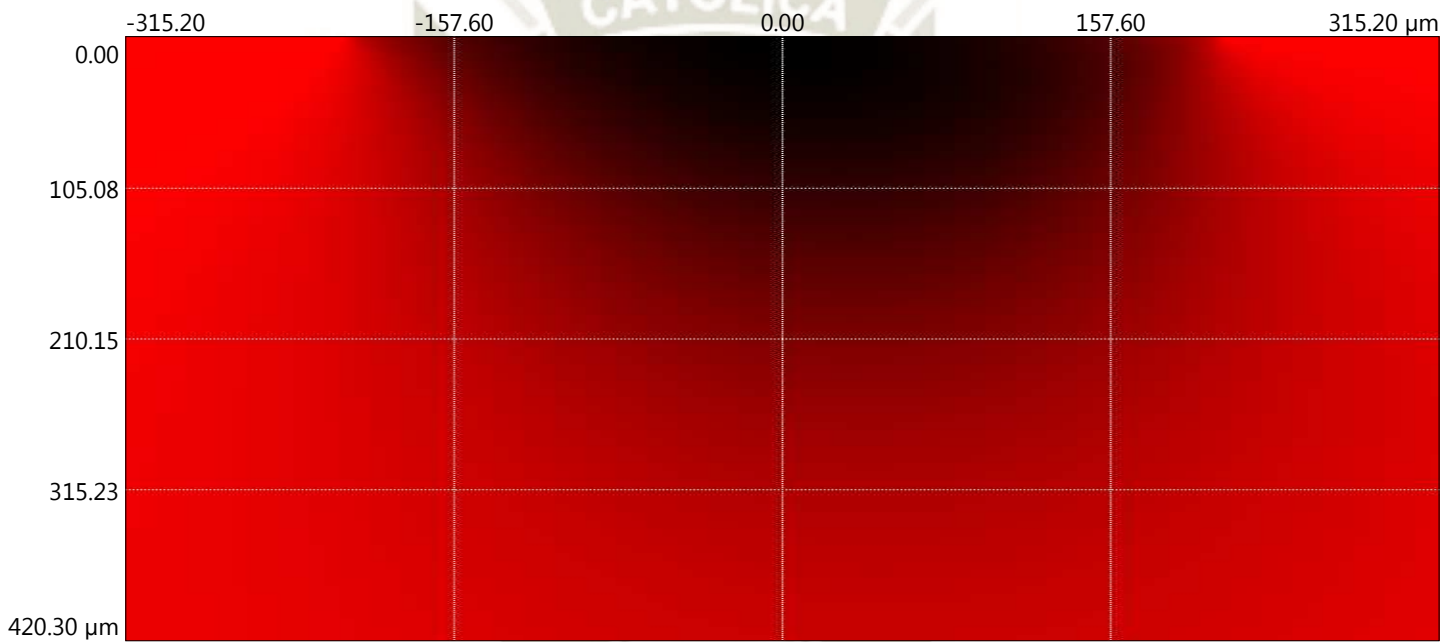
Radius (r) : 6000.00  $\mu\text{m}$   
Young modulus (e) : 600.000 gpa  
Poisson ratio (v) : 0.30

#### Sample : Sold. Exadur-43

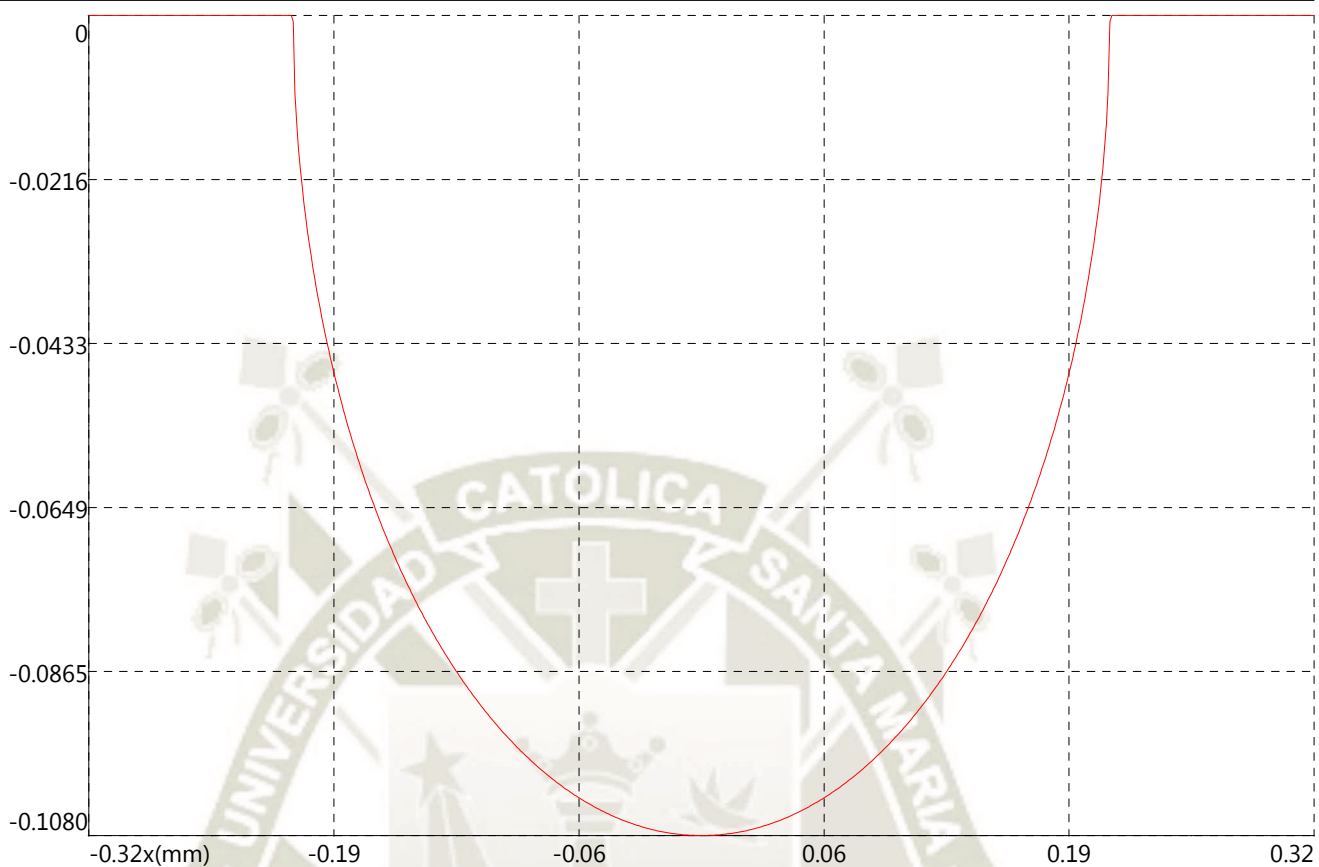
Radius (r) : 100000.00  $\mu\text{m}$   
Young modulus (e) : 4.550 gpa  
Poisson ratio (v) : 0.26

Load : 10000.0 mn friction coefficient ( $\mu$ ) : 0.533

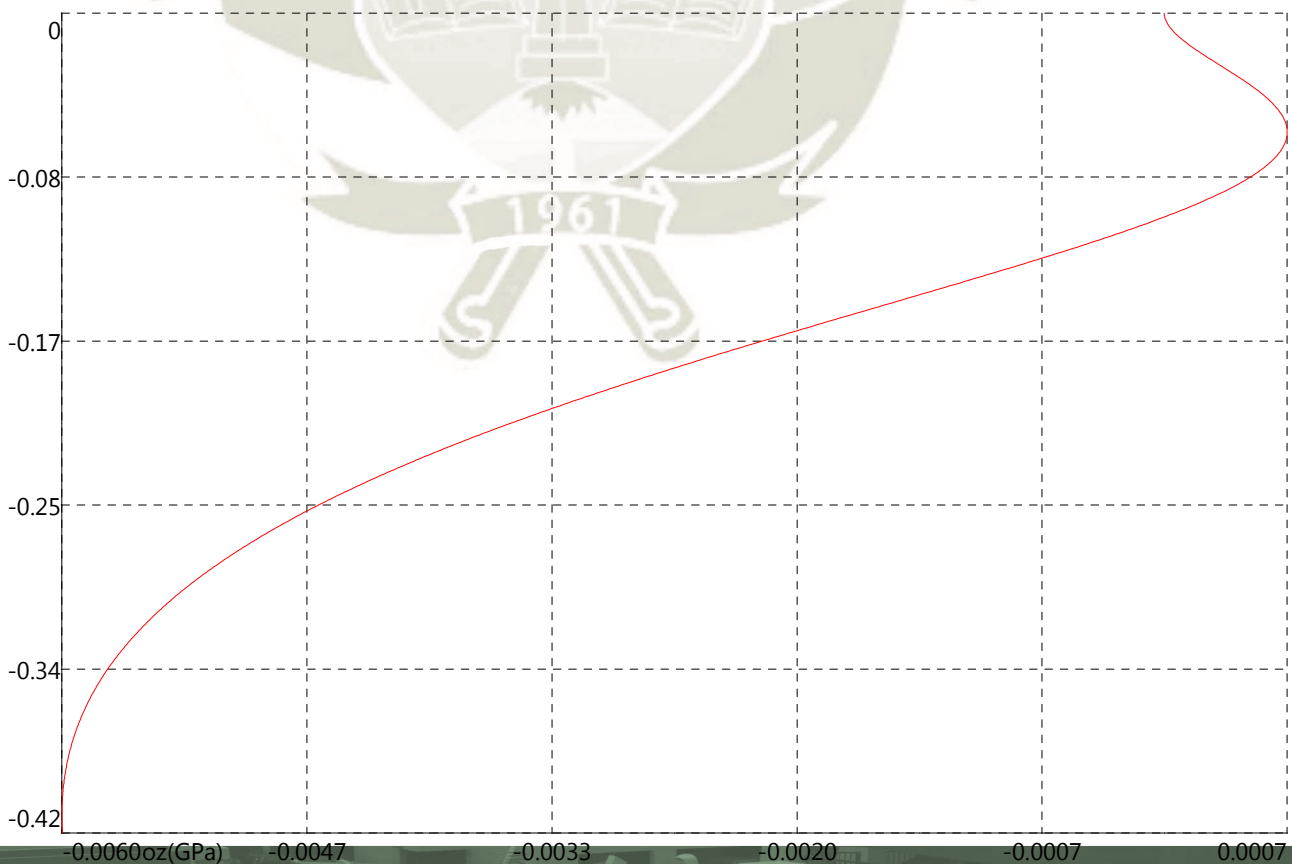
■ -0.108 gpa ■ 0.000817 GPa



oz as a function of x for z=0.000



oz as a function of z for x=-0.315



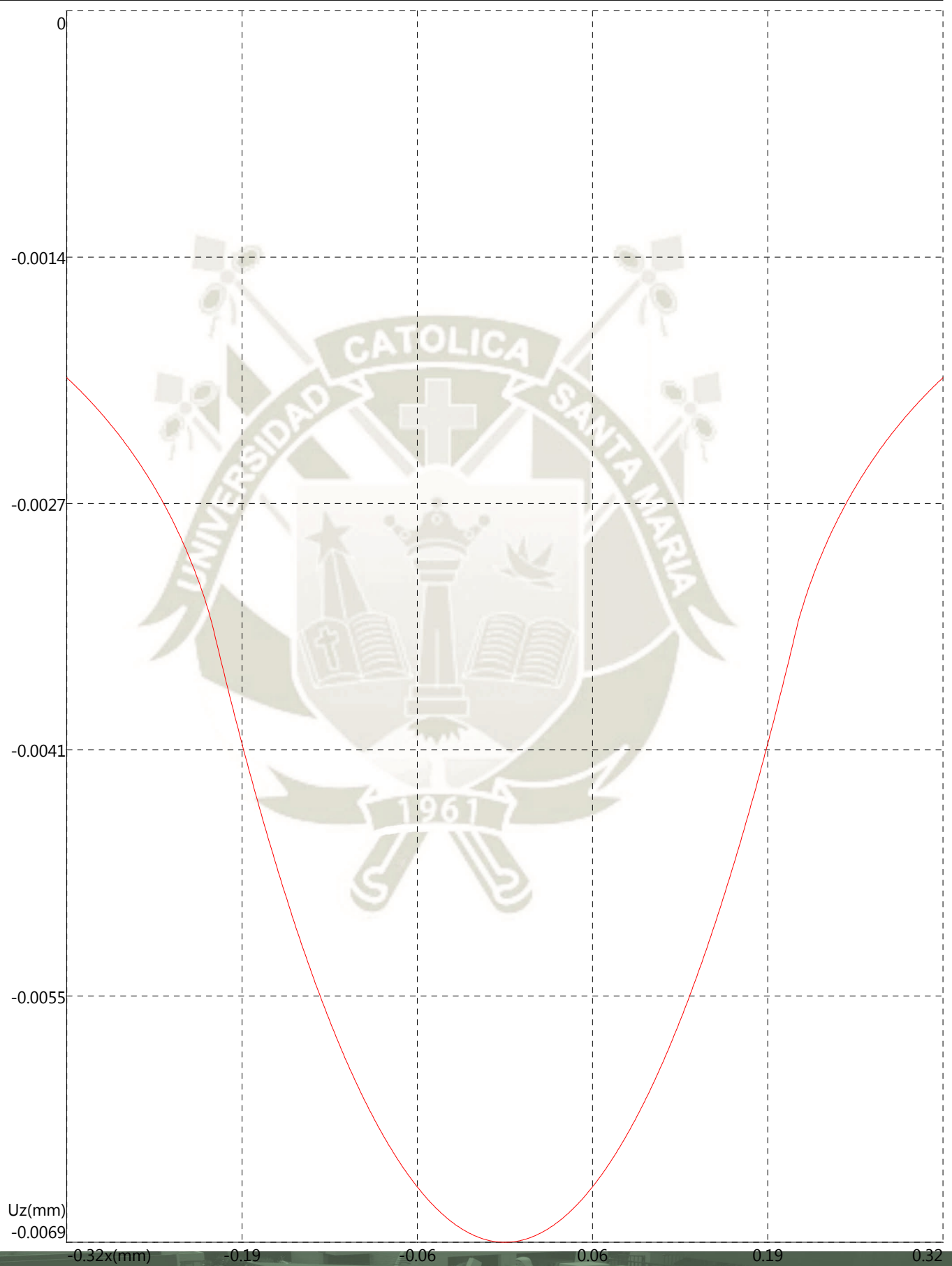
oz as a function of x and z

- oz
- X
- Z





Strain as a function of x



## Muestra C

### Standard parameters

#### Instrument

- Standard tribometer
- Serial number: 1000059319
- Tribometer / Version 7.3.17
- Date of measurement: 8/1/2019 12:33:36 PM

#### Static partner

- Coating: -
- Substrate: WC
- Dimension: 6.00 [mm]
- Geometry: Ball

#### Sample

- Coating: -
- Substrate: Muestra C
- Cleaning: -
- Supplier: -

#### Environment

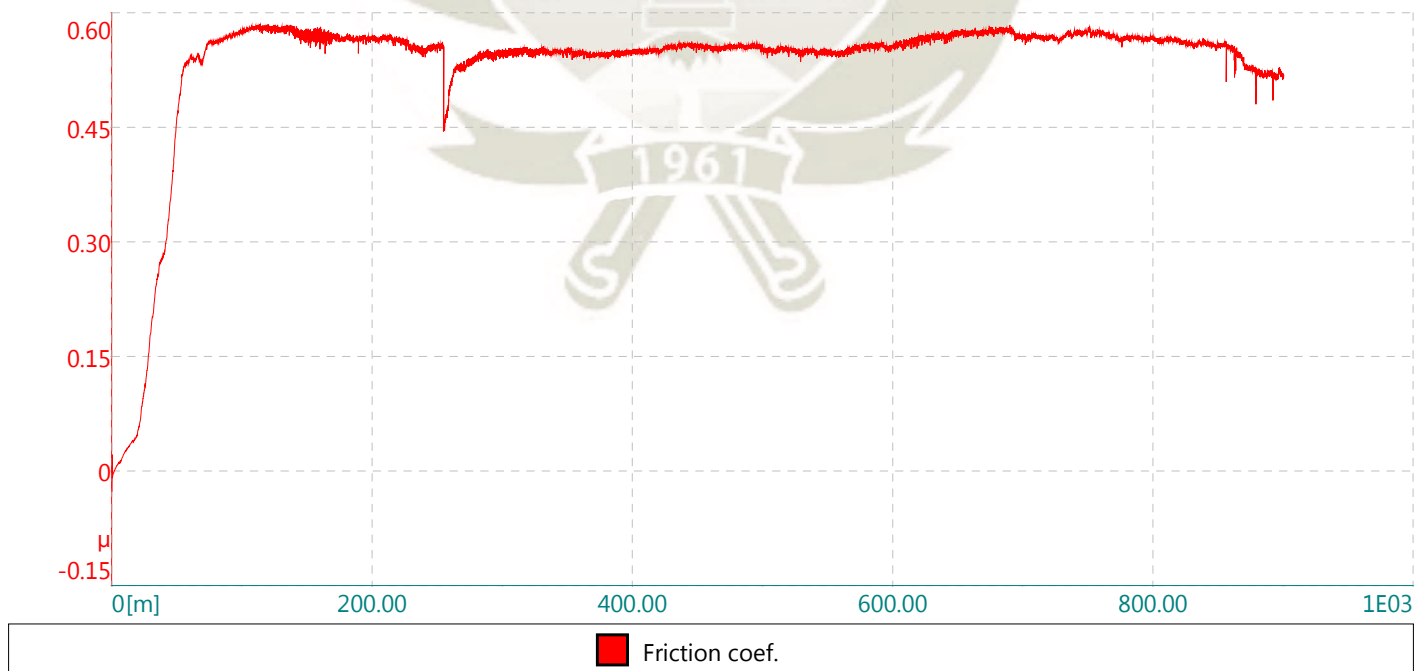
- Temperature: 20.50 [°C]
- Atmosphere: Air
- Humidity: 10.00 [%]

#### Sequence

- Sequence count: 1
- Single-way mode
- Radius: 8.00 [mm]
- Lin. Speed: 25.00 [cm/s]
- Acquisition rate: 5.0 [Hz]
- Cycles sampled: 1/1
- Pause: 0 [s]
- Homing at begin: Yes
- Normal load: 10.00 [N]
- Unload at end: No
- Stop condit.: 905.00 [m]  
Or  $\mu > 0.80$
- Effective Stop: Meters

Sample	Static partner	Calculations
Worn track section: 53006.0 [ $\mu\text{m}^2$ ]	Worn cap diameter: 976.3 [ $\mu\text{m}$ ]	Sample Wear Rate: 0.0002944 [ $\text{mm}^3/\text{N}/\text{m}$ ]
Young's Modulus: 4.1 [GPa]	Young's Modulus: 600.0 [GPa]	Partner Wear Rate: 1.657E-006 [ $\text{mm}^3/\text{N}/\text{m}$ ]
Poisson ratio: 0.220	Poisson ratio: 0.300	Max Herzian Stress: 0.1569 [GPa]

Start : 0.021    min : -0.027    max : 0.585    mean : 0.534    std. dev. : 0.099



## Modelization C

Analysis : "oz"  
plane : XZ - y=0.00  $\mu\text{m}$

Radius of contact(a) : 219.6191  $\mu\text{m}$   
Maximal stress(pmax) : 0.099 gpa

### Indenter : WC

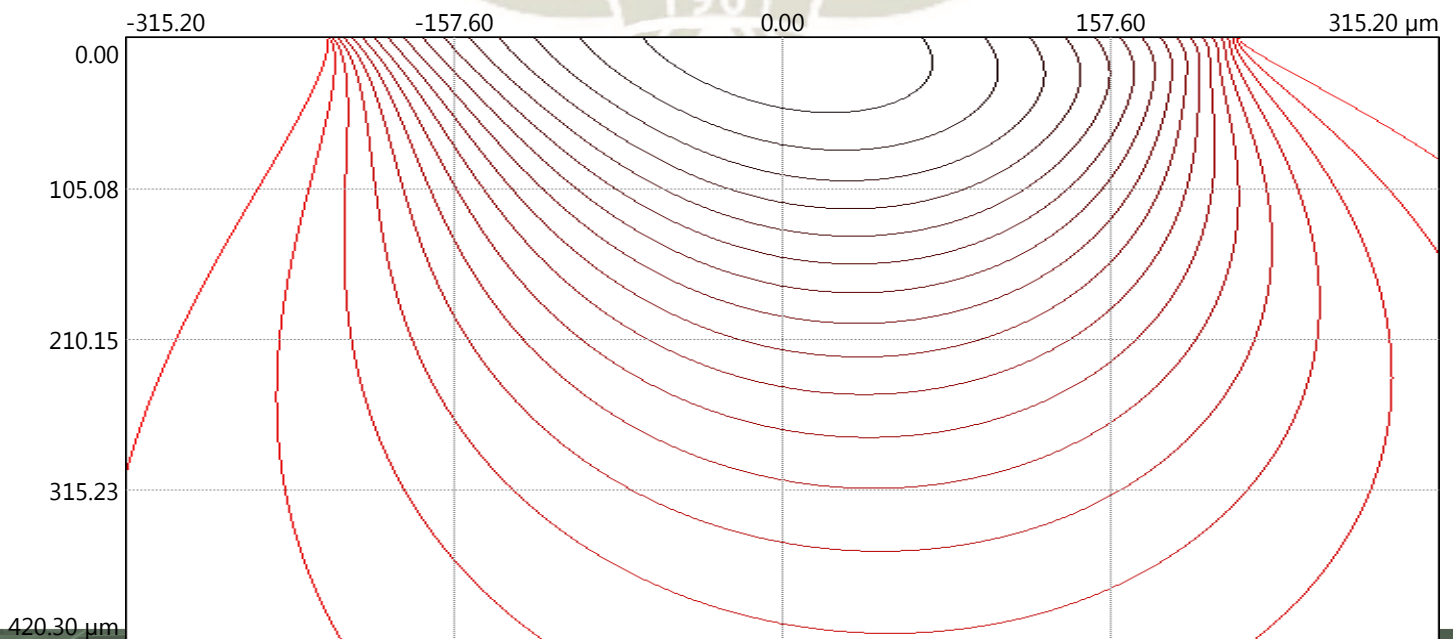
Radius (r) : 6000.00  $\mu\text{m}$   
Young modulus (e) : 600.000 gpa  
Poisson ratio (v) : 0.30

### Sample : Sold. Citodur-1000

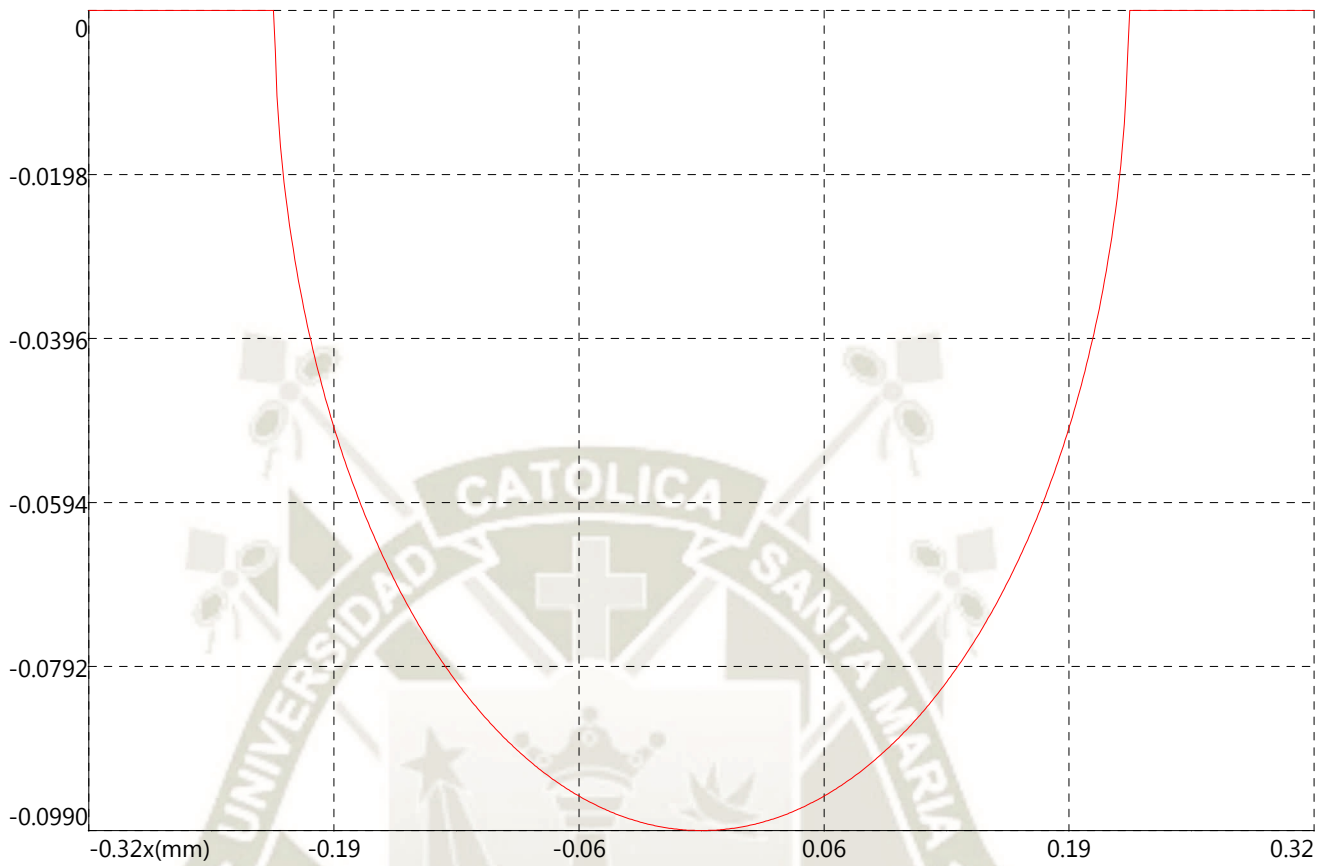
Radius (r) : 100000.00  $\mu\text{m}$   
Young modulus (e) : 4.065 gpa  
Poisson ratio (v) : 0.22

Load : 10000.0 mn friction coefficient ( $\mu$ ) : 0.533

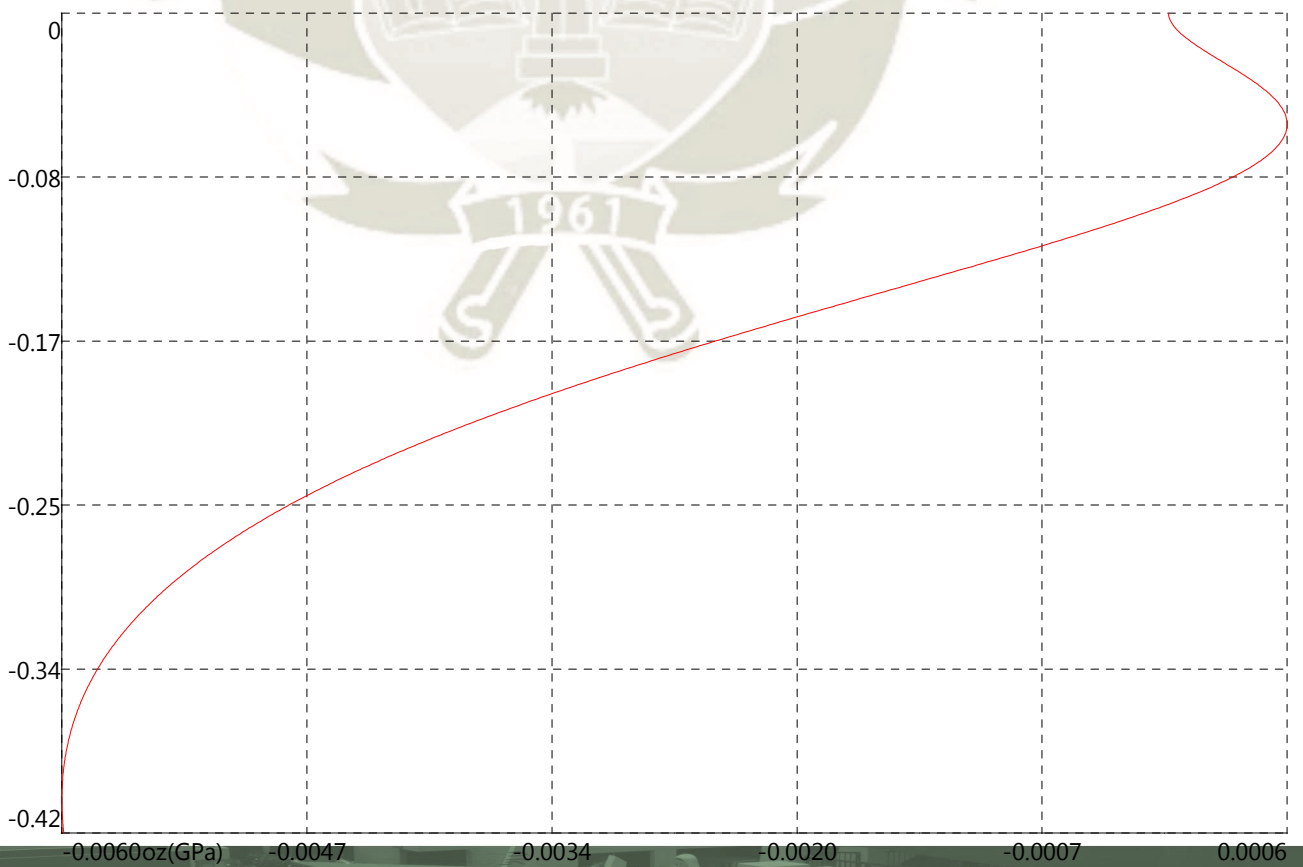
■ -0.099 gpa ■ 0.000748 GPa



oz as a function of x for z=0.000



oz as a function of z for x=-0.315

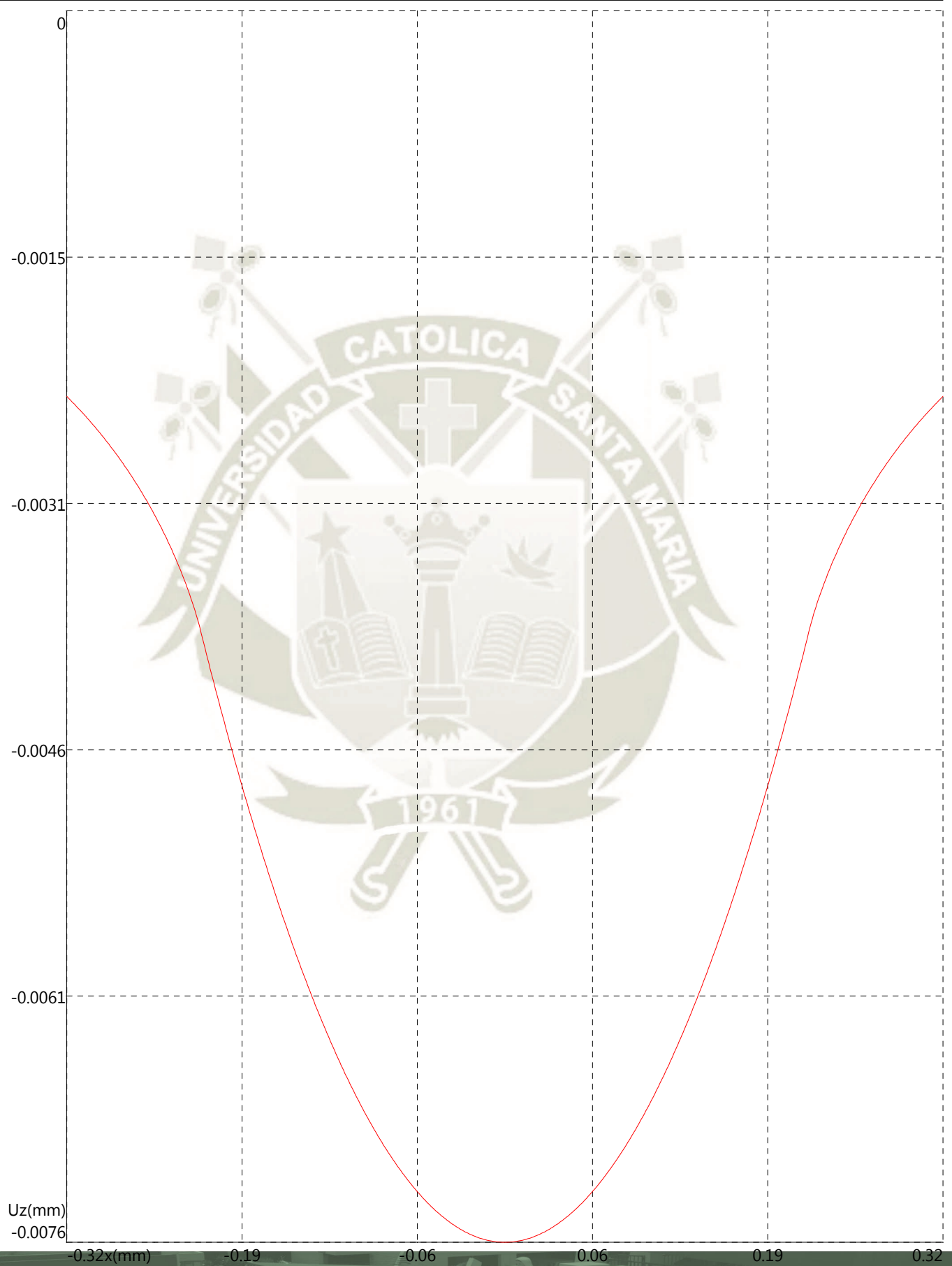


oz as a function of x and z

- oz
- X
- Z



Strain as a function of x



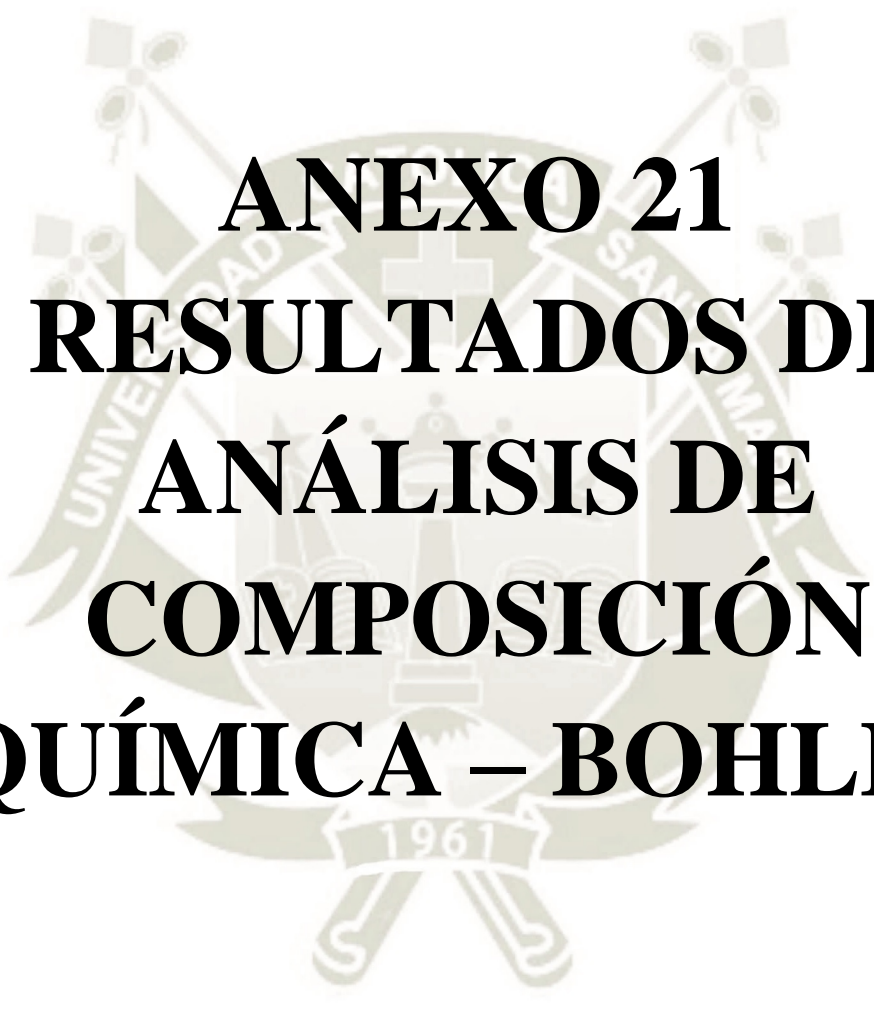
## Summary

Ensayo de desgaste de procesos de soldadura	1
Base 1	1
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oz as a function of z for $x=0.000$	3
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*Rivalino GURMAN ALE*  
ENCARGADO DEL LABORATORIO  
de CARACTERIZACIÓN FUNDACIONAL DE  
MATERIALES - UNSA





**ANEXO 21  
RESULTADOS DE  
ANÁLISIS DE  
COMPOSICIÓN  
QUÍMICA – BOHLER**



voestalpine High Performance Metals del Perú S.A.

**CM-18-086**

Lima, 12 de julio de 2018

**ATENCIÓN:**

SR. RUBEN RODRIGO PURCA JUSTO

**Presente.-**

En representación de la empresa voestalpine High Performance Metals del Perú S.A. (División de Control de Materiales), le hago llegar la presente carta a fin de ampliar las observaciones a la que se ha llegado después de realizar el análisis químico en un componente (*UÑA K-130 EXCAVADORA HIDRAULICA CAT*), el mismo que ha sido detallado mediante el **Informe Técnico CERT-DCM-2018-086**.

El componente analizado químicamente, hace referencia a un **acero de mediano carbono y baja aleación (Manganeso – Cromo – Molibdeno)**, similar químicamente con la designación **DIN 32MnCrMo 6-4-3 (Wnr° 1.7910)** según "Llave del Acero" (Stahlschlüssel), versión 2013.

Se adjunta informe de laboratorio y registro fotográfico.

Sin otro particular le envío un cordial saludo.

Atentamente,

voestalpine High Performance Metals del Perú S.A.



Tec. Pedro S. Guevara Solís  
Jefe de Control de Materiales

Of. Principal: Calle Luis Castro Rancero 777 Lima 01 - Perú  
Ventas: 619-3232 / Administración: 619-3250 / Tratamientos Térmicos: 619-3240  
Asesoría: 619-3251 / Soldaduras: 619-3248 / Control de Materiales: 619-3252  
Sucursal ATE: Av. Nicolás Ayllón 2158 Zona Industrial Santa Lucía - A te / 619-3247  
Sucursal LOS OLIVOS: Av. Carlos Izaguirre 1347 - Los Olivos / 619-3231  
Sucursal AREQUIPA: Calle Angamos 204 Urb. María Isabel - Arequipa / (051) 28-2884  
www.bohlerperu.com / E-mail: ventas@bohlerperu.com  
Representantes en: HUANCAYO - PIURA

voestalpine

ONE STEP AHEAD.

Pág. 1 de 1



voestalpine High Performance Metals del Perú S.A.

CERT – DCM-2018/086

**ANÁLISIS QUÍMICO**  
**INFORME DE LABORATORIO**

**SOLICITADO POR** : SR. RUBEN RODRIGO PURCA JUSTO  
**COMPONENTE** : UÑA K-130 EXCAVADORA HIDRAULICA CAT  
**ZONA ANALIZADA** : SUPERFICIE ACONDICIONADA  
**REALIZADO POR** : ANALISTA 1 / ANALISTA 2  
**FECHA DE EMISIÓN** : 11 DE JULIO DE 2018

**RESULTADOS:**

ELEMENTO QUÍMICO	CANTIDAD (%)
Carbono (C)	0,27
Silicio (Si)	1,31
Manganeso (Mn)	1,28
Fósforo (P)	0,035
Azufre (S)	0,034
Cromo (Cr)	1,42
Molibdeno (Mo)	0,27
Níquel (Ni)	0,05
Aluminio (Al)	0,03
Cobre (Cu)	0,02
Titanio (Ti)	0,007
Niobio (Nb)	0,01
Vanadio (V)	0,02
Boro (B)	0,003
Hierro (Fe)	95,1

**OBSERVACIONES:**

- ❖ Método utilizado: Espectrometría de emisión óptica (Arco / Chispa).
- ❖ Marca del Equipo: SPECTRO - Alemán.
- ❖ El **SR. RUBEN RODRIGO PURCA JUSTO**; proporcionó el componente.
- ❖ La evaluación se realizó en el Laboratorio de Control de Materiales.
- ❖ Fecha de evaluación: 10 de julio de 2018.
- ❖ Temperatura Ambiente: 21° C.
- ❖ Ver registro Fotográfico en la página siguiente para identificación de la zona evaluada.

voestalpine High Performance Metals del Perú S.A.

  
**Tec. Pedro S. Guevara Solís**  
Jefe de Control de Materiales

Of. Principal: Calle Luis Castro Rancero 777 Lima 01 - Perú  
Ventas: 619-3232 / Administración: 619-3250 / Tratamientos Térmicos: 619-3250  
Asesoría: 619-3251 / Soldaduras: 619-3248 / Control de Materiales: 619-3252  
Sucursal ATE: Av. Nicolás Ayllón 2158 Zona Industrial Santa Lucía - Ate / 619-3247  
Sucursal LOS OLIVOS: Av. Carlos Izaguirre 1347 - Los Olivos / 619-3231  
Sucursal AREQUIPA: Calle Angamas 204 Urb. María Isabel - Arequipa / (051) 28-2884  
www.boehlerperu.com / E-mail: ventas@boehlerperu.com  
Representantes en: HUANCAYO - PIURA

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ONE STEP AHEAD.

voestalpine High Performance Metals del Perú S.A.



REGISTRO FOTOGRAFICO

ZONA DE ENSAYO  
ANÁLISIS QUÍMICO



*UÑA K-130 EXCAVADORA HIDRAULICA CAT*



Of. Principal: Calle Luis Castro Roncero 777 Lima 01 - Perú  
Ventas: 619-3232 / Administración: 619-3250 / Tratamientos Térmicos: 619-3240  
Asesoría: 619-3251 / Soldaduras: 619-3248 / Control de Materiales: 619-3252  
Sucursal ATE: Av. Nicolás Ayllón 2158 Zona Industrial Santa Lucía - A te / 619-3247  
Sucursal LOS OLIVOS: Av. Carlos Izaguirre 1347 - Los Olivos / 619-3231  
Sucursal AREQUIPA: Calle Angamos 204 Urb. María Isabel - Arequipa / (051) 28-2884  
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Representantes en: HUANCAYO - PIURA

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ONE STEP AHEAD.

Pág. 2 de 2

voestalpine High Performance Metals del Perú S.A.

**CM-18-169-P1**

Lima, 28 de diciembre de 2018

**SR.**

RUBEN RODRIGO PURCA JUSTO.

**Presente.-**

En representación de la empresa voestalpine High Performance Metals del Perú S.A. (División de Control de Materiales), le hago llegar la presente carta a fin de ampliar las observaciones a la que se ha llegado después de realizar el análisis químico en un componente (**MATERIAL DE APORTE – CÓDIGO: P-1 E-43**) el mismo que ha sido detallado mediante el **Informe Técnico CERT-DCM-2018-169-P1**.

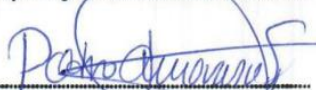
La zona analizada químicamente, hace referencia a un **material de alto carbono y alta aleación (Cromo – Niobio)**, similar químicamente con la designación **EXADUR 43**.

Se adjunta informe de laboratorio y registro fotográfico.

Sin otro particular le envío un cordial saludo.

Atentamente,

voestalpine High Performance Metals del Perú S.A.



**Tec. Pedro S. Guevara Solís**  
Jefe de Control de Materiales

voestalpine High Performance Metals del Perú S.A.



CERT – DCM-2018/169-P1

**ANÁLISIS QUÍMICO**  
**INFORME DE LABORATORIO**

**SOLICITADO POR** : SR. RUBEN RODRIGO PURCA JUSTO.  
**COMPONENTE** : MUESTRA METALICA.  
**CÓDIGO** : P-1 E-43.  
**ZONA ANALIZADA** : MATERIAL DE APORTE (SOLDADURA).  
**REALIZADO POR** : ANALISTA 1 / ANALISTA 4.  
**FECHA DE EMISIÓN** : 28 DE DICIEMBRE DE 2018.

**RESULTADOS:**

ELEMENTO QUÍMICO	CANTIDAD (%)
Carbono (C)	3,96
Silicio (Si)	1,59
Manganeso (Mn)	1,24
Fósforo (P)	0,028
Azufre (S)	0,013
Cromo (Cr)	20,30
Molibdeno (Mo)	0,10
Níquel (Ni)	0,15
Aluminio (Al)	0,05
Cobre (Cu)	0,07
Titanio (Ti)	0,08
Niobio (Nb)	~4,20
Vanadio (V)	0,04
Boro (B)	0,0005
Hierro (Fe)	67,8

**OBSERVACIONES:**

- ❖ Método utilizado: Espectrometría de emisión óptica (Arco / Chispa).
- ❖ Marca del Equipo: SPECTRO - Alemán.
- ❖ El cliente **SR. RUBEN RODRIGO PURCA JUSTO** proporcionó el componente.
- ❖ La evaluación se realizó en el Laboratorio de Control de Materiales.
- ❖ Fecha de evaluación: 27 de diciembre de 2018.
- ❖ Temperatura Ambiente: 22,5° C.
- ❖ Ver en la página siguiente el registro fotográfico de la zona analizada.

voestalpine High Performance Metals del Perú S.A.  
REGISTRO FOTOGRÁFICO

ZONA ANALIZADA



**CÓDIGO P-1 E-43.**  
**MATERIAL DE APORTE (SOLDADURA).**



voestalpine High Performance Metals del Perú S.A.

**CM-18-169-P2**

Lima, 28 de diciembre de 2018

**SR.**

RUBEN RODRIGO PURCA JUSTO.

**Presente.-**

En representación de la empresa voestalpine High Performance Metals del Perú S.A. (División de Control de Materiales), le hago llegar la presente carta a fin de ampliar las observaciones a la que se ha llegado después de realizar el análisis químico en un componente (*MATERIAL DE APORTE – CÓDIGO: P-2 CTMG.*) el mismo que ha sido detallado mediante el **Informe Técnico CERT-DCM-2018-169-P2.**

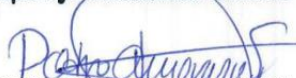
La zona analizada químicamente, hace referencia a un **material de alto carbono y alta aleación (Manganeso)**, similar químicamente con la designación **CITOMANGAN.**

Se adjunta informe de laboratorio y registro fotográfico.

Sin otro particular le envío un cordial saludo.

Atentamente,

voestalpine High Performance Metals del Perú S.A.



**Tec. Pedro S. Guevara Solís**  
Jefe de Control de Materiales



voestalpine High Performance Metals del Perú S.A.  
CERT – DCM-2018/169-P2



**ANÁLISIS QUÍMICO**  
**INFORME DE LABORATORIO**

**SOLICITADO POR** : SR. RUBEN RODRIGO PURCA JUSTO.  
**COMPONENTES** : MUESTRA METALICA.  
**CÓDIGO** : P-2 CTM6.  
**ZONA ANALIZADA** : MATERIAL DE APORTE (SOLDADURA).  
**REALIZADO POR** : ANALISTA 1 / ANALISTA 4.  
**FECHA DE EMISIÓN** : 28 DE DICIEMBRE DE 2018.

**RESULTADOS:**

ELEMENTO QUÍMICO	CANTIDAD (%)
Carbono (C)	0,82
Silicio (Si)	0,72
Manganeso (Mn)	11,98
Fósforo (P)	0,042
Azufre (S)	0,017
Cromo (Cr)	0,48
Molibdeno (Mo)	0,10
Níquel (Ni)	0,06
Aluminio (Al)	0,02
Cobre (Cu)	0,09
Titanio (Ti)	0,02
Niobio (Nb)	0,01
Vanadio (V)	0,01
Boro (B)	0,004
Hierro (Fe)	85,3

**OBSERVACIONES:**

- ❖ Método utilizado: Espectrometría de emisión óptica (Arco / Chispa).
- ❖ Marca del Equipo: SPECTRO - Alemán.
- ❖ El cliente **SR. RUBEN RODRIGO PURCA JUSTO** proporcionó el componente.
- ❖ La evaluación se realizó en el Laboratorio de Control de Materiales.
- ❖ Fecha de evaluación: 27 de diciembre de 2018.
- ❖ Temperatura Ambiente: 22,5° C.
- ❖ Ver en la página siguiente el registro fotográfico de la zona analizada.

voestalpine High Performance Metals del Perú S.A.

## REGISTRO FOTOGRÁFICO



ZONA ANALIZADA

**CÓDIGO P-2 CTMG**  
**MATERIAL DE APORTE (SOLDADURA).**

voestalpine High Performance Metals del Perú S.A.

**CM-18-169-P3**

Lima, 28 de diciembre de 2018

**SR.**

RUBEN RODRIGO PURCA JUSTO.

**Presente.-**

En representación de la empresa voestalpine High Performance Metals del Perú S.A. (División de Control de Materiales), le hago llegar la presente carta a fin de ampliar las observaciones a la que se ha llegado después de realizar el análisis químico en un componente (*MATERIAL DE APORTE – CÓDIGO: P-3 C-1000.*) el mismo que ha sido detallado mediante el **Informe Técnico CERT-DCM-2018-169-P3.**


La zona analizada químicamente, hace referencia a un **material de alto carbono y alta aleación (Cromo)**, similar químicamente con la designación **CITODUR 1000.**

Se adjunta informe de laboratorio y registro fotográfico.

Sin otro particular le envío un cordial saludo.

Atentamente,

voestalpine High Performance Metals del Perú S.A.



Tec. Pedro S. Guevara Solís  
Jefe de Control de Materiales

voestalpine High Performance Metals del Perú S.A.  
CERT – DCM-2018/169-P3



**ANÁLISIS QUÍMICO**  
**INFORME DE LABORATORIO**

**SOLICITADO POR** : SR. RUBEN RODRIGO PURCA JUSTO.  
**COMPONENTES** : MUESTRA METALICA.  
**CÓDIGO** : P-3 C-100.  
**ZONA ANALIZADA** : MATERIAL DE APORTE (SOLDADURA).  
**REALIZADO POR** : ANALISTA 1 / ANALISTA 4.  
**FECHA DE EMISIÓN** : 28 DE DICIEMBRE DE 2018.

**RESULTADOS:**

ELEMENTO QUÍMICO	CANTIDAD (%)
Carbono (C)	3,60
Silicio (Si)	1,13
Manganeso (Mn)	1,10
Fósforo (P)	0,014
Azufre (S)	0,003
Cromo (Cr)	31,57
Molibdeno (Mo)	0,10
Níquel (Ni)	0,06
Aluminio (Al)	0,05
Cobre (Cu)	0,04
Titanio (Ti)	0,16
Niobio (Nb)	0,10
Vanadio (V)	0,02
Boro (B)	<0,0005
Hierro (Fe)	61,6

**OBSERVACIONES:**

- ❖ Método utilizado: Espectrometría de emisión óptica (Arco / Chispa).
- ❖ Marca del Equipo: SPECTRO - Alemán.
- ❖ El cliente **SR. RUBEN RODRIGO PURCA JUSTO** proporcionó el componente.
- ❖ La evaluación se realizó en el Laboratorio de Control de Materiales.
- ❖ Fecha de evaluación: 27 de diciembre de 2018.
- ❖ Temperatura Ambiente: 22,5° C.
- ❖ Ver en la página siguiente el registro fotográfico de la zona analizada.

voestalpine High Performance Metals del Perú S.A.

## REGISTRO FOTOGRÁFICO



***CÓDIGO P-3 C-1000.  
MATERIAL DE APORTE (SOLDADURA).***



# **ANEXO 22**

# **COSTO DE GETS**

# **TRACTO PARTES**

**EQUIPOS ATENUZ SA**

RUC: 20371463586

DIRECCION FISCAL: AV. MARISCAL BENAVIDES NRO. 615 URB. SELVA ALEGRE

Teléfono +5154 223866

Fecha de impresión: 20/12/2017

Proyecto: BARRICK-LAG.NORTE

Motivo compra:

REQUERIMIENTOS Y AUTORIZACIONES	Requerimiento	Fecha	Requerido por	Aprobado por
	1712000062	18/12/2017	MANTENIMIENTO AREQUIPA	dguzman

**Proveedor:** RG TRACTO PARTS S.A.C.

**Dirección:** MZA. E LOTE. 12 URB. POPULAR COOPERATIVA DE VIVIENDA BATASOL LTDA (COOP. BATASOL CARRETERA CENTRAL) -LURIGANCHO-LIMA LIMA

**RUC:** 20565496761

**Contacto:**

**e-mail:**

**Fecha emisión:** 20/12/2017

**Moneda:** Dolar Americano

**N° Cotización:**

**Condición pago:** Contado

**Contrato**

**Del**

**Al**

Cod. SAP	N° Parte	Descripción	Cantidad UM	Fecha de entrega	P.U. US\$	%Dcto	Valor total US\$
170ED00042	220-9133	PUNTA DE PENETRACION K130	20.00 UND	20/12/2017	91.00	0.00	1,820.00
Equipo: 47018079 - EXCAVADORA - EXC - 076 Placa/N° serie: BARRICK-LAGUNAS NORTE, STOCK DE EDD, CAMBIO DE UÑAS K130							

**DEBE CONSIGNAR EL NÚMERO DE ORDEN DE COMPRA EN SU FACTURA Y/O GUIA DE REMISIÓN**

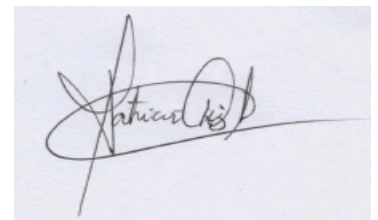
<b>SUB TOTAL</b>	US\$ 1,820.00
<b>Impuesto</b>	US\$ 327.60
<b>TOTAL</b>	US\$ 2,147.60



Marco Antonio Manzaneda Rojas  
COORDINADOR LOGISTICA  
EQUIPOS ATENUZ S.A.

Coordinador Logístico

Jefe del área



Gerente de Administración

- La mercadería deberá ser entregada en nuestros almacenes adjuntando la Guia de Remisión y la Orden de Compra respectivas.
- Remitir su factura a la Av. Mariscal Benavides N 615 - Urb. Selva Alegre - Arequipa - Arequipa; adjuntando copia de la Orden de Compra y copia de la Guia de Remisión debidamente sellada por Equipos Atenuz S.A. En señal de conformidad.
- Las Facturas que no contengan los documentos indicados, no serán aceptadas por recepción.
- Los proveedores tienen que estar sujetos a las condiciones de seguridad para ingresar a mina según el proyecto lo requiera



**ANEXO 23**  
**EXCAVADORA**  
**CAT- 336D2 L**



Excavadora Hidráulica

# 336D2/D2 L



## Motor

Modelo del motor	Cat® C9 ACERT™	
Potencia del motor (ISO 14396)	209 kW	280 hp
Potencia neta (SAE J1349/ISO 9249)	200 kW	268 hp

## Pesos

Peso en orden de trabajo: tren de rodaje estándar	34.489 kg	76.035 lb
Peso en orden de trabajo: tren de rodaje largo	37.086 kg	81.761 lb

## Características diferenciales del modelo 336D2/D2 L

### Motor y sistema hidráulico

Un potente Motor Cat C9 ACERT que cumple con las normas Tier 2 de la EPA de EE.UU., Stage II de la Unión Europea y con las normas de emisiones Tier 2 de China y, junto con el sistema hidráulico altamente eficiente, proporciona un excelente rendimiento con un bajo consumo de combustible. De hecho, el modelo 336D2/D2 L utiliza hasta un 8 % menos de combustible que su predecesor al mover la misma cantidad de material.

### Estructuras

Las técnicas de diseño y fabricación de Caterpillar garantizan una durabilidad y una vida útil extraordinarias en las aplicaciones más exigentes.

### Estación del operador

La espaciosa cabina cuenta con excelente visibilidad y fácil acceso a todos los interruptores. El monitor cuenta con pantalla gráfica a todo color que es fácil ver y utilizar. En general, la nueva cabina proporciona un entorno cómodo de trabajo para lograr la máxima producción y eficiencia.

### Costos de servicio y mantenimiento reducidos

El servicio y mantenimiento de rutina se pueden completar rápida y fácilmente para ayudarle a reducir los costos de propiedad. Los puntos de acceso convenientes, los intervalos prolongados de servicio y la filtración avanzada permiten mantener el tiempo de inactividad al mínimo.

### Respaldo total al cliente

Su distribuidor Cat le ofrece una amplia variedad de servicios que usted puede configurar en un Convenio de Respaldo al Cliente (CSA, Customer Support Agreement) al comprar su equipo.

### Soluciones totales

Caterpillar y su extensa red de distribuidores ofrecen amplia variedad de soluciones diseñadas para cumplir con las necesidades únicas de su negocio.

## Contenido

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**El modelo 336D2/D2 L incorpora innovaciones para mejorar la eficiencia del lugar de trabajo con bajos costos de posesión y operación, un excelente rendimiento y una alta versatilidad.**

## Estación del operador

Diseñada ergonómicamente para mantenerlo cómodo y productivo durante todo el día.





### **Estructura y montajes de la cabina**

El revestimiento de la cabina está sujeto al bastidor con montajes de cabina de caucho viscoso, que amortiguan las vibraciones y los niveles de ruido para aumentar la comodidad del operador. Una tubería de acero grueso a lo largo del perímetro inferior mejora la resistencia a la fatiga y a la vibración de la cabina.

### **Asiento**

El asiento con suspensión proporciona una amplia variedad de ajustes para adaptarse a una amplia gama de operadores. El asiento incluye un respaldo reclinable, ajustes deslizantes superior e inferior del asiento y ajustes de la altura y del ángulo de inclinación para satisfacer las necesidades de comodidad y productividad.

### **Control de palanca universal y consola**

Los controles de la palanca universal de bajo esfuerzo operados por piloto están diseñados para adaptarse a la posición natural de la muñeca y del brazo, de manera que puedan entregar máxima comodidad y producir mínima fatiga. Las consolas de palanca universal derecha e izquierda se pueden ajustar para satisfacer sus preferencias individuales, lo que aumenta la comodidad y la productividad general durante toda la jornada de trabajo.

### **Climatización**

La ventilación filtrada positiva con una cabina presurizada es estándar. Puede seleccionarse aire fresco o aire recirculado con un interruptor ubicado en la consola izquierda.

### **Ventanas y limpiaparabrisas**

Todo el vidrio está fijo directamente en la cabina para proporcionar una excelente visibilidad y eliminar los marcos de ventanas. El parabrisas delantero superior se abre, cierra y guarda en el techo sobre el operador con el sistema de liberación con la acción de un toque. Los limpiaparabrisas montados en el pilar aumentan el área de visualización y ofrecen modalidades continuas e intermitentes.

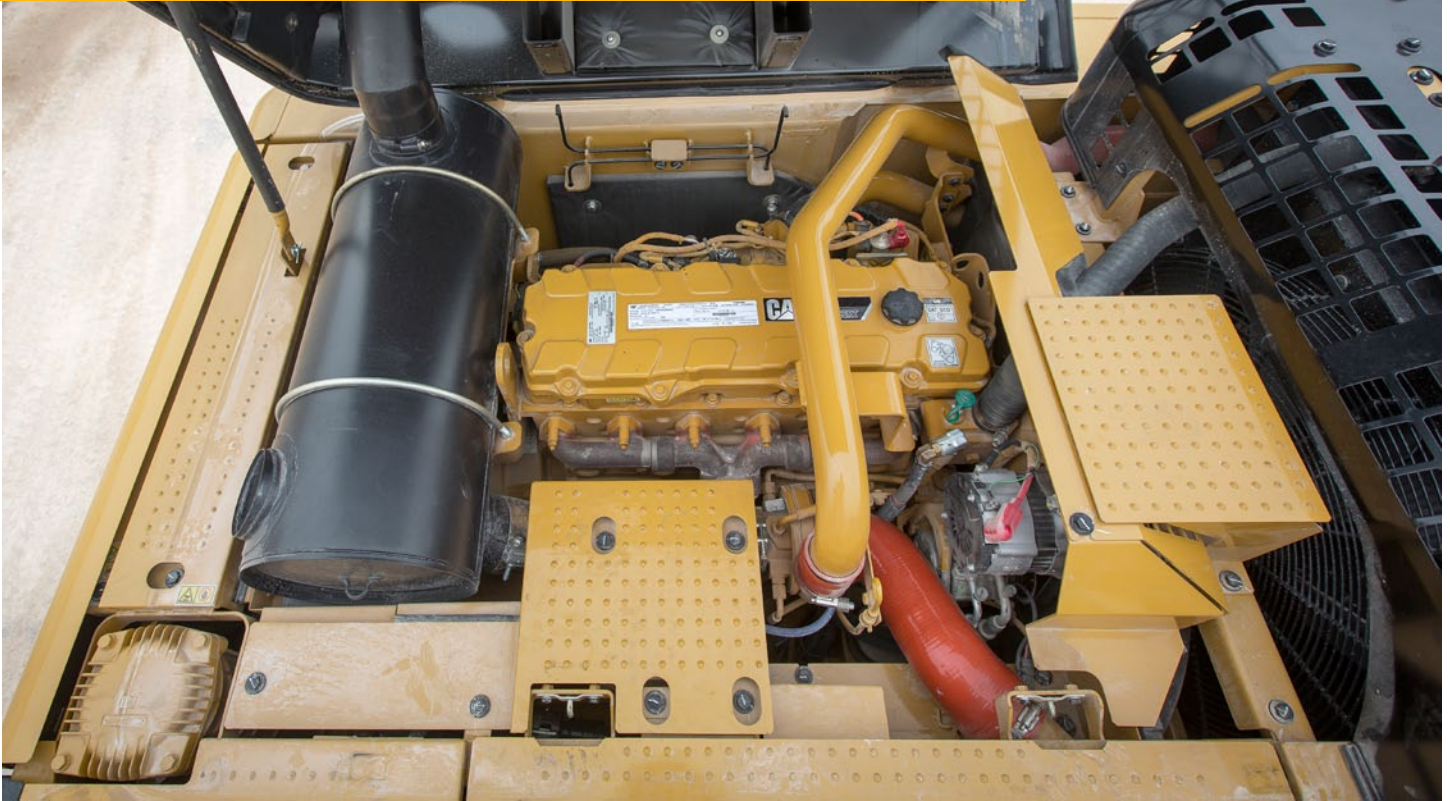


### **Monitor**

El monitor LCD a color se puede ajustar para minimizar el reflejo y tiene la capacidad de mostrar información en 28 idiomas para cumplir con las necesidades de la diversa fuerza de trabajo actual.

# Motor

Potente, fiable y eficiente en el consumo de combustible para lograr un mejor resultado final



## Estándares de emisiones

El Motor Cat C9 ACERT está diseñado para cumplir los estándares de emisiones Tier 2 de la EPA de EE.UU., Stage II de la UE y Tier 2 de China. El motor incorpora componentes resistentes y comprobados, y fabricación de precisión con la que puede contar para conseguir una operación fiable y eficiente.

## Sistema de filtrado

El motor cuenta con un sistema de filtración mejorado para garantizar la fiabilidad incluso con combustible de menor calidad. Se extendieron los intervalos de servicio y la cantidad de filtros se redujo para aumentar al máximo su potencial de beneficios.

## Control automático de velocidad del motor

El control automático de velocidad del motor se activa en condiciones sin carga o con carga liviana para reducir la velocidad del motor, lo que ayuda a minimizar el consumo de combustible.

## Bajos niveles de ruido y vibración

El Motor Cat C9 ACERT está diseñado para funcionar silenciosamente con vibración limitada, lo que contribuye a mejorar la comodidad.

# Sistema hidráulico

Potencia y control asombrosos para varias aplicaciones



## Sistema hidráulico

La presión del sistema hidráulico desde el sistema de dos bombas proporciona un grandioso rendimiento y productividad de excavación.- El sistema hidráulico y la ubicación de los componentes están diseñados para proporcionar altos niveles de eficiencia del sistema. Las bombas principales, las válvulas de control y el tanque hidráulico están ubicados cerca entre sí para permitir el uso de tubos y tuberías más cortos entre los componentes, lo que reduce la pérdida por fricción y las caídas de presión.

## Sistema piloto

Una bomba piloto independiente permite un control preciso para las operaciones del varillaje delantero, de rotación y desplazamiento.

## Sistema hidráulico de detección cruzada

El sistema hidráulico de detección cruzada utiliza ambas bombas hidráulicas al 100 % de la potencia del motor, en todas las condiciones de operación. Esto mejora la productividad gracias a velocidades más altas del implemento y a giros del pivote más rápidos y fuertes.

## Válvula hidráulica auxiliar

Los circuitos de control están disponibles como accesorios para aumentar la versatilidad. Los controles permiten la operación de herramientas de presión media y alta, como cizallas, garfios, martillos, pulverizadores, multiprocesadores y compactadores de placas vibratorias.

## Circuito de recuperación de la pluma y del brazo

Los circuitos de recuperación del brazo y de la pluma ahorran energía durante las operaciones en las que la pluma está hacia abajo y el brazo está insertado. Esto aumenta la eficiencia y reduce los tiempos de ciclo y la pérdida de presión para obtener mayor productividad, costos de operación más bajos y mayor eficiencia del combustible.

## Amortiguadores de cilindro hidráulico

Ubicados en el extremo de varilla de los cilindros de la pluma y en ambos extremos del cilindro del brazo para amortiguar impactos y, al mismo tiempo, reducir los niveles de ruido y prolongar la vida útil del componente.

## Palanca de control de accionamiento hidráulico

Con la palanca de activación hidráulica en la posición neutral se aíslan todas las funciones de varillaje delantero, rotación y desplazamiento.



## Estructuras

Resistentes y duraderas, todo lo que se espera de las excavadoras Cat

### Bastidor principal

El resistente bastidor principal está fabricado para desempeñarse en las aplicaciones más exigentes. El bastidor principal de sección de caja en forma de X proporciona una excelente resistencia a flexión torsional y los bastidores de rodillos de cadena con soldadura robótica y formados en prensa proporcionan resistencia y durabilidad excepcionales.

### Rodillos y ruedas locas

Los rodillos de cadena, los rodillos portadores y ruedas locas sellados y lubricados proporcionan una excelente vida útil de servicio para mantener la máquina en terreno y trabajar durante más tiempo.

### Tren de rodaje estándar

El tren de rodaje estándar se adapta bien para aplicaciones que requieren volver a ubicar con frecuencia la máquina en otro lugar; es también una buena alternativa para espacios de trabajo reducidos o terreno desigual y rocoso.

### Tren de rodaje largo

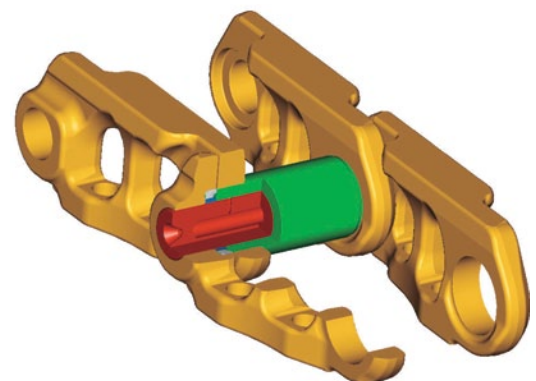
El tren de rodaje largo, amplio y resistente ofrece una excelente plataforma de trabajo para aplicaciones que requieren la máxima estabilidad y capacidad de levantamiento.

### Contrapeso

Un peso de 6,0 m (6,6 tons) funciona bien en aplicaciones que requieren levantamiento pesado. Está empernado directamente al bastidor principal para ofrecer mayor rigidez.

### Tren de rodaje

El tren de rodaje Cat duradero absorbe los esfuerzos y proporciona una estabilidad excelente. El modelo 336D2/D2 L viene de manera estándar con cadenas lubricadas con grasa. Los eslabones de las cadenas están armados y sellados con grasa para disminuir el desgaste de los bujes internos, reducir el ruido del desplazamiento y prolongar la vida útil, lo que permite bajar los costos de operación.







## Varillaje delantero

Fiable, duradero y versátil para satisfacer todas las necesidades de las aplicaciones.

### Varillaje delantero para servicio pesado

El varillaje delantero de alcance (R, reach) de servicio pesado (HD) está fabricado para trabajar en una variedad de aplicaciones difíciles y exigentes, como carga de rocas o martilleo de concreto. La pluma de alcance de servicio pesado de 6,5 m (21' 4") está fabricada con acero sólido de alta resistencia a la tracción y cuenta con un diseño de sección de caja grande y placas deflectoras interiores que permiten obtener mayor durabilidad.

Hay tres opciones de brazo disponibles para satisfacer todos los requisitos de las aplicaciones:

- El brazo de 3,9 m (12' 10") es una excelente elección cuando necesita más alcance del trabajo, como carga de camiones y apertura de zanjas profundas.
- El brazo de 3,2 m (10' 6") es una opción versátil que cumple con las necesidades de la mayoría de las aplicaciones de construcción.
- El brazo de 2,8 m (9' 2") se utiliza mejor cuando se trabaja principalmente en aplicaciones de carga de camiones para maximizar la fuerza de desprendimiento y aumentar el factor de llenado del cucharón.

### Varillaje delantero de excavación de gran volumen

El varillaje delantero para excavación de gran volumen (ME, Mass Excavation) está diseñado para aumentar al máximo el rendimiento de la máquina gracias a fuerzas de excavación superiores y a una mayor capacidad del cucharón. La pluma para excavación de gran volumen de 6,18 m (20' 3") está reforzada con una sección transversal grande y placas deflectoras internas para una larga vida útil y durabilidad.

La pluma de alcance ME tiene dos opciones de brazos para satisfacer las aplicaciones exigentes:

- El brazo de 2,55 m (8' 4") está diseñado para movimiento de tierra de alto volumen.
- El brazo de 2,15 m (7' 1") se utiliza mejor cuando se usa principalmente cucharones de gran capacidad en aplicaciones de carga de camiones para maximizar la fuerza de desprendimiento y aumentar el factor de llenado del cucharón.

# Servicio y mantenimiento

Diseño simplificado para ahorrar tiempo y dinero

## Servicio a nivel de suelo

El diseño y la distribución del modelo 336D2/D2 L se realizaron teniendo en cuenta al técnico de servicio. La mayor parte de los puntos de servicio son de fácil acceso a nivel del suelo para permitir que el servicio y mantenimiento se terminen rápida y eficientemente.

## Compartimiento de filtro de aire

El filtro de aire cuenta con un diseño de elemento doble para ofrecer una eficiencia de limpieza superior. Cuando el filtro de aire se obstruye, se muestra una advertencia en el monitor de la cabina. Las baterías libres de mantenimiento son estándar, junto con un interruptor de desconexión de la batería.

## Puntos de engrase

Un bloque concentrado de engrase remoto en la pluma permite la lubricación de lugares difíciles de alcanzar en la pluma y el brazo.

## Protector del ventilador

El ventilador del radiador del motor está protegido por una protección de acero que proporciona la máxima protección durante el servicio y mantenimiento de rutina.



## Placas antipatinaje

Las planchas antipatinaje cubren toda la estructura superior y la caja de almacenamiento para evitar el resbalamiento durante el mantenimiento. La seguridad mejora aún más con la adición de pernos abocardados para reducir los riesgos de tropezones.

## Diagnóstico y monitoreo

Los orificios para prueba hidráulica estándar permiten que un técnico de servicio evalúe el sistema hidráulico, el aceite del motor y el refrigerante, rápida y fácilmente, para un mantenimiento más eficiente.

## Compartimiento de la bomba

Una puerta de servicio en el lado derecho de la estructura superior permite el acceso a nivel del suelo a las bombas hidráulicas, los filtros hidráulicos, el filtro de aceite del motor y los filtros de combustible.

## Compartimiento del radiador

La puerta de servicio trasera izquierda permite el fácil acceso al radiador del motor, al enfriador de aceite hidráulico, al posenfriador aire a aire y al condensador de aire acondicionado. Hay un tanque de reserva y un grifo de drenaje conectados al radiador para realizar mantenimiento a nivel del suelo.



# Respaldo total al cliente

Una amplia gama de soluciones personalizadas de su distribuidor Cat.



## Respaldo al producto

Los distribuidores Cat utilizan una red mundial computarizada para localizar piezas en existencias a fin de reducir el tiempo de inactividad de la máquina. También puede ahorrar dinero con nuestra línea de componentes remanufacturados.

## Selección de la máquina

Sus distribuidores Cat pueden proporcionar recomendaciones específicas con comparaciones detalladas de las máquinas Cat que sean de su interés antes de efectuar la compra. Esto garantiza que obtenga la máquina del tamaño correcto y las herramientas apropiadas para satisfacer todas las necesidades de su aplicación.

## Servicio de mantenimiento

Los programas optativos de reparación garantizan el costo de las reparaciones por adelantado. Los programas de diagnóstico y servicios de supervisión de estado, como el análisis programado de aceite, el análisis de refrigerante y el análisis técnico, lo ayudan a evitar reparaciones no programadas.

## Convenios de Respaldo al Cliente

Los distribuidores Cat ofrecen una variedad de convenios de respaldo al producto que se pueden adaptar para satisfacer sus necesidades específicas. Estos planes pueden cubrir toda la máquina, incluidos los accesorios, para ayudarlo a proteger la inversión.

## Reemplazo

¿Reparar, reconstruir o reemplazar? Sus distribuidores Cat pueden ayudarlo a evaluar los costos involucrados para que pueda tomar la decisión correcta.

# Herramientas

Excave, martille, desgarrar y corte con confianza.



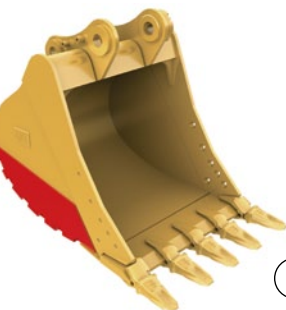
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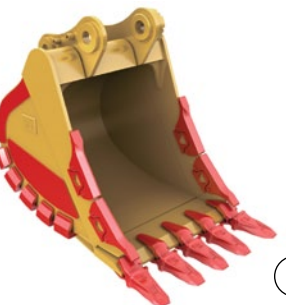
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## Versatilidad y rendimiento

Cada herramienta Cat está diseñada para optimizar la versatilidad y el rendimiento de la máquina. Para el modelo 336D2/D2 L, se encuentra disponible una extensa gama de cucharones, compactadores, garfios, procesadores múltiples, desgarradores, trituradoras, pulverizadores, martillos y cizallas.

## Cucharones y GET

Los cucharones y las herramientas de corte (GET, Ground Engaging Tools) de Cat están diseñados para adaptarse a la máquina, lo que garantiza un rendimiento y una eficiencia del combustible óptimos.

## Cucharones de servicio general (UD, Utility Buckets)

Estos cucharones son para excavar en materiales de bajo impacto y baja abrasión, como tierra, marga y arcilla.

## Cucharones de servicio general (GD, General Duty)

Estos cucharones están diseñados para excavar en materiales de bajo impacto y moderadamente abrasivos, como tierra, marga, grava y arcilla.

## Cucharones de servicio pesado (HD, Heavy Duty)

Los cucharones HD son un buen punto de partida cuando varían las condiciones de la aplicación. Especialmente, cuando entre las condiciones se incluyen tierra mezclada, arcilla, arena y grava.

## Cucharones de servicio exigente (SD, Severe Duty)

Los cucharones SD son ideales para materiales altamente abrasivos como roca triturada, arena, piedra y granito.

## Cucharones de servicio extremo (XD, Extreme Duty)

Los cucharones XD son para materiales muy abrasivos, como granito de alta cuarcita.

1) Cucharones de servicio general (UD)

2) Cucharones de servicio general (GD)

3) Cucharones de servicio pesado (HD)

4) Cucharones de servicio exigente (SD)

5) Cucharones de servicio extremo (XD)

## Acopladores

Los acopladores rápidos permiten que una persona pueda cambiar las herramientas en segundos para ofrecer un rendimiento y una flexibilidad máximos en un lugar de trabajo. Una máquina puede moverse rápidamente de una tarea a otra, y una flota de máquinas equipadas de modo similar puede compartir un inventario común de herramientas.

### Acoplador Center-Lock™

Center-Lock es un acoplador y cuenta con un sistema de traba con patente pendiente. Una traba secundaria altamente visible permite que el operador vea claramente si el acoplador está conectado o no al cucharón o a la herramienta.

### Martillos de la serie E

Los martillos de la serie E reúnen las expectativas del cliente en cuanto a rendimiento, calidad y facilidad de servicio junto con la experiencia de Caterpillar en fabricación. También son silenciosos; un beneficio significativo en entornos urbanos y áreas de trabajo con restricción de ruido.

### Desgarradores

Hechos de aceros de alta resistencia y fabricados para durar, los desgarradores Cat resisten las condiciones de trabajo más difíciles. La estructura de sección en caja se ha reforzado para lograr la máxima rigidez y transmitir toda la potencia de la máquina al material en el que se usa. Los desgarradores cuentan con una punta de desgaste reemplazable y la mayoría de los modelos están equipados con un protector del vástago reemplazable.

### Garfios

Los garfios Cat hacen que las excavadoras Cat sean la máquina ideal para manipular material suelto, clasificar la basura y limpiar el sitio de demolición. Se dispone de una variedad de estilos y tamaños para adaptar las excavadoras a la tarea actual.

## Procesadores múltiples

Los multiprocesadores realizan el trabajo de muchos tipos de herramientas de demolición al usar mandíbulas intercambiables. El cambio de mandíbulas permite que una sola unidad triture, pulverice y realice una variedad de tareas especializadas como corte de barras de refuerzo de acero y tanques.

### Cizallas

Las cizallas Cat están diseñadas para aprovechar plenamente los flujos hidráulicos y las presiones producidas por las excavadoras Cat; todo esto para aumentar la productividad sin sacrificar la seguridad y sin causar el desgaste prematuro de la cizalla o del portador.

### Pulverizadores

Los pulverizadores mecánicos son herramientas económicas para reciclar basura de hormigón demolida. El cilindro del cucharón en la excavadora propulsa al pulverizador, lo que elimina la necesidad de un cilindro dedicado, un sistema hidráulico asociado y costos de instalación adicionales.

### Compactadores

Los compactadores Cat permiten que la compactación en el sitio de trabajo sea eficiente, rápida y económica.

### Trituradoras

El triturador hidráulico de concreto es idóneo para los trabajos de demolición en áreas residenciales. La herramienta combina varias operaciones de demolición en un solo equipo:

- Desprendimiento de hormigón desde estructuras fijas
- Pulverización de hormigón
- Corte de varillas de reforzamiento y perfiles de acero pequeños



# Especificaciones de la Excavadora Hidráulica 336D2/D2 L

## Motor

Modelo del motor	Cat C9 ACERT	
Potencia del motor (ISO 14396)	209 kW	280 hp
Potencia neta (SAE J1349/ISO 9249)	200 kW	268 hp
Calibre	112 mm	4,41"
Carrera	149 mm	5,87"
Cilindrada	8,8 L	537 pulg <sup>3</sup>

- El Cat C9 cumple con las emisiones de escape equivalentes a las regulaciones de emisiones Tier 2 de la EPA de EE.UU., Stage II de la Unión Europea y Tier 2 de China.
- La potencia neta publicada es la potencia disponible en el volante cuando el motor está equipado con ventilador, filtro de aire, silenciador y alternador.
- El Motor C9 probado en terreno puede trabajar eficazmente en altitudes de hasta 2.300 m (7.546 pies).

## Pesos

Peso en orden de trabajo		
Tren de rodaje estándar*	34.489 kg	76.035 lb
Tren de rodaje largo**	37.086 kg	81.761 lb

\*Tren de rodaje estándar, con brazo de alcance de 2,8 m (9' 2"), zapatas de 600 m (24"), contrapeso de 6,0 tons métricas (6,6 tons EE.UU.).

\*\*Tren de rodaje largo con brazo de excavación de gran volumen de 2,55 m (8' 4"), zapatas de 800 m (32"), contrapeso de 6,0 tons métricas (6,6 tons EE.UU.).

## Mecanismo de giro

Velocidad de giro	8,98 rpm	
Par de giro	108,6 kN·m	80.142 lb-pie

## Mando

Rendimiento en pendientes	30°/70 %	
Velocidad máxima de desplazamiento	4,85 km/h	3,0 mph
Tracción máxima en la barra de tiro	300,5 kN	67.555 lb-pie

## Sistema hidráulico

Sistema principal: flujo máximo (cada uno)	265 L/min	70 gal EE.UU.
Sistema de rotación: flujo máximo	265 L/min	70 gal EE.UU.
Presión máxima: equipo	35.000 kPa	5.076 lb/pulg <sup>2</sup>
Presión máxima: desplazamiento	35.000 kPa	5.076 lb/pulg <sup>2</sup>
Presión máxima: giro	29.000 kPa	4.061 lb/pulg <sup>2</sup>
Sistema piloto: flujo máximo	40 L/min	10,6 gal EE.UU./min
Sistema piloto: presión máxima	4.000 kPa	580,2 lb/pulg <sup>2</sup>
Cilindro de la pluma: calibre	150 mm	5,9"
Cilindro de la pluma: carrera	1.440 mm	56,7"
Cilindro del brazo: calibre	170 mm	6,7"
Cilindro del brazo: carrera	1.738 mm	68,4"
Cilindro del cucharón: calibre	150 mm	5,9"
Cilindro del cucharón: carrera	1.151 mm	45,3"

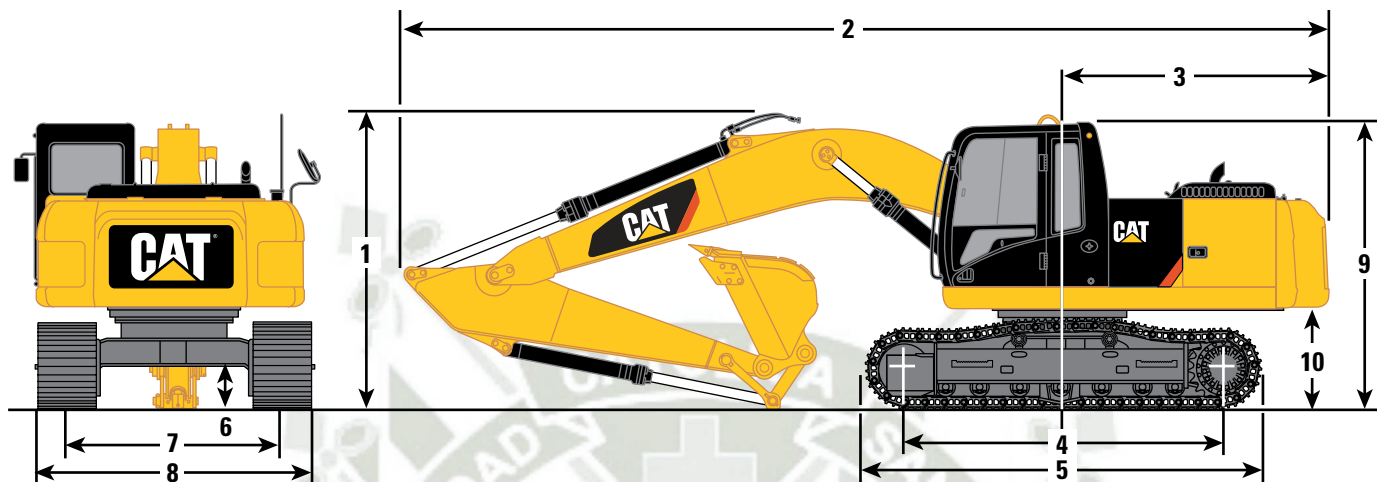
## Capacidades de llenado de servicio

Capacidad del tanque de combustible	620 L	163,79 gal EE.UU.
Sistema de enfriamiento	40 L	10,57 gal EE.UU.
Aceite del motor	40 L	10,57 gal EE.UU.
Mando de giro	19 L	5,02 gal EE.UU.
Mando final (cada uno)	8 L	2,11 gal EE.UU.
Capacidad de aceite del sistema hidráulico (tanque incluido)	410 L	108,31 gal EE.UU.
Aceite del tanque hidráulico	175 L	46,2 gal EE.UU.

# Especificaciones de la Excavadora Hidráulica 336D2/D2 L

## Dimensiones

Todas las dimensiones son aproximadas.



Opciones de pluma	Pluma de alcance de servicio pesado 6,50 m (21' 4")			Pluma para excavación de gran volumen 6,18 m (20' 3")	
Opciones de brazos	R3.9DB (12' 10")	R3.2DB (10' 6")	R2.8DB (9' 2")	M2.55TB (8' 4")	M2.15TB (7' 1")
<b>1</b> Altura de embarque*	3.700 mm (12' 2")	3.340 mm (11' 0")	3.570 mm (11' 9")	3.650 mm (12' 0")	3.680 mm (12' 1")
<b>2</b> Longitud de embarque	11.200 mm (36' 9")	11.150 mm (36' 7")	11.210 mm (36' 9")	10.910 mm (35' 10")	11.200 mm (36' 9")
<b>3</b> Radio de giro de la cola	3.500 mm (11' 6")	3.500 mm (11' 6")	3.500 mm (11' 6")	3.500 mm (11' 6")	3.500 mm (11' 6")
<b>4</b> Longitud hasta el centro de los rodillos					
Tren de rodaje estándar	3.610 mm (11' 10")	3.610 mm (11' 10")	3.610 mm (11' 10")	3.610 mm (11' 10")	3.610 mm (11' 10")
Tren de rodaje largo	4.040 mm (13' 3")	4.040 mm (13' 3")	4.040 mm (13' 3")	4.040 mm (13' 3")	4.040 mm (13' 3")
<b>5</b> Longitud de la rueda					
Tren de rodaje estándar	4.590 mm (15' 1")	4.590 mm (15' 1")	4.590 mm (15' 1")	4.590 mm (15' 1")	4.590 mm (15' 1")
Tren de rodaje largo	5.020 mm (16' 6")	5.020 mm (16' 6")	5.020 mm (16' 6")	5.020 mm (16' 6")	5.020 mm (16' 6")
<b>6</b> Espacio libre sobre el suelo**	450 mm (1' 6")	450 mm (1' 6")	450 mm (1' 6")	450 mm (1' 6")	450 mm (1' 6")
<b>7</b> Entrevía					
Tren de rodaje estándar	2.590 mm (8' 6")	2.590 mm (8' 6")	2.590 mm (8' 6")	2.590 mm (8' 6")	2.590 mm (8' 6")
Tren de rodaje largo	2.590 mm (8' 6")	2.590 mm (8' 6")	2.590 mm (8' 6")	2.590 mm (8' 6")	2.590 mm (8' 6")
<b>8</b> Ancho de transporte: tren de rodaje largo o estándar					
Zapatas de 600 mm (24")	3.190 mm (10' 6")	3.190 mm (10' 6")	3.190 mm (10' 6")	3.190 mm (10' 6")	3.190 mm (10' 6")
Zapatas de 700 mm (28")	3.290 mm (10' 10")	3.290 mm (10' 10")	3.290 mm (10' 10")	3.290 mm (10' 10")	3.290 mm (10' 10")
Zapatas de 800 mm (32")	3.390 mm (11' 2")	3.390 mm (11' 2")	3.390 mm (11' 2")	3.390 mm (11' 2")	3.390 mm (11' 2")
<b>9</b> Altura de la cabina*	3.140 mm (10' 4")	3.140 mm (10' 4")	3.140 mm (10' 4")	3.140 mm (10' 4")	3.140 mm (10' 4")
<b>10</b> Espacio libre del contrapeso**	1.220 mm (4' 0")	1.220 mm (4' 0")	1.220 mm (4' 0")	1.220 mm (4' 0")	1.220 mm (4' 0")

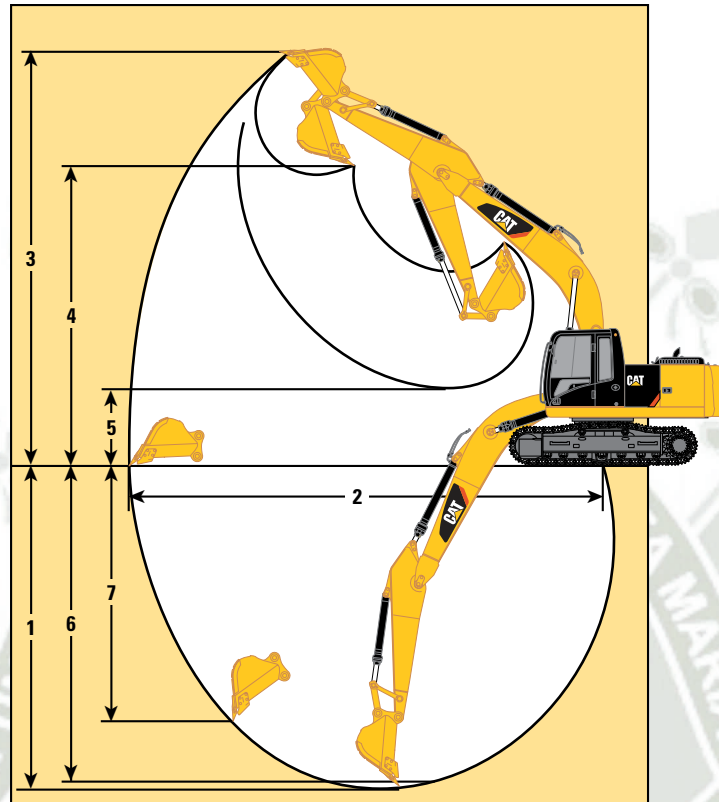
\*Incluye la altura de las orejetas de las zapatas.

\*\*Sin incluir la altura de las orejetas de las zapatas.

# Especificaciones de la Excavadora Hidráulica 336D2/D2 L

## Gamas de trabajo

Todas las dimensiones son aproximadas.



Opciones de pluma	Pluma de alcance de servicio pesado 6,50 m (21' 4")			Pluma para excavación de gran volumen 6,18 m (20' 3")	
	R3.9DB (12' 10")	R3.2DB (10' 6")	R2.8DB (9' 2")	M2.55TB (8' 4")	M2.15TB (7' 1")
<b>Opciones de brazos</b>					
<b>1</b> Profundidad máxima de excavación	8.090 mm (26' 7")	7.390 mm (24' 3")	6.990 mm (22' 11")	6.570 mm (21' 7")	6.170 mm (20' 3")
<b>2</b> Alcance máximo a nivel del suelo	11.640 mm (38' 2")	10.920 mm (35' 10")	10.620 mm (34' 10")	10.180 mm (33' 5")	9.760 mm (32' 0")
<b>3</b> Altura máxima de corte	10.710 mm (35' 2")	10.240 mm (33' 7")	10.300 mm (33' 10")	10.070 mm (33' 1")	9.740 mm (32' 0")
<b>4</b> Altura máxima de carga	7.640 mm (25' 1")	7.200 mm (23' 8")	7.200 mm (23' 8")	6.690 mm (21' 11")	6.410 mm (21' 0")
<b>5</b> Altura mínima de carga	2.010 mm (6' 7")	2.710 mm (8' 11")	3.110 mm (10' 2")	3.000 mm (9' 10")	3.400 mm (11' 2")
<b>6</b> Profundidad máxima de corte con fondo plano de 2.440 mm (8' 0")	7.960 mm (26' 1")	7.230 mm (23' 9")	6.820 mm (22' 5")	6.400 mm (21' 0")	5.970 mm (19' 7")
<b>7</b> Profundidad máxima de excavación vertical	6.700 mm (22' 0")	5.830 mm (19' 2")	5.770 mm (18' 11")	5.340 mm (17' 6")	4.710 mm (15' 5")



# Especificaciones de la Excavadora Hidráulica 336D2/D2 L

## Pesos de los componentes principales

Base de la máquina: contrapeso de 6,0 tons métricas/6,6 tons EE.UU. (con contrapeso y sin varillaje delantero)	
Tren de rodaje estándar: zapatas de 600 mm (24")	26.753 kg (58.980 lb)
Tren de rodaje largo: zapatas de 700 mm (28")	27.987 kg (61.701 lb)
Contrapeso	
Contrapeso estándar	6.018 kg (13.267 lb)
Dos cilindros de la pluma	668 kg (1.473 lb)
Pluma (incluye tuberías, pasadores y cilindro del brazo)	
Pluma de alcance HD: 6,50 m (21' 4")	3.526 kg (7.773 lb)
Pluma para excavación de gran volumen: 6,18 m (20' 3")	3.294 kg (7.262 lb)
Brazo (incluye tuberías, pasadores, varillaje y cilindro del cucharón)	
R3.9DB (12' 10")	2.089 kg (4.605 lb)
R3.2DB (10' 6")	2.015 kg (4.442 lb)
R2.8DB (9' 2")	1.907 kg (4.204 lb)
M2.55TB (8' 4")	2.024 kg (4.462 lb)
M2.15TB (7' 1")	1.949 kg (4.296 lb)
Zapata de cadena (tren de rodaje estándar/por cada cadena)	
Zapatas con garras triples de 600 mm (24")	1.867 kg (4.116 lb)
Zapatas con garras triples de 700 mm (28")	2.016 kg (4.445 lb)
Zapatas con garras triples de 800 mm (32")	2.330 kg (5.137 lb)
Zapata de cadena (tren de rodaje largo/por cada cadena)	
Zapatas con garras triples de 600 mm (24")	2.033 kg (4.482 lb)
Zapatas con garras triples de 700 mm (28")	2.196 kg (4.841 lb)
Zapatas con garras triples de 800 mm (32")	2.538 kg (5.595 lb)

# Especificaciones de la Excavadora Hidráulica 336D2/D2 L

## Pesos en orden de trabajo y presiones sobre el suelo

336D2 – Tren de rodaje estándar – Contrapeso de 6,0 mt (6,6 tons EE.UU.)						
	Zapatas con garras triples de 600 mm (24")		Zapatas con garras triples de 700 mm (28")		Zapatas con garras triples de 800 mm (32")	
Pluma de alcance HD: 6,50 m (21' 4")						
R3.9DB (12' 10")	34.671 kg (76.436 lb)	71,7 kPa (10,4 lb/pulg <sup>2</sup> )	34.969 kg (77.093 lb)	62,0 kPa (8,99 lb/pulg <sup>2</sup> )	35.597 kg (78.478 lb)	55,2 kPa (8,01 lb/pulg <sup>2</sup> )
R3.2DB (10' 6")	34.597 kg (76.273 lb)	71,5 kPa (10,37 lb/pulg <sup>2</sup> )	34.895 kg (76.930 lb)	61,9 kPa (8,98 lb/pulg <sup>2</sup> )	35.523 kg (78.315 lb)	55,1 kPa (8,0 lb/pulg <sup>2</sup> )
R2.8DB (9' 2")	34.489 kg (76.035 lb)	71,3 kPa (10,34 lb/pulg <sup>2</sup> )	34.787 kg (76.692 lb)	61,7 kPa (8,95 lb/pulg <sup>2</sup> )	35.415 kg (78.077 lb)	54,9 kPa (7,96 lb/pulg <sup>2</sup> )
Pluma para excavación de gran volumen: 6,18 m (20' 3")						
M2.55TB (8' 4")	35.168 kg (77.532 lb)	72,7 kPa (10,54 lb/pulg <sup>2</sup> )	35.466 kg (78.189 lb)	62,9 kPa (9,12 lb/pulg <sup>2</sup> )	36.094 kg (79.574 lb)	56,0 kPa (8,12 lb/pulg <sup>2</sup> )
M2.15TB (7' 1")	35.093 kg (77.367 lb)	72,6 kPa (10,53 lb/pulg <sup>2</sup> )	35.391 kg (78.024 lb)	62,7 kPa (9,09 lb/pulg <sup>2</sup> )	36.019 kg (79.408 lb)	55,9 kPa (8,11 lb/pulg <sup>2</sup> )
336D2 L – Tren de rodaje largo – Contrapeso de 6,0 mt (6,6 tons EE.UU.)						
	Zapatas con garras triples de 600 mm (24")		Zapatas con garras triples de 700 mm (28")		Zapatas con garras triples de 800 mm (32")	
Pluma de alcance HD: 6,50 m (21' 4")						
R3.9DB (12' 10")	35.579 kg (78.438 lb)	66,3 kPa (9,62 lb/pulg <sup>2</sup> )	35.905 kg (79.157 lb)	57,3 kPa (8,31 lb/pulg <sup>2</sup> )	36.589 kg (80.665 lb)	51,1 kPa (7,41 lb/pulg <sup>2</sup> )
R3.2DB (10' 6")	35.505 kg (78.275 lb)	66,1 kPa (9,59 lb/pulg <sup>2</sup> )	35.831 kg (78.994 lb)	57,2 kPa (8,30 lb/pulg <sup>2</sup> )	36.515 kg (80.502 lb)	51,0 kPa (7,40 lb/pulg <sup>2</sup> )
R2.8DB (9' 2")	35.397 kg (78.037 lb)	65,9 kPa (9,56 lb/pulg <sup>2</sup> )	35.723 kg (78.756 lb)	57,0 kPa (8,27 lb/pulg <sup>2</sup> )	36.407 kg (80.264 lb)	50,9 kPa (7,38 lb/pulg <sup>2</sup> )
Pluma para excavación de gran volumen: 6,18 m (20' 3")						
M2.55TB (8' 4")	36.076 kg (79.534 lb)	67,2 kPa (9,75 lb/pulg <sup>2</sup> )	36.402 kg (80.253 lb)	58,1 kPa (8,43 lb/pulg <sup>2</sup> )	37.086 kg (81.761 lb)	51,8 kPa (7,51 lb/pulg <sup>2</sup> )
M2.15TB (7' 1")	36.001 kg (79.369 lb)	67,1 kPa (9,73 lb/pulg <sup>2</sup> )	36.327 kg (80.087 lb)	58,0 kPa (8,41 lb/pulg <sup>2</sup> )	37.011 kg (81.595 lb)	51,7 kPa (7,50 lb/pulg <sup>2</sup> )

## Fuerzas de excavación del cucharón y del brazo

	Pluma de alcance HD: 6,50 m (21' 4")			Pluma para excavación de gran volumen: 6,18 m (20' 3")	
	R3.9DB (12' 10")	R3.2DB (10' 6")	R2.8DB (9' 2")	M2.55TB (8' 4")	M2.15TB (7' 1")
<b>Cucharón para servicio pesado</b>					
Fuerza de excavación del cucharón (ISO)	211 kN (47.460 lb-pie)	211 kN (47.460 lb-pie)	211 kN (47.460 lb-pie)	265 kN (59.570 lb-pie)	265 kN (59.570 lb-pie)
Fuerza de excavación del cucharón (SAE)	185 kN (41.440 lb-pie)	185 kN (41.440 lb-pie)	185 kN (41.440 lb-pie)	229 kN (51.410 lb-pie)	229 kN (51.410 lb-pie)
Fuerza de excavación del brazo (ISO)	145 kN (32.600 lb-pie)	167 kN (37.520 lb-pie)	186 kN (41.760 lb-pie)	191 kN (42.880 lb-pie)	222 kN (49.950 lb-pie)
Fuerza de excavación del brazo (SAE)	141 kN (31.700 lb-pie)	162 kN (36.360 lb-pie)	179 kN (40.320 lb-pie)	183 kN (41.130 lb-pie)	212 kN (47.630 lb-pie)

# Especificaciones de la Excavadora Hidráulica 336D2/D2 L

**Capacidades de levantamiento de la pluma de alcance de servicio pesado – Tren de rodaje estándar – Contrapeso: 6,0 mt (6,6 tons EE.UU.)**

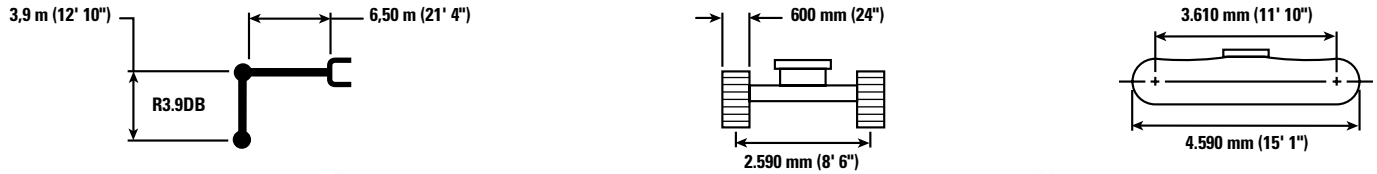


Diagrama de la pluma	1.500 mm/60"		3.000 mm/120"		4.500 mm/180"		6.000 mm/240"		7.500 mm/300"		9.000 mm/360"		Diagrama de la pluma		mm "		
	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb			
9.000 mm 360"														*5.850 *13.000	*5.850 *13.000	7.370 290	
7.500 mm 300"									*7.100 *15.700	7.050 15.100				*5.400 *11.950	*5.400 *11.950	8.560 340	
6.000 mm 240"									*7.400 *16.150	6.900 14.850	6.800 *13.800	5.000 10.650		*5.250 *11.550	4.650 10.300	9.360 370	
4.500 mm 180"							*9.050 *19.550	*9.050 *19.550	*8.050 *17.550	6.650 14.250	6.700 14.350	4.900 10.450		*5.250 *11.550	4.150 9.100	9.860 390	
3.000 mm 120"					*14.150 *30.400	13.600 29.350	*10.700 *23.100	8.800 19.000	8.650 18.650	6.300 13.550	6.500 13.950	4.700 10.100		5.350 11.800	3.850 8.450	10.120 400	
1.500 mm 60"					*17.050 *36.700	12.400 26.650	11.600 25.000	8.200 17.700	8.300 17.850	5.950 12.800	6.300 13.500	4.500 9.700		5.250 11.500	3.750 8.200	10.150 400	
0 mm 0"					*7.850 *17.850	*7.850 *17.850	17.550 37.600	11.700 25.200	11.150 23.950	7.750 16.700	8.000 17.200	5.700 12.200	6.150 13.200	4.350 9.400	5.300 11.650	3.750 8.300	9.950 400
-1.500 mm -60"		*8.200 *18.300	*8.200 *18.300	*12.400 *27.950	*12.400 *27.950	17.250 36.950	11.450 24.600	10.850 23.350	7.550 16.200	7.850 16.850	5.500 11.850	6.050 13.000	4.300 9.200	5.600 12.400	4.000 8.750	9.510 380	
-3.000 mm -120"		*13.150 *29.400	*13.150 *29.400	*18.150 *41.050	*18.150 *41.050	17.250 37.000	11.450 24.650	10.800 23.250	7.500 16.100	7.800 16.800	5.500 11.800			6.300 13.900	4.450 9.850	8.790 350	
-4.500 mm -180"		*18.950 *42.600	*18.950 *42.600	*22.150 *47.750	*22.150 *47.750	*15.950 *34.400	11.700 25.150	10.950 23.600	7.600 16.450	7.950 17.200	5.650 12.200			7.700 17.150	5.450 12.150	7.710 310	
-6.000 mm -240"						*12.100 *25.500	*12.100 *25.500	*8.550	8.050					*8.350 *18.200	7.900 17.000	6.090 240	



ISO 10567



\* Indica que la carga está limitada por la capacidad hidráulica de levantamiento y no por la carga de equilibrio. Las cargas anteriores cumplen con la norma ISO 10567:2007 para la capacidad de levantamiento de la excavadora hidráulica. No exceden el 87 % de la capacidad hidráulica de levantamiento ni el 75 % de la capacidad de carga límite de equilibrio. El peso de todos los accesorios de levantamiento debe restarse de las capacidades de levantamiento indicadas anteriormente. Las capacidades de levantamiento corresponden a una máquina en una superficie de apoyo firme y uniforme. El uso de un punto de sujeción del accesorio de la herramienta para manipular o levantar objetos puede afectar el rendimiento de levantamiento de la máquina.

La capacidad de levantamiento permanece en  $\pm 5\%$  en todas las zapatas de cadena disponibles.

Consulte siempre el Manual de Operación y Mantenimiento apropiado para obtener información específica del producto.

# Especificaciones de la Excavadora Hidráulica 336D2/D2 L

## Capacidades de levantamiento de la pluma de alcance de servicio pesado – Tren de rodaje estándar – Contrapeso: 6,0 mt (6,6 tons EE.UU.)

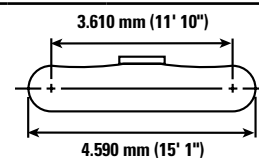
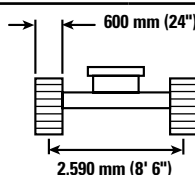
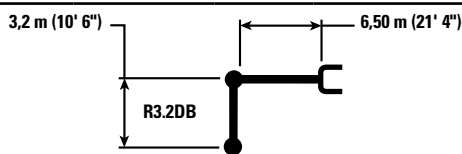


Diagrama de la pluma	3.000 mm/120"		4.500 mm/180"		6.000 mm/240"		7.500 mm/300"		9.000 mm/360"		Diagrama de la máquina		mm "
	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	
7.500 mm 300"							*7.750 6.800				*6.700 *14.800	6.450 14.550	7.710 300
6.000 mm 240"							*7.850 *17.200	6.750 14.450			*6.500 *14.300	5.300 11.750	8.580 340
4.500 mm 180"			*12.050 12.050	*12.050 12.050	*9.650 *20.850	9.200 19.850	*8.450 *18.350	6.500 13.950	6.550	4.750	6.400 14.150	4.650 10.250	9.130 360
3.000 mm 120"			*15.200 *32.650	13.050 28.200	*11.150 *24.100	8.600 18.550	8.550 18.400	6.200 13.300	6.450	4.650	6.000 13.200	4.300 9.500	9.410 370
1.500 mm 60"			*17.500 *37.700	12.050 26.000	11.500 24.700	8.050 17.400	8.250 17.700	5.900 12.650	6.250	4.500	5.850 12.850	4.150 9.150	9.440 380
0 mm 0"			17.500 37.500	11.650 25.050	11.100 23.850	7.750 16.650	8.000 17.200	5.650 12.200	6.150	4.400	5.950 13.100	4.250 9.300	9.220 370
-1.500 mm -60"	*13.250 *29.900	*13.250 *29.900	17.400 37.300	11.550 24.850	10.950 23.550	7.600 16.300	7.900 17.000	5.550 12.000			6.400 14.100	4.550 10.000	8.750 350
-3.000 mm -120"	*20.900 *47.350	*20.900 *47.350	*16.550 *35.800	11.700 25.150	11.000 23.600	7.600 16.400	7.950 17.150	5.600 12.100			7.350 16.300	5.200 11.550	7.960 320
-4.500 mm -180"	*18.550 *39.900	*18.550 *39.900	*13.950 *30.000	12.050 25.900	*10.550 *22.450	7.850 16.950					*8.900 *19.550	6.750 15.050	6.750 270



ISO 10567



\* Indica que la carga está limitada por la capacidad hidráulica de levantamiento y no por la carga de equilibrio. Las cargas anteriores cumplen con la norma ISO 10567:2007 para la capacidad de levantamiento de la excavadora hidráulica. No exceden el 87 % de la capacidad hidráulica de levantamiento ni el 75 % de la capacidad de carga límite de equilibrio. El peso de todos los accesorios de levantamiento debe restarse de las capacidades de levantamiento indicadas anteriormente. Las capacidades de levantamiento corresponden a una máquina en una superficie de apoyo firme y uniforme. El uso de un punto de sujeción del accesorio de la herramienta para manipular o levantar objetos puede afectar el rendimiento de levantamiento de la máquina.

La capacidad de levantamiento permanece en  $\pm 5\%$  en todas las zapatas de cadena disponibles.

Consulte siempre el Manual de Operación y Mantenimiento apropiado para obtener información específica del producto.

# Especificaciones de la Excavadora Hidráulica 336D2/D2 L

## Capacidades de levantamiento de la pluma de alcance de servicio pesado – Tren de rodaje estándar – Contrapeso: 6,0 mt (6,6 tons EE.UU.)

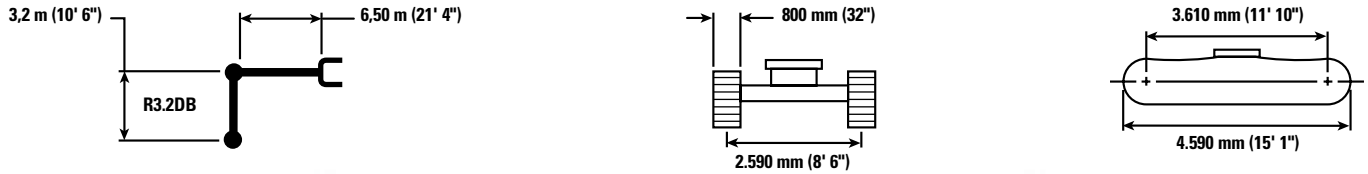


Diagrama de la pluma	3.000 mm/120"		4.500 mm/180"		6.000 mm/240"		7.500 mm/300"		9.000 mm/360"		Diagrama de la excavadora		mm "
	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	
7.500 mm 300"							*7.750	6.950			*6.700	6.650	7.710
6.000 mm 240"							*7.850	6.900			*6.500	5.450	8.580
4.500 mm 180"			*12.050	*12.050	*9.650	9.450	*8.450	6.650	6.750	4.900	*6.550	4.750	9.130
3.000 mm 120"			*15.200	13.400	*11.150	8.800	8.750	6.350	6.600	4.750	6.150	4.450	9.410
1.500 mm 60"			*17.500	12.400	11.800	8.300	8.450	6.050	6.450	4.600	6.000	4.300	9.440
0 mm 0"			17.950	11.950	11.400	7.950	8.250	5.850	6.350	4.500	6.100	4.350	9.220
-1.500 mm -60"	*13.250	*13.250	*17.850	11.900	11.250	7.800	8.100	5.750			6.550	4.650	8.750
-3.000 mm -120"	*20.900	*20.900	*16.550	12.000	11.300	7.850	8.150	5.750			7.550	5.350	7.960
-4.500 mm -180"	*18.550	*18.550	*13.950	12.350	*10.550	8.050					*8.900	6.900	6.750
	*39.900	*39.900	*30.000	26.550	*22.450	17.400					*19.550	15.450	270



ISO 10567



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La capacidad de levantamiento permanece en  $\pm 5\%$  en todas las zapatas de cadena disponibles.

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# Especificaciones de la Excavadora Hidráulica 336D2/D2 L

## Capacidades de levantamiento de la pluma de alcance de servicio pesado – Tren de rodaje estándar – Contrapeso: 6,0 mt (6,6 tons EE.UU.)

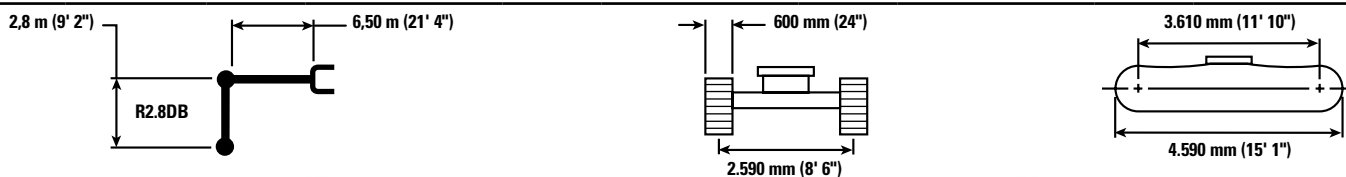


Diagrama de la herramienta	3.000 mm/120"		4.500 mm/180"		6.000 mm/240"		7.500 mm/300"		9.000 mm/360"		Diagrama de la máquina		mm "		
	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb			
7.500 mm 300"													*8.400 *18.550	6.950 15.650	7.340 290
6.000 mm 240"					*9.000 *19.500	*9.000 *19.500	*8.350 *18.250	6.650 14.300					7.700 17.100	5.600 12.500	8.250 330
4.500 mm 180"			*13.000 *27.850	*13.000 *27.850	*10.200 *22.050	9.100 19.650	8.850 19.000	6.450 13.850					6.750 14.950	4.900 10.850	8.820 350
3.000 mm 120"			*16.100 *34.600	12.800 27.700	*11.650 *25.150	8.550 18.400	8.550 18.350	6.150 13.250	6.400	4.650			6.300 13.900	4.550 10.000	9.110 360
1.500 mm 60"			*15.900 38.350	12.000 25.800	11.450 24.650	8.050 17.350	8.250 17.750	5.900 12.700	6.300	4.500			6.150 13.550	4.400 9.700	9.140 360
0 mm 0"			17.550 37.600	11.700 25.150	11.150 23.950	7.750 16.700	8.050 17.300	5.700 12.300					6.300 13.850	4.500 9.900	8.920 350
-1.500 mm -60"	*12.350 *28.100	*12.350 *28.100	17.550 37.600	11.700 25.150	11.050 23.700	7.650 16.500	8.000 17.150	5.650 12.150					6.800 15.050	4.850 10.700	8.420 340
-3.000 mm -120"	*21.050 *45.750	*21.050 *45.750	*16.000 *34.700	11.850 25.500	11.100 23.900	7.750 16.700	8.100 17.700	5.750					7.950 17.650	5.650 12.550	7.600 300
-4.500 mm -180"	*16.750 *35.950	*16.750 *35.950	*13.000 *27.850	12.250 26.400	*9.650 *20.250	8.050 17.450							*8.800 *19.350	7.550 16.950	6.330 250



ISO 10567



\* Indica que la carga está limitada por la capacidad hidráulica de levantamiento y no por la carga de equilibrio. Las cargas anteriores cumplen con la norma ISO 10567:2007 para la capacidad de levantamiento de la excavadora hidráulica. No exceden el 87 % de la capacidad hidráulica de levantamiento ni el 75 % de la capacidad de carga límite de equilibrio. El peso de todos los accesorios de levantamiento debe restarse de las capacidades de levantamiento indicadas anteriormente. Las capacidades de levantamiento corresponden a una máquina en una superficie de apoyo firme y uniforme. El uso de un punto de sujeción del accesorio de la herramienta para manipular o levantar objetos puede afectar el rendimiento de levantamiento de la máquina.

La capacidad de levantamiento permanece en  $\pm 5\%$  en todas las zapatas de cadena disponibles.

Consulte siempre el Manual de Operación y Mantenimiento apropiado para obtener información específica del producto.

# Especificaciones de la Excavadora Hidráulica 336D2/D2 L

## Capacidades de levantamiento de excavación de gran volumen – Tren de rodaje estándar – Contrapeso: 6,0 tons métricas (6,6 tons EE.UU.)

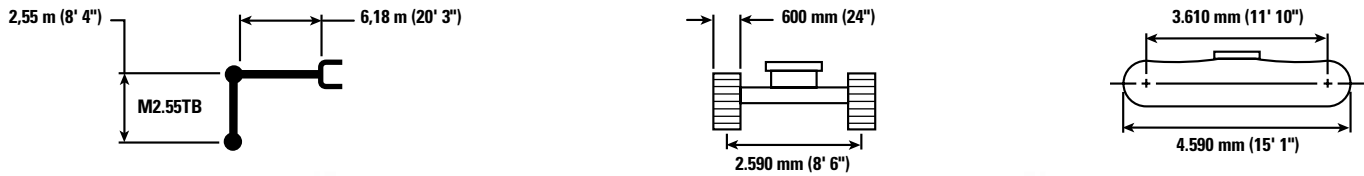


Diagrama de la herramienta	3.000 mm/120"		4.500 mm/180"		6.000 mm/240"		7.500 mm/300"		Diagrama de la herramienta		mm "
	Diagrama de la herramienta	Diagrama de la herramienta	Diagrama de la herramienta	Diagrama de la herramienta	Diagrama de la herramienta	Diagrama de la herramienta	Diagrama de la herramienta	Diagrama de la herramienta	Diagrama de la herramienta	Diagrama de la herramienta	
7.500 mm 300"	kg				*9.250	*9.250			*8.300	8.200	6.590
	lb				<b>*20.450</b>	<b>*20.450</b>			<b>*18.400</b>	<b>*18.400</b>	<b>260</b>
6.000 mm 240"	kg				*9.600	9.500	8.900	6.500	*7.900	6.350	7.600
	lb				<b>*20.850</b>	<b>20.450</b>	<b>20.450</b>	<b>14.500</b>	<b>*17.450</b>	<b>14.200</b>	<b>300</b>
4.500 mm 180"	kg		*13.400	*13.400	*10.650	9.050	8.750	6.350	7.500	5.450	8.210
	lb		<b>*28.750</b>	<b>*28.750</b>	<b>*23.050</b>	<b>19.500</b>	<b>18.750</b>	<b>13.650</b>	<b>16.650</b>	<b>12.100</b>	<b>330</b>
3.000 mm 120"	kg		*16.350	12.850	11.950	8.500	8.450	6.100	6.950	5.000	8.520
	lb		<b>*35.150</b>	<b>27.700</b>	<b>25.650</b>	<b>18.300</b>	<b>18.200</b>	<b>13.150</b>	<b>15.300</b>	<b>11.050</b>	<b>340</b>
1.500 mm 60"	kg		17.900	12.000	11.450	8.050	8.200	5.850	6.750	4.850	8.550
	lb		<b>38.450</b>	<b>25.900</b>	<b>24.600</b>	<b>17.300</b>	<b>17.650</b>	<b>12.650</b>	<b>14.900</b>	<b>10.700</b>	<b>340</b>
0 mm 0"	kg		17.600	11.750	11.150	7.750	8.050	5.700	6.950	5.000	8.310
	lb		<b>37.700</b>	<b>25.250</b>	<b>23.950</b>	<b>16.750</b>	<b>17.300</b>	<b>12.300</b>	<b>15.350</b>	<b>10.950</b>	<b>330</b>
-1.500 mm -60"	kg	*16.900	*16.900	*17.450	11.750	11.050	7.700	8.050	5.700	7.650	5.450
	lb	<b>*38.350</b>	<b>*38.350</b>	<b>37.700</b>	<b>25.300</b>	<b>23.800</b>	<b>16.600</b>	<b>17.300</b>	<b>12.300</b>	<b>16.900</b>	<b>12.000</b>
-3.000 mm -120"	kg	*19.950	*19.950	*15.350	12.000	11.200	7.850		9.250	6.550	6.880
	lb	<b>*43.300</b>	<b>*43.300</b>	<b>*33.200</b>	<b>25.750</b>	<b>24.150</b>	<b>16.900</b>		<b>20.550</b>	<b>14.550</b>	<b>270</b>
-4.500 mm -180"	kg			*11.250	*11.250				*8.900	*8.900	5.430
	lb			<b>*23.800</b>	<b>*23.800</b>				<b>*19.450</b>	<b>*19.450</b>	<b>210</b>



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\* Indica que la carga está limitada por la capacidad hidráulica de levantamiento y no por la carga de equilibrio. Las cargas anteriores cumplen con la norma ISO 10567:2007 para la capacidad de levantamiento de la excavadora hidráulica. No exceden el 87 % de la capacidad hidráulica de levantamiento ni el 75 % de la capacidad de carga límite de equilibrio. El peso de todos los accesorios de levantamiento debe restarse de las capacidades de levantamiento indicadas anteriormente. Las capacidades de levantamiento corresponden a una máquina en una superficie de apoyo firme y uniforme. El uso de un punto de sujeción del accesorio de la herramienta para manipular o levantar objetos puede afectar el rendimiento de levantamiento de la máquina.

La capacidad de levantamiento permanece en  $\pm 5\%$  en todas las zapatas de cadena disponibles.

Consulte siempre el Manual de Operación y Mantenimiento apropiado para obtener información específica del producto.

# Especificaciones de la Excavadora Hidráulica 336D2/D2 L

## Capacidades de levantamiento de excavación de gran volumen – Tren de rodaje estándar – Contrapeso: 6,0 tons métricas (6,6 tons EE.UU.)

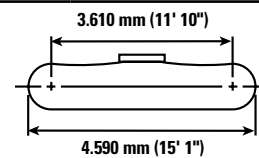
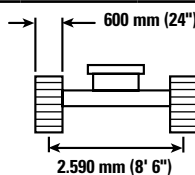
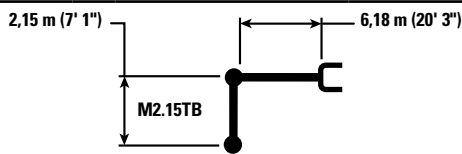


Diagrama de la herramienta	3.000 mm/120"		4.500 mm/180"		6.000 mm/240"		7.500 mm/300"		Diagrama de la excavadora		mm "
	Diagrama 1	Diagrama 2	Diagrama 1	Diagrama 2	Diagrama 1	Diagrama 2	Diagrama 1	Diagrama 2	Diagrama 1	Diagrama 2	
7.500 mm 300"	kg				*10.050	9.550			*10.050	9.450	6.030
	lb				*22.300	21.500			*22.300	21.500	240
6.000 mm 240"	kg				*10.150	9.400			9.650	7.050	7.120
	lb				*22.150	20.200			*21.350	15.750	280
4.500 mm 180"	kg		*14.250	13.850	*11.150	8.950	8.700	6.300	8.200	5.950	7.780
	lb		*30.650	29.850	*24.150	19.300	18.650	13.550	18.150	13.200	310
3.000 mm 120"	kg				11.850	8.400	8.450	6.100	7.500	5.450	8.100
	lb				*36.850	27.150	25.500	18.150	16.550	11.950	320
1.500 mm 60"	kg				11.400	8.000	8.200	5.900	7.300	5.250	8.140
	lb				24.500	17.250	17.700	12.650	16.100	11.550	320
0 mm 0"	kg		17.600	11.800	11.150	7.800	8.100	5.750	7.550	5.400	7.890
	lb		37.750	25.300	24.000	16.800	17.450	12.450	16.650	11.900	310
-1.500 mm -60"	kg	*17.800	*17.800	*16.950	11.850	11.150	7.800		8.400	6.000	7.320
	lb	*40.750	*40.750	*36.750	25.500	23.950	16.750		18.600	13.200	290
-3.000 mm -120"	kg	*17.950	*17.950	*14.500	12.150	*11.050	8.000		*10.100	7.450	6.360
	lb	*39.050	*39.050	*31.350	26.100	*23.550	17.250		*22.250	16.500	250



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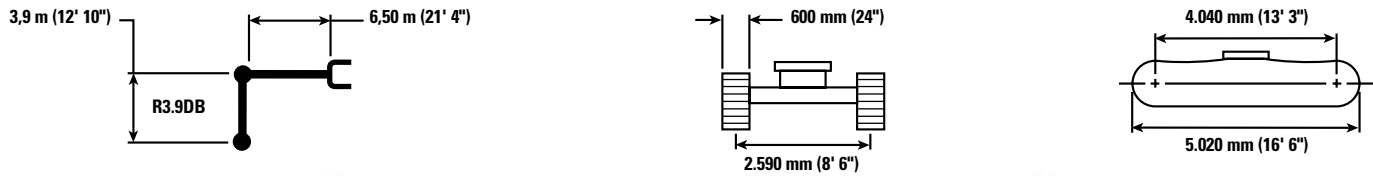
La capacidad de levantamiento permanece en  $\pm 5\%$  en todas las zapatas de cadena disponibles.

Consulte siempre el Manual de Operación y Mantenimiento apropiado para obtener información específica del producto.



# Especificaciones de la Excavadora Hidráulica 336D2/D2 L

**Capacidades de levantamiento de la pluma de alcance de servicio pesado – Tren de rodaje largo – Contrapeso: 6,0 mt (6,6 tons EE.UU.)**



		1.500 mm/60"		3.000 mm/120"		4.500 mm/180"		6.000 mm/240"		7.500 mm/300"		9.000 mm/360"		mm		
9.000 mm 360"	kg lb													*5.850 *13.000	*5.850 *13.000	7.370 290
7.500 mm 300"	kg lb									*7.100 *15.700	*7.100 15.400			*5.400 *11.950	*5.400 *11.950	8.560 340
6.000 mm 240"	kg lb									*7.400 *16.150	7.050 15.150	*7.100 *13.800	5.100 10.900	*5.250 *11.550	4.750 10.550	9.360 370
4.500 mm 180"	kg lb							*9.050 *19.550	*9.050 *19.550	*8.050 *17.550	6.800 14.600	*7.500 *16.450	5.000 10.700	*5.250 *11.550	4.250 9.350	9.860 390
3.000 mm 120"	kg lb					*14.150 *30.400	13.900 29.950	*10.700 *23.100	9.000 19.450	*8.950 *19.450	6.450 13.850	7.650 16.450	4.800 10.350	*5.400 *11.850	3.950 8.700	10.120 400
1.500 mm 60"	kg lb					*17.050 *36.700	12.650 27.300	*12.250 *26.500	8.400 18.100	9.850 21.150	6.100 13.100	7.450 16.000	4.650 9.950	*5.700 *12.550	3.850 8.450	10.150 400
0 mm 0"	kg lb			*7.850 *17.850	*7.850 *17.850	*18.550 *40.100	12.000 25.800	*13.350 *28.850	7.950 17.150	9.550 20.550	5.800 12.550	7.300 15.650	4.500 9.650	*6.200 *13.650	3.850 8.500	9.950 400
-1.500 mm -60"	kg lb	*8.200 *18.300	*8.200 *18.300	*12.400 *27.950	*12.400 *27.950	*18.750 *40.600	11.750 25.250	13.150 28.250	7.750 16.600	9.350 20.150	5.650 12.200	7.200 15.500	4.400 9.450	6.700 14.700	4.100 9.000	9.510 380
-3.000 mm -120"	kg lb	*13.150 *29.400	*13.150 *29.400	*18.150 *41.050	*18.150 *41.050	*17.950 *38.800	11.750 25.250	13.100 28.100	7.700 16.500	9.350 20.100	5.650 12.150			7.500 16.550	4.600 10.150	8.790 350
-4.500 mm -180"	kg lb	*18.950 *42.600	*18.950 *42.600	*22.150 *47.750	*22.150 *47.750	*15.950 *34.400	12.000 25.800	*12.100 *25.950	7.800 16.850	*9.050 *19.050	5.800 12.500			*8.600 *18.950	5.600 12.450	7.710 310
-6.000 mm -240"	kg lb					*12.100 *25.500	*12.100 *25.500	*8.550	8.250					*8.350 *18.200	8.100 *18.200	6.090 240



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La capacidad de levantamiento permanece en ± 5 % en todas las zapatas de cadena disponibles.

Consulte siempre el Manual de Operación y Mantenimiento apropiado para obtener información específica del producto.

# Especificaciones de la Excavadora Hidráulica 336D2/D2 L

## Capacidades de levantamiento de la pluma de alcance de servicio pesado – Tren de rodaje largo – Contrapeso: 6,0 mt (6,6 tons EE.UU.)

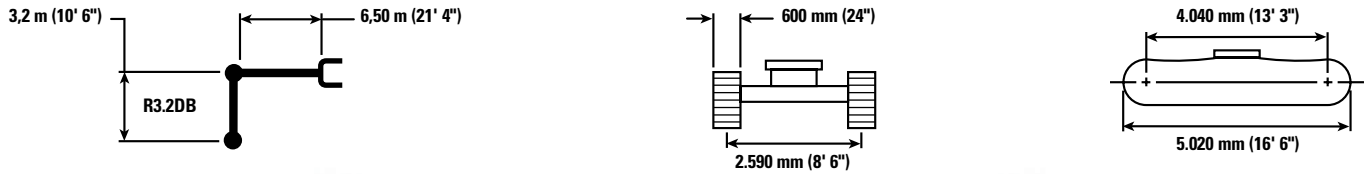


Diagrama de la pluma	3.000 mm/120"		4.500 mm/180"		6.000 mm/240"		7.500 mm/300"		9.000 mm/360"		Diagrama de la máquina		mm "
	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	
7.500 mm 300"							*7.750	6.950			*6.700	6.600	7.710
6.000 mm 240"							*7.850	6.900			*6.500	5.450	8.580
4.500 mm 180"			*12.050	*12.050	*9.650	9.450	*8.450	6.650	*7.700	4.900	*6.550	4.750	9.130
3.000 mm 120"			*15.200	13.400	*11.150	8.800	*9.200	6.350	7.600	4.750	*6.800	4.400	9.410
1.500 mm 60"			*17.500	12.400	*12.450	8.300	*9.800	6.050	7.450	4.600	6.950	4.300	9.440
0 mm 0"			*18.250	11.950	*13.250	7.950	9.550	5.800	7.350	4.500	7.100	4.350	9.220
-1.500 mm -60"	*13.250	*13.250	*17.850	11.850	13.250	7.800	9.450	5.700			7.600	4.650	8.750
-3.000 mm -120"	*20.900	*20.900	*16.550	12.000	*12.600	7.800	9.500	5.750			8.750	5.350	7.960
-4.500 mm -180"	*18.550	*18.550	*13.950	12.350	*10.550	8.050					*8.900	6.900	6.750
	*39.900	*39.900	*30.000	26.550	*22.450	17.400					*19.550	15.450	270



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\* Indica que la carga está limitada por la capacidad hidráulica de levantamiento y no por la carga de equilibrio. Las cargas anteriores cumplen con la norma ISO 10567:2007 para la capacidad de levantamiento de la excavadora hidráulica. No exceden el 87 % de la capacidad hidráulica de levantamiento ni el 75 % de la capacidad de carga límite de equilibrio. El peso de todos los accesorios de levantamiento debe restarse de las capacidades de levantamiento indicadas anteriormente. Las capacidades de levantamiento corresponden a una máquina en una superficie de apoyo firme y uniforme. El uso de un punto de sujeción del accesorio de la herramienta para manipular o levantar objetos puede afectar el rendimiento de levantamiento de la máquina.

La capacidad de levantamiento permanece en  $\pm 5\%$  en todas las zapatas de cadena disponibles.

Consulte siempre el Manual de Operación y Mantenimiento apropiado para obtener información específica del producto.

# Especificaciones de la Excavadora Hidráulica 336D2/D2 L

Capacidades de levantamiento de la pluma de alcance de servicio pesado – Tren de rodaje largo – Contrapeso: 6,0 mt (6,6 tons EE.UU.)

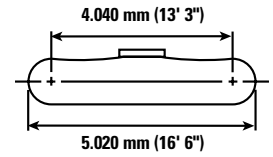
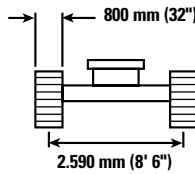
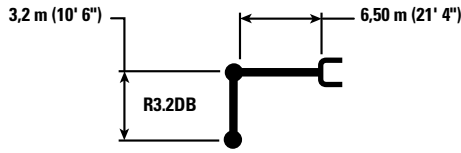


Diagrama de la herramienta	3.000 mm/120"		4.500 mm/180"		6.000 mm/240"		7.500 mm/300"		9.000 mm/360"		Diagrama de la excavadora		mm "
	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	
7.500 mm 300"							*7.750 17.200	7.150 15.150			*6.700 14.800	*6.700 14.800	7.710 300
6.000 mm 240"							*7.850 17.200	7.050 15.150			*6.500 14.300	5.550 12.400	8.580 340
4.500 mm 180"			*12.050 26.450	*12.050 26.450	*9.650 20.850	*9.650 20.800	*8.450 18.350	6.800 14.650	*7.700 16.800	5.050 10.500	*6.550 14.350	4.900 10.850	9.130 360
3.000 mm 120"			*15.200 32.650	13.700 29.600	*11.150 24.100	9.050 19.500	*9.200 19.950	6.500 14.000	7.800 16.800	4.900 10.500	*6.800 14.900	4.550 10.050	9.410 370
1.500 mm 60"			*17.500 37.700	12.700 27.400	*12.450 26.950	8.500 18.350	*9.950 21.550	6.200 13.350	7.650 16.450	4.750 10.200	7.150 15.700	4.400 9.700	9.440 380
0 mm 0"			*18.250 39.500	12.300 26.450	*13.250 28.650	8.150 17.600	9.850 21.150	6.000 12.900	7.550 16.250	4.650 10.000	7.300 16.050	4.500 9.900	9.220 370
-1.500 mm -60"	*13.250 29.900	*13.250 29.900	*17.850 38.700	12.200 26.250	*13.300 28.800	8.000 17.250	9.750 20.950	5.900 12.700			7.850 17.300	4.800 10.600	8.750 350
-3.000 mm -120"	*20.900 47.350	*20.900 47.350	*16.550 35.800	12.350 26.500	*12.600 27.150	8.050 17.350	*9.700 20.800	5.950 12.800			*8.850 19.550	5.500 12.200	7.960 320
-4.500 mm -180"	*18.550 39.900	*18.550 39.900	*13.950 30.000	12.650 27.250	*10.550 22.450	8.300 17.900					*8.900 19.550	7.100 15.900	6.750 270



ISO 10567



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La capacidad de levantamiento permanece en  $\pm 5\%$  en todas las zapatas de cadena disponibles.

Consulte siempre el Manual de Operación y Mantenimiento apropiado para obtener información específica del producto.

# Especificaciones de la Excavadora Hidráulica 336D2/D2 L

**Capacidades de levantamiento de la pluma de alcance de servicio pesado – Tren de rodaje largo – Contrapeso: 6,0 mt (6,6 tons EE.UU.)**

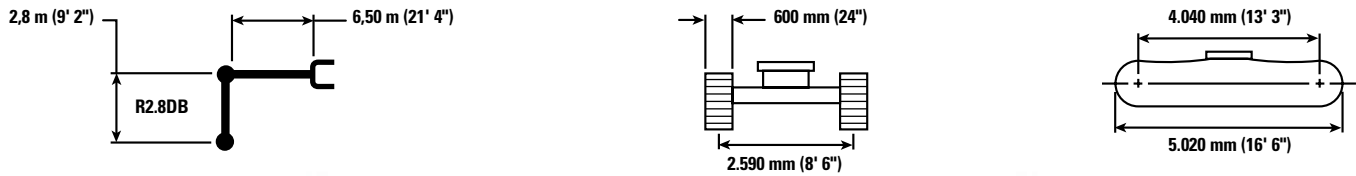


Diagram	3.000 mm/120"		4.500 mm/180"		6.000 mm/240"		7.500 mm/300"		9.000 mm/360"		Diagram		mm "		
	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb			
7.500 mm 300"													*8.400 *18.550	7.100 16.000	7.340 290
6.000 mm 240"					*9.000 *19.500	*9.000 *19.500	*8.350 *18.250	6.800 14.650					*8.150 *18.000	5.750 12.800	8.250 330
4.500 mm 180"			*13.000 *27.850	*13.000 *27.850	*10.200 *22.050	9.300 20.100	*8.850 *19.200	6.600 14.200					8.000 17.650	5.050 11.150	8.820 350
3.000 mm 120"			*16.100 *34.600	13.150 28.350	*11.650 *25.150	8.750 18.850	*9.550 *20.700	6.300 13.600	7.600	4.750			7.450 16.400	4.650 10.300	9.110 360
1.500 mm 60"			*15.900 *38.700	12.300 26.450	*12.850 *27.750	8.250 17.800	9.800 21.100	6.050 13.000	7.450	4.650			7.300 16.050	4.550 9.950	9.140 360
0 mm 0"			*18.300 *39.700	12.000 25.800	*13.450 *28.900	7.950 17.150	9.600 20.650	5.850 12.600					7.500 16.500	4.650 10.200	8.920 350
-1.500 mm -60"	*12.350 *28.100	*12.350 *28.100	*17.650 *38.250	12.000 25.800	*13.300 *28.650	7.850 16.950	9.550 20.500	5.800 12.500					8.100 17.900	5.000 11.000	8.420 340
-3.000 mm -120"	*21.050 *45.750	*21.050 *45.750	*16.000 *34.700	12.200 26.200	*12.300 *26.550	7.950 17.150	*9.300	5.900					*9.050 *19.950	5.800 12.900	7.600 300
-4.500 mm -180"	*16.750 *35.950	*16.750 *35.950	*13.000 *27.850	12.550 27.050	*9.650 *20.250	8.250 17.900							*8.800 *19.350	7.750 17.350	6.330 250



ISO 10567



\* Indica que la carga está limitada por la capacidad hidráulica de levantamiento y no por la carga de equilibrio. Las cargas anteriores cumplen con la norma ISO 10567:2007 para la capacidad de levantamiento de la excavadora hidráulica. No exceden el 87 % de la capacidad hidráulica de levantamiento ni el 75 % de la capacidad de carga límite de equilibrio. El peso de todos los accesorios de levantamiento debe restarse de las capacidades de levantamiento indicadas anteriormente. Las capacidades de levantamiento corresponden a una máquina en una superficie de apoyo firme y uniforme. El uso de un punto de sujeción del accesorio de la herramienta para manipular o levantar objetos puede afectar el rendimiento de levantamiento de la máquina.

La capacidad de levantamiento permanece en  $\pm 5\%$  en todas las zapatas de cadena disponibles.

Consulte siempre el Manual de Operación y Mantenimiento apropiado para obtener información específica del producto.

# Especificaciones de la Excavadora Hidráulica 336D2/D2 L

**Capacidades de levantamiento de la puma para excavación de gran volumen – Tren de rodaje largo – Contrapeso: 6,0 tons métricas (6,6 tons EE.UU.)**

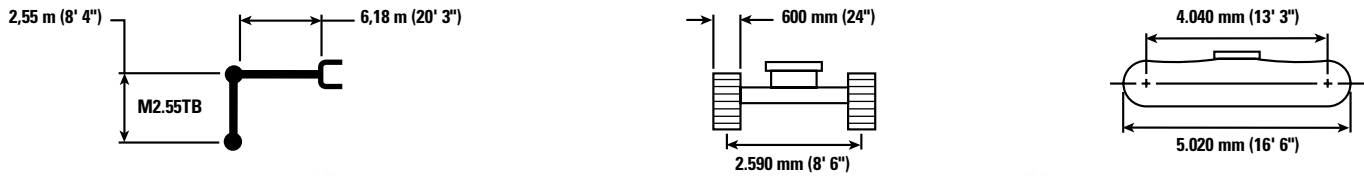


Diagrama de la puma	3.000 mm/120"		4.500 mm/180"		6.000 mm/240"		7.500 mm/300"		Diagrama de la puma		mm "
	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	
7.500 mm 300"					*9.250 *20.450	*9.250 *20.450			*8.300 *18.400	*8.300 *18.400	6.590 260
6.000 mm 240"					*9.600 *20.850	*9.600 *20.850	*9.050 6.650		*7.900 *17.450	6.550 14.550	7.600 300
4.500 mm 180"			*13.400 *28.750	*13.400 *28.750	*10.650 *23.050	9.250 19.900	*9.300 *20.300	6.500 14.000	*7.900 *17.400	5.600 12.400	8.210 330
3.000 mm 120"			*16.350 *35.150	13.150 28.350	*11.950 *25.900	8.700 18.750	*9.900 *21.500	6.250 13.500	*8.200 *18.050	5.150 11.350	8.520 340
1.500 mm 60"			*18.200 *39.250	12.350 26.550	*13.050 *28.250	8.250 17.750	9.750 21.000	6.050 12.950	8.050 17.700	5.000 11.000	8.550 340
0 mm 0"			*18.350 *39.800	12.050 25.950	13.450 28.900	8.000 17.200	9.600 20.650	5.850 12.650	8.300 18.250	5.100 11.250	8.310 330
-1.500 mm -60"	*16.900 *38.350	*16.900 *38.350	*17.450 *37.800	12.050 25.950	*13.200 *28.550	7.900 17.050	9.600 20.650	5.850 12.650	9.100 20.100	5.600 12.350	7.780 310
-3.000 mm -120"	*19.950 *43.300	*19.950 *43.300	*15.350 *33.200	12.300 26.400	*11.700 *25.100	8.050 17.350			*9.650 *21.200	6.750 14.950	6.880 270
-4.500 mm -180"			*11.250 *23.800	*11.250 *23.800					*8.900 *19.450	*8.900 *19.450	5.430 210



ISO 10567



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La capacidad de levantamiento permanece en  $\pm 5\%$  en todas las zapatas de cadena disponibles.

Consulte siempre el Manual de Operación y Mantenimiento apropiado para obtener información específica del producto.

# Especificaciones de la Excavadora Hidráulica 336D2/D2 L

**Capacidades de levantamiento de la pluma para excavación de gran volumen – Tren de rodaje largo – Contrapeso: 6,0 tons métricas (6,6 tons EE.UU.)**

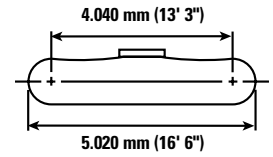
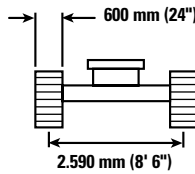
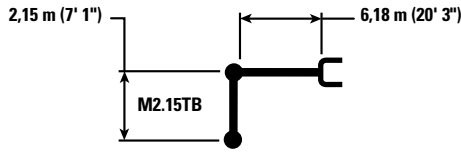


Diagram	3.000 mm/120"		4.500 mm/180"		6.000 mm/240"		7.500 mm/300"		Diagram		mm "
	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	kg lb	
7.500 mm 300"					*10.050 9.750				*10.050 22.300	9.650 21.950	6.030 240
6.000 mm 240"					*10.150 22.150	9.600 20.650			*9.700 21.350	7.200 16.100	7.120 280
4.500 mm 180"			*14.250 30.650	14.150 30.500	*11.150 24.150	9.150 19.750	*9.750 21.300	6.500 13.900	*9.600 21.150	6.100 13.500	7.780 310
3.000 mm 120"			*36.850 27.800		*12.400 26.800	8.650 18.600	*10.000 21.550	6.250 13.450	8.900 19.600	5.550 12.250	8.100 320
1.500 mm 60"					*13.350 28.850	8.200 17.700	9.800 21.050	6.050 13.000	8.700 19.100	5.400 11.850	8.140 320
0 mm 0"			*18.150 39.450	12.100 26.000	13.450 28.900	8.000 17.200	9.650 20.800	5.900 12.750	9.000 19.800	5.550 12.200	7.890 310
-1.500 mm -60"	*17.800 40.750	*17.800 40.750	*16.950 36.750	12.150 26.150	*13.000 28.100	8.000 17.200			10.050 22.150	6.150 13.550	7.320 290
-3.000 mm -120"	*17.950 39.050	*17.950 39.050	*14.500 31.350	12.450 26.750	*11.050 23.550	8.200 17.700			*10.100 22.250	7.600 16.950	6.360 250



ISO 10567



\* Indica que la carga está limitada por la capacidad hidráulica de levantamiento y no por la carga de equilibrio. Las cargas anteriores cumplen con la norma ISO 10567:2007 para la capacidad de levantamiento de la excavadora hidráulica. No exceden el 87 % de la capacidad hidráulica de levantamiento ni el 75 % de la capacidad de carga límite de equilibrio. El peso de todos los accesorios de levantamiento debe restarse de las capacidades de levantamiento indicadas anteriormente. Las capacidades de levantamiento corresponden a una máquina en una superficie de apoyo firme y uniforme. El uso de un punto de sujeción del accesorio de la herramienta para manipular o levantar objetos puede afectar el rendimiento de levantamiento de la máquina.

La capacidad de levantamiento permanece en  $\pm 5\%$  en todas las zapatas de cadena disponibles.

Consulte siempre el Manual de Operación y Mantenimiento apropiado para obtener información específica del producto.

# Especificaciones de la Excavadora Hidráulica 336D2/D2 L

## Guía de opciones de herramientas del modelo 336D2\*

Tipo de pluma	Alcance de servicio pesado			Gran volumen
Tamaño del brazo	R3.9DB	R3.2DB	R2.8DB	M2.55
Martillo hidráulico	H140Es H160Es	H140Es H160Es	H140Es H160Es	H140Es H160Es H180Es
Procesador múltiple	MP20 con mandíbula CC  MP20 con mandíbula CR MP20 con mandíbula PP MP20 con mandíbula PS MP20 con mandíbula S MP20 con mandíbula TS	MP20 con mandíbula CC  MP20 con mandíbula CR MP20 con mandíbula PP MP20 con mandíbula PS MP20 con mandíbula S MP20 con mandíbula TS	MP20 con todas las opciones de mandíbula MP30 con mandíbula CC MP30 con mandíbula CR MP30 con mandíbula PS	MP30 con mandíbula CC  MP30 con mandíbula CR MP30 con mandíbula PP MP30 con mandíbula PS MP30 con mandíbula S
Trituradora	P325	P325	P325 P335	P335
Pulverizador	P225	P225	P225 P235	P325
Garra de demolición y selección	G325B	G325B G330	G325B G330	G330
Cizalla móvil para chatarra y demolición	S325B	S325B	S325B	S365C
Compactador (placas vibratorias)	CVP110	CVP110	CVP110	CVP110
Garfio de contratista	G130B	G130B	G130B	
Garfio para basura				
Tenazas				
Garfios Orange Peel				
Rastrillos				
Acoplador Center-Lock				
Acoplador rápido CW				

Se encuentran disponibles las siguientes herramientas para el modelo 336D2. Consulte a su distribuidor Cat para conocer la opción compatible adecuada.

## Guía de opciones de herramientas del modelo 336D2 L\*

Tipo de pluma	Alcance de servicio pesado			Gran volumen
Tamaño del brazo	R3.9DB	R3.2DB	R2.8DB	M2.55
Martillo hidráulico	H140Es H160Es	H140Es H160Es	H140Es H160Es H180Es	H140Es H160Es H180Es
Procesador múltiple	MP20 con mandíbula CC  MP20 con mandíbula CR MP20 con mandíbula PP MP20 con mandíbula PS MP20 con mandíbula S MP20 con mandíbula TS	MP20 con todas las opciones de mandíbula MP30 con mandíbula CC MP30 con mandíbula CR MP30 con mandíbula PS MP30 con mandíbula S	MP20 con todas las opciones de mandíbula MP30 con mandíbula CC MP30 con mandíbula CR MP30 con mandíbula PS MP30 con mandíbula S	MP30 con mandíbula CC  MP30 con mandíbula CR MP30 con mandíbula PP MP30 con mandíbula PS MP30 con mandíbula S MP30 con mandíbula TS
Trituradora	P325	P325 P335	P325 P335	P335
Pulverizador	P225	P225 P235	P225 P235	P325
Garra de demolición y selección	G325B	G325B G330	G325B G330	G330
Cizalla móvil para chatarra y demolición	S325B	S325B	S325B	S365C
Compactador (placas vibratorias)	CVP110	CVP110	CVP110	CVP110
Garfio de contratista	G130B	G130B	G130B	
Garfio para basura				
Tenazas				
Garfios Orange Peel				
Rastrillos				
Acoplador Center-Lock				
Acoplador rápido CW				

Se encuentran disponibles las siguientes herramientas para el modelo 336D2 L. Consulte a su distribuidor Cat para conocer la opción compatible adecuada.

\*Las ofertas pueden no estar disponibles en todas las áreas.

Las compatibilidades dependen de la configuración de la excavadora, con pasador o con instalación de acoplador rápido, montadas en el brazo o en la pluma, trabajo sobre la parte delantera o la parte lateral.

Consulte a su distribuidor Cat para determinar lo que se ofrece en su área y para obtener la compatibilidad de herramienta adecuada.

# Especificaciones de la Excavadora Hidráulica 336D2/D2 L

## Especificaciones y compatibilidad del cucharón

	Varillaje	Ancho		Capacidad		Peso		Llenado	336D2				336D2 L				
		mm	"	m³	yd³	kg	lb		%	Pluma de alcance HD		Pluma para excavación de gran volumen		Pluma de alcance HD		Pluma para excavación de gran volumen	
										Brazo R3.2DB (10' 6")	Brazo R2.8DB (9' 2")	Brazo M2.55TB (8' 4")	Brazo M2.15TB (7' 1")	Brazo R3.2DB (10' 6")	Brazo R2.8DB (9' 2")	Brazo M2.55TB (8' 4")	Brazo M2.15TB (7' 1")
										Zapatos de cadena de 600 mm (24")				Zapatos de cadena de 600 mm (24")			
<b>Varillaje DB sin acoplador rápido</b>																	
Servicio general (GD)	DB	1.350	53	1,64	2,14	1.173	2.585	100 %	●	●			●	●			
	DB	1.650	65	2,11	2,76	1.352	2.979	100 %	○	○			●	●			
	DB	1.800	71	2,35	3,08	1.453	3.202	100 %	○	○			○	○			
	TB	1.500	60	2,14	2,80	1.872	4.126	100 %			○	●			●	●	
	TB	1.650	66	2,41	3,16	2.027	4.468	100 %			○	○			○	○	
Servicio general (GDC)	DB	750	30	0,94	1,23	952	2.099	100 %	●	●			●	●			
	DB	900	36	1,19	1,56	1.040	2.292	100 %	●	●			●	●			
	DB	1.050	42	1,46	1,91	1.147	2.528	100 %	●	●			●	●			
	DB	1.200	48	1,73	2,26	1.232	2.716	100 %	●	●			●	●			
	DB	1.350	54	2,00	2,62	1.342	2.957	100 %	○	○			●	●			
	DB	1.500	60	2,27	2,98	1.451	3.197	100 %	○	○			○	○			
	DB	1.650	66	2,55	3,33	1.536	3.386	100 %	◇	◇			○	○			
Servicio pesado (HD)	DB	750	30	0,73	0,95	1.031	2.273	100 %	●	●			●	●			
	DB	900	36	0,95	1,24	1.178	2.595	100 %	●	●			●	●			
	DB	1.050	42	1,17	1,54	1.267	2.793	100 %	●	●			●	●			
	DB	1.200	48	1,40	1,84	1.398	3.080	100 %	●	●			●	●			
	DB	1.350	54	1,64	2,14	1.481	3.265	100 %	○	○			●	●			
	DB	1.350	54	1,64	2,14	1.459	3.215	100 %	○	○			●	●			
	DB	1.500	60	1,88	2,46	1.600	3.526	100 %	○	○			●	●			
	DB	1.500	60	1,88	2,46	1.566	3.452	100 %	○	○			●	●			
	DB	1.650	66	2,12	2,77	1.730	3.814	100 %	○	○			○	○			
	DB	1.650	66	2,12	2,77	1.697	3.740	100 %	○	○			○	○			
	DB	1.800	72	2,36	3,08	1.851	4.080	100 %	◇	◇			○	○			
	TB	1.650	66	2,41	3,16	2.210	4.871	100 %			○	○			○	○	
	TB	1.800	72	2,69	3,52	2.423	5.340	100 %			◇	○			○	○	
	TB	1.800	72	2,69	3,52	2.381	5.248	100 %			◇	○			○	○	
Servicio exigente (SD)	DB	750	30	0,73	0,95	1.096	2.415	90 %	●	●			●	●			
	DB	900	36	0,95	1,24	1.252	2.760	90 %	●	●			●	●			
	DB	1.050	42	1,17	1,54	1.353	2.981	90 %	●	●			●	●			
	DB	1.200	48	1,40	1,84	1.493	3.292	90 %	●	●			●	●			
	DB	1.350	54	1,64	2,14	1.599	3.524	90 %	●	●			●	●			
	DB	1.650	66	2,15	2,81	1.827	4.028	90 %	○	○			○	○			
	TB	1.350	54	1,87	2,44	2.065	4.551	90 %			○	●			●	●	
	TB	1.650	66	2,41	3,16	2.385	5.257	90 %			○	○			○	○	
	TB	1.750	69	2,40	3,14	2.454	5.409	90 %			○	○			○	○	
Potencia para servicio exigente (SDP)	TB	1.750	69	2,40	3,14	2.454	5.409	90 %			○	○			○	○	
Potencia para servicio extremo (XDP)	TB	1.550	61	2,00	2,59	2.516	5.545	90 %			○	○			○	○	
Carga máxima con pasador (carga útil + cucharón)								kg	4.240	4.405	5.145	5.765	5.160	5.365	5.535	6.065	
								lb	9.345	9.709	11.340	12.706	11.373	11.824	12.199	13.367	

Las cargas anteriores cumplen con la norma EN474 para excavadoras hidráulicas, ya que no exceden el 87 % de la capacidad de levantamiento hidráulica ni el 75 % de la capacidad de equilibrio con el varillaje delantero completamente extendido en la línea a nivel del suelo con el cucharón plegado.

La capacidad se basa en la norma ISO 7451.

Peso del cucharón con puntas de servicio general.

### Densidad máxima de material:

- 2.100 kg/m³ (3.500 lb/yd³)
- 1.200 kg/m³ (2.000 lb/yd³)
- 1.800 kg/m³ (3.000 lb/yd³)
- ◇ 900 kg/m³ (1.500 lb/yd³)
- 1.500 kg/m³ (2.500 lb/yd³)
- X No se recomienda



# Especificaciones de la Excavadora Hidráulica 336D2/D2 L

## Especificaciones y compatibilidad del cucharón

	Varillaje	Ancho		Capacidad		Peso		Llenado	336D2				336D2 L				
		mm	"	m³	yd³	kg	lb		%	Pluma de alcance HD		Pluma para excavación de gran volumen		Pluma de alcance HD		Pluma para excavación de gran volumen	
										Brazo R3.2DB (10' 6")	Brazo R2.8DB (9' 2")	Brazo M2.55TB (8' 4")	Brazo M2.15TB (7' 1")	Brazo R3.2DB (10' 6")	Brazo R2.8DB (9' 2")	Brazo M2.55TB (8' 4")	Brazo M2.15TB (7' 1")
									Zapatos de cadena de 600 mm (24")				Zapatos de cadena de 600 mm (24")				
<b>Varillaje DB con acoplador rápido Center-Lock</b>																	
Servicio general (GD)	DB	1.350	53	1,64	2,14	1.173	2.585	100 %	⊖	⊖			●	●			
	DB	1.650	65	2,11	2,76	1.352	2.979	100 %	◇	○			⊖	⊖			
	DB	1.800	71	2,35	3,08	1.453	3.202	100 %	◇	◇			○	⊖			
	TB	1.500	60	2,14	2,80	1.872	4.126	100 %			○	⊖			⊖	⊖	
	TB	1.650	66	2,41	3,16	2.027	4.468	100 %			◇	○			○	⊖	
Servicio general (GDC)	DB	750	30	0,94	1,23	952	2.099	100 %	●	●			●	●			
	DB	900	36	1,19	1,56	1.040	2.292	100 %	●	●			●	●			
	DB	1.050	42	1,46	1,91	1.147	2.528	100 %	⊙	⊙			●	●			
	DB	1.200	48	1,73	2,26	1.232	2.716	100 %	○	⊖			⊙	●			
	DB	1.350	54	2,00	2,62	1.342	2.957	100 %	○	○			⊖	⊙			
	DB	1.500	60	2,27	2,98	1.451	3.197	100 %	◇	◇			○	⊖			
	DB	1.650	66	2,55	3,33	1.536	3.386	100 %	⊖	◇			○	○			
Servicio pesado (HD)	DB	750	30	0,73	0,95	1.031	2.273	100 %	●	●			●	●			
	DB	900	36	0,95	1,24	1.178	2.595	100 %	●	●			●	●			
	DB	1.050	42	1,17	1,54	1.267	2.793	100 %	●	●			●	●			
	DB	1.200	48	1,40	1,84	1.398	3.080	100 %	⊖	⊙			●	●			
	DB	1.350	54	1,64	2,14	1.481	3.265	100 %	○	⊖			⊙	●			
	DB	1.350	54	1,64	2,14	1.459	3.215	100 %	○	⊖			⊙	●			
	DB	1.500	60	1,88	2,46	1.600	3.526	100 %	◇	○			⊖	⊖			
	DB	1.500	60	1,88	2,46	1.566	3.452	100 %	◇	○			⊖	⊙			
	DB	1.650	66	2,12	2,77	1.730	3.814	100 %	◇	◇			○	⊖			
	DB	1.650	66	2,12	2,77	1.697	3.740	100 %	◇	◇			○	⊖			
	DB	1.800	72	2,36	3,08	1.851	4.080	100 %	⊖	⊖			○	○			
	TB	1.650	66	2,41	3,16	2.210	4.871	100 %			◇	○			○	○	
	TB	1.800	72	2,69	3,52	2.423	5.340	100 %			⊖	◇			◇	○	
	TB	1.800	72	2,69	3,52	2.381	5.248	100 %			⊖	◇			◇	○	
	Servicio exigente (SD)	DB	750	30	0,73	0,95	1.096	2.415	90 %	●	●			●	●		
DB		900	36	0,95	1,24	1.252	2.760	90 %	●	●			●	●			
DB		1.050	42	1,17	1,54	1.353	2.981	90 %	●	●			●	●			
DB		1.200	48	1,40	1,84	1.493	3.292	90 %	⊙	⊙			●	●			
DB		1.350	54	1,64	2,14	1.599	3.524	90 %	○	⊖			●	●			
DB		1.650	66	2,15	2,81	1.827	4.028	90 %	◇	◇			⊖	⊖			
TB		1.350	54	1,87	2,44	2.065	4.551	90 %			⊖	⊙			⊙	●	
TB		1.650	66	2,41	3,16	2.385	5.257	90 %			◇	○			○	⊖	
TB		1.750	69	2,40	3,14	2.454	5.409	90 %			◇	○			○	○	
Potencia para servicio exigente (SDP)	TB	1.550	61	2,00	2,59	2.516	5.545	90 %			○	⊖			○	⊖	
Carga máxima con acoplador (carga útil + cucharón)									kg	3.682	3.847	4.587	5.207	4.602	4.807	4.977	5.507
									lb	8.115	8.479	10.110	11.476	10.143	10.594	10.969	12.137

Las cargas anteriores cumplen con la norma EN474 para excavadoras hidráulicas, ya que no exceden el 87 % de la capacidad de levantamiento hidráulica ni el 75 % de la capacidad de equilibrio con el varillaje delantero completamente extendido en la línea a nivel del suelo con el cucharón plegado.

La capacidad se basa en la norma ISO 7451.

Peso del cucharón con puntas de servicio general.

### Densidad máxima de material:

- 2.100 kg/m³ (3.500 lb/yd³)
- ⊙ 1.800 kg/m³ (3.000 lb/yd³)
- 1.200 kg/m³ (2.000 lb/yd³)
- ◇ 900 kg/m³ (1.500 lb/yd³)
- ⊖ 1.500 kg/m³ (2.500 lb/yd³)
- X No se recomienda

# Especificaciones de la Excavadora Hidráulica 336D2/D2 L

## Especificaciones y compatibilidad del cucharón

	Varillaje									336D2				336D2 L			
		Ancho		Capacidad		Peso		Llenado	Pluma de alcance HD		Pluma para excavación de gran volumen		Pluma de alcance HD		Pluma para excavación de gran volumen		
		mm	"	m³	yd³	kg	lb		%	Brazo R3.2DB (10' 6")	Brazo R2.8DB (9' 2")	Brazo M2.55TB (8' 4")	Brazo M2.15TB (7' 1")	Brazo R3.2DB (10' 6")	Brazo R2.8DB (9' 2")	Brazo M2.55TB (8' 4")	Brazo M2.15TB (7' 1")
										Zapatillas de cadena de 600 mm (24")				Zapatillas de cadena de 600 mm (24")			
<b>Con acoplador rápido (CW45, CW45s)</b>																	
Servicio general (GD)	DB	1.050	41	1,17	1,53	986	2.172	100 %	●	●			●	●			
	DB	1.200	47	1,40	1,83	1.064	2.345	100 %	⊙	●			●	●			
	DB	1.350	53	1,64	2,14	1.143	2.519	100 %	⊖	⊖			●	●			
	DB	1.500	59	1,87	2,45	1.245	2.745	100 %	○	⊖			⊙	⊙			
	DB	1.650	65	2,11	2,76	1.324	2.918	100 %	○	○			⊖	⊖			
Servicio pesado (HD)	DB	1.350	54	1,64	2,14	1.417	3.122	100 %	○	⊖			⊙	●			
	DB	1.500	60	1,88	2,46	1.514	3.337	100 %	○	○			⊖	⊙			
	DB	1.650	66	2,12	2,77	1.647	3.629	100 %	◇	◇			⊖	⊖			
	TB	1.650	66	2,41	3,16	2.117	4.666	100 %			◇	○			○	⊖	
Servicio exigente (SD)	DB	1.050	42	1,17	1,54	1.272	2.803	90 %	●	●			●	●			
	DB	1.650	66	2,15	2,81	1.802	3.971	90 %	◇	◇			⊖	⊖			
	TB	1.350	54	1,87	2,44	1.974	4.351	90 %			●	⊙			⊙	●	
	TB	1.650	66	2,41	3,16	2.295	5.058	90 %			◇	○			○	⊖	
Carga máxima con acoplador (carga útil + cucharón)								kg	3.750	3.915	4.640	5.260	4.670	4.875	5.030	5.560	
								lb	8.265	8.629	10.227	11.593	10.293	10.745	11.086	12.254	

Las cargas anteriores cumplen con la norma EN474 para excavadoras hidráulicas, ya que no exceden el 87 % de la capacidad de levantamiento hidráulica ni el 75 % de la capacidad de equilibrio con el varillaje delantero completamente extendido en la línea a nivel del suelo con el cucharón plegado.

La capacidad se basa en la norma ISO 7451.

Peso del cucharón con puntas de servicio general.

### Densidad máxima de material:

- 2.100 kg/m³ (3.500 lb/yd³)
- ⊙ 1.800 kg/m³ (3.000 lb/yd³)
- ⊖ 1.500 kg/m³ (2.500 lb/yd³)
- 1.200 kg/m³ (2.000 lb/yd³)
- ◇ 900 kg/m³ (1.500 lb/yd³)
- X No se recomienda

## Equipos estándar

Los equipos estándar pueden variar. Consulte a su distribuidor Cat para obtener más información.

### MOTOR

- Motor Diesel C9 ACERT
- Capacidad de altitud de 2.300 m (7.546')
- Alternador de 65 amperios
- Calentador de admisión de aire
- Versión de alta potencia con modalidad de administración de potencia
- Filtros de aire de sello radial (filtros primario y secundario)
- Control automático de velocidad del motor
- Separador de agua con sensor indicador del nivel de agua
- Radiador de la aleta de onda con espacio para permitir la limpieza
- Dos velocidades de desplazamiento
- Filtros de combustible de dos (2) micrones
- Bomba eléctrica de cebado

### SISTEMA HIDRÁULICO

- Capacidad de instalación de válvulas y circuitos adicionales
- Circuitos de recuperación para pluma y brazo
- Válvula de amortiguación de la rotación inversa
- Freno automático de estacionamiento de la rotación

### CABINA

- Cinturón de seguridad retráctil (51 mm [2"]; 76 mm [3"] de ancho)
- Parabrisas delantero dividido en 70/30
- Parabrisas delantero superior laminado y las otras ventanas templadas
- Ventana de puerta superior corrediza
- Aire acondicionado de dos niveles (automático) con desempañador (cabina presurizada)
- Pantalla LCD a color, con información de advertencia, cambio de filtro/fluido y horas trabajadas
- Palanca neutral (de traba) para todos los controles
- Pedales de control de desplazamiento con palancas manuales removibles
- Montaje de radio (tamaño DIN)
- Suministro de corriente de 10 A con máximo de 12 V – 2×
- Dos altavoces estéreo
- Portavasos
- Gancho para ropa, cenicero, portadocumentos
- Tragaluz con posibilidad de apertura
- Alfombra de piso lavable

### TREN DE RODAJE

- Protectores guía de cadena de la rueda loca y la sección central
- Cáncamo de remolque en bastidor básico
- Cadenas lubricadas con grasa GLT2, sello de resina

### SISTEMA ELÉCTRICO

- Disyuntor
- Luz, montada en la pluma, izquierda y derecha
- Luz, montada en la caja de almacenamiento

### SEGURIDAD

- Sistema de seguridad Cat de una sola llave
- Cerraduras en las puertas y compartimiento
- Bocina de señalización/advertencia
- Espejos retrovisores
- Interruptor de corte del motor de emergencia
- Ventana trasera de salida de emergencia
- Capacidad de conexión de una baliza

### CONTRAPESO

- Contrapeso de 6,0 tons métricas (6,6 tons EE.UU.)

## Equipos optativos

Los equipos optativos pueden variar. Consulte a su distribuidor Cat para obtener más información.

### PIEZAS DELANTERAS

- Pluma de alcance de servicio pesado
  - Brazo R3.9DB
  - Brazo R3.2DB
  - Brazo R2.8DB
- Pluma para excavación de gran volumen
  - Brazo M2.55TB
  - Brazo M2.15TB
- Varillaje del cucharón
  - Varillaje del cucharón DB (con o sin cáncamo de levantamiento)
  - Varillaje del cucharón TB (con o sin cáncamo de levantamiento)

### TREN DE RODAJE

- Protector inferior de servicio pesado
- Protector de la unión giratoria estándar o de servicio pesado
- Protector del motor de desplazamiento de servicio pesado
- Protectores de guía para toda la longitud de la cadena
- FOGS (Falling Object Guarding System, Sistema de protección contra la caída de objetos), empernado
- Cadenas de garra triple de 600 mm, 700 mm, 800 mm (24", 28", 32")

### SISTEMA HIDRÁULICO

- Tuberías de alta presión para plumas y brazos
- Tuberías de presión media para plumas y brazos
- Tuberías para la pluma, el brazo y el acoplador rápido
- Dispositivo de control de bajada de la pluma/brazo
- Circuito de acoplador rápido
- Control de rotación precisa
- Aceite biodegradable

### CABINA

- Asiento con suspensión mecánica y posacabeza
- Asiento con suspensión neumática, posacabeza y calentador
- Suministro de corriente de 12 V y 10 A con dos (2) enchufes tipo encendedor de cigarrillos
- Protector contra la lluvia en el parabrisas delantero
- Radio AM/FM
- Cambiador rápido del patrón de control
- Tercer pedal para desplazamiento recto

### OTROS EQUIPOS OPTATIVOS

- Alarma de desplazamiento
- Juego de arranque para tiempo frío
- Bomba eléctrica para el reabastecimiento de combustible con corte automático

### TECNOLOGÍAS INTEGRADAS

- Cámara de visión trasera
- Listo para instalación de accesorio AccuGrade™
- Cat Product Link™



Para obtener más información sobre los productos Cat, los servicios del distribuidor y las soluciones de la industria, visítenos en [www.cat.com](http://www.cat.com)

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