UNIVERSIDAD CATÓLICA SANTA MARIA

FACULTAD DE CIENCIAS E INGENIERIAS FÍSICAS Y FORMALES

PROGRAMA PROFESIONAL DE INGENIERIA MECÁNICA, MECÁNICA ELECTRICA Y MECATRÓNICA

TESIS
“ANALISIS DE LAS PROPIEDADES MECÁNICAS DE UN ACERO ESTRUCTURAL A - 36 QUE PRESENTA FASES DOBLES”.

Tesis presentada por:
BACH. PLETICKOSICH LOPEZ JOSIPH
Para optar el Título Profesional de
Ingeniero MECÁNICO ELECTRICISTA

AREQUIPA – PERÚ

2014

El presente proyecto de investigación quiero dedicarle a Dios todopoderoso que ilumina cada día mi camino.

A mi papá Alejandro, sé que me encuentro en cada pensamiento suyo.

A mamá Cristina que es mi motor y me da el empuje cada día de mi vida, a mis hermanitos Jianphier y Jefferson, que pasamos y pasaremos muchas aventuras juntos, a mi nueva hermana Romy.

A mis Ingenieros que gracias a ellos soy un profesional, no les decepcionare.

A mi vocecita que me sigue todos los días haciendo que sea mejor, y como no agradecer a mis dos grandes amigos Homero y Juan Pablo, decirles lo logramos muchachos.

Josiph P.

RESUMEN

Los aceros de doble fase presentan excelentes alternativas en la industria automotriz y han proporcionado progresos significativos en seguridad, ahorro de combustible, alta resistencia mecánica al impacto, elongación elevada y confort.

La presente investigación demuestra que el acero estructural ASTM A-36 puede presentar una microestructura de doble fase (martensita - ferrita). Este objetivo ha sido alcanzado a través de la demostración de los principios de la metalurgia y la iteración de las distintas variables para obtener una combinación martensita – ferrita.

Asimismo, se han realizado diferentes ensayos mecánicos de acuerdo a normas específicas, y poder determinar las variables más influyentes. Finalmente, se ha obtenido parámetros óptimos para que el acero estructural ASTM A-36 cuente con una fase doble en su microestructura.

ABSTRACT

The dual-phase steels offer excellent alternatives in the car industry and it had provided a great step forward in safety, fuel economy, high mechanical resistance to impact, high rate of lengthening and comfort.

This research expounds that the structural ASTM A-36 steels can present a dual-phase microstructure (martensite - ferrite). This objective has been achieved through the proof of the metallurgy principles and the iteration of the most influential different variable to obtain a martensite - ferrite combination.

Also, mechanic assays were carried out according to special regulations, and power determine the most influential variable. Finally, ideal parameters were obtained for that the structural ASTM A-36 steel counts with dual-phase in his structure.

INTRODUCCIÓN

En los últimos años, los investigadores en el área de Ingeniería de Materiales se han abocado a la búsqueda del “material perfecto” vinculado con la disminución de peso y aumento de la seguridad en los vehículos, esta tarea es actual y especialmente en la industria automotriz que se refleja en menor consumo de combustible. En este sentido los Aceros de Alta Resistencia y Baja Aleación (AHSS) han capturado su atención; sin embargo, junto con las ventajas que proveen estos nuevos aceros surge la necesidad de generar conocimiento sobre su conformabilidad y soldabilidad. Dentro de los aceros de alta resistencia avanzados se tienen dos familias.

La primera es la de los aceros de alta resistencia con una mayor conformabilidad para diseños que involucren partes más complejas. Estos son los aceros denominados *Dual Phase* (DP) y los aceros con Transformación Inducida por Plasticidad (TRIP).Los aceros *Dual Phase* (DP) consisten en una matriz ferrítica que contiene una fracción variable de fase martensítica de alta dureza. La fracción de la segunda fase martensítica aumenta con el aumento de la resistencia deseada del acero. La fase ferrítica blanda es generalmente continua, proveyendo una excelente ductilidad.

Cuando estos aceros se conforman, la deformación se concentra en la fase ferrítica blanda, rodeando las “islas” de martensita, generando una alta tasa de

endurecimiento por deformación para estos materiales[1] [2] [3]. Esto sumando a un excelente alargamiento a rotura provee a estos aceros de una mayor resistencia a la tracción que aceros convencionales con similar límite de fluencia.

Los aceros DP también presentan un efecto de *bake hardening* que se constituye en un beneficio importante en relación a otros aceros convencionales[1] [2].En estos aceros, el carbono permite la formación de martensita a velocidades de enfriamiento aceptables, debido a su efecto en la templabilidad del material. A su vez, Manganeso, Cromo, Molibdeno, Vanadio y Níquel incorporados también aumentan la templabilidad[2].

A su vez, el tamaño de grano de la matriz ferrítica es otro de los parámetros que controlan el endurecimiento y la buena tenacidad de estos materiales[2].Estos aceros de última generación se aplican en partes estructurales para la industria automotriz presentando una alta resistencia mecánica del orden de 600 a 1000 MPa, manteniendo buena conformabilidad. Sin embargo existen diversos materiales base (aceros micro aleados, aceros de grano ultra fino, aceros al Carbono – Manganeso, etc.) a partir de los cuales pueden obtenerse dichos aceros DP, siendo escasos los estudios sistemáticos realizados al respecto[1].

---

[1] Iron and Steel Institute, “Advanced High Strenght Steels (AHSS): Application Guidelines”, Iron and Steel Institute, Committee of Automotive Applications, 2005

[2] M. Delince, Y. Brechet, J.D. Embury, M.G.D. Geers, P.J. Jacques, T. Pardo, “Structure–property optimization of ultrafine-grained dual-phase steels using a microstructure-based strain hardening model”, Acta Materialia 55, 2007, pp. 2337-2350.

[3] S. Oliver, T.B. Jones, G. Fourlaris, “Dual phase versus TRIP strip steels: Microstructural changes as a consequence of quasi-static and dynamic tensile testing”, Materials Characterization, 58, 2007, pp. 390-400.

ÍNDICE

CAPITULO I

ANTECEDENTES GENERALES

1.1. ANTECEDENTES

En los últimos años el departamento de ingeniería de materiales ha tenido numerosos estudios relacionados con la tecnología de los aceros en especial con *dual phase.* Esto ya que la demanda del mercado automotriz así lo requiere: “Aceros de bajo carbono sin aleantes y que cumplan con buena deformabilidad”.

Entre los estudios recientes tenemos a Joel Guajardo Zygmunt Haduch quien expuso el tema “Aceros de construcción de propiedades especiales” en el 8º Congreso iberoamericano de ingeniería mecánica desarrollado en Cusco del 23 al 25 de Octubre del 2007. El autor expone que existen novedades en el diseño de aceros de propiedades especiales, de alta resistencia, deformabilidad y excelente soldabilidad, que sobrepasan los otros tipos de aceros, lo que es el futuro en la aplicación de aceros de construcción. Así, señala que se han elaborado varios tipos de aceros que unen estas propiedades de plasticidad y alta resistencia. Estos aceros son los HSLA, TRIP. Varias compañías automotrices, entre ellas Toyota, ya fabrican carrocerías en sus automóviles con 30% mayor resistencia y disminución de peso.

Asimismo, A. Monsalve G., A. Artigas A. y otros, en el estudio "Caracterización de aceros *dual-phase* obtenidos por laminación" publicado en la Revista de Metalurgia, 47 (1) en Enero – Febrero 05-14, 2011 indican que se tomaron aceros que se encuentran en el mercado con contenido de manganeso, cromo, molibdeno, vanadio y níquel incorporados que, mediante una laminación en caliente y bobinado dieron como resultado aceros *dual phase* con propiedades y rangos. En este proceso se elevaron las temperaturas y como resultado indican que es posible producir leves mejoras en el índice de anisotropía normal mediante una apropiada combinación de temperaturas de término de laminación y bobinado.

Finalmente, la revista Cesvimap 54 de Diciembre del 2005 publica el artículo de Pablo López Izquierdo. Este trabajo menciona la utilización de aceros *dual phase* en las carrocerías de automóviles.

1.2. PLANTEAMIENTO DEL PROBLEMA

Hoy en día existen numerosos estudios relacionados con la formación de fases dobles y su efecto sobre las propiedades mecánicas del material. Hay necesidad de saber cómo se comporta mecánicamente el acero estructural (America Society for Testing and Materials) ASTM A-36 cuando es sometido a un tratamiento térmico a temperaturas intercríticas A1 (725°C) ; A3 (850°C) y templadas.

Para este propósito es necesario realizar el temple de nuestras muestras de acero ASTM A – 36 en agua con temperaturas de 1°C a 17°C para poder pasar después a una evaluación de su comportamiento mecánico. Se consideraron las siguientes variables: Temperatura de calentamiento, temperatura del medio del temple, tiempo de temple, tiempo de calentamiento y velocidad del temple.

1.3. HIPÓTESIS

Dado que es posible obtener aceros de “doble fase” por la presencia de dos fases en la micro estructura del acero (ferrita y martensita) además de otras fases dispersas en menor relación (vainita, perlita y austenita retenida) mediante el recocido a temperaturas intercríticas (A1 ; A3) para aceros de bajo contenido de carbono (menor a 0.83 %C); es probable que se obtenga un material con una excelente combinación de resistencia, dureza y sin dejar de la lado la ductibilidad.

1.4. JUSTIFICACIÓN DE LA INVESTIGACIÓN

La investigación es importante porque:

- Permite conocer un nuevo material para su aplicación en diversas industrias, por ejemplo la automotriz.

- Permite conocer materiales que presentan propiedades de alta resistencia mecánica.

- Desarrolla un marco teórico necesario para la discusión y el debate en torno a materiales con propiedades de alta resistencia.

1.5. OBJETIVOS

1.5.1. OBJETIVO GENERAL

Determinar las propiedades mecánicas de un acero ASTM A – 36 que presenta en su microestructura fases dobles.

1.5.2. OBJETIVOS ESPECIFICOS

- Evaluar las variables que afectan la formación de martensita y ferrita (fases dobles) y el efecto en las propiedades mecánicas del acero estructural ASTM A - 36.

- Determinar las pruebas mecánicas necesarias para describir las propiedades de un acero ASTM A – 36 que presenta fases dobles.

- Demostrar que se puede obtener una buena combinación de resistencia y ductibilidad en un acero estructural ASTM A – 36 que presenta doble fase.

CAPITULO II

MARCO TEORICO

2.1. EL ACERO

El acero es una aleación de hierro con pequeñas cantidades de otros elementos, es decir, hierro combinado con aproximadamente 2% de carbono como máximo, que hecho ascua[1] y sumergido en agua fría adquiere por el temple gran dureza y elasticidad. Hay aceros especiales que contienen además, en pequeñísima proporción, cromo, níquel, titanio, volframio o vanadio.

El acero se caracteriza por tener una gran resistencia, contrariamente a lo que ocurre con el hierro. Ya que este resiste muy poco a la deformación plástica, por estar constituido solo con cristales de ferrita; cuando se alea con carbono, se forman estructuras cristalinas diferentes, que permiten un gran incremento de su resistencia.

Ésta cualidad del acero y la abundancia de hierro le colocan en un lugar preeminente, constituyendo el material básico del siglo XX. Un 92% de todos los aceros es simple acero al carbono; el resto es acero aleado: aleaciones de hierro con carbono y otros elementos tales como magnesio, níquel, cromo, molibdeno y vanadio.

[1] Pedazo de cualquier materia sólida y combustible que por la acción del fuego se pone incandescente y sin llama. Diccionario RAE

2.1.1. ESTRUCURA DEL ACERO

La gran mayoría de los metales por su naturaleza son cristalinos. En el proceso de la solidificación del acero, se forman en pequeños granos o cristales los que se encuentran compuestos por un patrón de átomos definido ya que a una temperatura determinada los átomos están espaciados una distancia definida y estas no cambian.

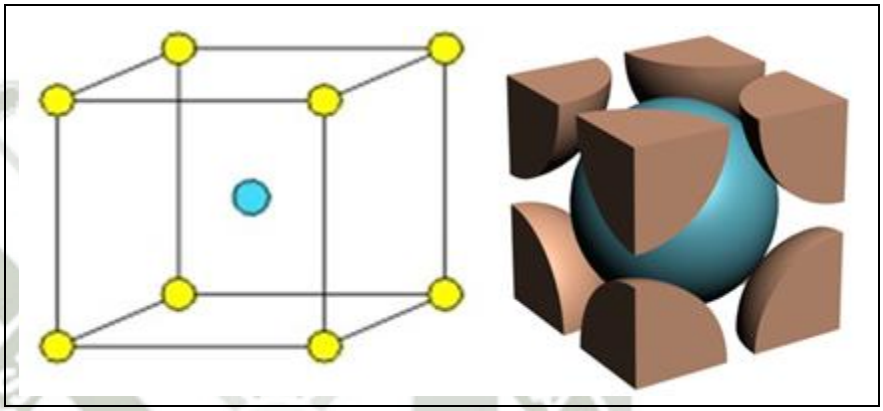
Esta estructura atómica al repetirse muchas veces en el espacio es constituida como la red cristalina. Existen catorce tipos de celdas unitarias o red de Bravías. Los metalurgistas necesitan conocer solamente tres de ellas con sus variantes en los metales y aleaciones metálicas. Estas son:

a) Cúbico centrado en el cuerpo (*Body centered cubic* – BCC): Esta red se representa en un cubo cuyo parámetro es (a), sus átomos se encuentran dispersos en cada vértice y en el centro del cubo. Esta red tiene muy poca densidad de compactación porque su fracción de empaquetamiento 68 % de la red. La característica principal de esta estructura es :

- La cantidad de átomos por cedilla es solo de dos átomos uno en el centro y $^{1}/_{8}$ x 8 átomos en los vértices.

- El número de coordinación es de ocho para esta estructura.

Gráfico N° 1 : Forma de Representación de la Estructura Cristalina Red Cúbico Centrado En El Cuerpo (*Body centered cubic* – BCC)



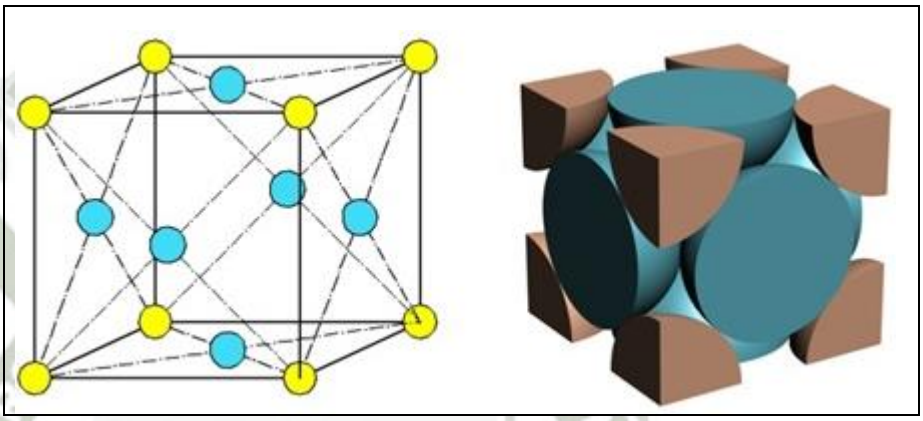
Fuente : Ciencia e Ingeniería de los Materiales Donald R Askeland edición tercera 1998.

b) Cúbico centrado en la cara (*Face centered cubic* – FCC): La red cubico centrado en las caras está representado en forma de cubo con ocho átomos en sus vértices y seis en los centros de cada cara del cubo su fracción de empaquetamiento es del 75 % las características principales de esta red son :

- Los átomos que contiene la celdilla es de 4 : $^{1}/_{6}$ x 6 átomos en los centros de las caras y $^{1}/_{8}$ x 8 en cada uno de los vértices.

- La cantidad e números de coordinación de esta estructura es doce.

Gráfico N° 2 : Forma de Representación de la Estructura Cúbico Centrado en la Cara (*Face centered cubic* – FCC).



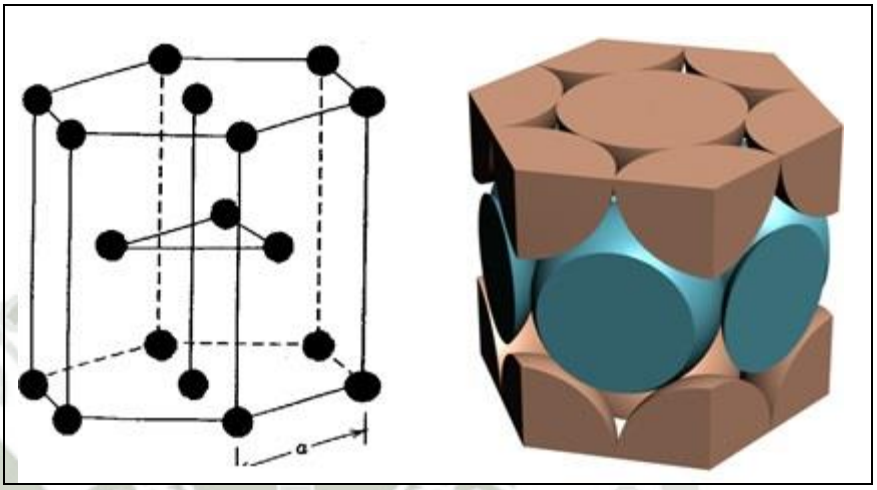
Fuente : Ciencia E Ingeniería de los Materiales Donald R Askeland Edición Tercera 1998.

c) Hexagonal compacta (*Hexagonal close packed* – HCP) : Dicha red tiene forma de un prisma cuya superficie y base es un hexaedro. Cuenta con dos parámetros uno es la base del prisma y el segundo es la altura en ella se encuentran doce átomos que están dispuestos en los vértices de la red. Dos átomos en el centro de la base y tres átomos en el interior de la red, la fracción de empaquetamiento es de 74% sus principales características son :

- El número total de átomos por celdilla es de 6: $^1/_2$ x 2 en el centro de las bases más 1x3 en la capa intermedia más $^1/_6$ x 12 en sus vértices del prisma. Se nos plantea una duda, porque en la capa intermedia se cuentan seis porciones de átomos y antes contamos sólo tres. Nótese, que sólo tres de dichas porciones tienen sus centros dentro de la celdilla; las tres restantes lo tienen en celdillas contiguas y además, el volumen que les falta a las porciones atómicas que tienen su centro en el interior de la celdilla es, precisamente el que aportan las porciones que tienen su centro fuera, por lo tanto, son tres los átomos con que contribuye el plano intermedio.

- El número de coordinación de la estructura HC es 12, como puede comprobarse fácilmente haciendo recuento del número de vecinos del átomo del centro de una base.

Gráfico N° 3: Estructura Hexagonal Compacta (*Hexagonal close packed* HCP).



Fuente : Ciencia E Ingeniería de los Materiales Donald R Askeland Edición Tercera 1998.

2.1.2. MICROESTRUCTURA DEL ACERO

La microestructura de los aceros al carbono recocidos y fundiciones blancas deben de ser analizados en base al diagrama meta estable Hierro-carburo de hierro. Para el contenido de 2.0% carbono se encuentra la división entre acero y hierro fundido. El punto eutectoide, F que se muestra en la imagen, se encuentra en 0.77% carbono el que marcará una clasificación del acero que se mencionará más adelante.

La estructura del acero se compone de una mezcla de fases, con diversas propiedades mecánicas. Las proporciones de estas fases

y sus composiciones serán determinantes del comportamiento de este material. Las fases que posee el acero en estado de equilibrio son: ferrita, cementita, perlita, sorbita, troostita, martensita, bainita, y rara vez austenita, aunque nunca como único constituyente. También pueden estar presentes constituyentes no metálicos como óxidos, silicatos, sulfuros y aluminatos. La formación de estas fases dependerá de la temperatura y del contenido de carbono como por ejemplo: Cuando el enfriamiento es muy lento se tendrán 4 fases: ferrita α y ferrita δ, austenita (γ) y cementita (Fe3C).El diagrama de fase hierro-carbono (Fe-C), permite visualizar las condiciones que existen en las fases que conforman el acero.

2.1.2.1. DIAGRAMA DE HIERRO CARBONO (Fe – C)

Este diagrama de hierro carbono nos muestra las distintas fases del hierro, una de las principales que debemos saber son las formas alotrópicas del estado sólido del hierro, BCC y FCC en sus distintas temperaturas: Hierro alfa (α): Se cristaliza a 768 ºC. Su estructura cristalina es BCC con una distancia interatómica de 2.86 Å[2]. Prácticamente no disuelve en carbono.

- Hierro gamma (γ): Se presenta de 910ºC a 1400ºC. Cristaliza en la estructura cristalina FCC con mayor

[2] 1 Angstrom (Å) = 0,1nm = 10^{-10}m. = 10^{-8} ; 1 nanómetro (nm) = 10^{-9}m. = 10^{-7} cm

volumen que la estructura cristalina de hierro alfa. Disuelve fácilmente en carbono y es una variedad de Fe a magnético.

- Hierro delta (δ): Se da inicio a los 1400ºC y presenta una reducción en la distancia interatómica que la hace retornar a una estructura cristalina BCC. Su máxima solubilidad de carbono es 0.007% a 1487ºC. No posee una importancia industrial relevante. A partir de 1537ºC se inicia la fusión del Fe puro.

El porcentaje de carbono puede clasificarse en:

- Aceros con menor % de Carbono ≤ 1.76 %.
- Fundiciones con mayor % de Carbono ≥ 1.76% – 6.667%.

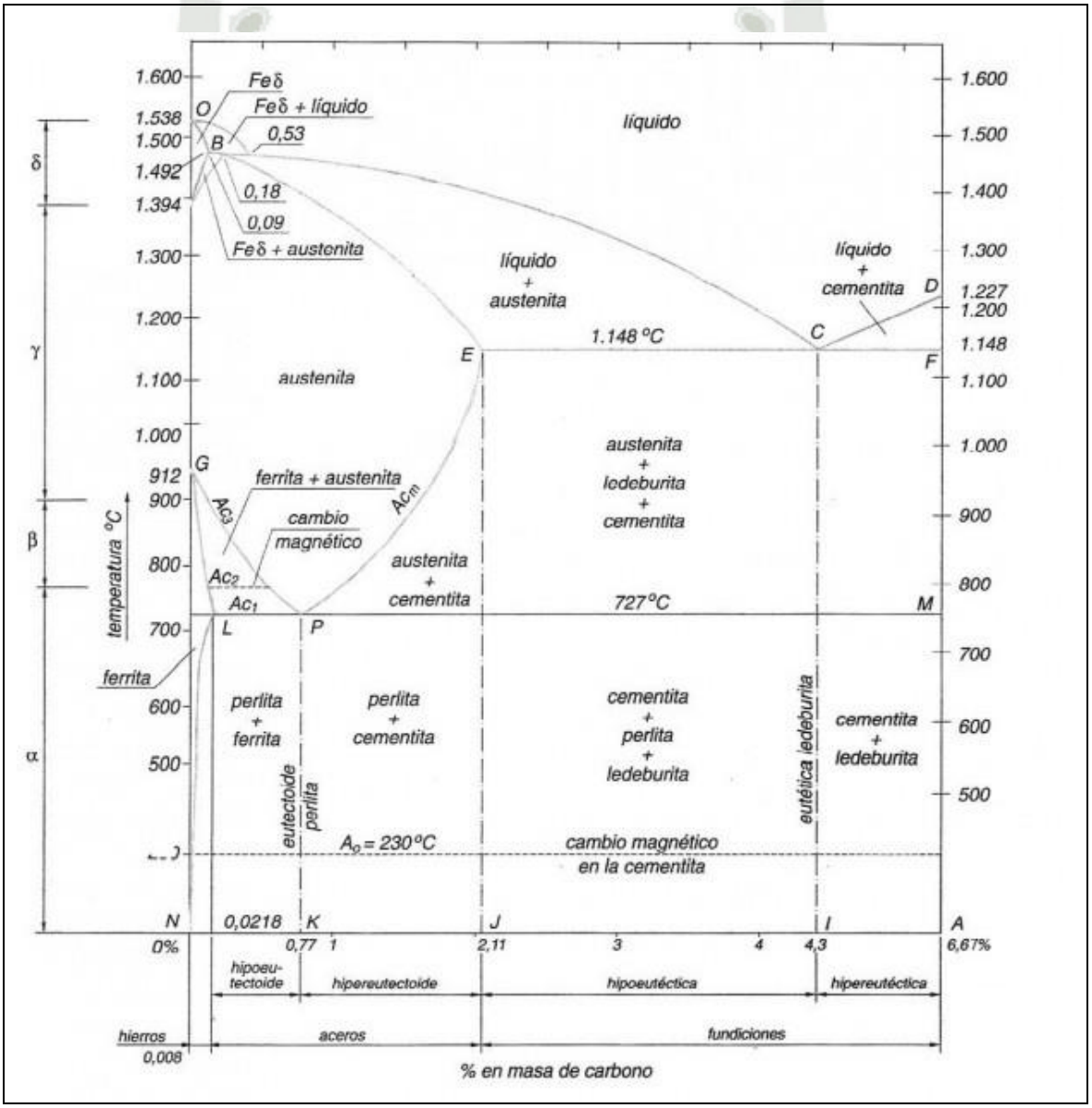
El carbono puede presentarse en tres formas distintas en las aleaciones Fe-C:

- En solución intersticial.
- Como carburo de hierro.
- Como carbono libre o grafito.

El diagrama Fe – C (Grafico 4) fue establecido como resultado de las investigaciones realizadas por varios científicos. Esta elaboración del diagrama la inició D. Chernov, quien estableció en 1968 los puntos críticos del acero. Posterior mente retomaron el estudio del diagrama.

N. Gutovski, M. Wittorft, Roberts Austen, Roozebom dando una gran aporte al estudio de este diagrama Fe - C. Los últimos datos acerca del diagrama están expuestos en las obras de I. Kornilov.

Gráfico N° 4: Diagrama de Fase Hierros – Carbono.



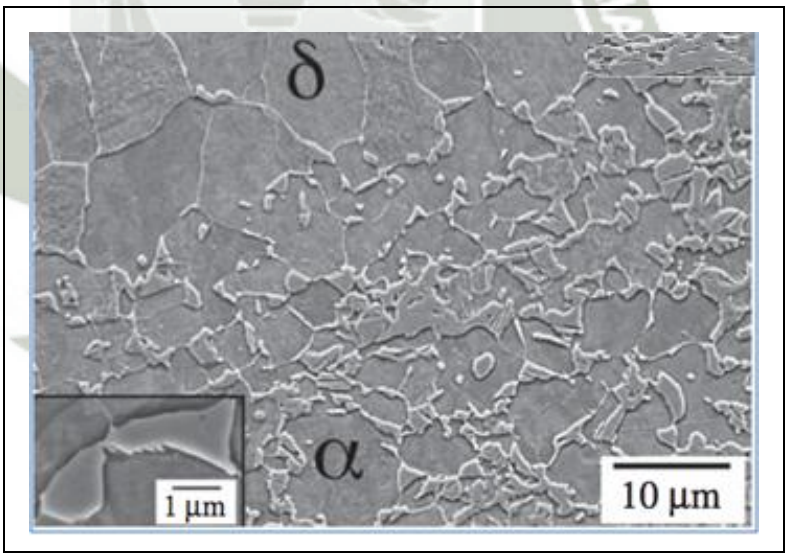
Fuente: Departamento de Tecnología Ing. José Jiménez R. 2008

2.1.2.2. FERRITA DELTA (δ)

Es una solución solida de carbono se inicia a los 1400°C presentando una reducción en la distancia interatómica, retornando una estructura cristalina BCC. La máxima solubilidad de carbono varía entre 0.007% a 1487°C ver grafica 5, las características principales de la ferrita δ son:

- La disolución del carbono es muy poca.
- Es magnético.
- Muy blando.

Gráfico N° 5: Microestructura de Ferrita δ.



Fuente : Proceedings of the Royal Society A, 467 (2011) 234-243 Extraordinary ductility in Al-bearing δ-TRIP steel H. L. Yi, K. Y. Lee and H. K. D. H. Bhadeshia.

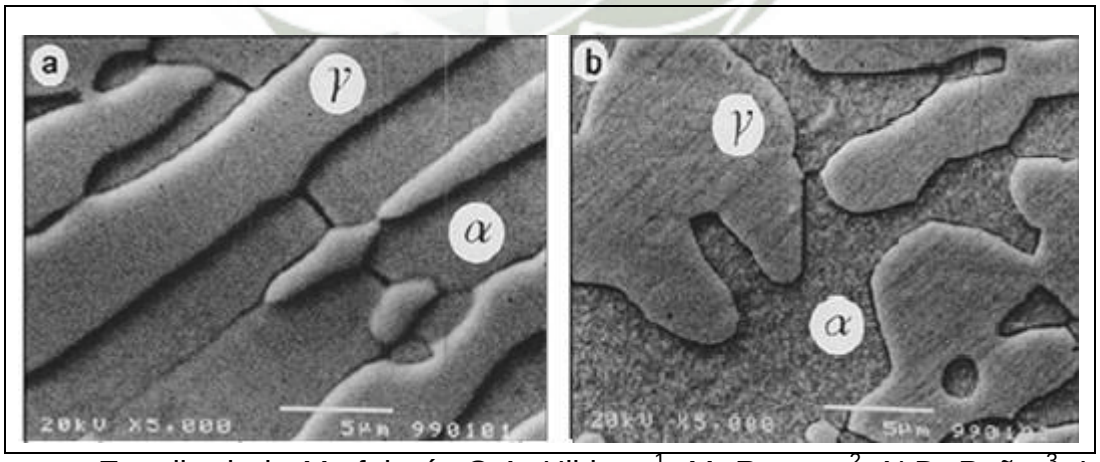
Nota: La ferrita δ y la ferrita α, son muy parecidas su diferencia es el tramo de las temperaturas en el que existen.

2.1.2.3. FERRITA ALFA (α)

La solución solida de ferrita α es estable hasta alcanzar una temperatura 721°C, su estructura es cúbica centrada en el cuerpo BCC con una distancia interatómica de 2.86 Å. La cantidad de átomos presentes es menor a 0,008% de carbono y cuenta con las siguientes características:

- Es suave y blanda con una dureza de 90 HB.
- Su ductibilidad va entre 35% a 40% de alargamiento.
- Tiene una baja resistencia a la rotura.

Gráfico N° 6: Microestructura dúplex: austenita (γ) y ferrita (α), del acero SAF 2205 (MEB). (a) Sección Longitudinal, (b) Sección Transversal.



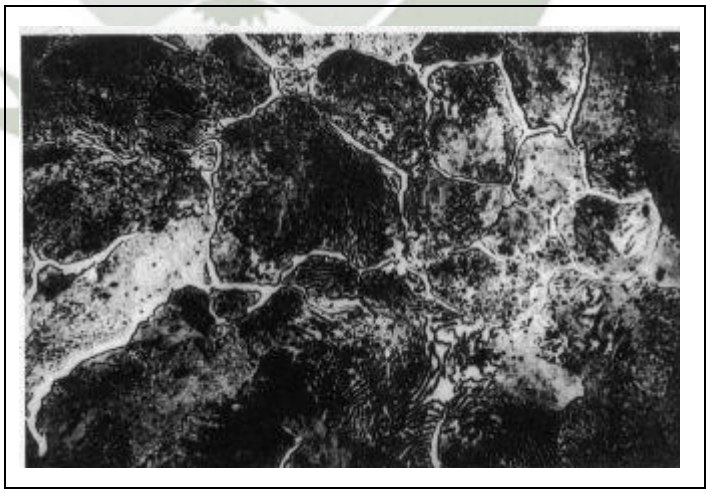
Fuente: Estudio de la Morfología O.A. Hilders [1], M. Ramos [2], N.D. Peña [3], L. Berrío [1] Y A. Ichaso [1] Rev. Fac. Ing. UCV vol.22 no.1 Caracas 2007.

2.1.2.4. CEMENTITA

Esta solución es un carburo de hierro, su composición es 6.67% de carbono y 93.33% de fierro en peso, es un compuesto itermetálico de formula Fe_3C. Es el microconstituyente más duro y frágil de los aceros. Se cristaliza en un sistema ortorrómbico de grandes dimensiones, su temperatura magnética llega hasta los 201°C temperatura a partir de la cual comienza a perder las propiedades magnéticas, las principales características son:

- Es el más duro y frágil de los aceros.
- Su dureza puede alcanzar hasta los 700HB.
- Componente de glóbulos en perlita laminar.

Gráfico N° 7: Acero al carbono 1% C – Red blanca de Cementita



Fuente: Curso Selección de Aceros Especiales autor ing. Samuel Rosario Francia.

2.1.2.5. AUSTENITA GAMMA (γ)

Esta solución solida se encuentra formada por cristales cúbicos centrados en las caras de hierro gamma con átomos de carbono intercalados en las aristas y en el centro, es por ello su estructura FCC. Su proporción de carbono disuelto puede variar entre 0 a 1.76%, correspondiente este último porcentaje de máxima solubilidad a la temperatura de 1130°C. La austenita se comienza a formar a una temperatura de 723°C sin aleantes, también se puede obtener una estructura austenítica en los aceros a temperatura ambiente, pero estos no son muy estables pero existen algunos aceros al cromo – níquel denominados austenítico cuya estructura es austenita a temperatura ambiente. Su principal característica es:

- Cuenta con una dureza de 300 Brinell.

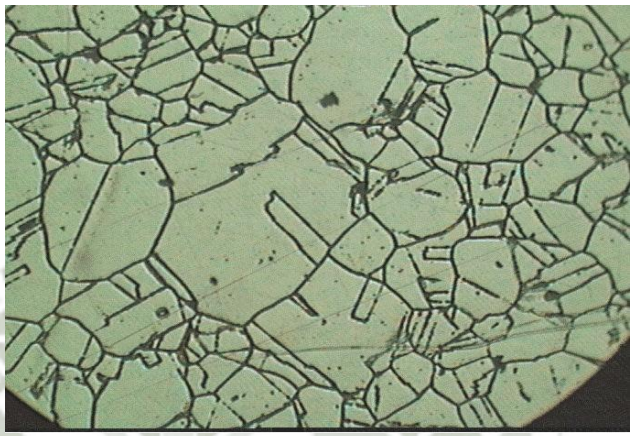
- Resistencia a la tracción 100 kg/mm^2 .

- Un alargamiento del 30 %.

- No es magnético.

- Destaca su gran plasticidad, característica que se aprovecha en la transformación por forja de los aceros.

Gráfico N° 8 : Microestructura de Austenita.



Fuente: Curso selección de Aceros Especiales Autor Ing. Samuel Rosario Francia

2.1.2.6. PERLITA

La perlita no se considera como fase ya que es una mezcla eutectoide que contiene aproximadamente 0.77% de carbono con capas bifásicas de ferrita y cementita de morfología laminar esto se puede formar a partir de 727°C de temperatura. Su nombre de perlita se debe a la irisación[3] que adquiere al iluminarla, parecida a las perlas. Esta estructura laminar aparece por lo general en el

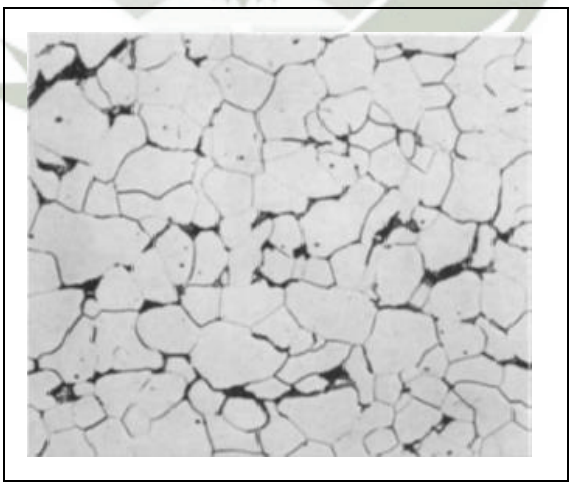
[3] Vislumbre que se produce en las láminas delgadas de los metales cuando, candentes, se pasan por el agua. Diccionarios RAE

proceso de enfriamiento lento de la austenita y por la transformación isotérmica de la austenita en rango de temperatura de 650°C a 723°C, si el proceso de enfriamiento es muy rápido (100°C – 200°C/seg.) su estructura se pondrá borrosa y se le denominara Sorbita. Si la perlita laminar es sometida a un recocido a temperatura menor a la crítica 723°C la cementita adopta la forma de glóbulos incrustados en la masa de ferrita denominándolos perlita globular. Las características de la perlita son:

- Su dureza es de 250 Brinell.

- Resistencia a la tracción 80kg/mm^2 con una ductibilidad de alargamiento de 15%

Gráfico N° 9: Micro-estructura interna de la perlita.



Fuente: Curso Selección De Aceros Especiales Autor Ing. Samuel Rosario Francia

2.1.2.7. BAINITA

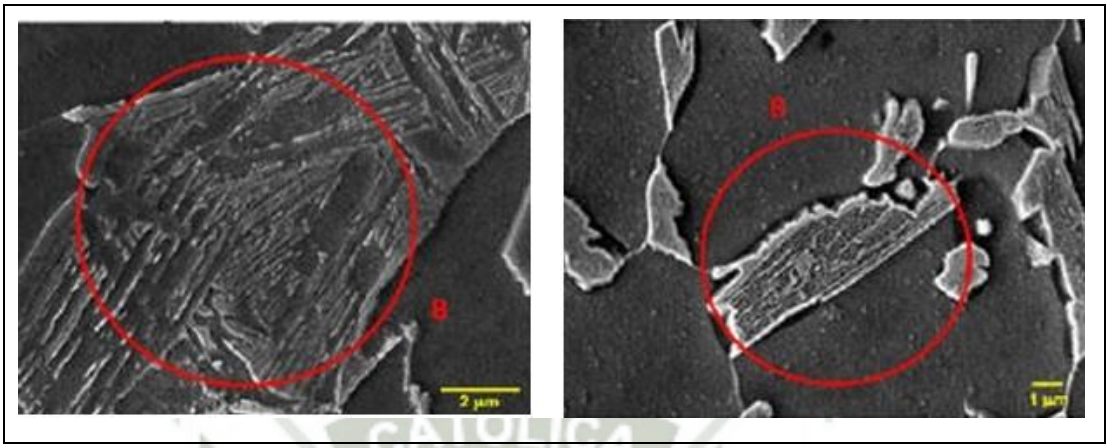
La formación de bainita se obtiene en la trasformación isotérmica de la austenita, en los rangos de temperaturas de 250°C a 550°C. Donde se encontrara dos tipos de estructuras, la bainita superior de aspecto arborescente formada a los 500°C a 580°C, compuesta por una matriz ferrítica conteniendo carburos. Bainita inferior, formada a 250°C a 400°C cuenta con un aspecto acicular[4] similar a la martensita y constituida por agujas alargadas de ferrita que contiene delgadas placas de carburo.

La obtención de bainita se consigue enfriando rápidamente la austenita hasta tener una temperatura contante y manteniéndola hasta lograr la trasformación total de austenita en bainita. Su principal caracterizas es:

- Su dureza varía entre 40 a 60 RC.

[4] Se dice de la estructura micrográfica, en forma de agujas o angulosa, que se observa en algunas fundiciones y aceros. Diccionario REA

Gráfico N° 10: Bainita en Acero a Temperatura de 800°C por 600s (a) Normalizado (20.000X). (b) Normalizado (15.000X).



Fuente: Revista Latinoamericana de Metalurgia y Materiales Autores Alberto Monsalve, Alexis Guzmán y Otros Obtención de un Acero Multifásico a Partir de un Acero 0,084% C, 1,44% Mn y 0,81% Si vol.33 no.2 Caracas dic. 2013.

2.1.2.8. MARTENSITA

La estructura martensita se obtiene por medio del control de las velocidades de enfriamiento bajas o moderadas cuando se encuentra en un estado de austenita, ya que los átomos de carbono pueden difundirse hacia afuera de la estructura austenítica. De este modo, los átomos de Fe se mueven ligeramente para convertir su estructura en una tipo BCC. Esta transformación de fases gamma-alfa tiene lugar mediante un proceso de nucleación y crecimiento

dependiente del tiempo (si aumentamos la velocidad de enfriamiento no habrá tiempo suficiente para que el carbono se difunda en la solución y, aunque tiene lugar a algún movimiento local de los átomos de Fe, la estructura resultante no podrá llegar a ser BCC, ya que el carbono está “atrapado” en la solución). La estructura resultante la denominamos martensita, ya que es una solución sólida sobresaturada de carbono atrapado en una estructura tetragonal centrada en el cuerpo.

Esta estructura reticular altamente distorsionada es la principal razón para la alta dureza de la martensita, ya que como los átomos en la martensita están empaquetados con una densidad menor que en la austenita, entonces durante la transformación (que nos lleva a la martensita) ocurre una expansión que produce altos esfuerzos localizados que dan como resultado la deformación plástica de la matriz.

La martensita se presenta en forma de agujas y cristaliza en la red tetragonal. Después de la cementita, la martensita es el constituyente más duro de los aceros, la elevada dureza que cuenta esta estructura se debe al porcentaje de carbono que varía hasta un máximo de 0.75% C, cuando se supera estos límites queda proporciones de austenita sin trasformar haciendo que su promedio de dureza

decrezca ligeramente. Las propiedades mecánicas más notables de la martensita son:

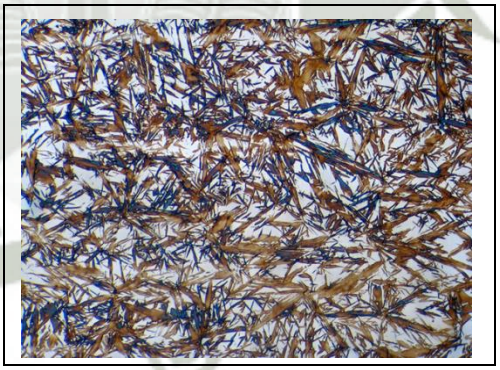
- Su dureza va entre 48 a 68 HRc para 0.35% y 0.9%C.

- Una resistencia mecánica varia de 175 a 250 Kg/mm^{2,} con alargamiento de 0.5 al 2.5 %.

- Es una estructura magnética.

- Presenta un aspecto acicular formando grupos en zig – zag con ángulos de 60 grados en la matriz austenita.

Gráfico N° 11: Martensita Sobre Austenita Retenida



F**uente:** Curso Selección De Aceros Especiales Autor Ing. Samuel Rosario Francia.

2.1.2.9. TROOSTITA

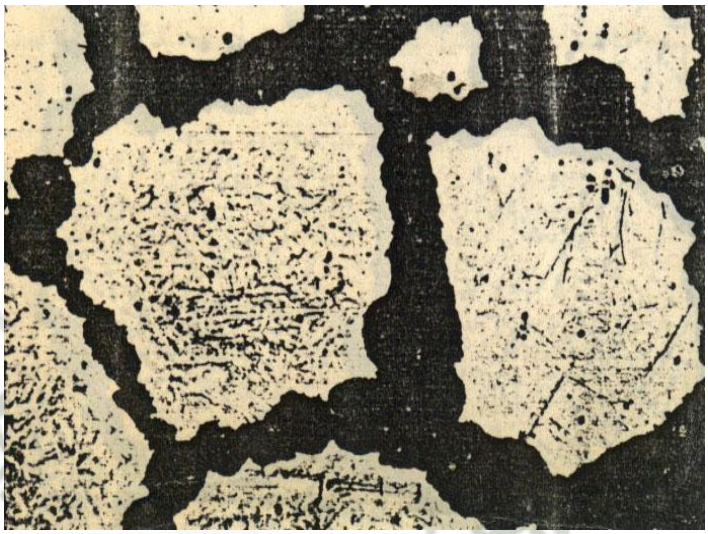
La formación de la troostita es un agregado muy fino de cementita y ferrita, esto se genera cuando se enfría la austenita a una velocidad ligeramente inferior a la crítica de temple o también se genera por la transformación isotérmica de la austenita en el rango de temperaturas de 500°C a 600°C y también contaremos con su presencia en el revenido a una temperatura de 400°C las propiedades de la troostita son:

- Una dureza de 400 a 500 Brinell.

- Resistencia a la tracción de 140 a 175Kg/mm^2.

- Alargamiento de 5 al 10 %.

Gráfico N° 12: Estructura Resultante de un Temple Incorrecto: Troostita en Bordes de Grano (Oscuro) el Resto es Martensita



Fuente: Metalografía y Tratamientos Térmicos. Cap V Estructuras del Acero Basado en Texto del Ing. Va Larre

2.1.2.10. SORBITA

La Sornita es también un agregado fino de sorbita y ferrita. Esta se obtiene por un enfriamiento de la austenita a temperaturas bastante inferior a la crítica del temple o por la transformación isotérmica de la austenita en un rango de temperaturas de 600°C a 650°C y la podemos obtener también por un revenido a temperaturas de 600°C. Sus características son:

- Dureza es de 250 a 400 Brinell.

- Resistencia a la tracción es de 88 a 140 kg/mm^2

- Alargamiento del 10 al 20%.

2.1.3. CLASIFICACIÓN DEL ACERO

Según su función de la fase presente, los aceros se pueden clasificar de la siguiente forma:

2.1.3.1. ACERO EUTECTOIDE

La reacción eutectoide se describe como la transformación de fase de un sólido en dos sólidos diferentes. En el diagrama de fases Fe - C, hay un punto eutectoide en aproximadamente 0.77% de carbono, a una temperatura de 723 °C.

La fase que se encuentra justo por encima de la temperatura eutectoide para aceros al carbono se conoce como austenita gamma γ. Que al enfriar esta fase, se desarrolla dos fases ferrita y cementita en láminas, formando una microestructura única llamada "perlita", como se observa en el GRÁFICO, la cual, en relación con las

propiedades mecánicas posee características intermedias de las dos fases que la componen, entre blanda, dúctil, dura y quebradiza.

Gráfico N° 13: Transformación y Microestructura de un Acero Eutectoide

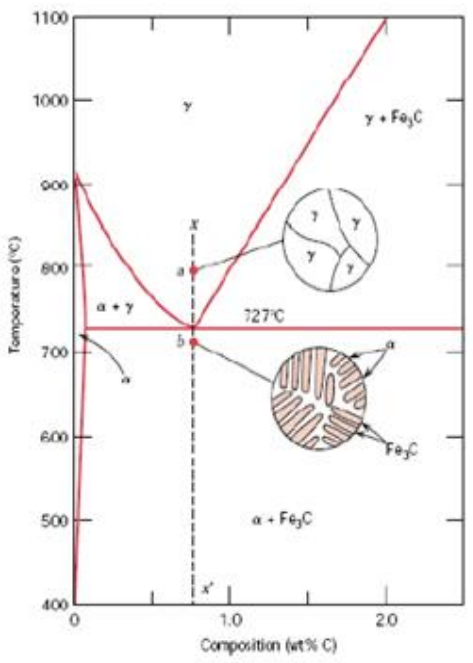


Figura 9.0 Representacion esquematica de un acero eutectoide

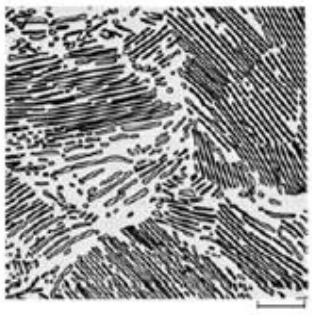


Figura 10.0 Microestructura perlitica de un acero eutectoide mostrando laminas de ferrita fase clara, y cementia laminas mas delgadas y oscuras

Fuente: Askeland, Donald R. Ciencia e Ingeniería de los Materiales. 3. Ed. United Stated: Thomson Editorial. 2004.

2.1.3.2. ACERO HIPOEUTECTOIDE

Los aceros hipoeutectoide son aquellos que cuentan con su fase austenítica sólida y cuentan con una aleación menor

que la del eutectoide que es 0.77% carbono que se puede observar dentro del diagrama hierro carbono. La microestructura da inicio a sus cambios a partir de una temperatura de 875°C, donde su microestructura a esta temperatura es de fase γ es homogénea con granos orientados al azar (punto c).

Al enfriar comienza a desarrollarse la ferrita (fase γ **)** y se entra en la región bifásica α + γ (punto d), donde la ferrita (fase γ **)** sufre una segregación formándose en los límites de grano la fase α. Al seguir bajando la temperatura (punto e) incrementa notablemente la presencia de la fase α (Tomando en cuenta que la proporción dependerá de la composición inicial del acero hipoeutectoide).

Al seguir con el enfriamiento sobrepasamos a la línea A1 (punto f) en la trasformación que sufre esta fase la ferrita no cambia su estado en cambio la austenita se transforma en perlita dando lugar a la microestructura característica de los aceros hipoeutectoides.

La ferrita más la perlita se le denomina ferrita eutectoide (Ya que fue formada a la temperatura del eutectoide, y proveniente de los granos que restaban de la austenita), la ferrita que fue formada antes del eutectoide (en los límites

de grano de la austenita) se denominara ferrita proeutectoide. En la perlita la relación de fases es ≈ 9:1, pero en los aceros hipoeutectoides la relación perlita y ferrita proeutectoide depende del porcentaje inicial de carbono. Esta microestructura siempre se observa en los aceros hipoeutectoides si han sido enfriados lentamente y son los más comunes.

Los aceros hipoeutectoide pueden ser usados en elementos de máquinas (Elementos de sujeción y transmisión de potencia) y tienen las siguientes características:

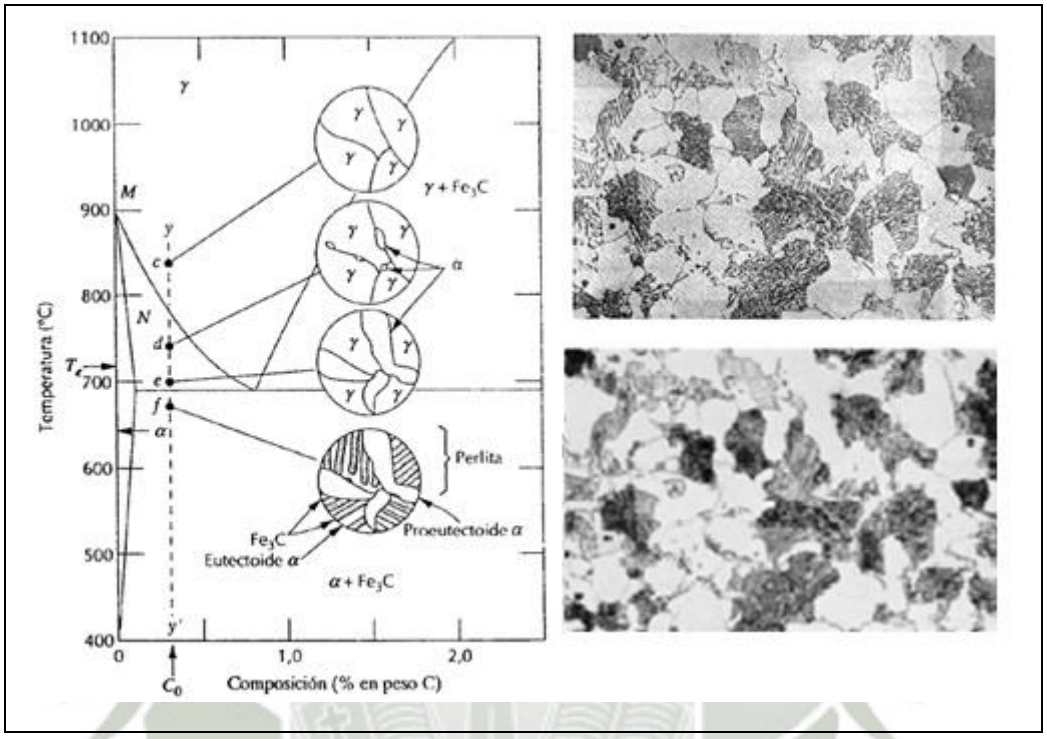
- Son plásticos y poseen buena resistencia mecánica.
- Bajo carbono hasta 0.2 % C, medio carbono 0.2%-0.5% C y alto carbono 0.5 %C.

Los aceros hipoeutectoides se pueden dividir en tres tipos:

- Acero bajo en carbono**:** Son aceros que su porcentaje de carbono no supera el 0,2%, se llaman *aceros* ferrítica, son muy suaves, dúctiles, deformables y de baja resistencia. Se usan en carrocerías de automóviles, planchas, en elementos

estructurales como perfiles, barras corrugadas, alambres y otros.

Gráfico N° 14: Transformación y microestructura de un acero hipoeutectoide.



Fuente: ASKELAND, Donald R. Ciencia e Ingeniería de los Materiales. 3. Ed. United Stated: Thomson Editorial. 2004.

- Acero al carbono medio: A este grupo pertenecen la mayoría de los acero comerciales que se produce, su porcentaje de carbono está comprendida entre el 0,2% y 0,5%. Sus propiedades dependen de la cantidad de ferrita y perlita que tienen ya que varían sus prestaciones en un rango muy amplio. Estos aceros se

emplean en la fabricación de elementos de máquinas para minería y naval, engranajes, cigüeñales, levas y ejes; equipos para remover tierra.

- Aceros de alto carbono: Estos aceros tienen un porcentaje de carbono comprendido entre el 0,5% y el 2%, se denominan aceros perlíticos. Su resistencia y dureza son elevadas pero su ductilidad y tenacidad son bajas. Este acero tiene una utilización para herramientas, muelles, ruedas de ferrocarriles, matrices y rodillos de laminación.

2.1.3.3. ACERO HIPEREUTECTOIDE

Se denomina acero hipereutectoide a aquellos aceros que por su composición de fase austenítica sólida y de acuerdo con el diagrama hierro-carbono tienen un porcentaje de carbono entre 0,77% y 2,11%. Su microestructura de este acero comienza a tener cambios en su composición a partir de la temperatura de 900°C (punto g), donde su principal constituyente es la fase austenítica (fase γ) con granos orientados al azar.

Al dar inicio al enfriamiento se comienza a formar la cementita y nos encontramos a una región bifásica γ + cementita (punto h) en la que la cementita comienza a

formarse en los límites de grano de la austenita o comúnmente llamado cementita proeutectoide ya que fue formada antes que se dé la relación eutectoide.

Al seguir enfriando sobrepasamos la línea A1 y la austenita remanente se transforma en perlita (punto i),en este punto su microestructura es perlita y cementita proeutectoide pero hay que tener en cuenta a la hora de la trasformación de la austenita ya que además de perlita aparece un constituyente denominado bainita, esta microestructura consta de las fases ferrita y cementita.

Dando así forma al acero, los aceros hipereutectoide presentan las siguientes características:

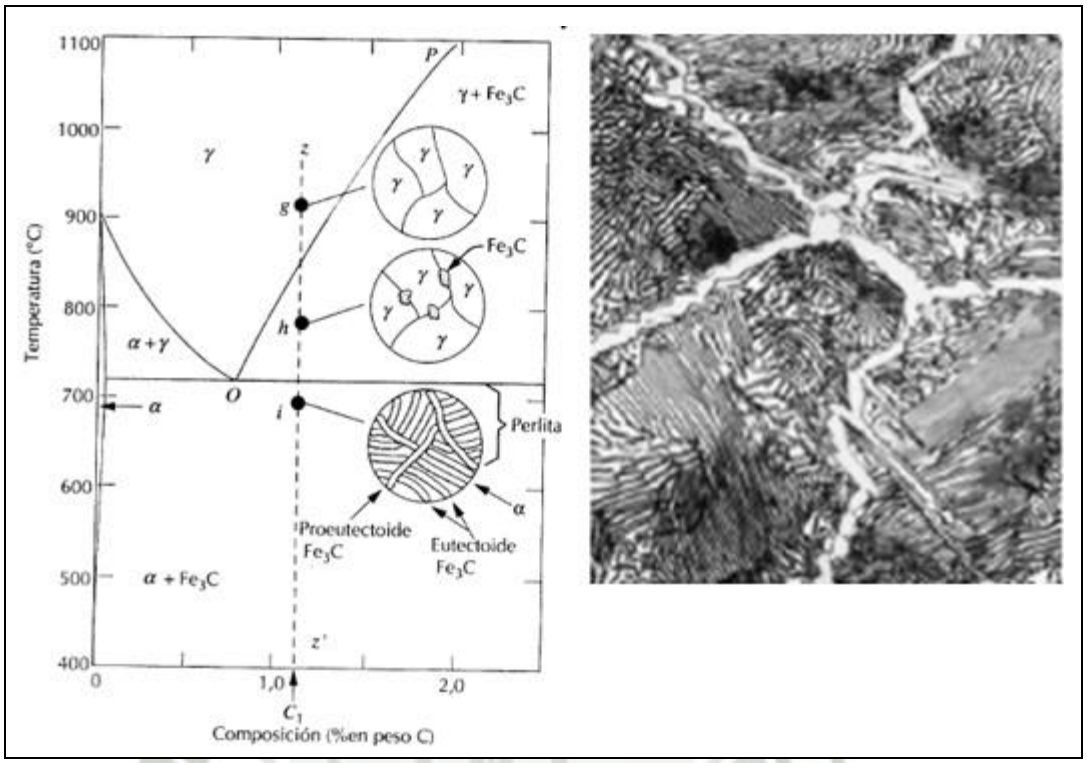
- Generalmente aleados.

- Muy alta resistencia mecánica.

- Mayor módulo de Young (módulo de elasticidad), muy elásticos.

- Alta resistencia mecánica y muy alta dureza.

Gráfico N° 15: Transformación y Microestructura de un Acero Hipereutectoide.



Fuente: Askeland, Donald R. Ciencia e Ingeniería de los Materiales. 3. Ed. United Stated: Thomson Editorial. 2004.

2.1.4. DENOMINACION DE LOS ACEROS SENGÚN NORMAS

En la actualidad que nos encontramos se hace muy difícil establecer una clasificación exacta y completa para todos los tipos de acero existentes en el mundo. Más difícil aún, es establecer una equivalencia precisa entre los aceros que presentan diferentes denominaciones, dado que el ordenamiento de estos materiales en clasificaciones y normas difiere según el país de

origen. Estas nomas difieren entre sí, pero tienen un lenguaje en común para que se comuniquen entre si y estas son:

- Fabricantes.

- Compradores.

- Vendedores.

- Constructores.

- Calculistas.

En el proceso de la globalización cada país creo su norma, las más importantes las indicamos a continuación:

- SAE (*Society of Automotive Engineer)* Sociedad de Ingenieros Automotrices su país de origen Estados Unidos.
- ASTM (*American Society for Testing and Materials*) Sociedad Americana para Pruebas de Materiales su país de origen Estados Unidos.
- DIN (*Deutsches Institut fur Normung*) Instituto Alemán de Normalización país de origen Alemania.
- JIS (*Japanese Industrial Standards*) Normas Industriales Japonesas su país de origen Japón.

- BS (*British Standards*) Normas Britanicas su país de origen Inglaterra.
- AFNOR (*Association Francaise de Normalisation*) Asociación Francesa de Normas país de origen Francia.
- ITINTEC (Instituto de Investigación Tecnológica Industrial y Normas Técnicas) su país de origen Perú.
- COVENIM (Comisión Venezolana de Normas Industriales) su país de origen Venezuela.
- UNE (Asociación Española de Normalización y Certificación) su país de origen España.
- UNI (*Ente Nazionale Italiano di Unificazione*) Ente nacional italiano de unificaciones su país de origen Italia.
- GOST (*Federal Agency on Technical Regulating and Metrology)* Agencia Federal de Regulación Técnica y Metrología su país de origen Rusia.

2.1.4.1. ESTRUCTURA DE LA NORMA ASTM

La finalidad de las normas es contar con un lenguaje común a nivel mundial ya que la norma ASTM es utilizada por muchas compañías, individuos y agencias. Estas normas ASTM son voluntarias porque ASTM no exige observarlas pero sin embargo sus autoridades gubernamentales con facultad normativa con frecuencia

dan fuerza de ley a las normas voluntarias, haciendo cita de ellas, regulaciones y códigos.

Gracias a estas normas se ha podido ahorrar millones de dólares a los contribuyentes, ya que se evita una duplicación de esfuerzos de normalización. El uso de las normas ASTM son innumerables entre ellos se encuentran petróleo, medio ambiente, estructuras, deportes y equipos recreativos, etc.

Si queremos indagar más sobre las normas de ASTM, podemos entrar a la base *Specs and Standards*, la que nos provee acceso inmediato a información técnica y regulatoria más completa del mundo. En ella incluye normas y especificaciones, con más de 480 organismos internacionales, así como códigos, reglamentos y manuales para todas las industrias.

O también tenemos información de ASTM *Digital Library*, con una base de datos que cuenta con más 19,000 documentos de las áreas de ingeniería de gran uso para la industria y la academia. Dentro de su contenido incluye: más de 13,000 artículos de revistas: *Journal of ASTM International (JAI), Geotechnical Testing Journal (GTJ), Journal of Testing and Evaluation (JOTE), Journal of*

Forensics Sciences, Journal of Composites, Technology and Research (JCTR) Journal of Cement, Concrete and Aggregates (CCA) y 50 manuals.

La norma ASTM está formada de la siguiente forma :

ASTM	A36 / A36M	96	a
Norma	Código (sistema Inglés y sistema métrico)	Año de la adopción	Revisión en año

Ejemplo:

ASTM A 6 / A6M	96 b 3° revisión en 1996	Requerimientos generales para planchas, perfiles y láminas de acero estructural laminados.
ASTM A615 / A615M	9 a 2° revisión año 1996	Barra de acero deformado y lisa para refuerzo de concreto armado

Cuando el acero tiene varios grados, la norma ASTM indica el grado del acero como a continuación lo mostramos en los ejemplos :

- ASTM A615 / A615M – 96a grado 60.

- ASTM A572 / A572 – 94c grado 50.

El grado que se indica es el valor del límite de fluencia en miles de libras por pulgada cuadrada (Kips.) lo indicamos en el siguiente ejemplo :

- ASTM A615 / A615M - 96a grado 60 indican que las barras de construcción tienen un límite de fluencia mínimo de 60000 Lb/pulg^2.
- ASTM A572 / A572M - 94c grado 50 indica que este acero de construcción su límite mínimo a la fluencia es 50000 Lb/pulg^2.

Esta norma ASTM establece valores mínimos para :

- Límite de fluencia.
- Resistencia a la tracción.
- Alargamiento.
- Doblado.

Estos cuatro valores lo podemos observar en el siguiente ejemplo :

- Acero ASTM A36
    - Límite de fluencia: 36000 Lb/pulg^2.
    - Resistencia a la tracción: 58000– 80000 Lb/pulg^2.
    - Alargamiento : 20 %

En el caso de los aceros y su composición química la norma ASTM garantiza la soldabilidad con unos valores máximos permisibles estos son :

- Carbono.
- Manganeso.
- Azufre.
- Fósforo.

Por ejemplo :

- ASTM A615 grado 60 :
    - Límite máximo de fósforo 0,050%.
- ASTM A36 :
    - Sodio (S) = 0,050% máximo.

- Potasio (P) = 0,040% máximo.

Esta norma ASTM es la que más se utiliza a nivel mundial por ese motivo se realiza mención en este capítulo ya que en el proyecto de investigación hemos considerado en trabajar con un acero A36.

2.1.5. ACERO ESTRUCTURAL

La sección de aceros estructurales es una de la gama más grande ya que tienen una gran variedad de usos y formas, centrándonos en esta familia de aceros estructurales, como ya se mencionó, son productos cuya característica principal es la de asegurar una excelente propiedad mecánica tales como (límite elástico, resistencia a la tracción, alargamiento, tenacidad, resistencia a la fatiga, etc.).

El bajo contenido de carbono hace que se aumenten la gama de diseños realizables con estos materiales. A continuación se detallara más sobre el acero estructural normalizado por la norma ASTM A36, el cual es el material a usar en este trabajo de tesis.

2.1.5.1. CARACTERÍSTICAS DEL ACERO ESTRUCTURAL ASTMA A – 36

Las características de este acero estructural A – 36 que presentamos en el proyecto investigación, la separamos en dos grupos por su composición química y por sus propiedades mecánicas.

- Composición química : En la actualidad el acero A- 36 podemos adquirirlo en distintas formas de perfiles, planchas y barras hay que tener en cuenta que cada presentación del acero A – 36 tiene una composición química con ligeras diferencias, en la tabla que se muestra a continuación presentamos las composiciones químicas del acero A - 36 según su presentación y diámetro.

- Propiedades mecánicas: La propiedades de este acero A – 36 nos indica que es un material dúctil, lo que le hace adecuado para el ámbito estructural de ahí su nombre comercial “ Acero estructural A – 36 ”.

Tabla N° 1: Composición Química Acero A – 36 / A – 36M

Producto	Perfil	Barra			
Espesor (in.)	Todos	Hasta ¾ in	De ¾ a 1½ in.	De 1½ a 4 in	De 4 in
Carbón, máx. %	0.26	0.26	0.27	0.28	0.29
Magnesio, %	…..	…..	0.60 – 0.90	0.60 – 0.90	0.60 – 0.90
Fosforo, máx. %	0.04	0.04	0.04	0.04	0.04
Azufré, máx. %	0.05	0.05	0.05	0.05	0.05
Silicio, %	0.40max	0.40max	0.40max	0.40max	0.40max
Cobre, min %	0.20	0.20	0.20	0.20	0.20

Fuente: *ASTM International, Designation: A36/A36M – 08. West Conshohocken,USA, Edición 2008.*

Tabla N° 2: Propiedades Mecánicas Acero A – 36 / A – 36M

Planchas, perfiles y barras	
Resistencia a la tracción, ksi [MPa]	58 - 80 [400 - 550]
Resistencia a la fluencia, ksi [MPa]	36 [250]
Planchas y barras	
Elongación en 8 pulgadas [200 mm] min,% 20	20
Elongación en 2 pulgadas [50 mm] min,% 23	23
Perfiles	
Elongación en 8 pulgadas [200 mm] min,% 20	20
Elongación en 2 pulgadas [50 mm] min,% 21	21

Fuente: *ASTM International, Designation: A36/A36M – 08. West Conshohocken,USA, Edición 2008.*

2.2. TRATAMIEMTOS TERMICOS DEL ACERO

Los tratamientos térmicos son básicamente una trasformación estructural que experimenta el acero a esta le llamamos transformaciones alotrópica, ya que también dependerá de los procesos de re cristalización y de difusión. Una definición más exacta de tratamiento térmico lo podemos obtener en *Metals Handbook* que nos dice : "Que es una combinación de operaciones de calentamiento y enfriamiento, en tiempos determinados y aplicadas a un metal o aleación en el estado sólido en una forma tal que producirá propiedades deseadas[5] ".

Gran parte de los procesos básicos de los tratamientos térmicos en aceros dan cabida a la trasformación o descomposición de la austenita. Es por ello que se clasifico en cuatro grupos de tratamientos térmicos.

- El recocido.
- El normalizado.
- El temple o templado.
- El revenido.

[5] Metals Handbook. 8th Edition Vol.: 1, 2, 7 y 8. American Society for Metals.

- Tratamientos térmicos especiales.

En los procesos de tratamientos térmicos ya mencionados se tiene que considerar un ciclo de calentamiento, mantenimiento de temperatura seleccionada y el ciclo de enfriamiento. Estos ciclos van a depender del tamaño, forma y espesor de las piezas. Por dicha razón se tomara en cuenta estos factores ya que afectaran en gran medida los resultados esperados en las piezas después del tratamiento térmico.

Estos ciclos que mencionamos realizan los cambios alotrópicos en el acero realizando que cambien el tamaño y la forma de los granos, logrando así una variación en la dureza, resistencia y ductibilidad de las piezas.

2.2.1. EL RECOCIDO

Este tratamiento térmico está diseñado para eliminar los efectos del trabajo en frío cuyo objetivo principal es ablandar el acero, en este tipo de tratamiento térmico también podemos regenerar su estructura o hasta eliminar tensiones internas. El principio del recocido es calentar a una temperatura de austenización de 800°C a 925°C, y después seguirá un enfriamiento generalmente. Gracias a este proceso ganamos aumentar su elasticidad y disminuir su dureza. La evolución de este tratamiento térmico ha llevado que las industrias se puedan clasificar en tres grupos :

- Recocidos con austenización completa o de regeneración de estructura.

- Recocido suscritico.

- Recocidos con austenización incompleta.

2.2.1.1. RECOCIDO DE AUSTENIZACION COMPLETA O DE REGENERACIÓN DE ESTRUCTURA

En este tipo de recocidos se calienta la pieza a una temperatura ligeramente más elevada que la crítica superior para después enfriarla muy lentamente este puede ser en el horno o en arena previamente calentada. Este tipo de recocido nos sirve para ablandar y regenerar su estructura. Como lo demostramos en la siguiente tabla

Tabla N° 3: Temperatura Recomendable para el Recocido de Regeneración de los Aceros al Carbono

Composición % de C	Austenización completa °C	Composición % de C	Austenización completa °C
0.10	910°	0.70	775°
0.20	980°	0.80	760°
0.30	860°	0.90	760°
0.40	840°	1.00	825°
0.50	820°	1.10	860°
0.60	800°	1.20	900°

Fuente: Apraiz Barrero, Madrid 1961

2.2.1.2. RECOCIDO SUBCRITICO

En un recocido subcritico hay que tener en cuenta que su procedimiento varia ya para obtener este tipo de tratamiento hay que calentar la pieza por debajo de la temperatura critica inferior, no teniendo tanta importancia como en el caso anterior su velocidad de enfriamiento, ya que puede enfriarse el acero al aire sin que se endurezca. La finalidad de este tratamiento es eliminar las tensiones del material y aumentar su ductilidad. Para observar más detalle podemos distinguir tres clases de recocidos subcríticos:

- Recocido de ablandamiento.
- Recocido contra acritud.
- Recocido globular.

a) RECOCIDO DE ABLANDAMIENTO

El proceso de obtención del recocido de ablandamiento es calentar el acero hasta una temperatura por debajo de la Ac1 y a su vez que sea lo más elevada posible para que después sea enfriado al aire. El objetivo de este tipo de recocido como dice su nombre es ablandar el acero , aunque a veces no se llega a obtener la dureza necesaria para su mecanizado.

Su principal ventaja es que es un procedimiento rápido y económico.

b) RECOCIDO CONTRA ACRITUD

Este recocido se efectúa a una temperatura de 550°C a 630°C, y tiene como objeto aumentar la ductilidad de los aceros con poco contenido de carbono (menos de 0.40%) deformados en frío. Alcanzando esta temperatura se destruye la cristalización alargada de la ferrita, apareciendo nuevos cristales poliédricos más dúctiles que los primitivos, permitiendo estirar o laminar nuevamente el material sin dificultad. El enfriamiento se suele hacer al aire.

c) RECOCIDO SUBCRITICO GLOBULAR

Para poder obtener en los aceros al carbono y de baja aleación una estructura globular de baja dureza, se tiene que someter a una temperatura inferior pero muy próxima a la crítica inferior Ac1 y después enfriarlo muy lentamente al aire o en el horno. Con el fin de obtener una estructura muy blanda, por eso se globuliza, aceros de bajo carbono.

2.2.1.3. RECOCIDO DE AUSTENIZACION INCOMPLETA

Son tratamientos que se suelen dar a los aceros al carbono o aleados, con más de 0.50% de carbono, para así poder ablandarlos y mejorar su maquinabilidad. Su proceso consiste en calentamientos prolongados a temperaturas intermedias entre la crítica superior e inferior, seguidamente por un enfriamiento lento. Este tipo de tratamientos se consigue con facilidad en los aceros hipereutectoides logrando que la cementita y los carburos de aleación adopten una disposición más o menos globular que da para cada composición una dureza muy inferior a cualquier otra micro estructura, incluso la perlita laminar.

El fin que se persigue con estos recocidos es obtener la menor dureza posible y una estructura microscópica favorable para el mecanizado de las piezas.

2.2.2. NORMALIZADO

La normalización también llamado perlitización, consiste en llevar el acero hipoeutectoides a una temperatura algo mayor que el recocido completo (temperatura de austenización 40°C a 60°C por encima de Ac3) y en el caso de aceros hipereutectoides temperatura mayor a Acm , tiene como propósito conseguir una

estructura perlitica de grano fino y distribución homogénea en ese estado y enfriarlo, con una velocidad mayor que en el recocido, al tener este enfriamiento a una mayor velocidad lograremos obtener una estructura perlitica laminar muy fina, lo que corresponde a las propiedades mecánicas optimas de un acero perlítico. En síntesis, el normalizado es apto para :

- Mejorar la maquinabilidad.
- Refinar el grano.
- Eliminar tensiones producidas por operaciones anteriores.
- Modificar y refinar las estructuras dendríticas[6] de piezas de función.
- Homogenizar la microestructura para su mejor respuesta en operaciones de endurecimiento.

La tabla que se muestra a continuación presenta las temperaturas de normalización para algunos grados comunes de acero al carbono. Basado en la experiencia a nivel industrial, las temperaturas dadas en la tabla pueden variar entre 28°C debajo y 56°C arriba de los valores indicados.

[6] Cristal metálico, producido generalmente por solidificación y caracterizado por una estructura parecida a la de un árbol de muchas ramas. Fuente RAE

Tabla N° 4: Temperaturas Típicas de Normalizado para Aceros al Carbono.

Acero SAE	Tem. Normalización ºC	Tem. Normalización ºF
1015	900 a 925	1650 a 1700
1020	900 a 925	1650 a 1700
1035	900 a 925	1650 a 1700
1040	870 a 900	1600 a 1650
1045	845 a 870	1550 a 1600
1050	845 a 870	1550 a 1600
1060	815 a 845	1500 a 1550
1095	815 a 845	1500 a 1550

Fuente: Metals Handbook. 8th Edition Vol.: 1, 2, 7 y 8. American Society for Metals.

2.2.3. TEMPLE O TEMPLADO

La finalidad de realizar el proceso del temple es lograr que su estructura sea plenamente martensítica. Lo que obtendremos es endurecer , aumentar la resistencia del acero , se debe entender con mucha claridad que el endurecimiento (*hardenability)* nos referimos al " ancho de endurecimiento " se puede lograr bajo

ciertas condiciones de enfriamiento establecidas. Para ello, necesitamos un calentamiento hasta la región de estabilidad de la austenita (temperatura de austenización) de la pieza manteniéndola durante un tiempo determinado a esa temperatura y después es enfriado a una temperatura por debajo de la temperatura de inicio de la formación de la martensita , a una velocidad de enfriamiento superior a la crítica con la finalidad de evitar las curvas de formación de perlita y de bainita dándole lugar a una trasformación de martensita, como ya se mencionó anteriormente tendremos una composición de acero con su máxima dureza.

En la práctica no toda la austenita se transforma en martensita ya que es imposible conseguir una velocidad de enfriamiento lo suficientemente rápida, por lo que tendremos tres factores que influyen en el temple estos son :

- CALENTAMIENTO : Como en todo los procesos el primer paso es el calentamiento a una temperatura a la cual se forme la austenita, temperatura que nos llevara a que todos los carburos se disuelvan y se encuentres en una solución solida intersticial dentro de la austenita, para poder tener el efecto de endurecimiento.

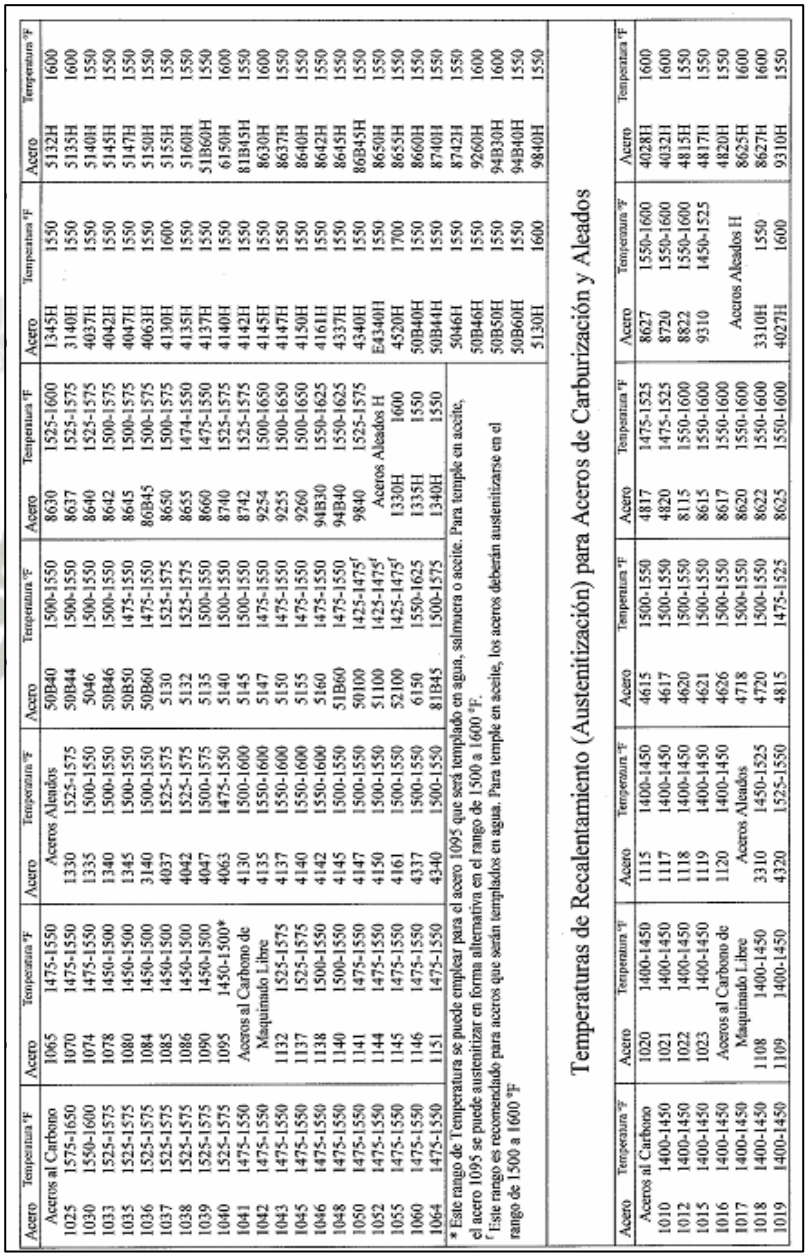
Esta temperatura de austenización no debe ser excesivamente alta ya que este sobrecalentamiento implicara un crecimiento pronunciado del grano (esto originaría una martensita grosera, poco tenaz) y / o " quemados ". Hay que tener en cuenta que la velocidad de calentamiento muy elevada puede crear esfuerzos muy altos, especialmente cuando están involucradas piezas irregulares, en la práctica común nos indica que es mejor calentar la pieza junto con el horno y no que el horno se encuentre a la temperatura de austenización también nos indican un tiempo de calentamiento que aproximadamente debe ser de una hora por 25 milímetros (una hora por pulgada) de sección, esta regla es de seguridad pero esta regla en la práctica se deberá determinar en forma experimental. La velocidad de calentamiento se designa según los siguientes factores :

- Área del componente a calentar.
- Velocidad de absorción de calor del componente.
- Temperatura de calentamiento.

Para una óptima temperatura de austenización previas al templado de aceros al carbono, baja aleación, aceros para

cementación, aleaciones ya se encuentran tabuladas según la tabla que se muestra a continuación.

Tabla N° 5 : Temperatura de Austenización para Aceros al Carbono y Aleados (AISI – SAE)



Temperaturas de Recalentamiento (Austenitización) para Aceros de Carburización y Aleados

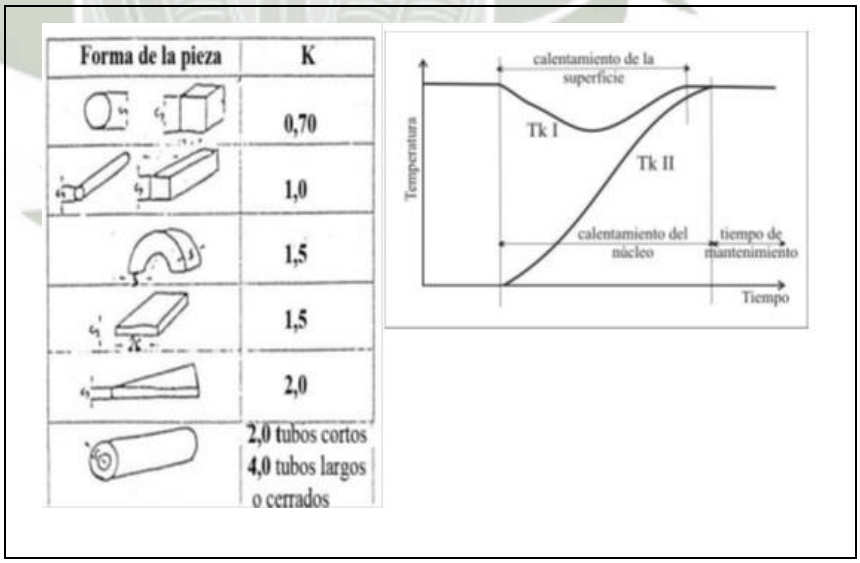
Acero	Temperatura °F	Acero	Temperatura °F	Acero	Temperatura °F	Acero	Temperatura °F	Acero	Temperatura °F	Acero	Temperatura °F	Acero	Temperatura °F
Aceros al Carbono		1065	1475-1550	Aceros Aleados		50B40	1500-1550	8630	1525-1600	1345H	1550	5132H	1600
1025	1575-1650	1070	1475-1550	1330	1525-1575	50B44	1500-1550	8637	1525-1575	3140H	1550	5135H	1600
1030	1550-1600	1074	1475-1550	1335	1500-1550	5046	1500-1550	8640	1525-1575	4037H	1550	5140H	1550
1033	1525-1575	1078	1450-1500	1340	1500-1550	50B46	1500-1550	8642	1500-1575	4042H	1550	5145H	1550
1035	1525-1575	1080	1450-1500	1345	1500-1550	50B50	1475-1550	8645	1500-1575	4047H	1550	5147H	1550
1036	1525-1575	1084	1450-1500	3140	1500-1550	50B60	1475-1550	86B45	1500-1575	4063H	1550	5150H	1550
1037	1525-1575	1085	1450-1500	4037	1525-1575	5130	1525-1575	8650	1500-1575	4130H	1600	5155H	1550
1038	1525-1575	1086	1450-1500	4042	1525-1575	5132	1525-1575	8655	1474-1550	4135H	1550	5160H	1550
1039	1525-1575	1090	1450-1500	4047	1500-1575	5135	1500-1550	8660	1475-1550	4137H	1550	51B60H	1550
1040	1525-1575	1095	1450-1500*	4063	1475-1550	5140	1500-1550	8740	1525-1575	4140H	1550	6150H	1600
1041	1475-1550	Aceros al Carbono de		4130	1500-1600	5145	1500-1550	8742	1525-1575	4142H	1550	81B45H	1550
1042	1475-1550	Maquinado Libre		4135	1550-1600	5147	1475-1550	9254	1500-1650	4145H	1550	8630H	1600
1043	1475-1550	1132	1525-1575	4137	1550-1600	5150	1475-1550	9255	1500-1650	4147H	1550	8637H	1550
1045	1475-1550	1137	1525-1575	4140	1550-1600	5155	1475-1550	9260	1500-1650	4150H	1550	8640H	1550
1046	1475-1550	1138	1500-1550	4142	1550-1600	5160	1475-1550	94B30	1550-1625	4161H	1550	8642H	1550
1048	1475-1550	1140	1500-1550	4145	1500-1550	51B60	1475-1550	94B40	1550-1625	4337H	1550	8645H	1550
1050	1475-1550	1141	1475-1550	4147	1500-1550	50100	1425-1475[†]	9840	1525-1575	4340H	1550	86B45H	1550
1052	1475-1550	1144	1475-1550	4150	1500-1550	51100	1425-1475[†]	Aceros Aleados H		E43400H	1550	8650H	1550
1055	1475-1550	1145	1475-1550	4161	1500-1550	52100	1425-1475[†]	1330H	1600	4520H	1700	8653H	1550
1060	1475-1550	1146	1475-1550	4337	1500-1550	6150	1550-1625	1335H	1550	50B40H	1550	8660H	1550
1064	1475-1550	1151	1475-1550	4340	1500-1550	81B45	1500-1575	1340H	1550	50B44H	1550	8740H	1550
* Este rango de Temperatura se puede emplear para el acero 1095 que será templado en agua, salmuera o aceite. Para temple en aceite, el acero 1095 se puede austenitizar en forma alternativa en el rango de 1500 a 1600 °F.										50B46H	1550	8742H	1550
[†] Este rango es recomendado para aceros que serán templados en agua. Para temple en aceite, los aceros deberán austenitizarse en el rango de 1500 a 1600 °F.										50B50H	1550	9260H	1600
										50B60H	1550	94B30H	1600
										5130H	1600	94B40H	1550
												9840H	1550

Acero	Temperatura °F	Acero	Temperatura °F	Acero	Temperatura °F	Acero	Temperatura °F	Acero	Temperatura °F	Acero	Temperatura °F	Acero	Temperatura °F
Aceros al Carbono		1020	1400-1450	1115	1400-1450	4615	1500-1550	4817	1475-1525	8627	1550-1600	4028H	1600
1010	1400-1450	1021	1400-1450	1117	1400-1450	4617	1500-1550	4820	1475-1525	8720	1550-1600	4032H	1600
1012	1400-1450	1022	1400-1450	1118	1400-1450	4620	1500-1550	8115	1550-1600	8822	1550-1600	4815H	1550
1015	1400-1450	1023	1400-1450	1119	1400-1450	4621	1500-1550	8615	1550-1600	9310	1450-1525	4817H	1550
1016	1400-1450	Aceros al Carbono de		1120	1400-1450	4626	1500-1550	8617	1550-1600	Aceros Aleados H		4820H	1550
1017	1400-1450	Maquinado Libre		Aceros Aleados		4718	1500-1550	8620	1550-1600			8625H	1600
1018	1400-1450	1108	1400-1450	3310	1450-1525	4720	1500-1550	8622	1550-1600	3310H	1550	8627H	1600
1019	1400-1450	1109	1400-1450	4320	1525-1550	4815	1475-1525	8625	1550-1600	4027H	1600	9310H	1550

Fuente : Aceros, Estructuras y Tratamientos Térmicos ”M.I. Felipe Díaz Del Castillo Rodríguez M.I. Alberto Reyes Solís.

- PERMANENCIA: En general el tiempo de permanencia a temperatura es aquel que transcurre entre el momento en que la temperatura es uniforme en toda la pieza y la homogenización de la austenita. Se podría determinar metalográficamente, pero en la práctica, se utilizan fórmulas empíricas, tablas o gráficos, de coeficientes de seguridad. El tiempo de permanecía para la disolución de los constituyentes y austenizar completamente, depende del tamaño, la forma de la pieza y de la estructura previa.

Graficó N° 16: (a) Coeficiente para calcular el Tiempo de Mantenimiento de Diferentes Piezas, **(b)** Variacion de la Temperatura en el Núcleo y la Superficie de una Pieza , Inicio de Tiempo de Mantenimiento.



Fuente : Metalografía y Tratamiento Térmicos

- ENFRIAMIENTO: La velocidad de enfriamiento ha de ser lo suficientemente rápida para impedir que se produzca cualquier transformación de la austenita antes de alcanzar la temperatura M_s de transformación martensítica. Existe una velocidad mínima de enfriamiento denominada velocidad crítica de temple que conduce al estado totalmente martensítico. Esta velocidad nos la define la curva de enfriamiento T=f(t), tangente a la nariz perlítica o al mentón bainítico de la curva TTT, tomándose siempre la más desplazada hacia la izquierda.

Esta velocidad crítica de temple está influenciada por:

a) Porcentaje de C del acero.

b) Porcentaje de los elementos de adición en los aceros aleados.

c) Tamaño de grano. Los aceros de grano más grueso se templan con velocidades de enfriamiento más bajas.

Se caracteriza por la velocidad de enfriamiento y se clasifica en:

- Lentos Velocidad menor 50°C / seg. se originan estructuras estables.

- Intermedios velocidades entre 50°C a 250°C /seg., se origina sorbita de temple.

- Rápidos velocidades de 250°C a 500°C /seg. , se originan mezclas de troostita y martensita.

- Muy rápido velocidades mayores a 500°C /seg. Se obtiene martensita.

Se tiene que tener en cuenta que el proceso de enfriamiento ocurre tres fases o etapas la de recubrimiento de vapor, de ebullición, de convección y conducción la que desarrolláremos a continuación :

a) Fase de recubrimiento de vapor : Es la primera etapa donde la pieza sumergida es rodeada por líquido vaporizado donde el enfriamiento se produce por conducción y radiación a través de la capa gaseosa.

   Esta etapa es muy lenta para el enfriamiento de la pieza ya que el vapor conduce mal el calor, se tiene que tener en cuenta que a mayor sea la temperatura mayor será la permanencia de esta fase o etapa y corremos el riesgo que queden puntos blandos al templar las piezas.

b) Fase de ebullición : Esta se considera como la segunda etapa ya que la temperatura de la pieza comienza a descender, el líquido entra en viva ebullición alcanzando la superficie de la pieza. Las burbujas son arrastradas por la convección hasta ser re-absorbidas por el líquido circundante.

Esta etapa se extrae el calor con elevada velocidad; es la de máxima importancia en el temple y debe ser lo suficiente para producir el endurecimiento. Durante ella no hay peligro de agrietamientos porque se mantiene la estructura austenítica, al menos parcialmente, hasta la temperatura más baja. La pendiente es mayor en el temple en agua que en aceite y por lo tanto, menor el tiempo de enfriamiento.

c) Fase de convección y conducción: Considerada como la última etapa ya que en ella el enfriamiento se produce por conducción y convección del líquido continuando con el enfriamiento pero a menor velocidad que la etapa de ebullición.

Hay que tener en cuenta que el agua enfría más rápidamente que el aceite , pero aquí es una desventaja, pues el enfriamiento demasiado brusco puede provocar fisuras y distorsión en las piezas.

2.2.4. REVENIDO

Es un proceso de tratamiento térmico que consiste en el calentamiento del acero que ya fue tratado térmicamente y se encuentra previamente templada, con este tratamiento consiste en calentar a temperatura inferior a la crítica Ac_1 las piezas , mantenimiento y enfriamiento posterior a la velocidad adecuada. Logrando estabilizar la estructura martensítica haciendo que disminuya la dureza y resistencia de los aceros templados, también tendremos la eliminación de las tensiones creadas en el temple y se mejora su tenacidad, quedando el acero con la dureza o resistencia deseada. El tiempo de revenido no interesa prolongar su duración más de una hora, pues no se obtiene beneficios apreciables que compensen el costo, en cambio por lo general dentro del rango de temperaturas de revenido, hay un decremento en dureza y un mayor aumento en tenacidad, conforme aumenta la temperatura del revenido es por eso que se considera cuatro tipos de etapas de revenido.

a) Etapa de 100°C a 200°C : La estructura que se adquiere a esta temperatura es de una tonalidad negra y es a veces conocida como martensita negra, la martensita original en la condición de temple está empezando a perder su estructura cristalina tetragonal mediante la formación de un “ carburo de transición ” hexagonal compacto (carburo épsilon) y

martensita de bajo carbono. En esta condición el acero endurece ligeramente, sobre todo aquellos aceros con alto contenido de carbono, y bajo estas condiciones el acero posee una alta resistencia, lo que trae como consecuencia una baja ductilidad y la tenacidad. Sin embargo, lo más importante es que gran parte de los esfuerzos internos se eliminan. Se utiliza para todos los aceros de herramientas de alto contenido de carbono.

b) Etapa de 200°C a 350°C : Al calentar el acero a esta temperatura su estructura cambia el carburo épsilon a cementita ortorrómbica (Fe3C), la martensita de bajo carbono se hace ferrita BCC haciendo que la austenita retenida se transforma en bainita. Los carburos son demasiado pequeños para ser resueltos mediante el microscopio óptico y la estructura entera se colora rápidamente en una masa negra. La resistencia es mayor de 200,000 Psi, la ductilidad ha aumentado ligeramente, pero la tenacidad es aún baja. La dureza esta varía entre 40 y 60 Rc dependiendo de la temperatura de revenido. Este tipo de tratamiento es muy utilizada en muelles y resortes.

c) Etapa de 350°C a 650°C : En este proceso, la martensita se transforma en sorbita de revenido. Esta estructura garantiza una mejor combinación de resistencia y plasticidad del acero.

En la sorbita de revenido la cementita adquiere forma granular, a diferencia de la obtenida en un normalizado. Como consecuencia de esto se eleva notablemente la resistencia con la misma dureza o aún más elevada con relación al acero normalizado. Este tipo de revenido se emplea para piezas de acero que estén sometidas a elevada fatiga o cargas de impacto .El temple del acero con un ulterior revenido alto se denomina termo mejoramiento o bonificado.

d) Etapa de 650°C a 750°C : En esta etapa se produce partículas grandes de cementita globular. Esta estructura es muy suave y tenaz , es semejante a la estructura de la cementita esferoidal obtenida directamente de la austenita mediante el recocido de esferoidización.

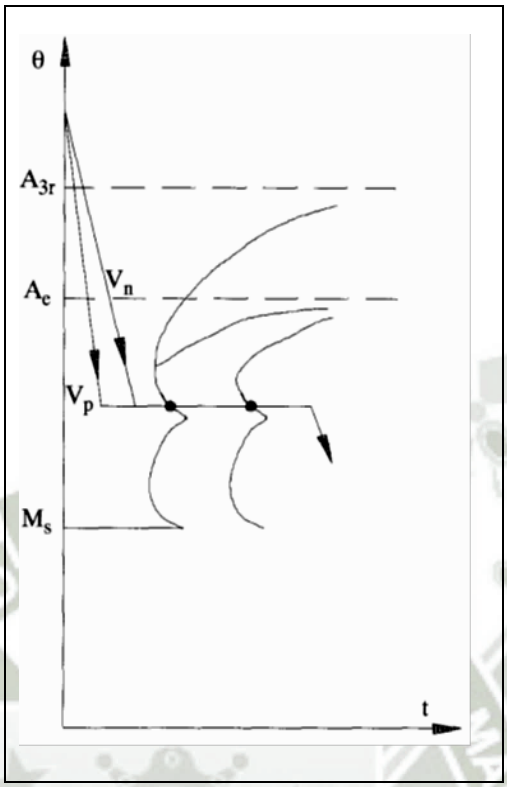
2.2.5. TRATAMIENTO ISOTERMICO

Reciben este nombre ciertos tratamientos isotérmicos pero resulta más propio decir que son tratamientos con enfriamiento isotérmico, este tipo de tratamiento se realizan elevando la temperatura de austenización y desde ahí, son enfriadas isotérmicamente por inmersión en sales fundidas, plomo fundido, u otro medio refrigerante líquido que permita mantener constante la temperatura durante la transformación de la austenita. En estos enfriamientos isotérmicos tenemos :

2.2.5.1. PATENTING

El patenting es un tratamiento isotérmico que suele darse, como operación final, a los alambres de acero de 0.7 - 0.9 % C , que requieren alta resistencia mecánica a tracción por ir destinados a hormigón pretensado. Para lograr esas características, el alambre después de ser austenizado se introduce en un baño de plomo fundido (o en sales), a temperatura correspondiente a la zona baja perlítica de la curva TTT del acero. Su finalidad es transformar la austenita en perlita muy fina, con separaciones entre láminas de cementita de 0.1 a 0.2 μm. Con ello se logran cargas de rotura del orden de 1600MPa y un alargamiento de 5 a 10%.

Grafico N° 17 : Patenting en el Diagrama T.T.T.



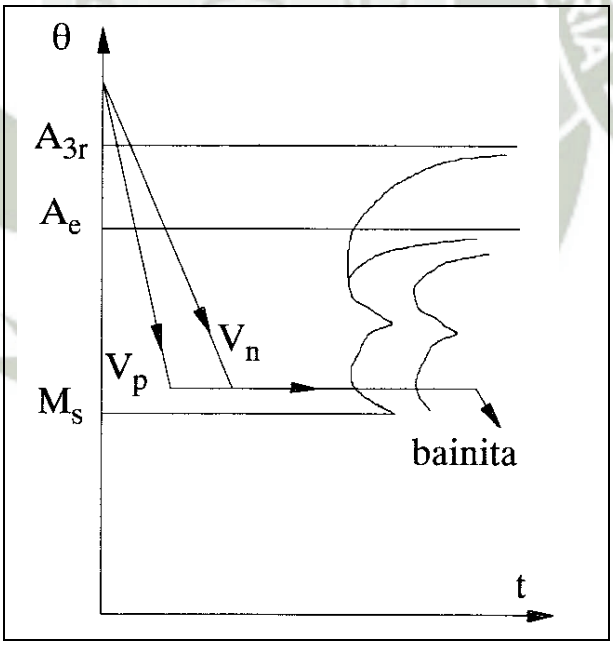
Fuente: Machado Isabel. Tratamientos Térmicos E De Superficie Prof. Escola Politécnica Da Universidade De São Paulo. Depto. De Engenharia Mecatrônica E De Sistemas Mecânicos Pmr 2002.

2.2.5.2. AUSTEMPERING O AUSTEMPERADO

Este tratamiento isotérmico que consiste en calentar el acero a una temperatura de austenización seguidamente de un enfriamiento rápido hasta una temperatura levemente superior a M_S baño de sal, (para mantener a una temperatura de la pieza constante) ya que esta temperatura tiene como finalidad obtener una estructura al 100%

bainítica (bainita superior o inferior), ya que este tipo de estructuras al no ser tan enérgico como los otros tratamientos térmicos tiene una ventaja que resulta ser más tenaz, para una igual dureza que se tiene con un proceso de temple o el revenido. Luego de haber obtenido esta estructura bainítica se enfría al aire hasta la temperatura ambiente, otra de sus grandes ventajas que se tiene es el proceso de austenpering no tiene las tensiones, deformaciones, y grietas que se presentan en un temple en refrigerantes severos.

Gráfico N° 18: Austempering



Fuente: Tratamientos Térmicos E De Superfície. Prof. Escola Politécnica Da Universidade De São Paulo. Depto. De Engenharia Mecatrônica E De Sistemas Mecânicos Pmr 2002

A continuación veremos un ejemplo donde se realizaron numerosos estudios comparando el proceso de austenpering frente a el proceso de temple y revenido, se consideraron probetas del mismo acero que ya fueron tratadas térmicamente y cuentan con la misma dureza o estricción[7] según la tabla a continuación se puede observar que con el austemperado se obtiene una mejor tracción y resistencia que con los aceros templados.

Tabla N° 6: Comparación de Propiedades entre Temple - Revenido y Austemperado.

Propiedad medida	Temple y revenido	Austemperado
Dureza Dockweil C	49,8	50,05
Carga de rotura Kg/mm^2	181	182
Alargamiento, % en 2 pulg.	3,75	5
Estricción %	26,1	46,4
Resistencia al choque Kgm (probetas cilíndricas sin entalla)	1,93	5

Fuente: Machado Isabel. Tratamientos Térmicos E De Superficie. Prof. Escola Politécnica Da Universidade De São Paulo. Depto. De Engenharia Mecatrônica E De Sistemas Mecânicos Pmr 2002.

[7] Estricción: es la reducción de la sección que se produce en la zona de la rotura.

Hay que tener en cuenta que el austenpering no puede darse en cualquier acero, este debe tener una templabilidad suficiente como para que la periferia y el núcleo de la pieza, alcance el baño de sales fundidas de temperatura isotérmica antes de que se inicie la transformación de austenita en bainita, si el acero no cuenta con las propiedades de templabilidad se podría obtener bainita en la periferia y perlita en las zonas más internas de las piezas, si bien es cierto que necesitamos que los aceros tengan templabilidad pero este no debe ser muy grande ya que si tuviera un gran templabilidad la duración del tratamiento será excesivo, ahora tampoco nos podemos ir a otro extremo que el acero tenga muy baja templabilidad, cuya curva TTT fuera tal que su zona perlitica resultara prácticamente tangente el eje de ordenadas, no podría ser austemperizado. El austenpering es un tratamiento que suele darse a algunos aceros al carbono entre 0.5%C a 1.20%C o de baja aleación, destinados a herramientas. También se emplea en algunas fundiciones esferoidales llamadas fundiciones A. D. I. (*austempered ductile iron*).

2.2.5.3. MARTEMPERING O MARTEMPERADO

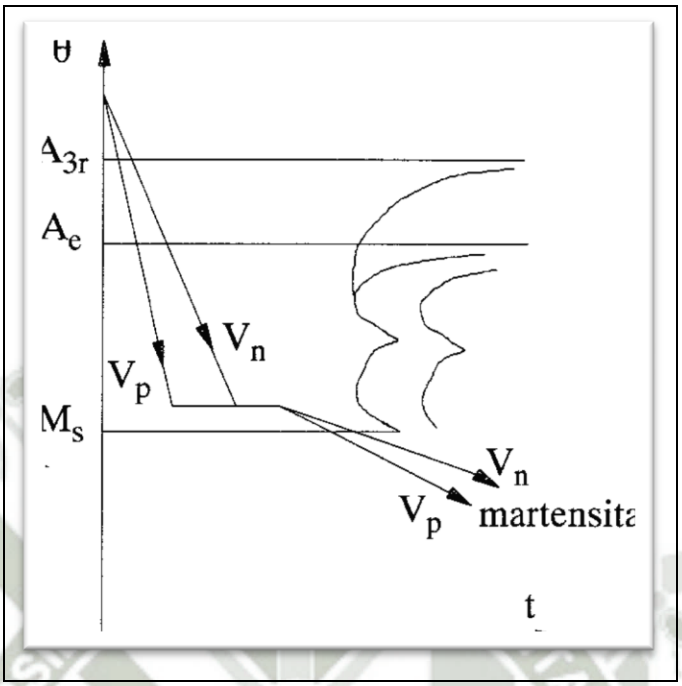
Este tratamiento térmico se da a grandes temperaturas el cual tiene como objetivo disminuir las grietas, distorsión o esfuerzos residuales, como todo proceso isotérmico se tiene que evaluar en las curvas TTT , en estas curvas se puede observar tres etapas :

a) El enfriamiento se realiza desde la temperatura de austenización en un medio fluido caliente como aceite caliente, sales fundidas, metal fundido o lecho de partículas fluidas a una temperatura que debe estar por encima de M_S.

b) Ahí se deja el acero hasta que su temperatura en toda la pieza se uniforme y no se puedan producir trasformaciones por bien sabemos que la pieza continúa siendo austenítica, se tiene que tener en cuenta que la pieza toda vía debe ser plástica y se puede restaurar si han sufrido alguna distorsión.

c) La pieza se enfría, casi siempre en aire quieto, a una velocidad moderada para evitar grandes diferencias en la pieza con este tiempo de enfriamiento obtendremos la formación de martensita uniformemente en toda la pieza y evitando formación de tensiones residuales.

Gráfico N° 19: Martempering



Fuente: Machado Isabel. Tratamentos Térmicos e de Superfície . Prof. Escola Politécnica da Universidade De São Paulo. Depto. de Engenharia Mecatrônica E De Sistemas Mecânicos Pmr 2002

2.2.6. TRATAMIENTOS SUPERFICIALES

Los tratamientos superficiales son aquellos que mejoran la superficie de la pieza, en esta ocasión no se afecta la composición química de la misma. Este tratamiento consiste en calentar únicamente la superficie a una temperatura critica superior o inferior según sea el caso (generalmente de 470°C a 880°C) mediante inducción o con soplete, para después enfriar rápidamente hasta una temperatura de 300 a 700 °C,

manteniéndose constante durante varias horas, para conseguir la completa transformación isotérmica de la austenita, y finalmente se enfría al aire y así producir un temple únicamente en la superficie. Este tipo de tratamientos superficiales se da para una gran variedad de uso ya que su versatilidad en los aceros y su combinación de propiedades así lo permite, muchas de estas piezas se encuentran sometidas a desgaste o tensión altas como por ejemplo engranes, flechas, rodillos de trenes de laminación, etc. Este tipo de tratamiento también nos ayuda a reducir la distorsión y eliminar la figuración que puede generarse durante un endurecimiento.

2.2.7. TRATAMIENTOS TERMOQUÍMICOS

Este tipo de tratamiento afecta directamente a sus cambios estructurales tanto internos (Estos dependerán de los diferentes productos químicos) como superficiales, este tipo de tratamiento dependerá del tiempo y la temperatura de calentamiento como factor fundamental, pero tenemos que tener en cuenta su control en atmósferas especiales que envuelvan al metal durante este proceso. El objetivito principal del tratamiento termoquímico es aumentar la dureza superficial para una resistencia al desgaste, una buena tenacidad en el núcleo, aumentar la resistencia a la corrosión, mayor resistencia a la fatiga, a este tipo de tratamientos termoquímicos pertenecen la cementación, cianuración,

sulfinizacion y nitriración

- Cementación (C): Este tipo de tratamiento aumenta la dureza superficial de una pieza de acero, haciendo que se incremente la concentración de carbono en la superficie. Esto se consigue teniendo en cuenta el medio o atmósfera que envuelve el acero durante el calentamiento y enfriamiento. El tratamiento logra aumentar el contenido de carbono de la zona periférica, obteniéndose después, por medio de temples y revenidos, una gran dureza superficial, resistencia al desgaste y buena tenacidad en el núcleo.

- Cianuración (C+N): Es un tratamiento parecido a la cementación, se da un endurecimiento superficial a pequeñas piezas de acero en el que el acero absorbe carbono y nitrógeno en la zona superficial, utilizando baños con cianuro, carbonato y cianato sódico, quedando luego en zona periférica muy dura después de un temple final. La temperatura de este tratamiento térmico es entre 760°C a 950°C.

- Sulfinización (S+N+C): El tratamiento térmico se da a los aceros a una temperatura por debajo de 565°C donde se incrementa azufre en un baño de sales, donde por acción del azufre aumenta la resistencia al desgaste.

- Nitruración (N): Aquí se da un endurecimiento superficial pero se da a una baja temperatura, el acero es calentado aproximadamente a 500°C donde al hacer contacto con una corriente de amoniaco, se introduce en la caja de nitrurar, absorben nitrógeno, formándose en la capa superficial nitruros de gran dureza, quedando las piezas muy duras sin necesidad de ningún otro tratamiento posterior.

- Carbonitruración (C+N): A igual que la cianuración, se introduce carbono y nitrógeno en una capa superficial, pero con hidrocarburos como metano, etano o propano; amoníaco (NH_3), monóxido de carbono (CO). En el proceso se requieren temperaturas de 650 a 850 °C y es necesario realizar un temple y un revenido posterior.

2.2.8. TRANSFORMACIONES DURANTE EL ENFRIAMIENTO DEL ACERO (DIAGRAMAS T. T. T.)

En la actualidad la transformación de los aceros se puede dar tanto para los aleados como para los carbono y estas pueden ser transformaciones isotérmicas (este se consigue por inmersión en un baño de sales fundidas que mantiene a una temperatura constante) o transformaciones de enfriamiento continuo (se enfría dentro del horno, al aire, en agua, aceite, etc.). El diagrama T. T. T. (Transformación – Temperatura – Tiempo) es una

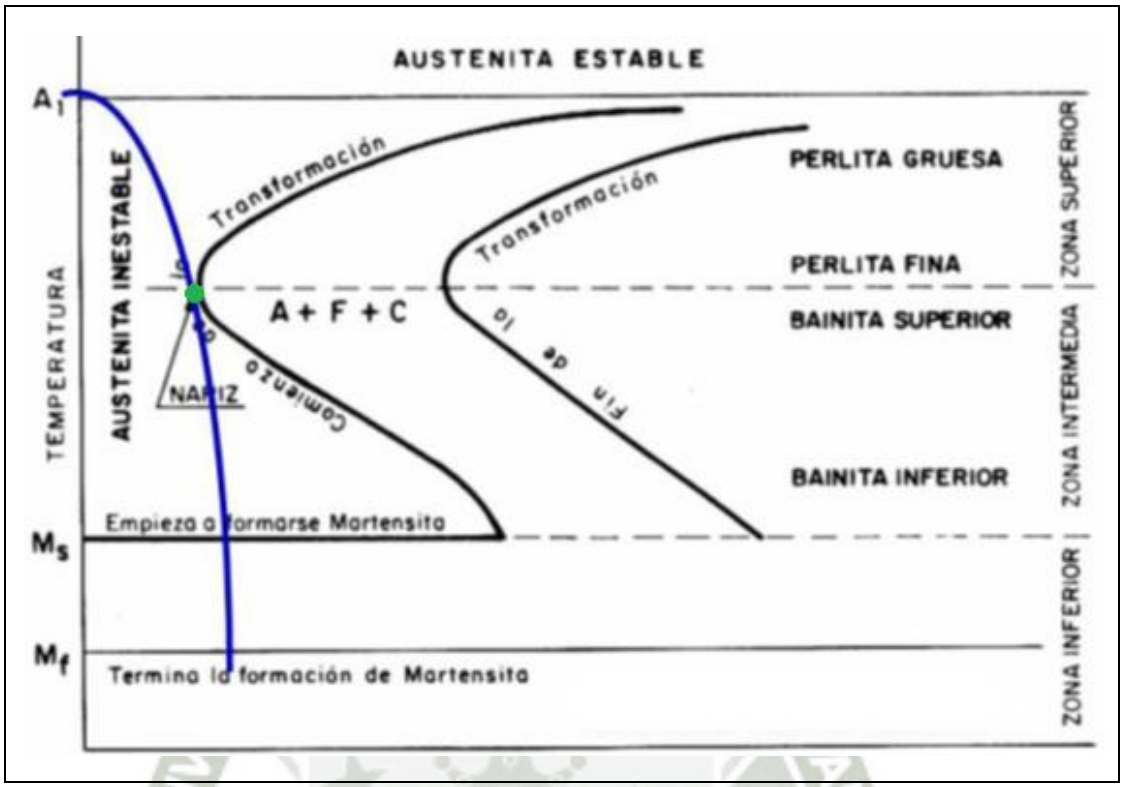
relación entre el tiempo y la temperatura requeridos para una trasformación isotérmica, el % de trasformación está dada en función de la temperatura (eje vertical) y el tiempo (eje horizontal escala logarítmica). Estos diagramas son muy útiles ya que nos ayuda a entender la transformación del acero que se enfría isotérmicamente. Y así podemos considerar como ejemplo una fase austenita, ya que como bien sabemos es inestable por debajo de la temperatura de transformación eutectoide y debes saber:

- Cuanto tiempo requiere para dar inicio a la transformación a la temperatura subcritica especifica.

- El tiempo exacto para un trasformación completa.

- La naturaleza del producto de esta transformación.

Gráfico N° 20: Diagrama T. T. T. de un Acero Eutectoide



Fuente: Eduardo Torres Alpízar 2004

2.3. ACEROS AVANZADOS DE ALTA RESISTENCIA (AHSS)

2.3.1. CONCEPTO GENERAL

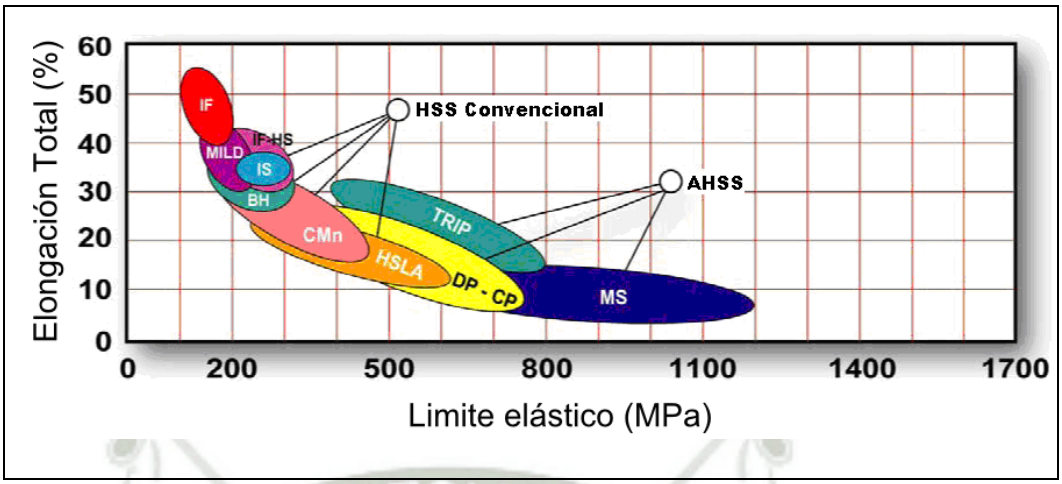
Los aceros a lo largo de su vida se han ido modificando desde su invención, estas modificaciones se efectuaron directamente o indirectamente en su estructura interna. Hoy en día tenemos una gran variedad de aceros para su aplicación una de ellas es utilizada para la industria automotriz donde la evolución del acero nos lleva a una reducción de espesores de los diferentes

componentes metálicos como montantes, taloneras, refuerzos laterales, etc. claro está que se tiene que tener un aumento a su resistencia al impacto para esto se están utilizando los aceros llamados avanzados de alta resistencia (*Advanced High Strength Steel AHSS)*. O comúnmente conocidos como aceros micro aleados, los que nos brindan mejores propiedades mecánicas o mayor resistencia a la corrosión que un acero simplemente al carbono.

Estos aceros que se usan en la industria automotriz se definen como los de alta resistencia HSS (*High Strength Steel*) los que poseen un límite elástico comprendido entre los 210 a 550 MPa y una tención a la rotura de 270 y 700 Mpa. Y los aceros avanzados de alta resistencia AHSS (Advanced High Strength Steels) cuentan con su límite elástico mayor a 550 MPa y una tención a la rotura mayor de 700MPa.

La diferencia entre los aceros convencionales (HSS) y los aceros avanzados de alta resistencia (AHSS) se dan en su micro estructura. La estructura de los HSS son monofásicos con una estructura ferrítica, en cambio AHSS son aceros que tienen múltiples fases de los que pueden contener ferrita, martensita, bainita, y/o austenita retenida en cantidades suficientes para producir una propiedades mecánicas únicas.

Gráfico N° 21: Diferencias de Distintos Tipos de Aceros



Fuente: International Iron And Steel Institute

2.3.2. TIPOS DE AHSS

La obtención de los aceros AHSS es compleja a comparación de los aceros convencionales, en necesario mayor control en su fabricación ya que se basa en los porcentajes de las diferentes fases presentes, estos se pueden clasificar en:

- Doble Fase (*Dual Phase* (DP)).
- Transformación inducida por Plasticidad *(Transformation Induced Plasticity* (TRIP)).
- Fase Compleja *(Complex Phase (CP)).*

- *Martensitic (MS).*

- *Ferritic Bainitic (FB).*

- Plasticidad Inducida por Maclaje *(Twinning Induced Plasticity (TWIP)).*

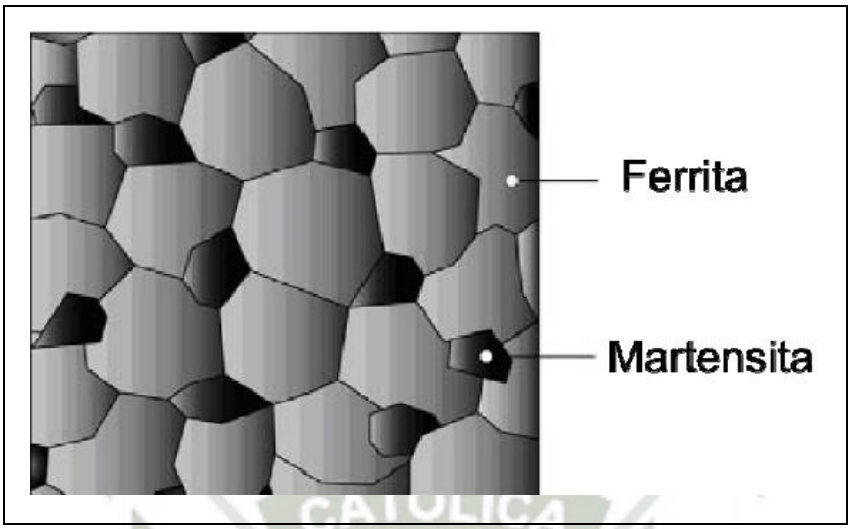
- *Hot Formed (HF).*

- *Post Forming Heat Treatable (PFHT).*

2.3.2.1. DOBLE FASE (*DUAL PHASE* (DP)).

Este tipo de aceros contiene en su micro estructura una matriz ferrítica con islotes de martensita. Con este tipo de estructura se pueden obtener altos valores de resistencia según la cantidad de martensita presente. Este tipo de aceros son fabricados con un alto control en el enfriamiento de la austenita para posteriormente transformar esta en martensita, aunque depende del proceso de fabricación porque se pueden mejorar por la aparición de bainita. El recocido al que se somete va a ser clave en estos tipos de aceros ya que de ahí se obtendrá la fase más dura.

Gráfico N° 22: Doble fase (Dual Phase (Ferrita – Martensita))

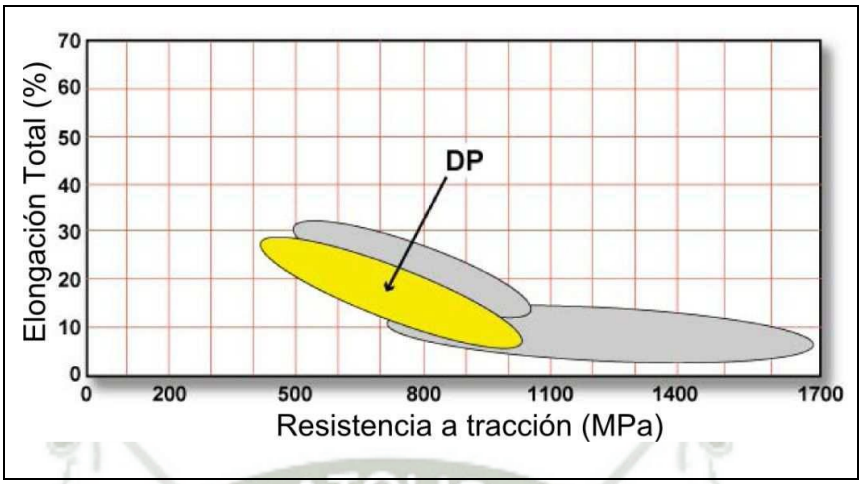


Fuente: International Iron And Steel Institute

El efecto de endurecimiento que se tiene en este tipo de aceros hace que se incremente el valor del límite elástico con una elevada temperatura de envejecimiento, hay que tener en cuenta que para tener un acero *dual phase* los elementos como el manganeso, cromo, molibdeno, vanadio y níquel ayudarán a la formación de martensita.

El acero *dual phase* cuenta con una muy buena conformabilidad, ya que coexiste una fase blanda como ferrita y otra que es muy dura como la martensita.

Gráfico N° 23: Resistencia Comparada con Porcentaje de Elongación



Fuente: International Iron And Steel Institute

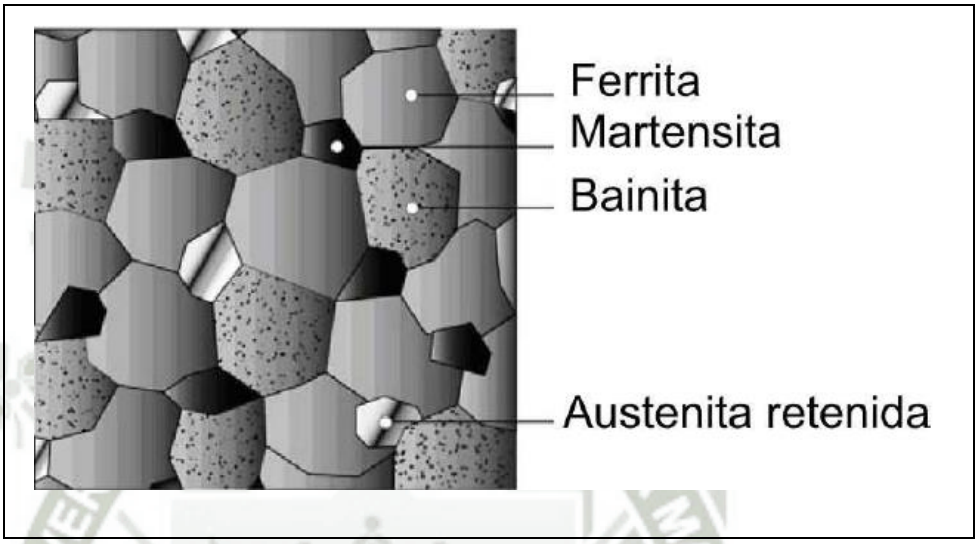
2.3.2.2. TRANSFORMATION INDUCED PLASTICITY (TRIP).

Los aceros TRIP tienen una microestructura distinta ya que tienen una formación de distintas fases donde la ferrita y bainita son las que forman la matriz. Sus fases bainitas y martensíticas estas serán las encargadas de darle al acero una alta resistencia. Ya que poseen una cantidad mínima de 5% de la austenita retenida.

En el proceso de su deformación, la aparición de una fase dura al entorno de la ferrita crea un endurecimiento por deformación como el observado en los DP. Pero, en los TRIP la austenita retenida también se transforma progresivamente en martensita con el aumento de la

tensión, con lo cual aumenta aún más la dureza consiguiendo niveles más altos que los DP.

Gráfico N° 24: Micro Estructura de un Acero Trip



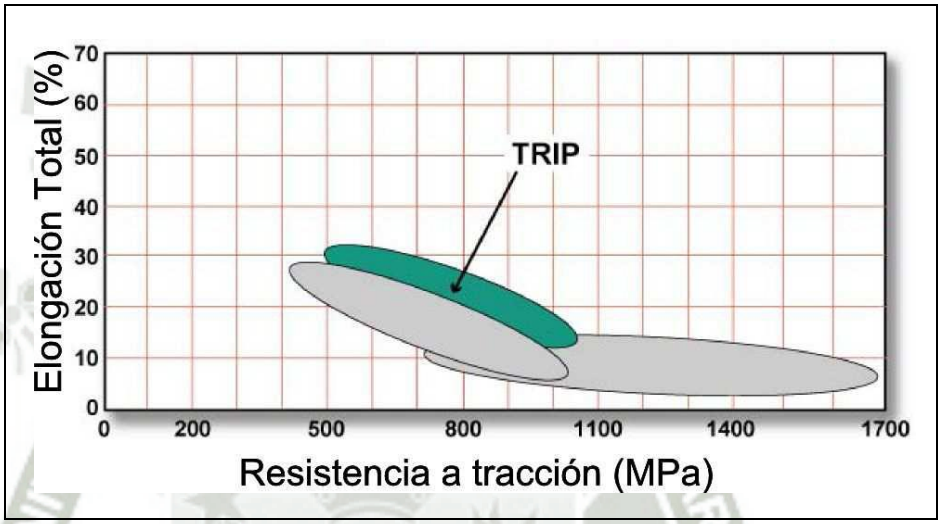
Fuente: International Iron And Steel Institute

En los aceros TRIP también interviene la velocidad de deformación, ya que este es un factor muy importante para las propiedades que afectan a la resistencia al impacto. Su nivel de austenita retenida que se transforma en martensita dependerá del contenido de carbono. A bajo carbono, la austenita retenida empezará a transformarse inmediatamente bajo deformaciones.

A alto carbono la austenita retenida será más estable y se transformará con niveles de esfuerzos mayores. Esta será

la causa de que este material tenga una excelente capacidad para absorción del impacto, e ira aumentando conforme aumente la deformación.

Gráfico N° 25: Resistencia Compara con Porcentaje de Elongación

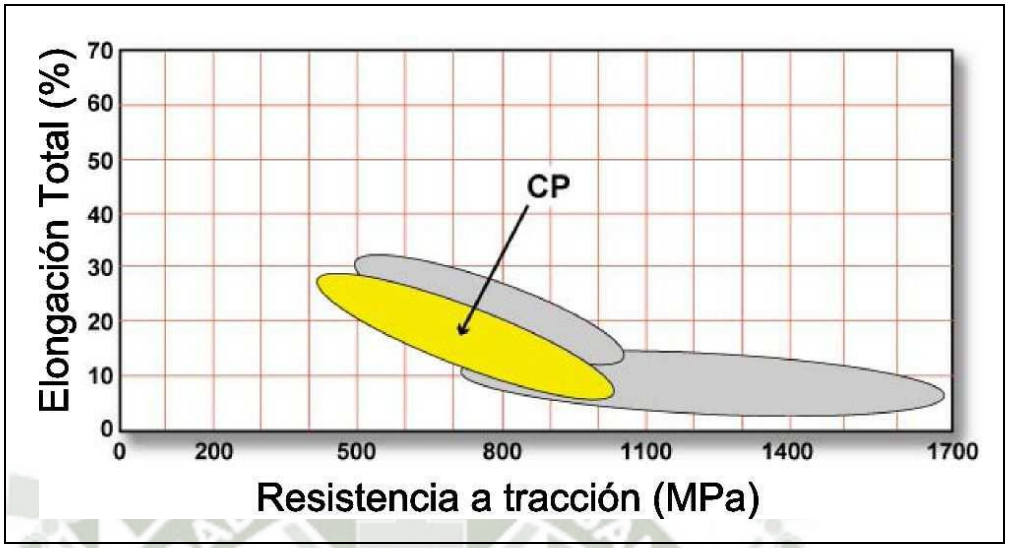


Fuente: International Iron And Steel Institute

2.3.2.3. FASE COMPLEJA COMPLEX PHASE (CP).

La característica principal de este tipo de aceros es tener una alta resistencia a tracción como se muestra en la siguiente gráfica.

Gráfico N° 26: Resistencia Compara con Porcentaje de Elongación Acero CP



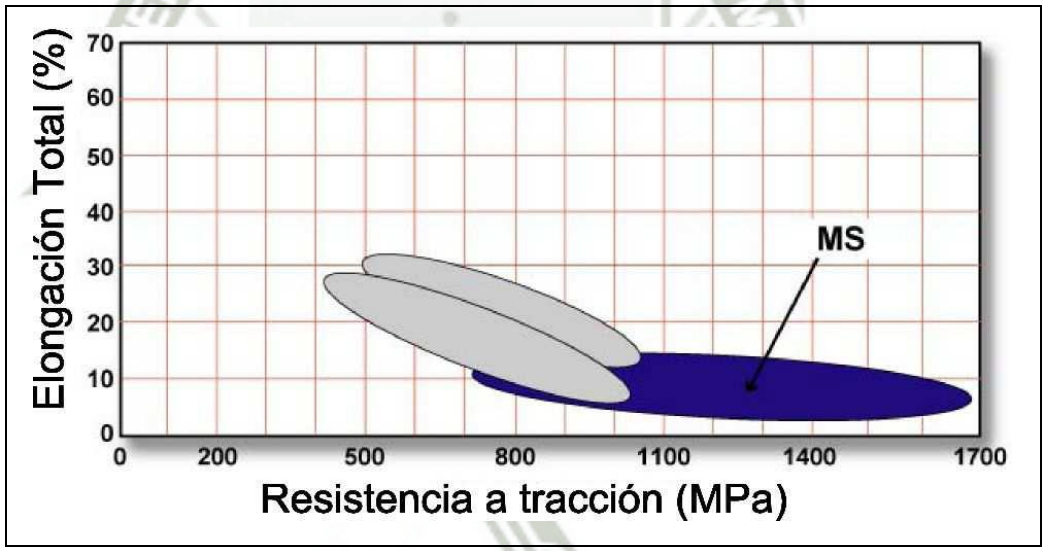
Fuente: International Iron And Steel Institute

La microestructura que posee este tipo de aceros en pequeñas cantidades es de martensita, austenita retenida y perlita en una matriz de ferrita y bainita. La propiedad de este acero es contar con un extremado grano fino producido por una re cristalización o por la acción de micro aleantes. Comparando con los Dual Phase, los Complex Phase cuentan con un mayor límite elástico y con una tensión de rotura de un máximo de 800 MPa. Estos aceros también tienen una alta capacidad de absorción al impacto con una alta capacidad de deformación residual.

2.3.2.4. MARTENSITIC (MS).

Los aceros MS gran parte de ellos se obtiene porque su matriz se transforma en martensita durante el proceso de templado conteniendo pequeñas cantidades de bainita y ferrita. Como se puede observar en la gráfica son los que mayor resistencia mecánica poseen alcanzando valores de hasta 1700 MPa.

Gráfico N° 27: Resistencia Comparada con Porcentaje de Elongación de un Acero MS



Fuente: International Iron And Steel Institute

Frecuentemente hay que someterlos a un post calentamiento para reducir su fragilidad logrando aumentar su conformabilidad ya que de esta forma obtenemos

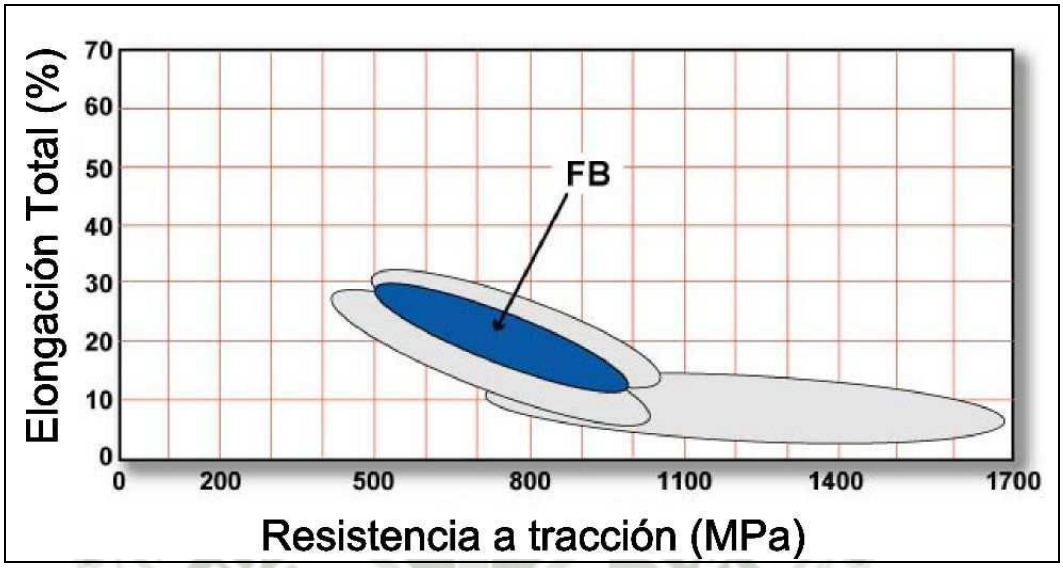
incrementar su ductilidad. En estos aceros el carbono es el encargado del aumento de la resistencia mecánica, aunque elementos como el Mn, Si, Cr, etc. pueden aumentar también esta característica. La fabricación es similar a la de los CP pero interviene una química más ajustada para producir una menor austenita retenida y formar precipitados.

2.3.2.5. FERRITIC BAINITIC (FB).

La particularidad de estos aceros es que poseen una alta capacidad de elongación. La microestructura que cuentan es de tipo ferrítica y bainítica, esta última será la encargada de darle una mayor resistencia mecánica junto con la morfología de grano fino.

La ventaja que se tiene con este acero al respecto a otros aceros es su gran capacidad para la conformación de bordes, también poseen buena soldabilidad y alta resistencia a la fatiga.

Gráfico N° 28: Resistencia Comparada con Porcentaje de Elongación de un Acero FB



Fuente: International Iron And Steel Institute

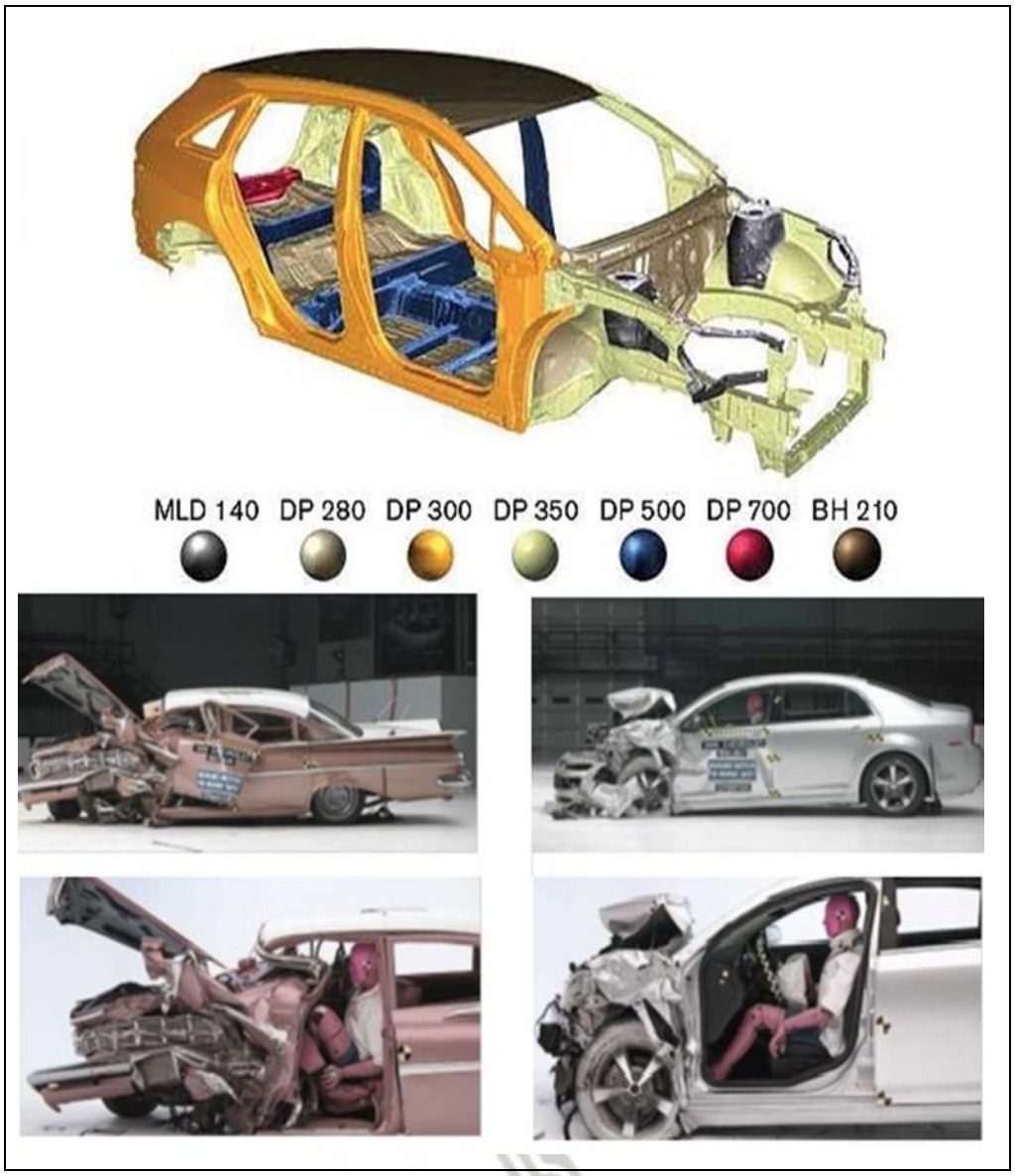
2.3.3. DESCRIPCIÓN DEL ACERO DE DOBLE FASE (DP)

Los aceros de doble fase (*Dual Phase*), se comenzaron a desarrollar a partir del año 1975 cuando se da descubrimiento que seguir con el recocido continuo en los rangos de temperaturas críticas, da como resultado un acero con microestructura ferrita y martensita haciendo que su ductibilidad sea mayor. Para poder obtener una microestructura doble fase es necesario llevar el acero al campo α + γ del diagrama Fe-C, esto se da en el rango de temperaturas entre A1 y A3, conocido como temperaturas intercríticas. Realizando un enfriamiento rápido a estas temperaturas la austenita presente se transforma en martensita

obteniendo las dos fases a temperatura ambiente, esta matriz de ferrita más martensita (fase de alta dureza) se encuentran en forma de islas, ya que al aumentar la temperatura desde A1 cambian las fracciones de los constituyentes modificando su estructura final.

Se tiene que tener en cuenta la velocidad de enfriamiento ya que el carbono permite la formación martensita en los aceros de doble fase logrando el incremento de la templabilidad del acero, se tiene otros elementos como el Mn, Cr, Mo, V, Ni en forma individual o en conjunto también incrementan en forma sustancial la templabilidad de acero. Otra propiedad del carbono es que endurece a la martensita como un endurecedor de fase sólida de la ferrita, como lo hace el silicio y el fósforo. Este tipo de acero nos ayudará para la industria automotriz ya que para un impacto es favorable por coeficiente de absorción.

Gráfico N° 29: Aplicación y Partes en los Automóviles de los Acero Fase Dual (Dual Phase)

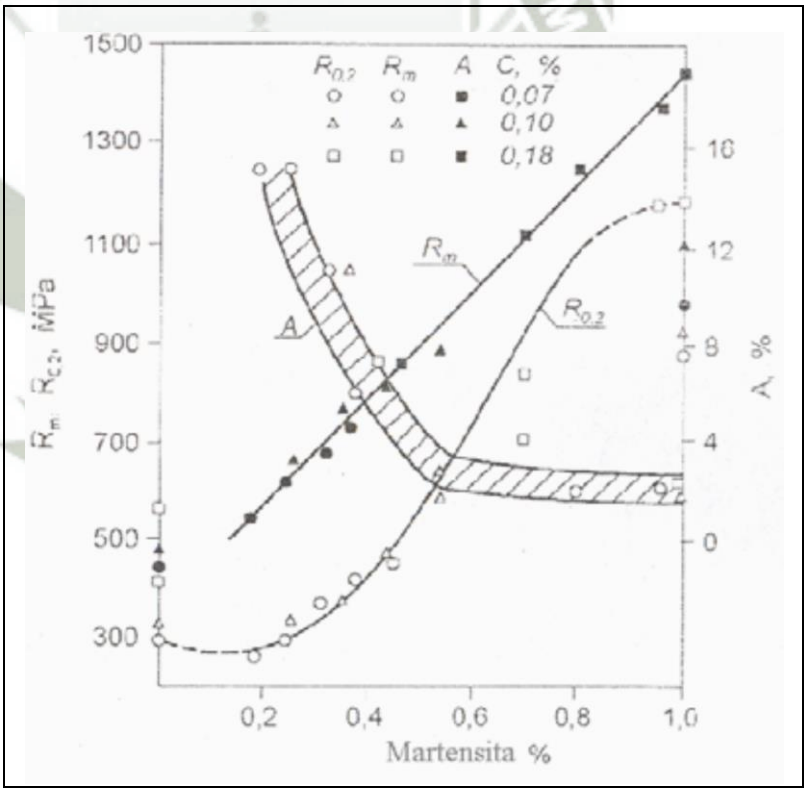


Fuente: Docol High Strength Steel , Kenneth Olsson, Business Development.

2.3.4. PROPIEDADES MECÁNICAS DEL ACERO DOBLE FASE

La propiedades mecánicas que caracterizan a los aceros de doble fase (*Dual Phase*) es la micro estructura bifásica que comprende en ferrita – martensita las que tienen una relación directa con su propiedad ya que si aumentamos las cantidades de martensita crece proporcionalmente la resistencia de acero.

Gráfico N° 30: Propiedades mecánicas del acero de doble fase en relación al contenido de carbono y fase martensita



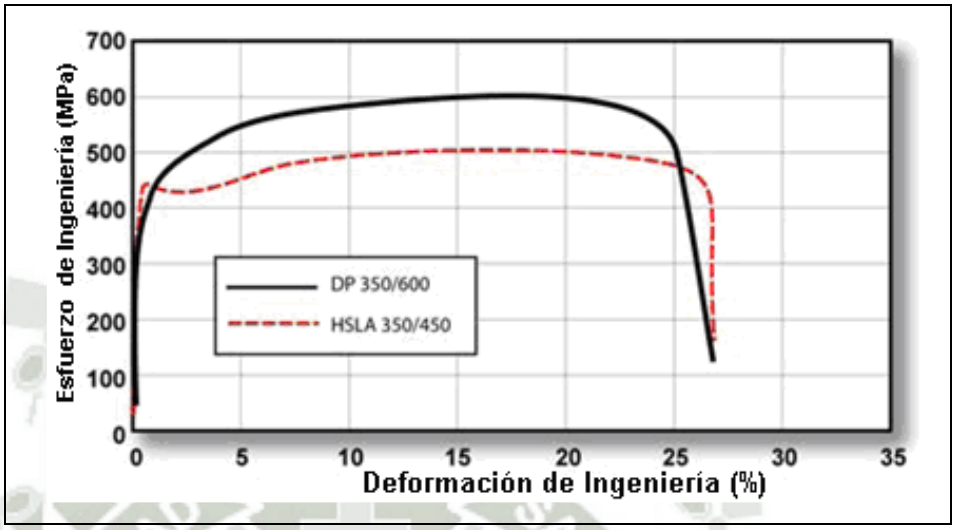
Fuente: Aceros de Construcción de Propiedades Especiales Autor Zygmunt Haduch, Joel Guajardo.

En general, aceros de ferrita - martensita no hacen mostrar un punto de fluencia muy marcado. La combinación de alta tensión residual y una alta densidad de dislocación móvil en la ferrita producen que la fluidez plástica ocurra fácilmente en bajas tensiones plásticas. Como resultado, se produce la cedencia en muchos lugares a través de la ferrita, haciendo que esta cedencia discontinua sea suprimida.

Como ya fue mencionado, la resistencia de la martensita depende directamente del carbón que contenga la fase, este es determinado por las condiciones de templado intercrítico y el contenido original de carbón en el acero, ahora la resistencia de la fase ferrita depende del tamaño de grano y las contribuciones del endurecimiento de la solución sólida de los elementos aleantes. Entonces podemos decir que la relación de propiedades mecánicas de acero de doble fase está en función del contenido de carbono y la fase de martensita.

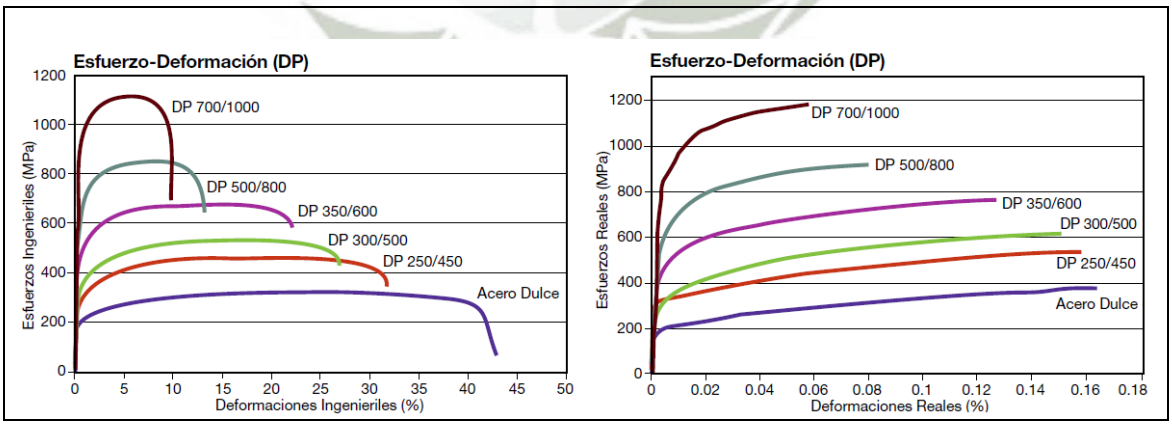
A continuación mostraremos diagramas donde se muestra el esfuerzo máximo permisible y la deformación de los aceros de fase dual comparados con los aceros convencionales y los HSLA.

Gráfico N° 31: Diagrama Esfuerzo – Deformación de Ingeniería para Acero DP y un Acero HSLA



Fuente: Los Nuevos Aceros para la Industria Automotriz Autor M. en Felipe Díaz del castillo Rodríguez – 2009

Gráfico N° 32: Curvas de Esfuerzo – Deformación, Ingenieriles y Reales para los Diferentes Grados de Aceros de Fase Doble (DP). El Acero Dulce se Considera como Referencia.



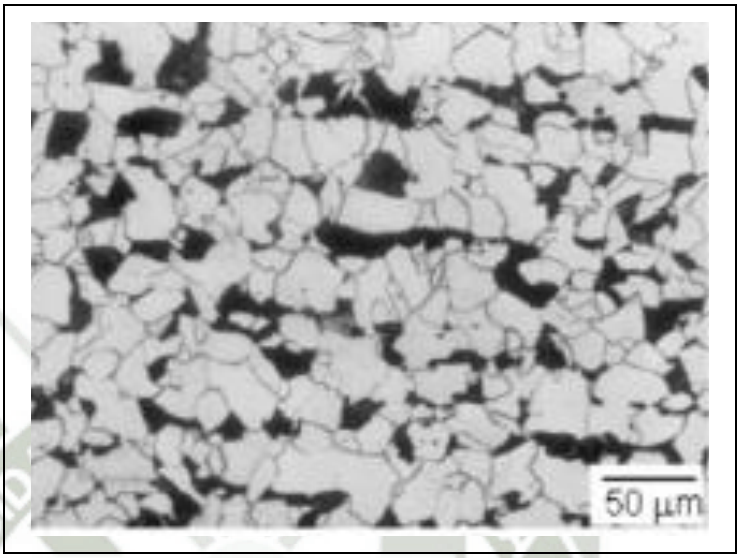
Fuente: La Ciencia del Formado , Autos Stuart Keeler con Permisos del Instituto Internacional de Hierro y el Acero (HSI)

2.3.5. ESTRUCTURA DE LOS ACEROS FASE DOBLES.

La estructura de los aceros de doble fase es muy interesante, hay que tener en cuenta que lo más importante es identificar correctamente la martensita y la ferrita. Considerando que la martensita da la dureza al acero, al ser aumentada proporcionalmente aumenta la resistencia del acero bifásico pero este no puede variar en su volumen fraccional entre un 10% a 20 % ya que al aumentar la martensita disminuye la ductilidad del acero, pero para mantener la ductibilidad tenemos que tomar en cuenta los contenidos de carbón en la fase.

El carbono tiene que ser menor a 0,1% ya que se podrá formar martensita de bajo carbono el que es ideal porque no es tan frágil y nos ayuda a mantener la fase ferrítico martensítico.

Gráfico N° 33: Micrografía de una Estructura Bifásica de un Acero de Bajo Carbono, Martensita (Secciones Oscuras) y la Ferrita (Secciones Claras)



Fuente: Aceros de Construcción de Propiedades Especiales Autor : Zygmunt Haduch, Joel Guajardo

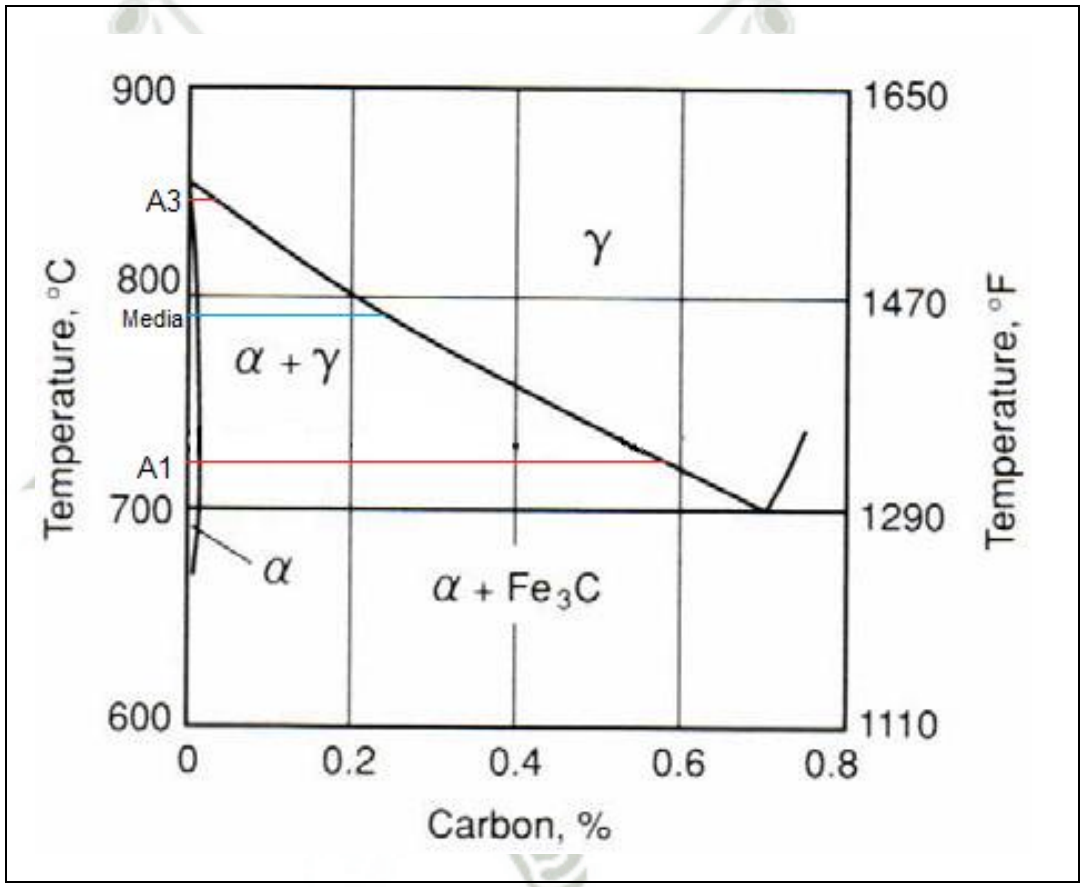
En la gráfica que mostramos se puede observar la formación del acero de doble fase ya que se presenta a nivel granular como una matriz de ferrita con " islas " de martensita el que nos brinda como resultado un acero tan duro por la martensita y dúctil por el contenido de la ferrita.

En el proyecto de investigación tomaremos como parámetros temperaturas intercriticas que comprende entre A1 y A3 esto lo mostraremos en el diagrama de hierro carbono ya que experimentaremos con aceros A – 36:

- Temperatura A1: 725°C para obtener aceros bifásicos con altos contenidos de ferrita.

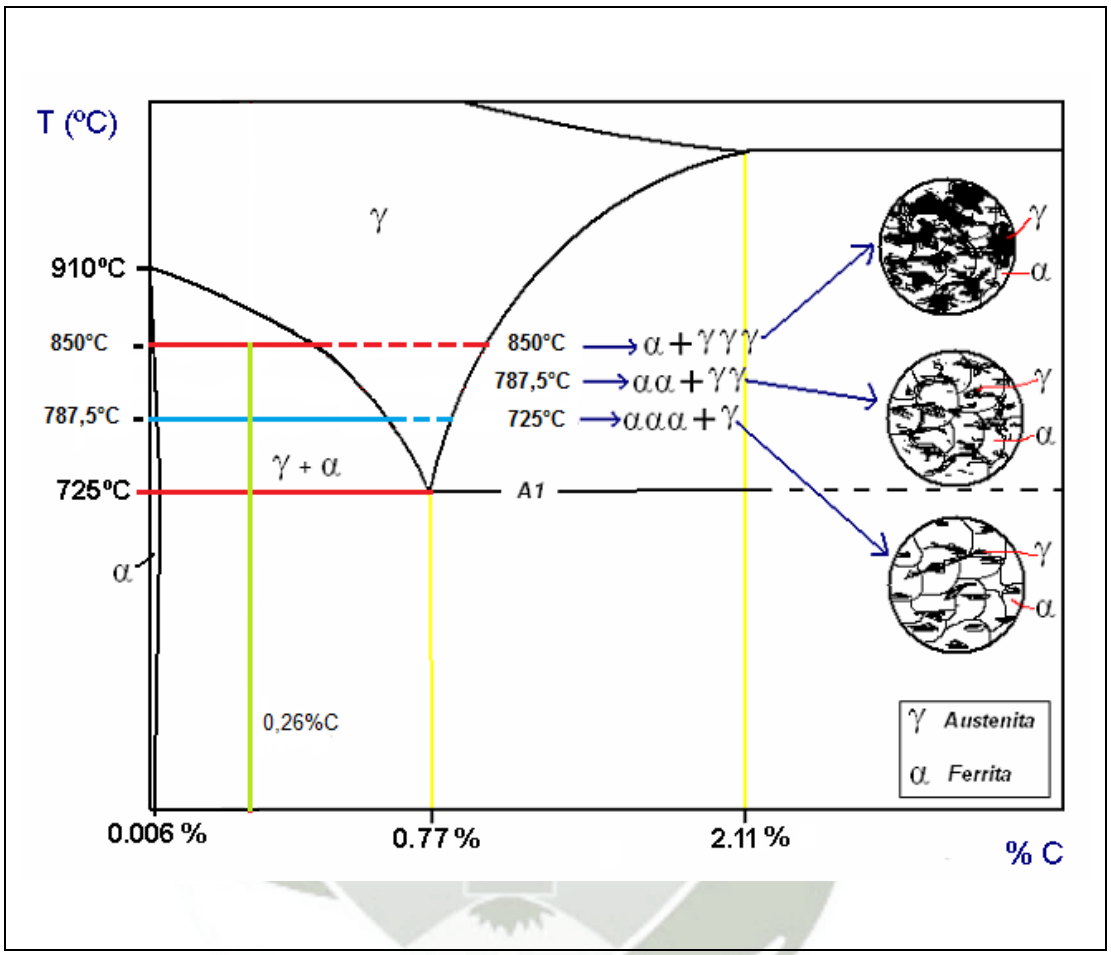
- Temperatura A3: 850°C para obtener aceros bifásicos con altos contenidos de martensita.

Gráfico N° 34: Diagrama Hierro Carbono con Temperaturas Intercriticas.



Fuente: Aceros de Construcción de Propiedades Especiales Autor: Zygmunt Haduch, Joel Guajardo Elaboración: Propia

Gráfico N° 35: Diagrama Hierro Carbono, Mostrando las Temperaturas de Calentamiento de Aceros de Bajo Carbono, y su Micro Estructura Resultante Después del Temple en Agua



Fuente: Aceros de Construcción de Propiedades Especiales Autor: Zygmunt Haduch, Joel Guajardo Elaboración: Propia

CAPITULO III

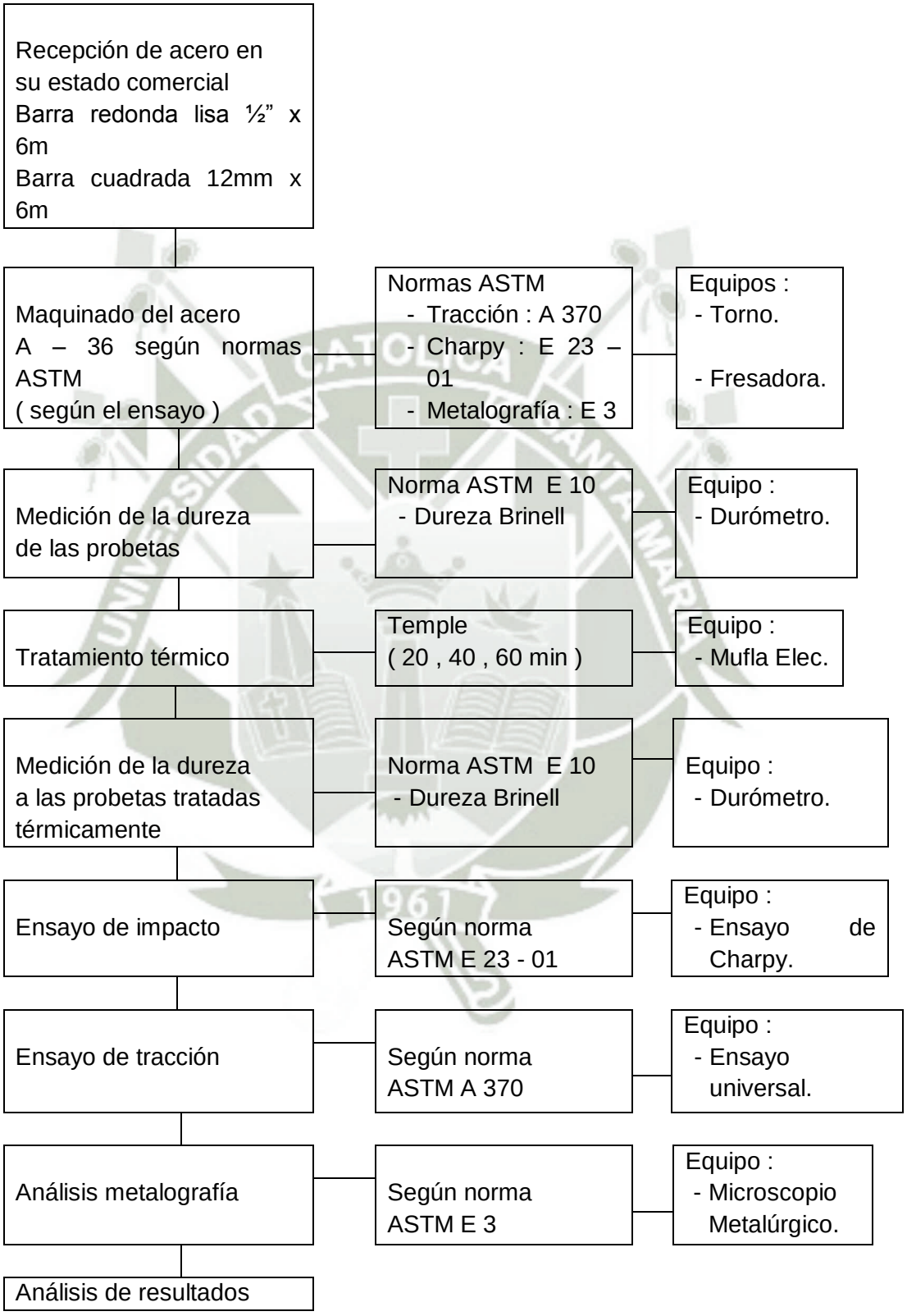
DESARROLLO TECNICO EXPERIMENTAL

El presente capítulo muestra el procedimiento empleado para la obtención de una doble fase (*Dual phase*) a un acero ASTM A – 36, así como las actividades realizadas para la determinación de las propiedades y las características de este acero. Los ensayos realizados fueron los de tracción, impacto, micro dureza en la escala de Rockwell B y, para poder observar su micro estructura, utilizamos el análisis metalográfico. Cabe resaltar que, para la obtención de una doble fase, se tiene que realizar un tratamiento térmico a cada probeta; para ello, utilizamos una mufla. Finalmente, las probetas con las que trabajamos se diseñaron bajo las normas ASTM.

3.1. PROCESO TECNICO EXPERIMENTAL

Para poder realizar con eficiencia el proceso experimenta se ha elaborado un gráfico, en el cual se establece el orden y las principales técnicas que utilizamos para el desarrollo de esta investigación así mismo también se indican los equipos, materiales e insumos necesarios.

Grafico N° 36: Diagrama de Ejecución del Proceso para la Obtención del Acero de Fase Dual, Ensayos y Análisis Correspondiente



3.2. CARACTERÍSTICAS DE LOS EQUIPOS A UTILIZAR EN EL PROCESO TÉCNICO EXPERIMENTAL

Los equipos que fueron utilizados se encuentran ubicados en el laboratorio de ensayo de materiales " pabellón R " de la facultad de Ciencias e Ingenierías Físicas y Formales que pertenece a la Universidad Católica de Santa María. En el laboratorio debemos seguir con sus normas e implementos de seguridad dispuestos por los encargados del laboratorio.

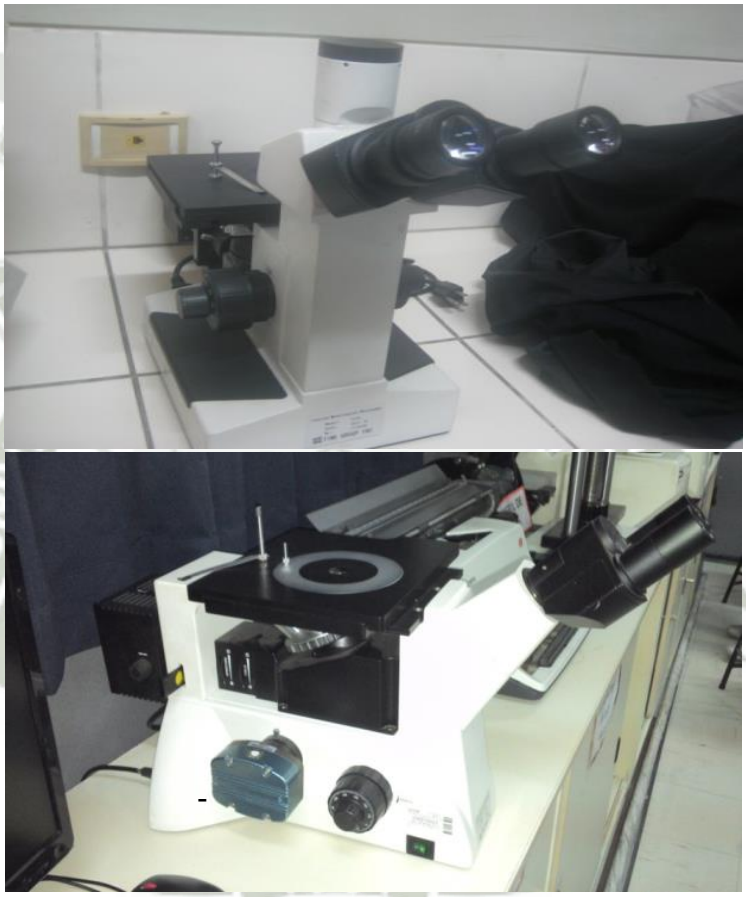
Grafico N° 37: Puerta de Ingreso a Laboratorio de Ensayo de Materiales.

Fuente: Elaboración Propia del Autor

3.2.1. MICROSCOPIO METALURGICO

El microscopio que contamos en el laboratorio es de modelo DX70A que cuenta con las siguientes características:

Grafico N° 38: Microscopio Metalúrgico Modelo DX70A



Fuente: Elaboración Propia del Autor

- Ultra clara visión de oculares de campo amplio.
- Chumacera grande con doble placa giratoria.
- Conmutación polarizante, salida de sincronización de imagen lateral.

Ocular y sus ampliaciones:

- Total de aumentos: 100X, 200X, 500X, 1000X.
- Objetivo infinito: 10x, 20x, 50x, 100x Dry.
- Convertidores de lente: Cinco bolas de agujero dentro de la colocación.
- Gran angular ocular: WF10X/22mm.
- Retícula: 10 zoom, 0,1mm, (dependiendo del grado de compensación).

Parámetros técnicos:

- Binocular : Abatible , inclinado 45° , PD 53 – 75mm , brillo del flexor de 5D ajustable
- Salida de la imagen: Vista de la salida óptica síncrona lateral, interfaz estándar.
- Fuente de alimentación : AC 220 V , 50/60 Hz , 40VA

3.2.2. TRACCIÓN

El laboratorio de ensayo de materiales cuenta con una maquina universal de ensayo de tracción modelo WDW – 300E:

Grafico N° 39: Maquina Universal de Ensayo de Tracción y Compresión Modelo WDW – 300E

Fuente: Elaboración Propia del Autor

Ficha técnica de maquina universal de ensayo de tracción y compresión modelo WDW – 300E:

- Modelo W-300E.
- Max. Tensión de fuerza 300 KN.
- Precisión de fuerza en el ensayo ±1%
- Medida de la fuerza en la prueba 600N～300kN
- Rango de medición Graduable (opción del usuario)

- Precisión de medida de deformación ±1%.
- Resolución de la capacidad de deformación 0.001mm.
- Precisión de la medida de desplazamiento ±0.5%
- Capacidad de la resolución de desplazamiento 0.002mm
- Velocidad de rango: 0.005mm/min～500mm/min, control de precisión ±1%.
- Máximo estiramiento / espacio de comprensión 590mm
- Mordaza plana（mm）: 0—7、7—14、14—20
- Mordaza redonda（mm）: Φ9—Φ14、Φ14—Φ20、Φ20—Φ26
- Fuente de alimentación 5kW 380V
- Motor Panasonic servo motor (users requirement)
- Dimensión externa 1100×770×2558mm
- Peso 1100 kg a 1560Kg

3.2.3. IMPACTÓ

Las pruebas de impacto se utilizó la máquina conocida con nombre Charpy de modelo JB-W300A sus especificaciones:

- Max. energía de impacto 300J/150J
- Max. velocidad de impacto 5.2m/s
- Angulo de levante 150º
- Distancia entre centros del péndulo y la muestra 750mm
- Span specimen plate 40mm
- Dimensión de la esquina del borde de impacto 30 grado
- Espesor de la hoja de impacto 16mm

- Min. resolución de la energía de impacto 2/1J
- Dimensiones 800x578x1400 mm , Peso 450Kg
- Fuente de alimentación AC 380V, 50Hz, 3 fases, 180W
- Tamaño de muestra 10 x 10 x 55 mm (U,V 2mm muesca)

Grafico N° 40: Máquina de Ensayo de Impacto Charpy

Fuente: Elaboración Propia del Autor

3.2.4. DUREZA

El durómetro en cual realizamos el ensayo de dureza es un modelo HBRVU-187.5 con las siguientes especificaciones:

- Modelo HBRVU187.5
- Unidad de medida : Brinell , Rockwell y Vickers Óptico
- Fuerza del ensayo preliminar (N) : 98.07
- Fuerza total del ensayo para dureza Rockwell (N): 588.4, 980.7, 1471.

- Fuerza total del ensayo para dureza Brinell (N): 306.5, 612.9, 1839.
- Fuerza total del ensayo para dureza Vickers (N) : 294.2 , 980.7.
- Rango de dureza para prueba Rockwell: 20~67 HRC / 30~100 HRB / 70~85 HRA.
- Rango de dureza para Brinell: 4~450 HB.
- Rango de dureza para Vickers: 14~1000 HV.
- Aumento del microscopio: 37.5x, 75x.
- Valor min. del calibrador micro. Medición del tambor de rueda: 0.004mm at 37.5x, 0.002mm at 75x.
- Max. Altura de las muestras (mm): 160 for Rockwell, 100 for Vickers, Brinell.
- Max profundidad de las muestra (mm) : 200
- Fuente de alimentación : 220V, 50Hz
- Peso y medidas: 90 Kg, 560 x 260 x 760 mm.

Grafico 41: Durómetro Modelo HBRVU-187.5

Fuente: Elaboración Propia del Autor

3.2.5. TRATAMIENTO TÉRMICO

Utilizamos una mufla Modelo L 9/13/P330 con aislamiento de ladrillo y puerta abatible. Con su robusto aislamiento de ladrillos refractarios.

- Tmáx 1300 °C.
- Calentamiento de dos lados mediante elementos calefactores.
- Los elementos calefactores de los tubos de apoyo proporcionan una radiación libre del calor y una larga vida útil.
- Aislamiento multicapa con robustos ladrillos refractarios en la cámara del horno.
- Carcasa de chapas estructurales de acero inoxidable

- Carcasa de doble pared para temperaturas exteriores bajas y elevada estabilidad
- A elegir con puerta abatible (L), que puede usarse como superficie de trabajo, o sin sobreprecio con puerta de elevación (LT), quedando la parte caliente alejada del operario.
- Apertura de aire adicional regulable en la puerta.
- Apertura de aire de escape en la parte trasera del horno.
- Calefacción silenciosa con relé semiconductor.
- Capacidad volumétrica 9 litros.
- Dimensiones: 480mm Ancho, 550mm Prof., 570mm Alt.
- Potencia 3.0 Kw conexión eléctrica monofásico.

Grafico 42: Mufla Modelo L 9/13/P330

Fuente: Elaboración Propia del Autor

3.3. TECNICAS EMPLEADAS EN EL PROCESO EXPERIMENTAL

En esta sección nombraremos los métodos experimentales, las normas Requeridas para los ensayos y los insumos que se requieren para la utilización de los equipos, con la finalidad de optimizar tiempo y recursos.

3.3.1. TRATAMIENTO TÉRMICO PARA LA OBTENCION DE LA FASE DOBLE DEL ACERO ASTM A – 36

El tratamiento térmico seleccionado fue un temple, para el cual consideramos las temperaturas intercriticas A1 y A3 (725°C – 850°C) respectivamente, dado que según nuestra teoría y en especial el diagrama de hierro carbono es posible experimentar a estas temperaturas para obtención de aceros bifásicos, por ejemplo si consideramos una temperatura de temple de 725°C obtendremos altos contenidos de ferrita, y si realizamos el temple a una temperatura de 850°C se obtendrá altos contenidos de martensita, según sea el caso hay que tener en cuenta las proporciones de martensita o de ferrita porque de estos dependerán las propiedades mecánicas del acero.

El tiempo de sostenimiento de la temperatura lo consideramos una vez que las probetas alcanzaron la misma temperatura que el horno, en ese preciso momento se empieza a cronometrar el tiempo. Los aceros de baja aleación contienen carburos fácilmente solubles, para asegurar que haya habido suficiente disolución de los carburos se determina suficiente un tiempo de

sostenimiento de 20 min., es considerado para secciones menores a 25mm, si las secciones son mayores se tomara una hora por cada 25mm (una hora por pulgada) de sección. La velocidad de calentamiento se determinará con base en los siguientes factores:

- Masa del material a calentar.
- Velocidad de absorción de calor del material.
- Temperatura del temple.
- Temperatura y trasferencia de calor del medio de temple.

Por lo que se consideró dos tiempos para poder realizar los ensayos el mínimo de 20 min. Y el máximo de 60min. Culminado el tiempo de mantención se procedió a enfriarlo en agua a 1°C y 17°C.

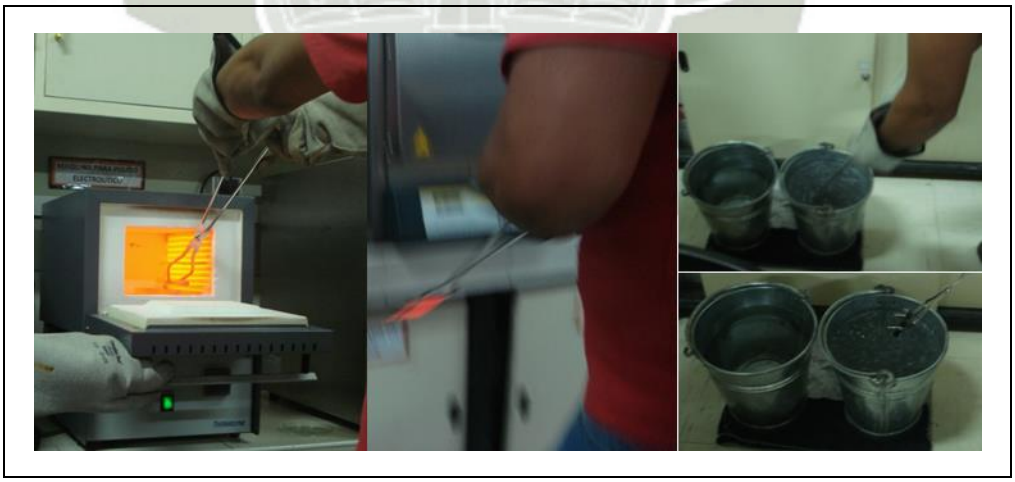
Grafico N° 43: Muflas en tiempo de mantención de temperatura (a) 725°C, (b) 850°C

Fuente: Elaboración Propia del Autor

Grafico N° 44: Recipientes con Agua (a) 17°C , (b) 1°C.

Fuente: Elaboración Propia del Autor.

Grafico N° 45: Retiro de las Probetas y Sumergidas a Agua para su Temple.



Fuente: Elaboración propia del autor.

Grafico N° 46: Probetas (a) Antes del Temple, (b) Después de Temple.

Fuente: Elaboración Propia del Autor.

Se recomienda calentar las piezas junto con el horno y no introducirlas cuando el horno ya este a la temperatura de indicada, también se tiene que tener mucho cuidado al retirar las probetas del horno ya que se podría ocasionar un accidente por las altas temperaturas alcanzadas.

3.3.2. DUREZA

Para que se pueda terminar la dureza del acero es necesario un durómetro el que se utilizo es un modelo HBRVU-187.5 y también se debe determinar las unidades, según el conformado del acero A – 36 indicando que cuenta con una dureza de 120 a 135 HB (dureza Brinell), para ello requeriremos a la norma ASTM E 10

Standars test method for Brinell hardness of metallic materials (anexo 1). En el cual la norma lo define como un método de ensayo por indentación, el que se fuerza una bola endurecida, bajo condiciones específicas, contra la superficie del material a ensayar y se mide el diámetro de la impresión resultante. Para la obtención de la dureza Brinell se tiene que aplicar la siguiente ecuación:

Formula N° 1: Método Brinell

$$\mathrm{HB} = \frac{2F}{\pi D(D - \sqrt{D^2 - d^2})}$$

Dónde:

F = Carga aplicada (N).

D = diámetro de la bola (mm).

D = diámetro medio de la indentación (mm).

Para obtener una mejor lectura del diámetro de impresión en el acero se pulió las probetas con lijar al agua de diferentes medidas 120, 240, 320, 600, 1000 estos están enumerados del 1 al 5 respectivamente, se utilizaron en forma ascendente y con agua.

Grafico N° 47: Tipos de Lijar

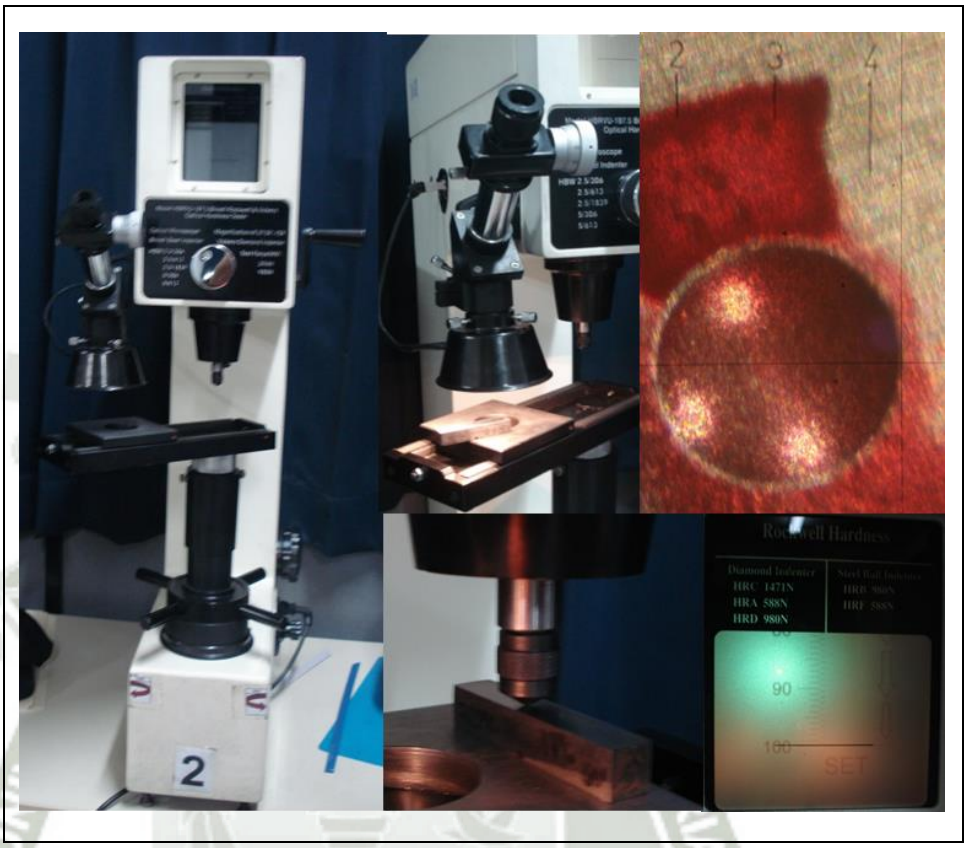
Fuente: Elaboración Propia del Autor.

Grafico 48: Proceso de Pulido de las Probetas

Fuente: Elaboración Propia del Autor.

Una vez pulido se procede a realizar la indentación, en el acero A - 36 utilizamos una bola de 2,5mm de diámetro y una fuerza de 187,6530 Kg-f.

Grafico N° 49: Proceso de Indentación en el Acero A – 36.



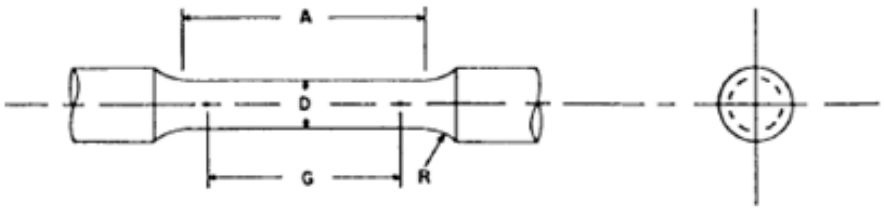
Fuente: Elaboración Propia del Autor.

3.3.3. TRACCIÓN

Para los ensayos de tracción se utilizó la maquina universal modelo WDW – 300E, la finalidad de este ensayo es definir la resistencia elástica, resistencia máxima y módulo de elasticidad de los materiales cuando son sometidos a fuerza uniaxial. Este ensayo consiste en someter una pieza de forma cilíndrica o prismática de dimensiones normalizadas a esta pieza se le llama probeta, para poder realizar esta probeta se recurrió a la norma ASTM E 8 *Standard test methods for tension testing of metallic*

materials (anexo 2) , que a su vez dicha cita nos indica una norma específica para aceros norma ASTM A 370 *Standard test methods and definitions for mechanical testing of Steel products* (anexo 3). En dicha norma ASTM A370 nos indica el tipo de probeta a fabricar.

Grafico N° 50: Probeta para Ensayo de Tracción Norma ASTM A370.



Muestra estándar			
		In.	mm.
G	Longitud media	2.00 ± 0.005	50 ± 0.10
D	Diámetro interno	0.500 ± 0.010	12.5 ± 0.25
R	Radio de filete	$^{3}/_{8}$	10
A	Longitud de la sección reducida	$2^{1}/_{4}$	60
L	Longitud total		230
B	Distancia entre mordazas		115

Fuente: Norma ASTM A 370

Las probetas fueron manufacturadas en el torno según estas especificaciones, después fueron tratadas térmicamente y sometidas al ensayo de tracción.

Grafico N° 51: Probeta para Ensayo de Tracción Norma ASTM A370 Antes de Tratamiento Térmico (a) y Después de Tratamiento Térmico (b).

(a)

(b)

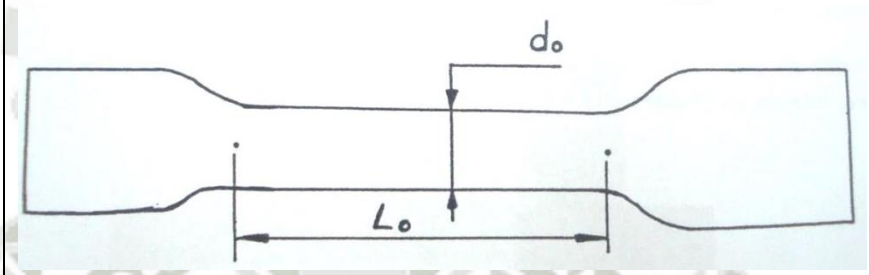
Fuente: Elaboración Propia del Autor.

Grafico 52: Probeta Ensayo de Tracción Norma A370 Medidas.

Fuente: Elaboración Propia del Autor.

Una vez tomadas las medidas que se indica en el grafico a continuación, se procede a colocar las probetas a las mordazas de la maquina universal de ensayos de tracción.

Grafico N° 53: Medidas a Tomar Antes del Ensayo.



Dónde :

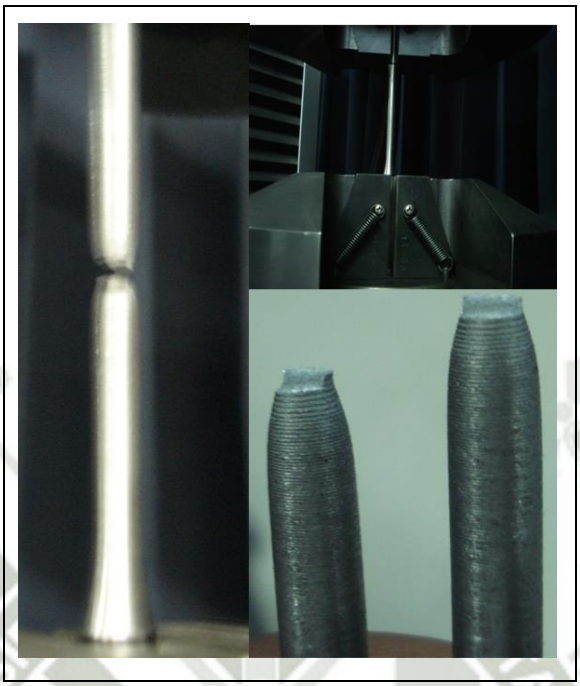
d_o = Diámetro inicial. (mm)

L_o = Longitud inicial entre marcas. (mm)

$Ao = \pi do^2/4$ Area inicial. (mm^2)

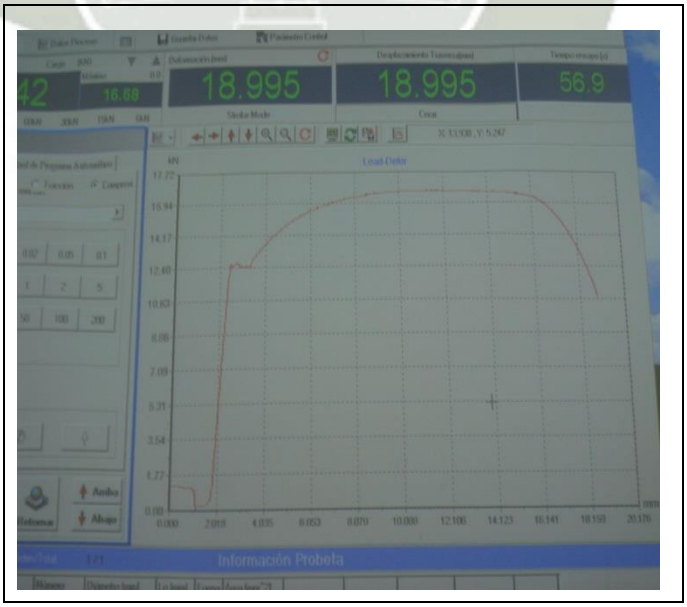
Fuente: Norma ASTM A370

Grafico N° 54: Probetas ASTM A370 E. Durante el Ensayo.



Fuente: Elaboración Propia del Autor.

Grafico N° 55: Representación Gráfica del Resultado de un Ensayo de Tracción



Fuente: Elaboración Propia del Autor.

Una vez realizado los ensayos a todas las probetas se procede a determinar su tensión nominal y su deformación nominal del material, para ello es necesaria la aplicación de dos fórmulas:

Formula 2: Tensión (nominal)

$$\delta = \frac{F}{Ao}$$

Dónde:

F = Fuerza (N)

A_o = Sección transversal (mm^2)

Formula 3: Deformación (nominal)

$$\varepsilon = \frac{lf - lo}{lo} = \frac{\Delta l}{lo}$$

Dónde:

l_f = Longitud final de la probeta. (mm)

l_o = Longitud inicial de la probeta. (mm)

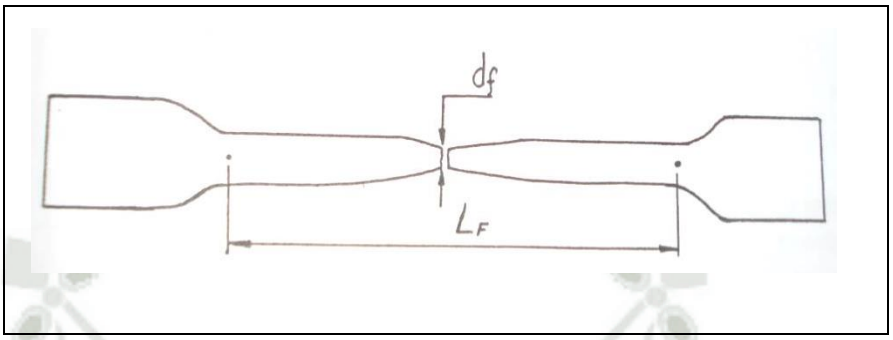
Es una unidad adimensional.

A veces se suele utilizar el porcentaje de alargamiento.

$$\%\ \text{deformacion} = \varepsilon\ (\%) = \frac{\Delta l}{lo}\ \text{x}\ 100$$

Para poder determinar bien la longitud final lo indicamos en el siguiente gráfico.

Grafico N° 56: Medidas a Tomar Después del Ensayo



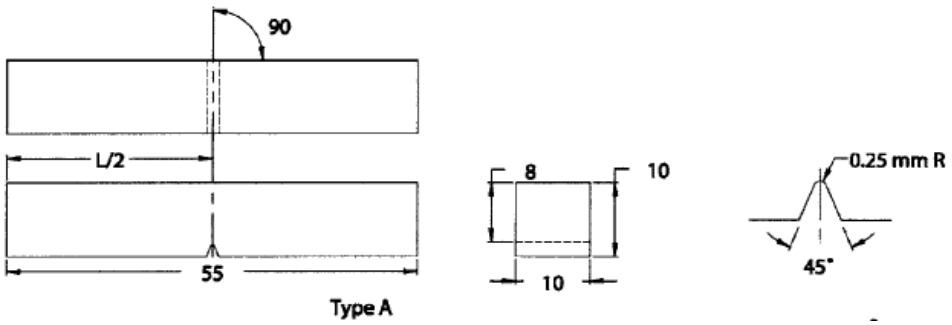
Fuente: Norma ASTM A370.

3.3.4. IMPACTÓ

El esfuerzo de impacto es un comportamiento de los que presentan materiales al someterlos a dicha fuerza, esta prueba se realiza con la ayuda de un péndulo de Charpy modelo JB-W300A, la energía absorbida del material por el impacto está dado por las unidades Joule (J).

Para poder realizar este ensayo se recurrió a la norma ASTM E 23 *Standard test methods for notched bar impact testing of metallic materials* (anexo 4) y se recomienda revisar la norma A 370 (anexo 3) , en la norma E 23 nos indica la probeta a manufacturar la que se considero fue la del tipo A con ranura en v, se tiene que tener en cuenta que la norma es muy estricta en tema de las tolerancia porque son muy precisas

Grafico N° 57: Probeta para Ensayo Charpy.



Longitud de la muestra (L) 0, -2,5 mm

Centrado de la muesca (L / 2) ± 1 mm

Ángulo de muesca ± 1 °

Perpendicularidad del eje muesca ± 2 °

Lados adyacentes (90 °) estarán a ± 10 min

Dimensiones de la sección transversal ± 0,075 mm

Radio de la entalladura ± 0,025 mm

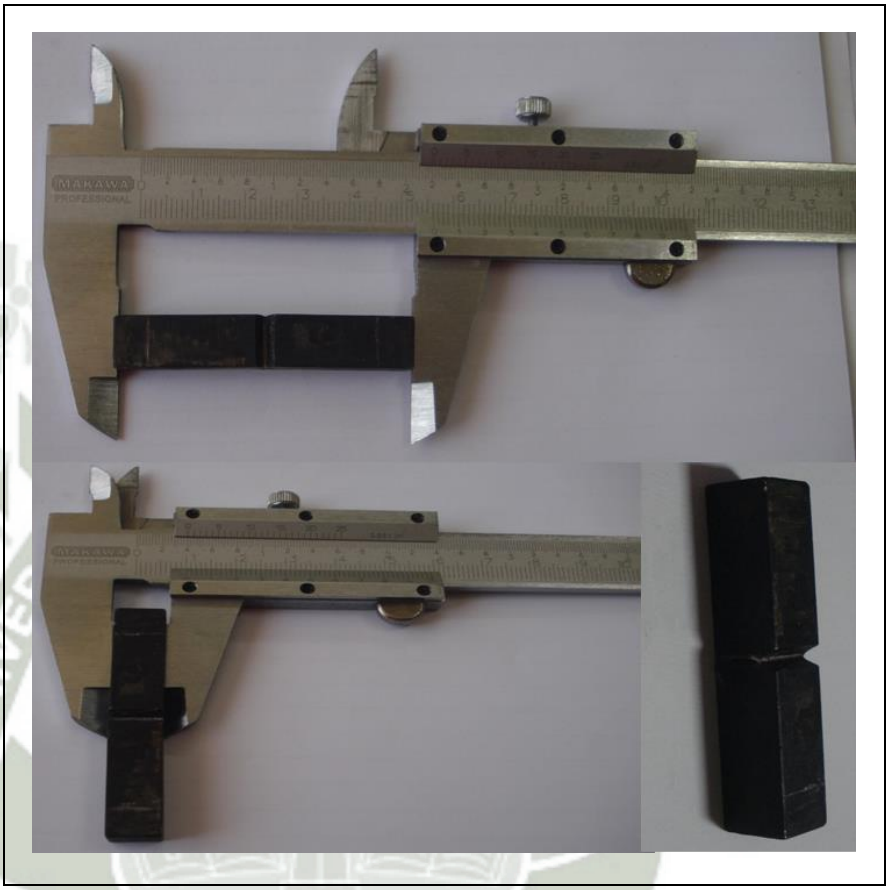
Longitud total : ± 0,025 mm

Requisitos de acabado Ra ≤ 2 µm sobre la superficie dentada y la cara opuesta; Ra ≤ 4 µm en otras dos superficies.

Fuente: Norma ASTM E 23.

Las probetas ya manufacturadas se proceden a registrar las medidas, peso y área de la probeta.

Grafico 58: Probeta Manufacturada / Ensayo Charpy.



Fuente: Elaboración Propia del Autor.

Seguidamente se realiza una prueba en vacío para determinar la energía disipada por fricción (Ef), luego se colocan la probeta en el péndulo de Charpy según el grafico y se procede al impacto para determinar la energía mostrada por el indicador (Ei).

Luego de obtener los datos de Ef, Ei se procede a calcular la energía de destrucción de la probeta Er el que requiere dentro de

su ecuación la energía cinética que se calcula con la siguiente formula:

$$Ek = \frac{1}{2} \times m \times v^2$$

Dónde:

m = masa de la probeta (Kg)

v = velocidad del péndulo en el momento del impacto $5.6^{m}/_{s.}$

Con ella se podrá calcular la energía de destrucción:

Formula 4: Energía de destrucción de la probeta:

$$Er = Ei - Ef - Ek$$

Dónde:

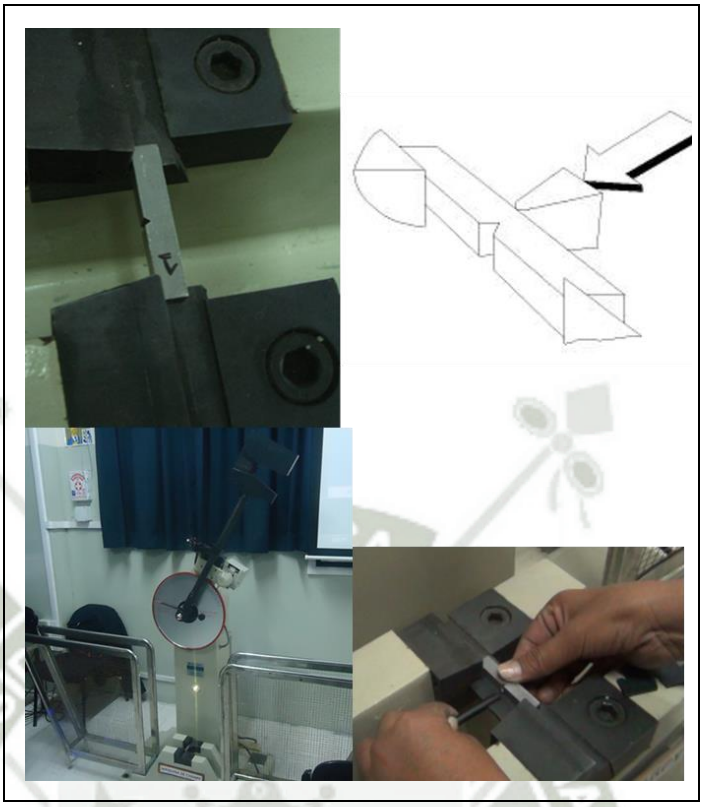
Er = Energía de destrucción de la probeta

Ei = Energía mostrada por el indicador.

Ef = Energía disipada por fricción.

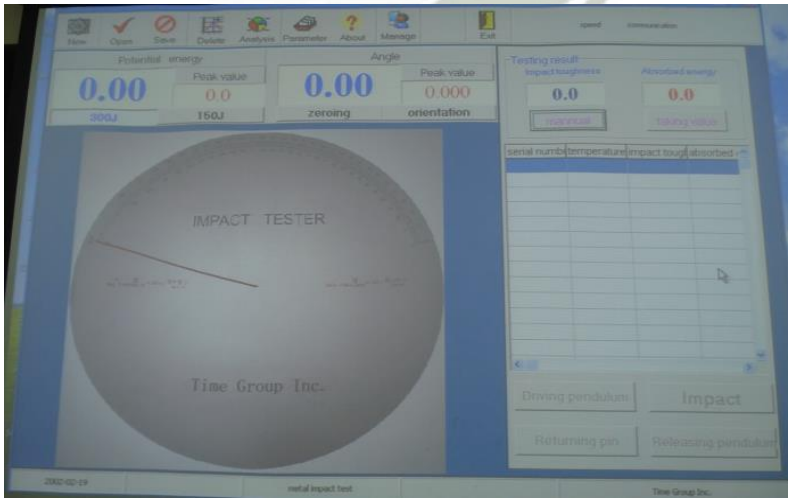
Ek = Energía cinética

Grafico N° 59: Posición de la Probeta / Ensayo de Charpy.



Fuente: Elaboración Propia del Autor.

Grafico N° 60: Proyección de Energía Mostrada por el Indicador Ei



Fuente: Elaboración Propia del Autor.

3.3.5. MICROSCOPIO METALURGICO

El uso del microscopio metalúrgico es necesario para poder los ensayos metalográfico, la metalografía es la parte de la metalurgia que estudia las características estructurales o su constitución de los metales para así poderlas relacionar con sus propiedades mecánicas, físicas y químicas de los mismos.

La importancia de este ensayo radica en que nos puede brindar la historia del tratamiento térmico y mecánico que se haya sometido el acero sus principales caracterizas que podemos determinar es el tamaño del grano, la distribución de las fases que se compone en el acero. Si bien es cierto que resulta el ensayo más sencillo por lo que solo se tiene que observar en el microscopio metalúrgico el acero, pero para que este ensayo refleje resultados confiables es imprescindible realizar una preparación adecuada la probeta a observar para ello tiene que ser, pulida y atacada químicamente para ello recurrimos a norma ASTM E 3 *Standard Guide for Preparation of Metallographic Specimens* (Anexo 5). Según la norma ASTM E 3 la preparación de la muestra para el análisis metalográfico lo podemos dividir en varios pasos:

- Toma de la muestra: Este paso se debe tener en cuenta que no es indiferente el lugar donde se extrae la muestra ya este debe ser según el examen a realizar porque este nos indicara tener la mayor información posible de las características del acero. Ahora también dependerá la forma de extracción ya que

este no debe de afectar la estructura superficial por lo que se debe de cuidar la temperatura del material que no se eleve demasiado durante el proceso de extracción. Dicha extracción se puede realizar utilizando herramientas de corte como cierras de corte manual, disco de corte muy bien refrigeradas.

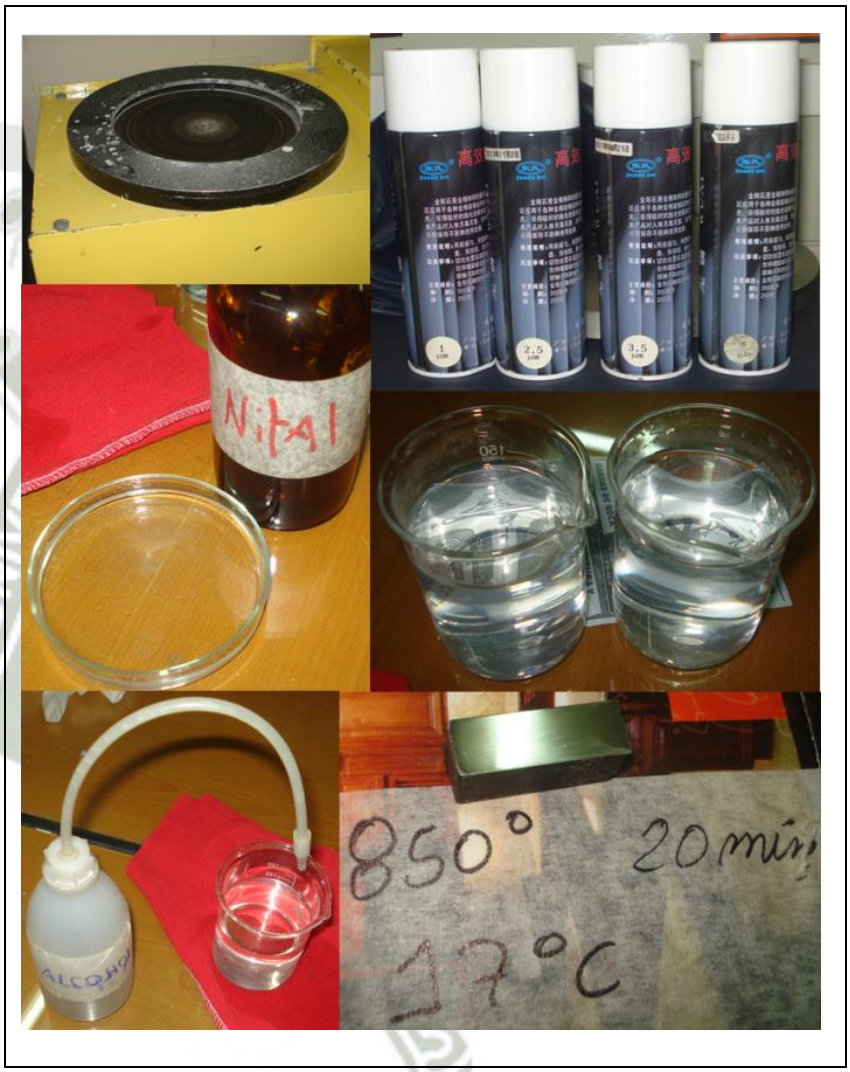
- Desbaste grosero: Este se practica una vez extraída la probeta con la finalidad de reducir las irregularidades en la superficie del espécimen tales como rebabas producto del corte, este degaste se debe de efectuar hasta obtener una cara lo más plana posible.
- Desbaste final: La etapa final es un poco extensa ya comenzamos la operación de desbaste con papel abrasivo de 150, 250, 400 para terminar con el 600 y un acabado con el 1000 para ello se debe realizar en una superficie plana moviendo la probeta longitudinalmente de un lado a otro aplicando una presión suave, hay que tener en cuenta que esta probeta se debe mover en la misma dirección para que todas las rayas sean paralelas. Cuando se encuentre realizando esta operación de pulido es muy importante dejar una corriente de agua para que limpie los desprendimientos de material también lograra lubricación y refrigeración de la zona desbastada.
- Pulido: El pulido tiene como finalidad eliminar las rayas producidas por el desbaste final, esta operación generalmente

se da en forma mecánica utilizando un paño impregnado con partículas de algún abrasivo en solución acuosa como por ejemplo: pasta de diamante, alúmina, alumdun, etc. Este proceso es el que nos brindara la claridad ya que entre más pulido este la probeta será mejor la imagen.

- Ataque químico: Su objetivo del ataque químico es revelar el tamaño del grano y las fases presentes. Al aplicar el reactivo sobre la superficie a observar, las características de la estructura son reveladas como consecuencia de un ataque selectivo de la superficie. Esto se debe a que las distintas fases así como los planos cristalográficos diferentemente orientados poseen diferencias en la susceptibilidad al ataque Para que el ataque sea apropiado es necesario elegir el reactivo de acuerdo a la composición de la probeta, es decir, un reactivo a base de per sulfato de amonio es ideal para atacar probetas de cobre y latón, pero no es adecuado para atacar al acero o aleaciones ferrosas. En cambio el nital (solución acuosa o alcohólica de ácido nítrico al 2% o hasta el 5%) es uno de los reactivos más comúnmente usado en aleaciones ferrosas y aceros. Para tener una verdadera microestructura, es necesario efectuar por lo menos 5 iteraciones. Se tiene que considerar un tiempo para el ataque el cual se recomienda pocos segundos y 30 minutos claro esta si el ataque se prolonga por más tiempo la probeta comenzara

a aparecer manchas evitando que la microestructura sea apreciada.

Grafico N° 61 : Proceso de Pulido y Ataque Químico con Nital.



Fuente : Elaboración Propia del Autor.

CAPITULO IV

ANÁLISIS DE RESULTADO

En el siguiente capítulo se analizaron los resultados obtenidos en los ensayos mencionados en el capítulo anterior. La primera parte de este capítulo es el análisis de comprobación de las propiedades mecánicas del acero A36 en su estado comercial; ya que, para iniciar el análisis de los resultados se debe conocer el estado que se encuentra el acero al que lo denominamos como el punto de partida para el análisis. Con este resultado se puede saber si fueron ascendentes o descendentes los resultados de esta experimentación y determinar si hubo alguna alotropía en sus propiedades mecánicas.

4.1. ANALISIS DEL ACERO ASTM A - 36 EN SU ESTADO COMERCIAL

El acero ASTM A - 36 fue adquirido en Aceros Comerciales S. C. R. L. ubicado en la ciudad de Arequipa siendo su proveedor Aceros Arequipa. Los aceros que se adquirieron fueron dos barras cuadradas de 12 x 12mm con un largo de 6 metros y el segundo una barra redonda lisa de ½ pulgada de diámetro y 6 metros de largo. Estos aceros cuentan con su certificado de calidad (Anexo 6) proporcionados por nuestro proveedor.

Grafico N° 62 : Barra Cuadrada de 12mm x 6m / Acero ASTM A – 36.

Fuente : Elaboración Propia del Autor.

Grafico N° 63 : Barra Circular Lisa de 1/2pulg. x 6m / Acero ASTM A – 36.

Fuente : Elaboración Propia del Autor.

En el certificado de calidad nos indica las propiedades mecánicas que cuenta nuestro acero y su composición química en la cuchara, la norma que se utilizó para determina su propiedad mecánica fue ASTM E – 8, realiza por el proveedor Aceros Arequipa en sus laboratorios. Tenemos que tener en cuenta que dicho certificado de calidad solo nos proporciona datos del ensayo de tracción.

Grafico N° 64 : Propiedades Mecánicas y Composición Química del Acero A - 36 de la Barra de Acero con Forma Cuadrada .

DIMENSIONES	N° DE COLADA	PROPIEDADES MECANICAS			DOBLADO 180°	COMPOSICION QUIMICA EN LA CUCHARA (%)			
		FLUENCIA kg/mm²	RESIST. TRACCION kg/mm²	ALARGAM. EN 200.0 mm %		C	Mn	P	S
12MM X 6M	260169	36.4	50.1	27.5	OK	0.16	0.76	0.021	0.025
12MM X 6M	264082	35.3	49.7	27.5	OK	0.15	0.74	0.012	0.019

Fuente : Certificada de Calidad del Acero A – 36 Barra Cuadrada

Grafico 65 : Propiedades Mecánicas y Composición Química del Acero A – 36 de la Barra de Acero de Forma Circular.

DIMENSIONES	N° DE COLADA	PROPIEDADES MECANICAS			DOBLADO 180°	COMPOSICION QUIMICA EN LA CUCHARA (%)			
		FLUENCIA kg/mm²	RESIST. TRACCION kg/mm²	ALARGAM. EN 200.0 mm %		C	Mn	P	S
1/2" X 6M	265297	37.9	52.1	22.5	OK	0.14	0.71	0.017	0.017

Fuente : Certificada de Calidad del Acero A – 36 Barra Circular.

Se tiene que tener en cuenta que la composición química y las propiedades mecánicas tiene que estar dentro de los parámetro de la norma ASTM A 36 *Standard specification for carbón structural stell* (anexo 7), en dicha norma nos indica los parámetros mínimos y máximos que deben contar los aceros para que se pueda designar como acero A 36 así también podemos considerar como una referencia la norma ASTM A 6 *Standard specification*

for general requirements for rolled structural Steel bars, plates, shapes, and sheet piling.

Grafico N° 66 : Composición Química del Acero Según Norma ASTM A 36.

Product	Shapes[A]	Bars			
Thickness, in. [mm]	All	To ¾ [20], incl	Over ¾ to 1½ [20 to 40], incl	Over 1½ to 4 [100], incl	Over 4 [100]
Carbon, max, %	0.26	0.26	0.27	0.28	0.29
Manganese, %	...	...	0.60–0.90	0.60–0.90	0.60–0.90
Phosphorus, max, %	0.04	0.04	0.04	0.04	0.04
Sulfur, max, %	0.05	0.05	0.05	0.05	0.05
Silicon, %	0.40 max	0.40 max	0.40 max	0.40 max	0.40 max
Copper, min, % when copper steel is specified	0.20	0.20	0.20	0.20	0.20

Fuente : Norma ASTM A 36.

Grafico N° 67 : Propiedades Mecánicas del Acero Según Norma ASTM A 36.

Plates, Shapes,[B] and Bars:	
Tensile strength, ksi [MPa]	58–80 [400–550]
Yield point, min, ksi [MPa]	36 [250][C]
Plates and Bars[D,E]:	
Elongation in 8 in. [200 mm], min, %	20
Elongation in 2 in. [50 mm], min, %	23
Shapes:	
Elongation in 8 in. [200 mm], min, %	20
Elongation in 2 in. [50 mm], min, %	21[B]

Fuente : Norma ASTM A 36.

4.2. ANÁLISIS DE LOS RESULTADOS DE LOS ENSAYOS APLICADOS AL ACERO ASTM A 36

Para poder realizar un análisis correcto lo primero que se desarrollo fue un ensayo sin tratamiento térmico al acero ASTM A 36 con la finalidad de verificar y poder saber a ciencia cierta sus propiedades mecánicas que cuenta nuestro acero A 36, a los resultados obtenidos del acero sin tratamiento térmico lo consideramos como el punto inicio, ya que seguidamente se realiza un análisis del acero con tratamiento térmico a diferentes temperaturas de calentamiento , tiempos y temperaturas de enfriamiento. Con los resultado obtenidos de los aceros con tratamiento térmico se procede a comprobar con los resultados sin tratamiento térmico, y se define si tuvo un incremento o un descenso de sus propiedades mecánicas, para poder así encontrara con la técnica experimentalmente el punto más óptimo de una estructura ferrítica y martensítica, logrando así obtener un acero A 36 con las características que estamos buscando de una fase dual.

4.2.1. SIN TRATAMIENTO TÉRMICO

Se considera sin tratamiento térmico al acero que fue adquirido y solo fue maquinado a probetas según norma y el ensayo a practicar, obteniendo los siguientes resultados :

- Ensayo de dureza bajo norma ASTM E 10 : 177,51 Brinell
- Ensayo de tracción sometido a la norma ASTM A 370 :
    - Deformación ε % : 20.73%

- Esfuerzo ultimo ($\sigma_{max.}$) : 52.90 Kg/mm^2
- Según la imagen de la rotura podemos decir que es una fractura dúctil ya que se presenta como parcial de taza y cono.

Grafico N° 68 : Ensayo a Tracción / Fractura Parcial de Taza y Cono.

Fuente : Elaboración Propia del Autor.

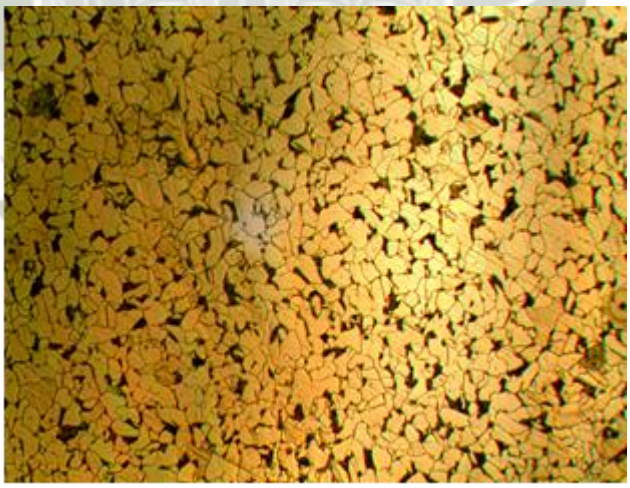
- Ensayo de impacto Charpy con norma ASTM E 23 : 163.98 J
  - Según la imagen de la energía absorbida por parte de la probeta podemos decir que es una fractura dúctil ya que no se rompió en dos partes.

Grafico N° 69 : Ensayo a Charpy / Fractura Dúctil.

Fuente : Elaboración Propia del Autor.

- Ensayo de metalografía

Grafico N° 70 : Metalografía Acero A 36 sin Tratamiento.



Fuente : Elaboración Propia del Autor.

4.2.2. CON TRATAMIENTO TÉRMICO

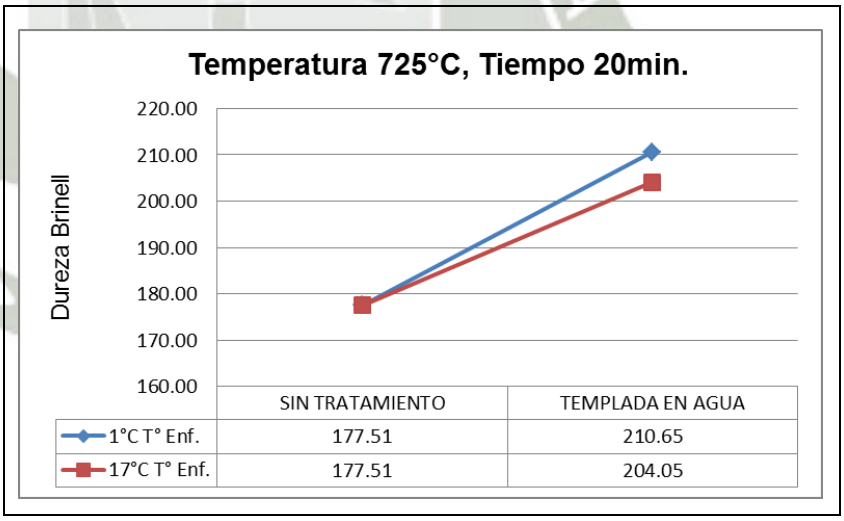
Se realizó el tratamiento térmico a las probetas después de haberlas manufacturado, se consideró realizar tres iteraciones por ensayo practicado con la finalidad de tener una muestra promedio.

- Ensayo de dureza bajo norma ASTM E 10 :

  El ensayo de dureza esta dado en las unidades Brinell.

  a) El primer ensayo se practicó a una temperatura de tratamiento 725°C, con un tiempo de mantenimiento 20 min. Y enfriado en agua a 1°C. y otras probetas a 17°C.

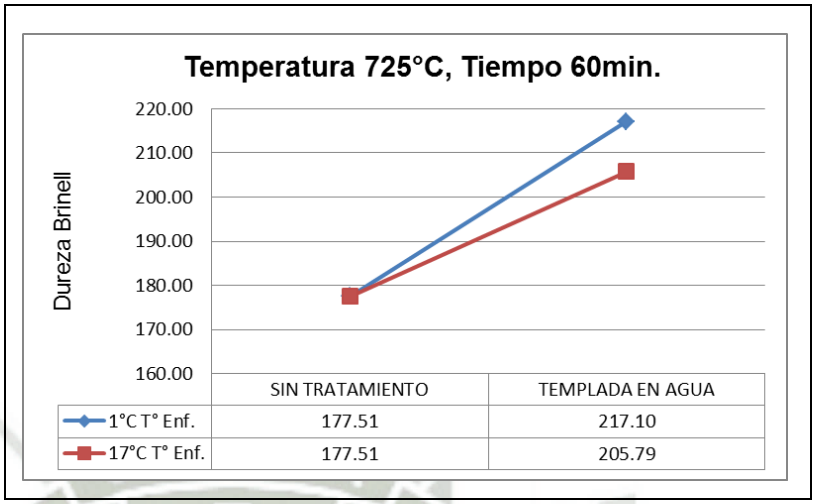
  Grafico N° 71 : Primer Ensayo de Dureza a 725°C, 20min. Enfriado a 1°C. y 17°C.



Fuente : Elaboración Propia del Autor.

  b) El segundo ensayo se realizó a una temperatura de 725°C, con un tiempo de mantenimiento de 60 min. Y enfriado en agua a 1°C y otra probeta a 17°C.

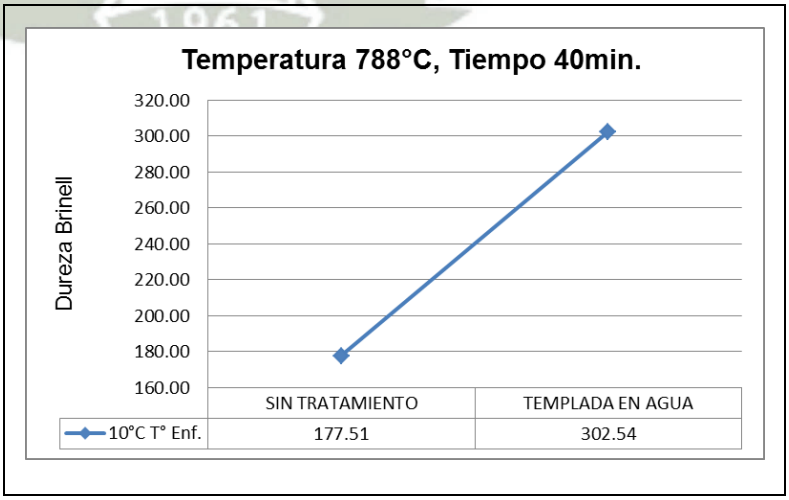
Grafico N° 72 : Segundo Ensayo de Dureza a 725°C, 60min. Enfriado a 1°C. y 17°C.



Fuente : Elaboración Propia del Autor.

c) Tercer ensayo se realizó a una temperatura de 788°C, con un tiempo de mantenimiento de 40 min. Y enfriado en agua a 10°C.

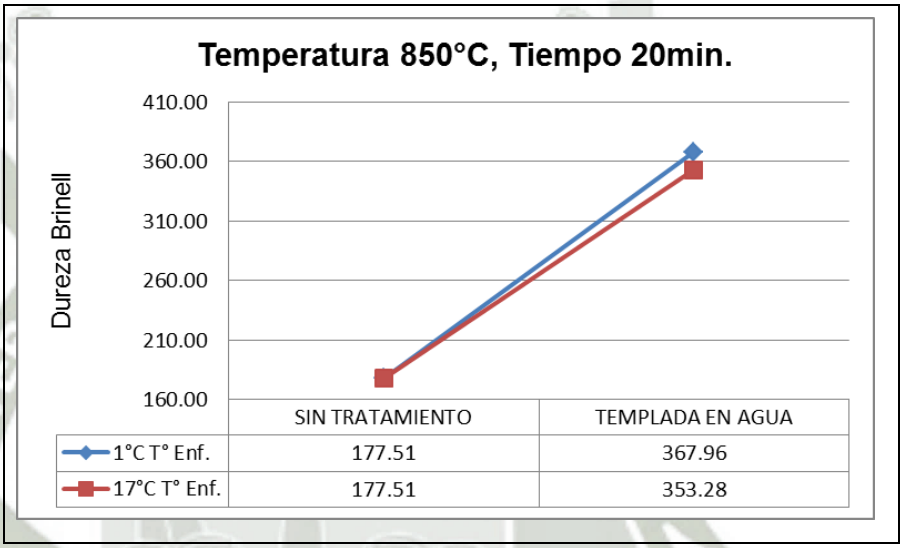
Grafico N° 73 : Tercer Ensayo de Dureza a 788°C, 60min. Enfriado a 10°C.



Fuente : Elaboración Propia del Autor.

d) Cuarto ensayo se realizó a una temperatura de 850°C, con un tiempo de mantenimiento de 20 min. Y enfriado en agua a 1°C.y a 17°C.

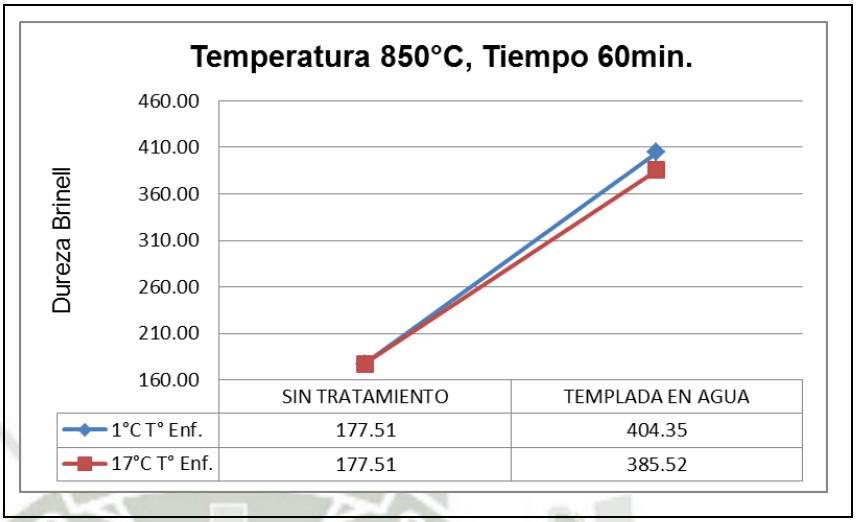
Grafico N° 74 : Tercer Ensayo de Dureza a 788°C, 60min. Enfriado a 10°C



Fuente : Elaboración Propia del Autor.

e) Quinto ensayo se realizó a una temperatura de 850°C, con un tiempo de mantenimiento de 60 min. Y enfriado en agua a 1°C.y a 17°C.

Grafico N° 75 : Cuarto Ensayo de Dureza a 850°C, 60min. Enfriado a 1°C. Y a 17°C.



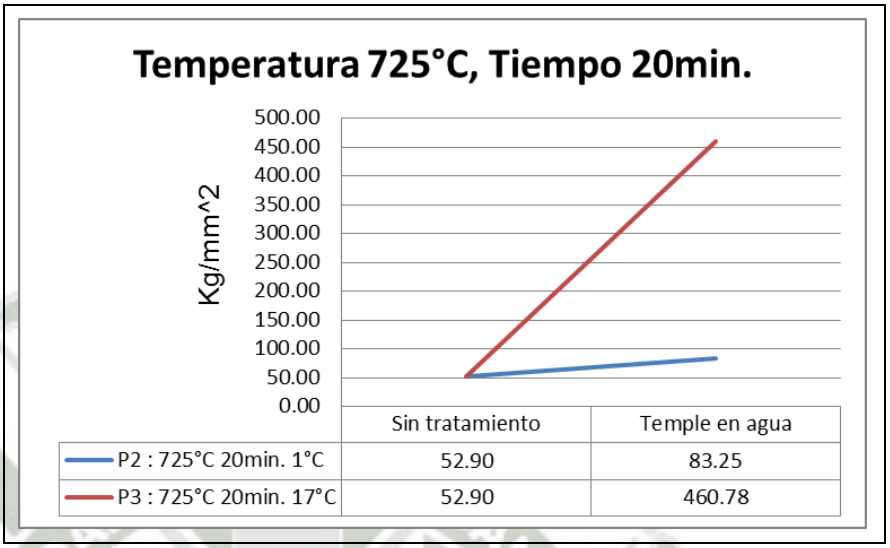
Fuente : Elaboración Propia del Autor.

Podemos decir que la dureza se ve incrementada ya que la dureza Brinell sin tratamiento es 177.51 DB, y la que obtuvo mejor resultado es la probeta que fue tratada térmicamente a 850°C con un tiempo de mantenimiento de 60min. Y enfriado en agua a 1°C. Dándonos como resultando una dureza de 404.35 DB.

- El ensayo de tracción que fueron sometidos las probetas son basadas en la norma ASTM A 370, nos dieron como resultados :

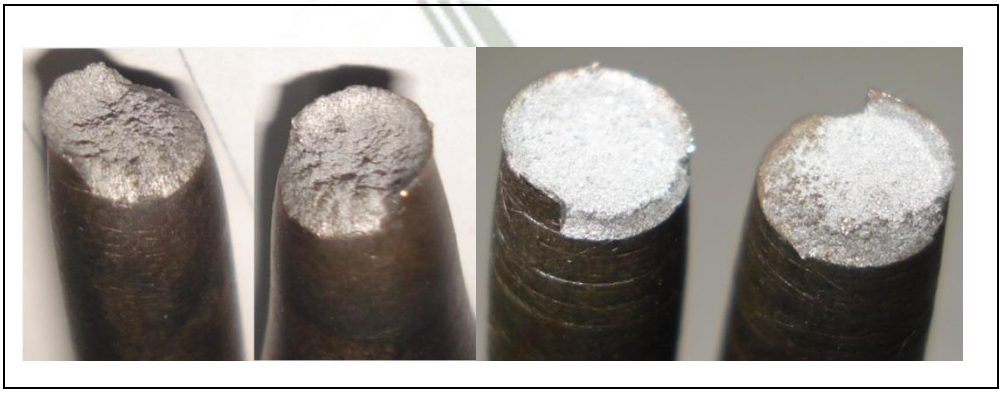
  a. El primer ensayo se practicó a una temperatura de tratamiento 725°C, con un tiempo de mantenimiento 20 min. Y enfriado en agua a 1°C. y otra probeta a 17°C.

Grafico N° 76 : Primer Ensayo de Tracción 750°C, 20min. Enfriado a 1°C. Y a 17°C.



Fuente : Elaboración Propia del Autor.

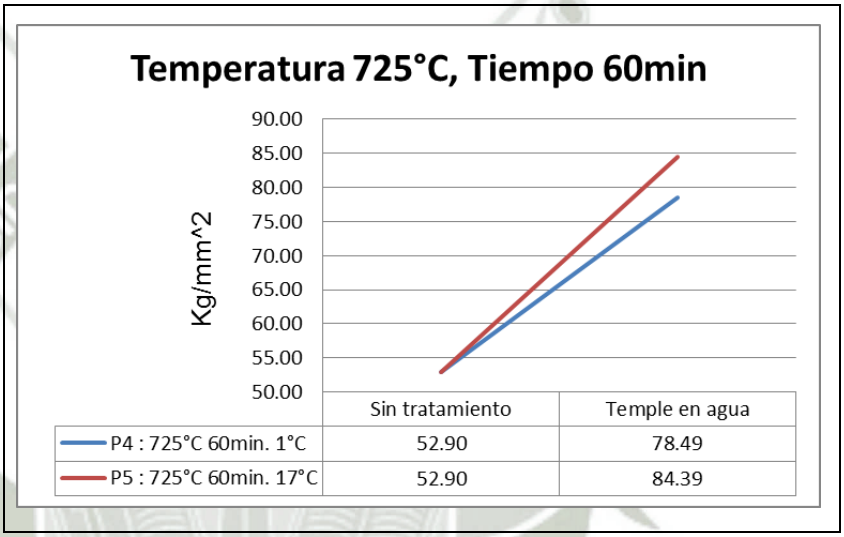
Grafico N° 77 : Probeta de Ensayos de Tracción Templado 750°C,Mantenido 20min.(a) Enfriado a 1°C. Y (b) Enfriado a 17°C.



Fuente : Elaboración Propia del Autor.

b. El segundo ensayo de tracción se realizó a una temperatura de 725°C, con un tiempo de mantenimiento de 60 min. Y enfriado en agua a 1°C y otra probeta a 17°C.

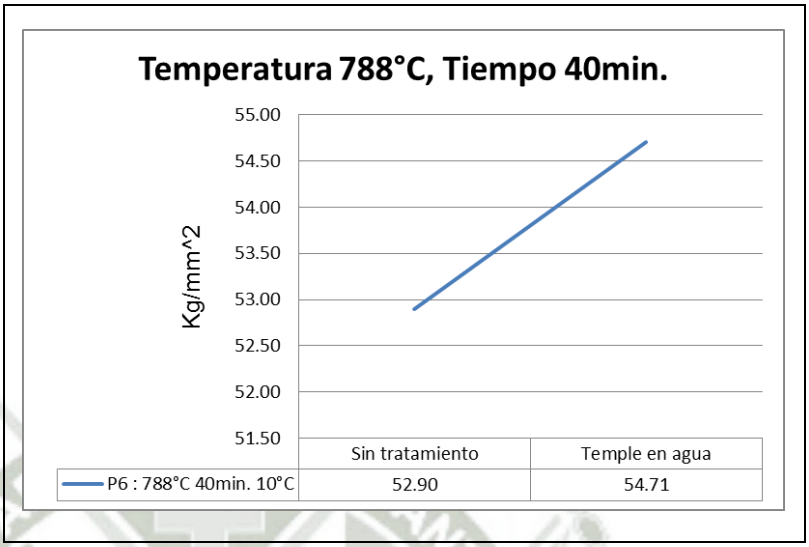
Grafico N° 78 : Segundo Ensayo de Tracción a 725°C, 60min. Enfriado a 1°C. Y 17°C.



Fuente : Elaboración Propia del Autor.

c. Tercer ensayo se realizó a una temperatura de 788°C, con un tiempo de mantenimiento de 40 min. Y enfriado en agua a 10°C.

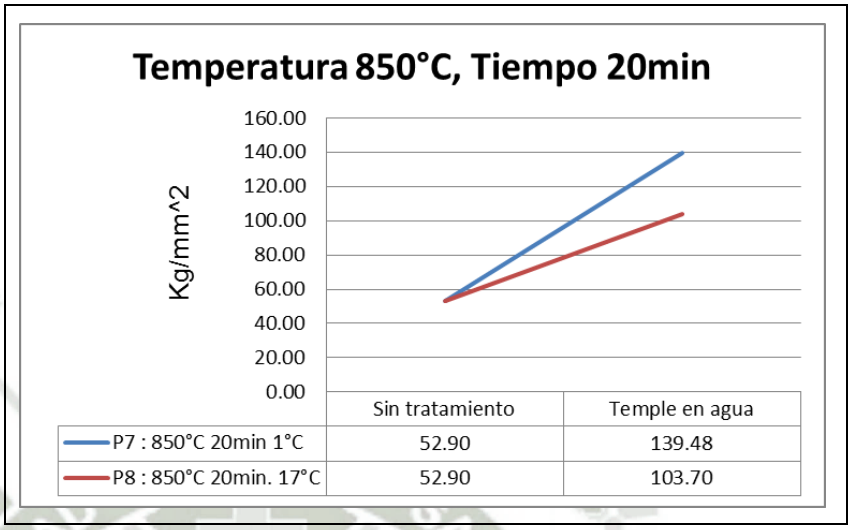
Grafico N° 79 : Tercer Ensayo de Dureza a 788°C, 60min. Enfriado a 10°C.



Fuente: Elaboración Propia del Autor.

d. Cuarto ensayo se realizó a una temperatura de 850°C, con un tiempo de mantenimiento de 20 min. Y enfriado en agua a 1°C.y a 17°C.

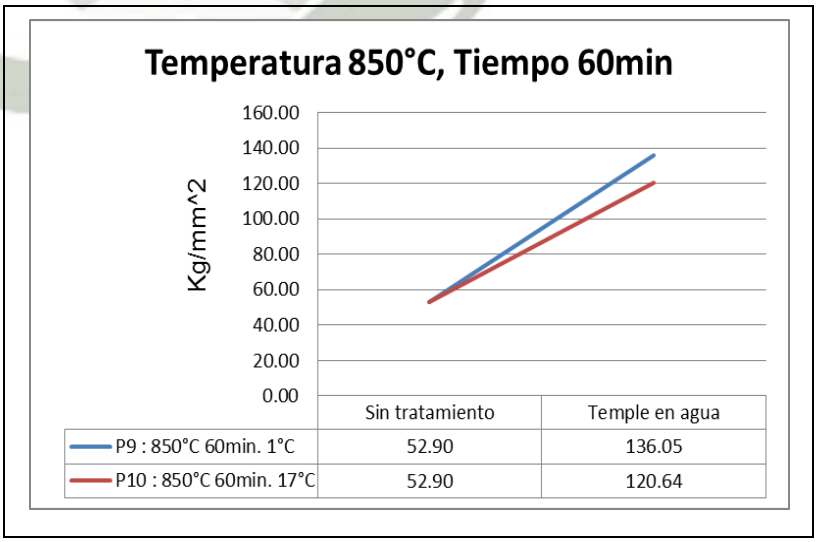
Grafico N° 80 : Cuarto Ensayo de Tracción a 850°C, 20min. Enfriado a 1°C. Y a 17°C.



Fuente : Elaboración Propia del Autor.

e. Quinto ensayo se realizó a una temperatura de 850°C, con un tiempo de mantenimiento de 60 min. Y enfriado en agua a 1°C.y a 17°C.

Grafico N° 81 : Cuarto Ensayo de Tracción a 850°C, 60min. Enfriado a 1°C. Y a 17°C.



Fuente : Elaboración Propia del Autor.

Como podemos ver el mejor resulta obtenido en todos los ensayos de tracción que se realizaron fue el temple a 725°C con un tiempo de mantenimiento de 20 min. Y enfriado a 17°C que obtuvo como resultado de su esfuerzo ultima de 460.78 Kg/mm^2.

Grafico N° 82 : Cuadro de Deformación E en Porcentaje.

Deformacion E	%
Sin tratamiento termico	20.73
725°C 20min. 1°C	8.978
725°C 20min. 17°C	2.25
725°C 60min. 1°C	2.06
725°C 60min. 17°C	4.55
788°C 40min. 10°C	0.16
850°C 20min 1°C	6.67
850°C 20min. 17°C	4.15
850°C 60min. 1°C	0.40
850°C 60min. 17°C	6.05

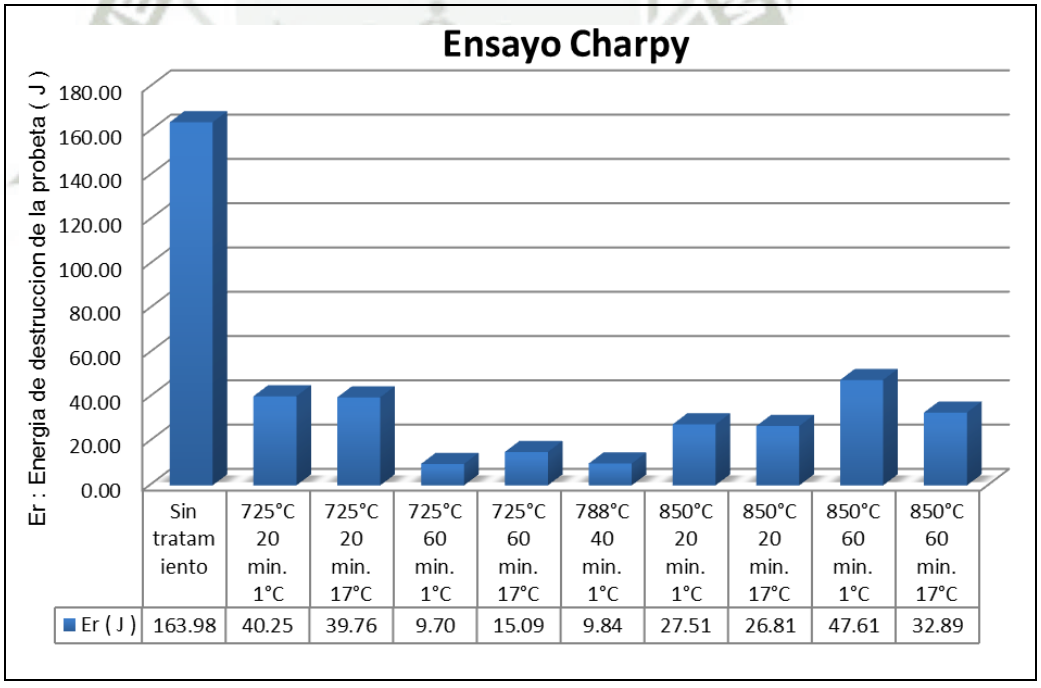
Fuente : Elaboración Propia del Autor.

En el grafico que se muestra podemos observar la deformación que se dio durante el ensayo de tracción a cada probeta ensayada, el que tuvo mayor porcentaje de deformación es el acero sin tratamiento térmico que presenta muy buena ductibilidad, en cambio la probeta que fue tratada térmicamente a 725°C con un tiempo de mantenimiento de 20min. Y enfriado a 17°C era el que nos daba el mejor resultado de esfuerzo

último, ahora nos entrega una deformación de 2.25% el que nos indica que es material dúctil pero no por mucho, su tipo de fractura es de parcial de tasa y cono.

- El ensayo Charpy que fueron sometidos las probetas son basadas bajo las condiciones de la norma ASTM E 24, el que realizando todos los ensayos a diferente temperatura, tiempos de mantenimiento y temperatura de enfriamiento nos dieron como resultados :

Grafico N° 83 : Ensayo de Charpy a Diferentes Temperaturas , Tiempo de Mantenimiento y Temperatura de Enfriamiento.



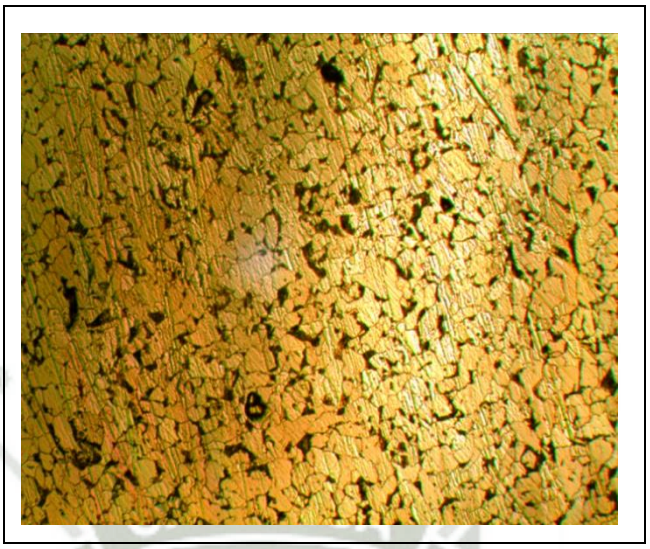
Fuente : Elaboración Propia del Autor.

Como se puede observar en la imagen el mejor resultado obtenido a la absorción de energía de impacto es la probeta sin tratamiento térmico, seguidamente la probeta que fue tratada térmicamente a 850°C tiempo de mantenimiento de 60 min. Y enfriada a 1°C es la que cuenta con la mejor absorción de energía de impacto con 47.61 joule de energía, en cambio la probeta trata térmicamente a 725°C tiempo de mantenimiento de 20min. Y enfriado a 17°C presenta 39.76 joule.

- El ensayo metalográfico se realizó a todas las probetas ensayadas, para contar con un mejores resultados nos ayudándonos con la norma ASTM E 112 *Standard Test Methods for Determining Average Grain Size* (anexo 8). Para contar un mayor entendimiento de la terminología de la metalografía nos ayudamos con la norma ASTM E 7 *Standard Terminology Relating to Metallograph (* anexo 9 *).*

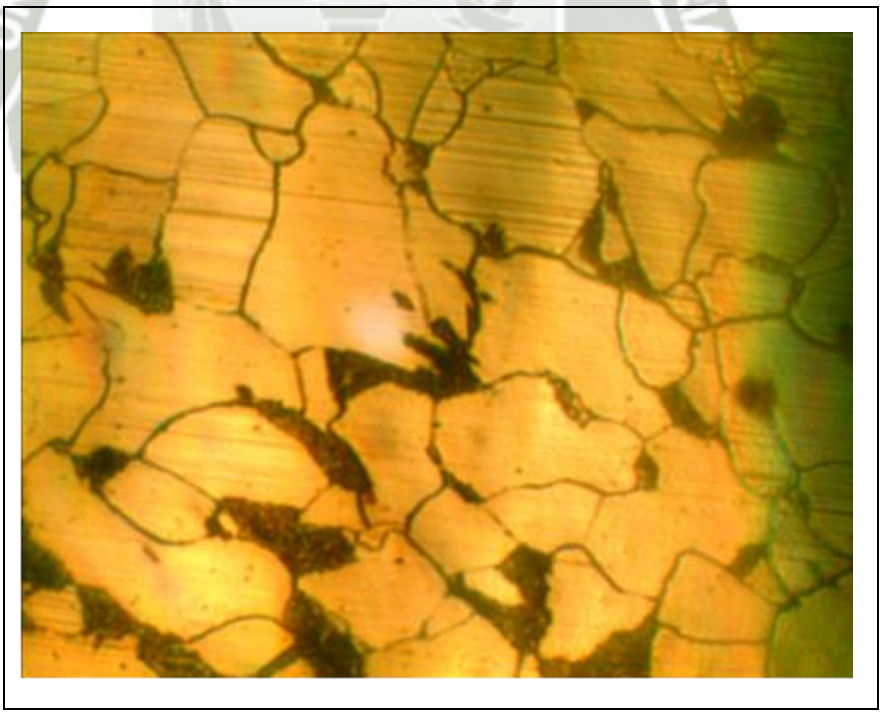
  a. Metalografía ensayo a 725°C tiempo de mantenimiento 20min. enfriado a 1°C presenta una mezcla de Ferrita equiaxial y Martensita.

Grafico N° 84 : Prueba a 725 °C , 20min, 1°C. Aumento 200x.



Fuente : Elaboración Propia del Autor.

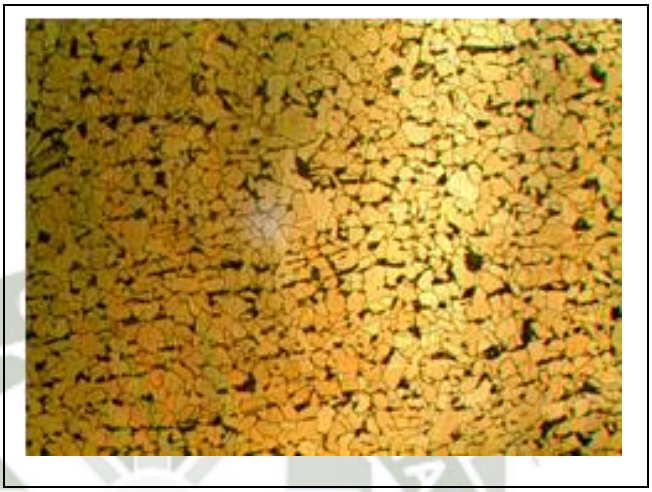
Grafico N° 85 : Prueba a 725 °C , 20min, 1°C. Aumento 1000x.



Fuente : Elaboración Propia del Autor.

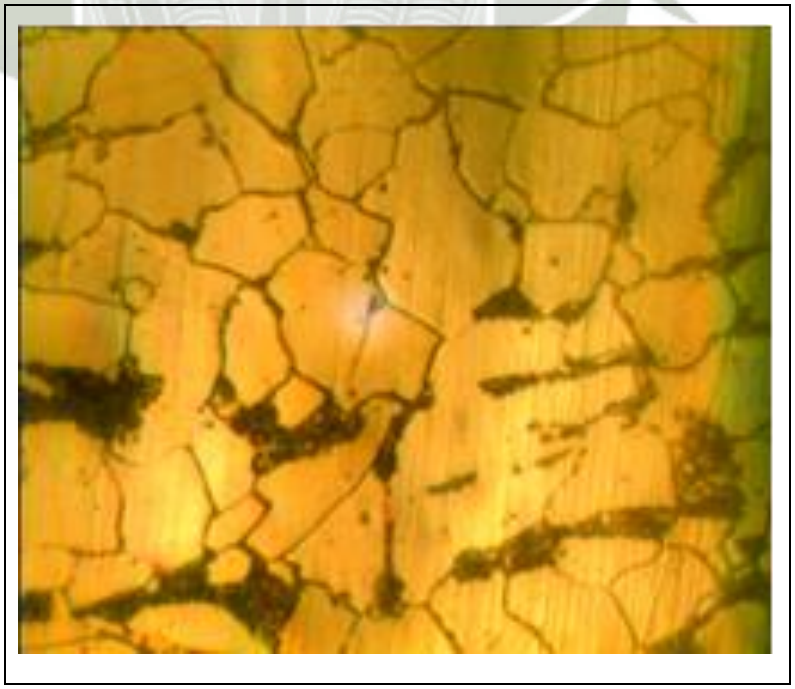
b. Metalografía ensayo a 725°C tiempo de mantenimiento 20min. enfriado a 17°C presenta una mezcla de Ferrita y Martensita.

Grafico N° 86 : Prueba a 725 °C , 20min, 17°C. Aumento 200x.



Fuente : Elaboración propia del autor.

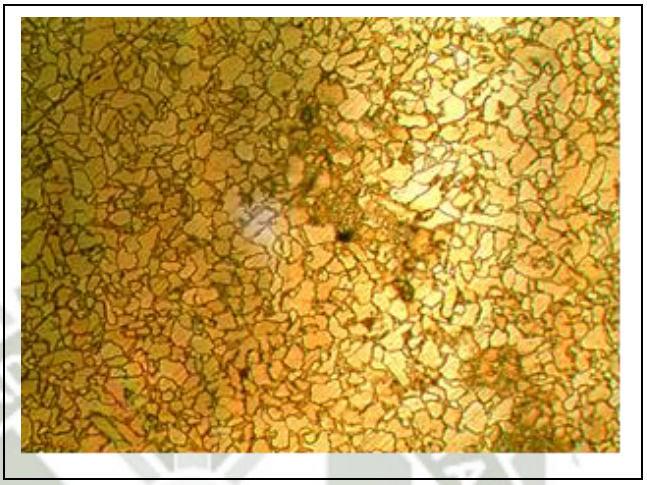
Grafico N° 87 : Prueba a 725 °C , 20min, 17°C. Aumento 1000x.



Fuente : Elaboración propia del autor.

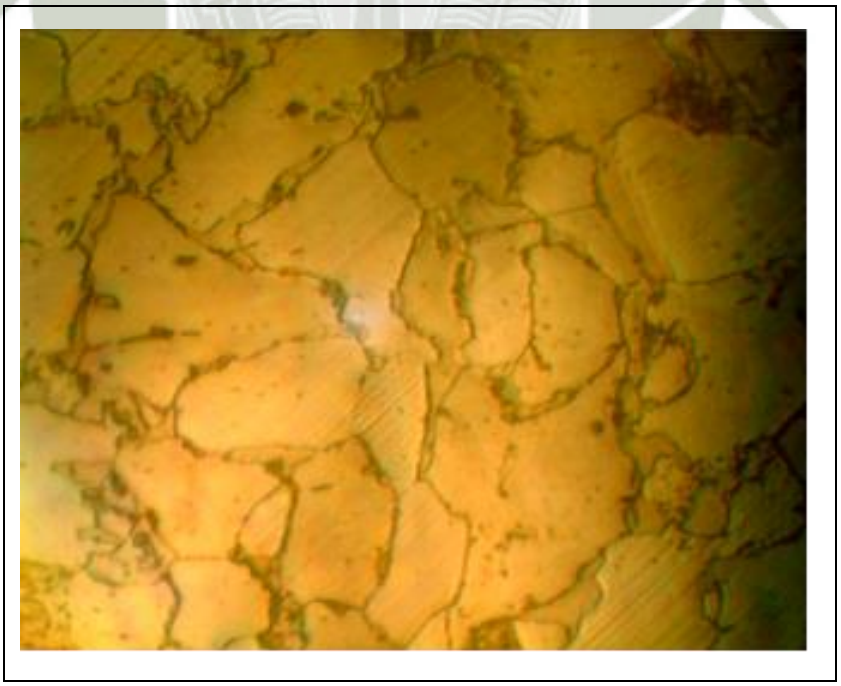
c. Metalografía ensayo a 725°C tiempo de mantenimiento 60min. enfriado a 1°C presenta una mezcla de Ferrita y Martensita.

Grafico N° 88 : Prueba a 725 °C , 60min, 1°C. Aumento 200x.



Fuente : Elaboración propia del autor.

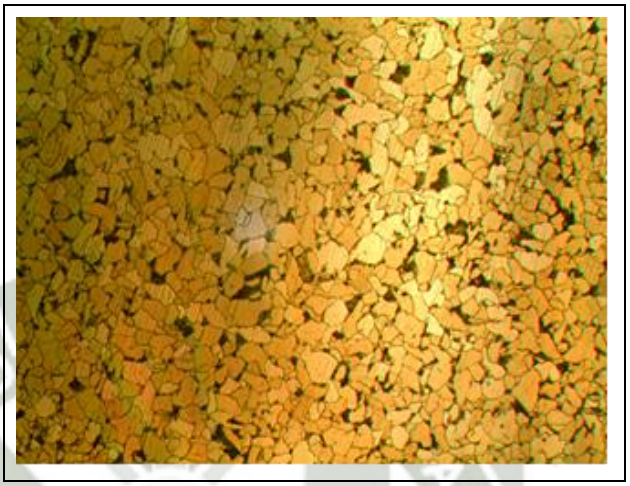
Grafico N° 89 : Prueba a 725 °C , 60min, 1°C. Aumento 1000x.



Fuente : Elaboración Propia del Autor.

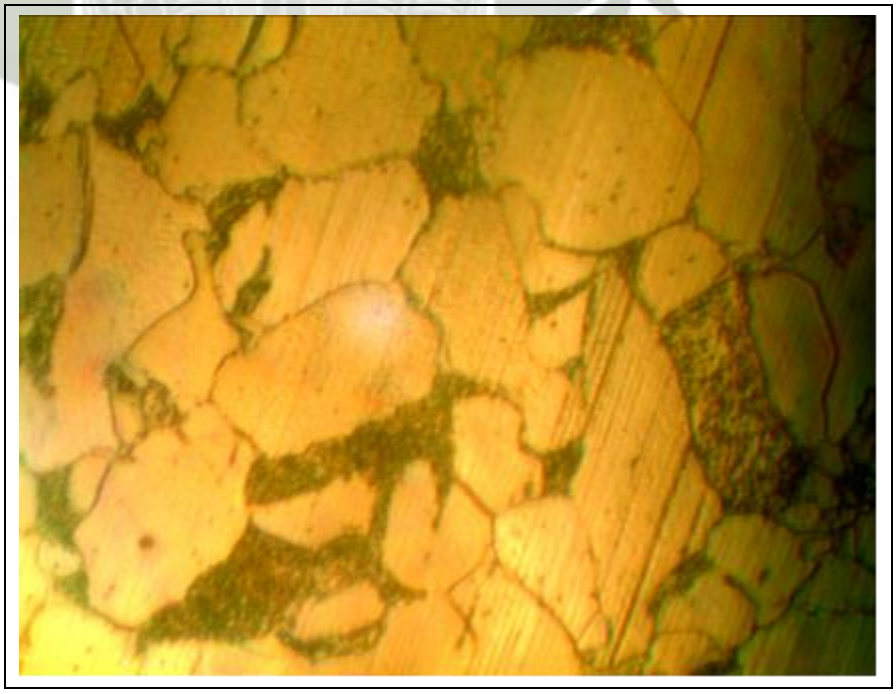
d. Metalografía ensayo a 725°C tiempo de mantenimiento 60min. enfriado a 17°C presenta una mezcla de Ferrita y Martensita.

Grafico N° 90 : Prueba a 725 °C , 60min, 17°C. Aumento 200x.



Fuente : Elaboración Propia del Autor.

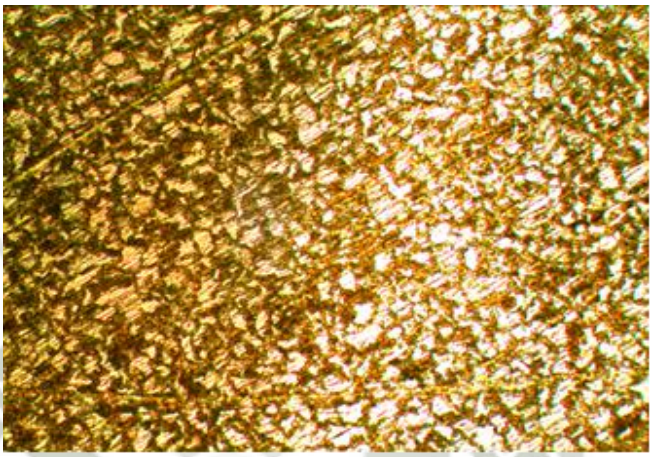
Grafico N° 91 : Prueba a 725 °C , 60min, 17°C. Aumento 1000x.



Fuente : Elaboración Propia del Autor.

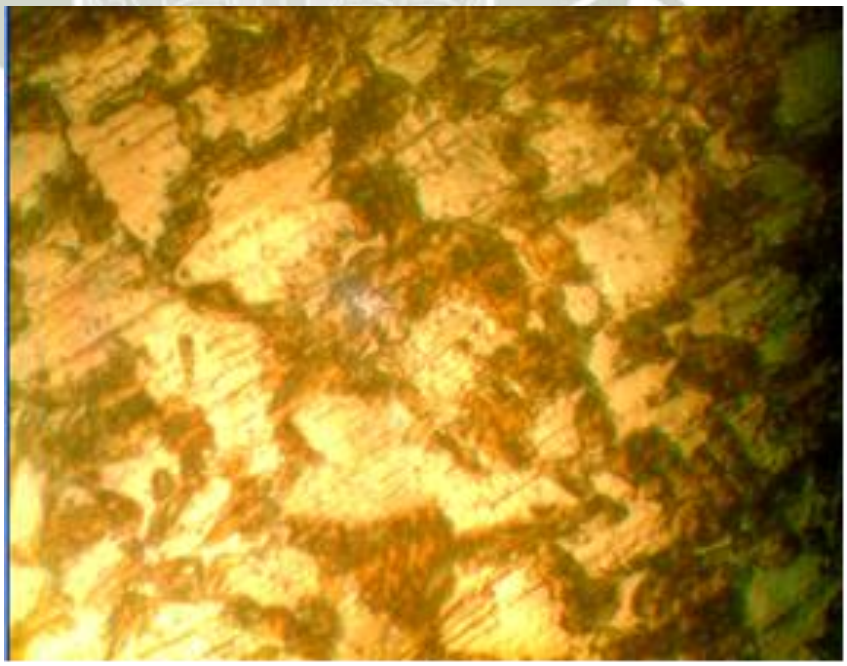
e. Metalografía ensayo a 788°C tiempo de mantenimiento 40min. enfriado a 10°C presenta una mezcla de Ferrita y Martensita.

Grafico N° 92 : Prueba a 788 °C , 40min, 10°C. Aumento 200x.



Fuente : Elaboración Propia del Autor.

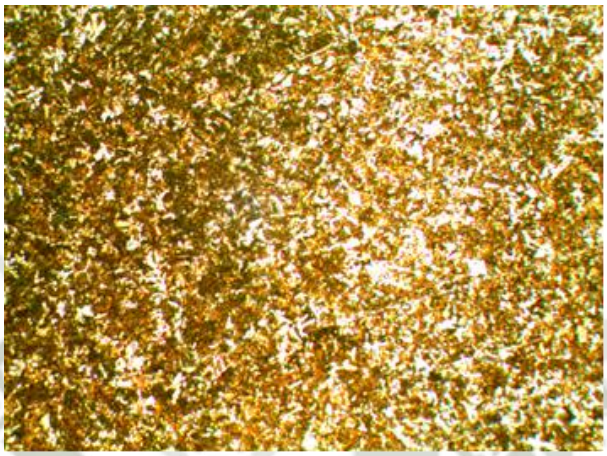
Grafico N° 93 : Prueba a 788 °C , 40min, 10°C. Aumento 1000x.



Fuente : Elaboración Propia del Autor.

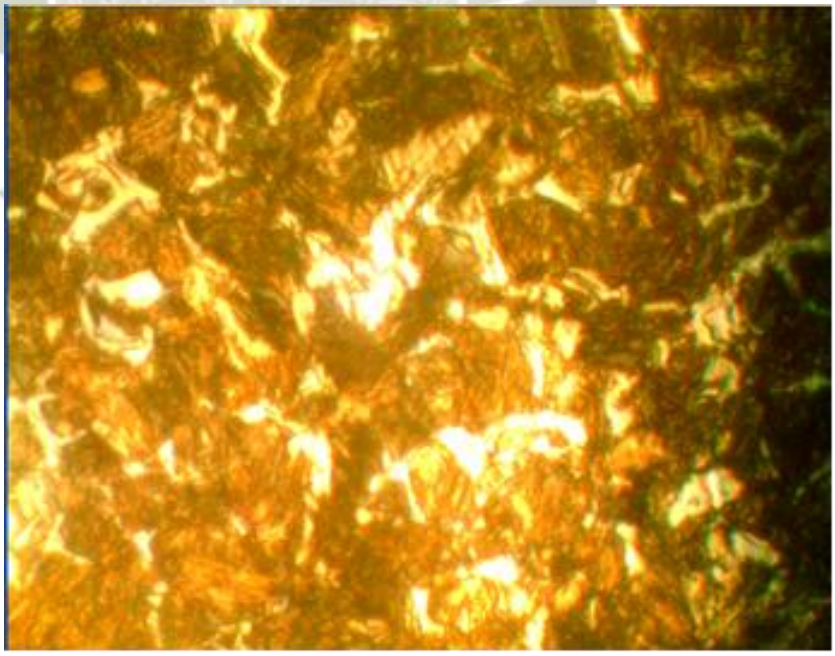
f. Metalografía ensayo a 850°C tiempo de mantenimiento 20min. enfriado a 1°C presenta una mezcla de Ferrita y Martensita .

Grafico N° 94 : Prueba a 850 °C , 20min, 1°C. Aumento 200x.



Fuente : Elaboración Propia del Autor.

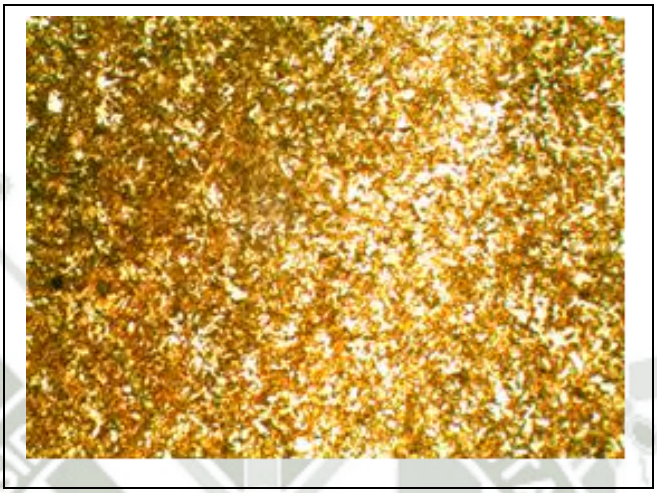
Grafico N° 95 : Prueba a 850 °C , 20min, 1°C. Aumento 1000x.



Fuente : Elaboración Propia del Autor.

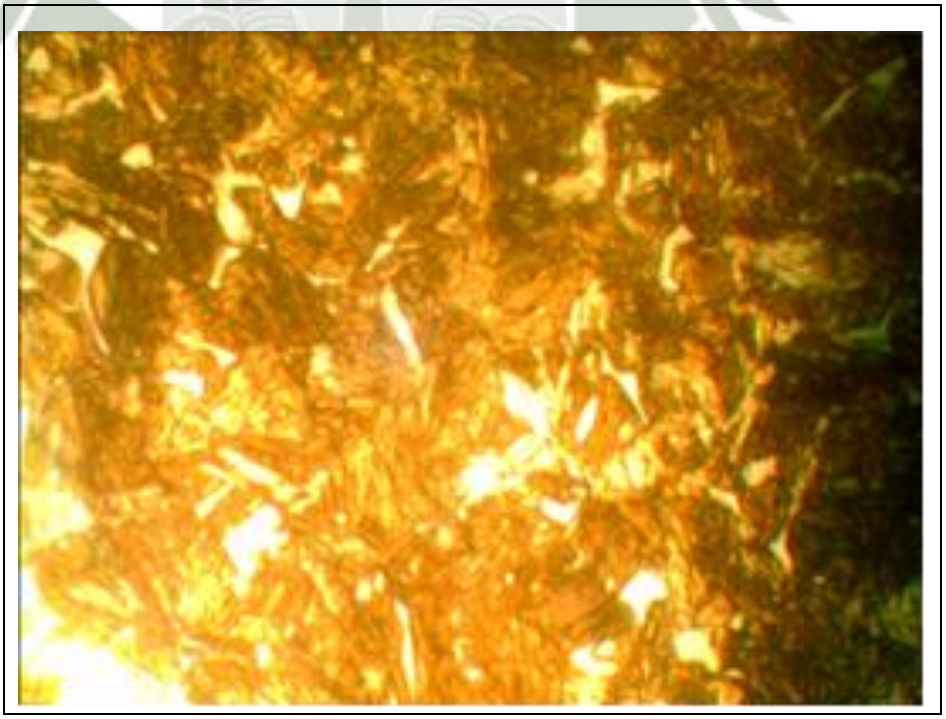
g. Metalografía ensayo a 850°C tiempo de mantenimiento 20min. enfriado a 17°C presenta una mezcla de Ferrita y Martensita.

Grafico N° 96 : Prueba a 850 °C , 20min, 17°C. Aumento 200x.



Fuente : Elaboración Propia del Autor

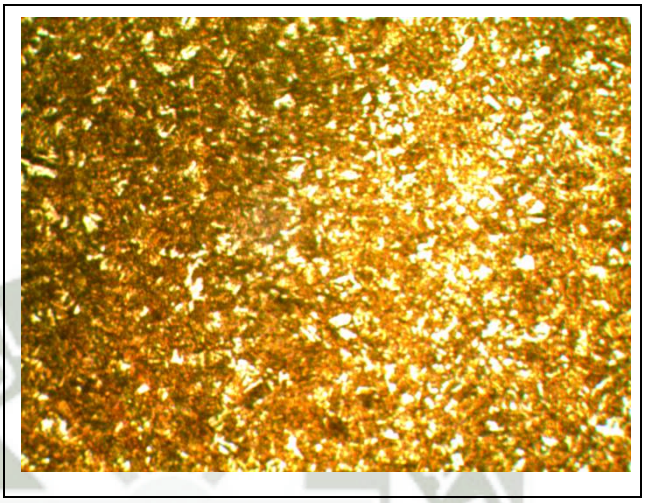
Grafico N° 97 : Prueba a 850 °C , 20min, 17°C. Aumento 1000x.



Fuente : Elaboración Propia del Autor.

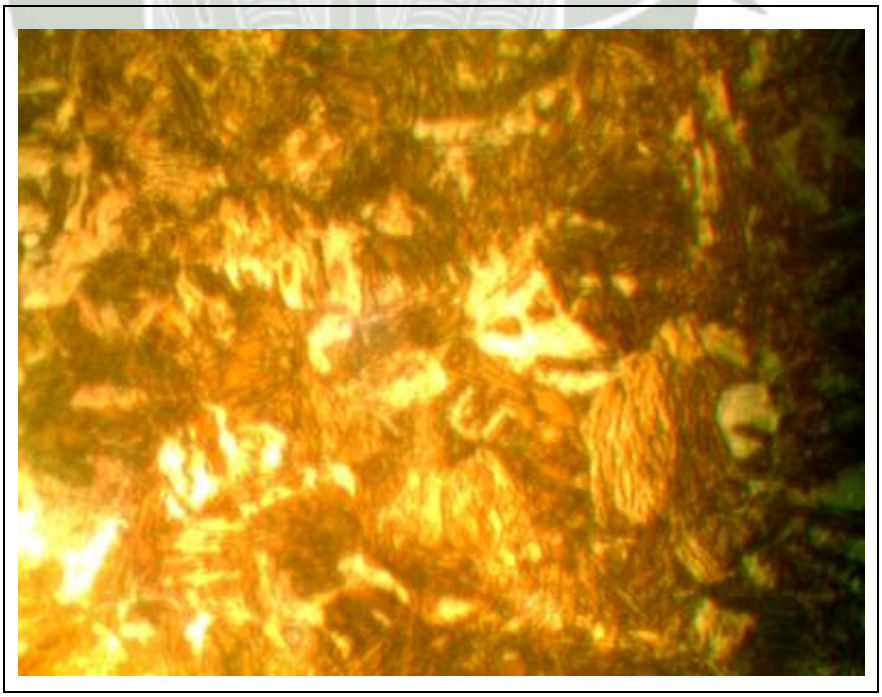
h. Metalografía ensayo a 850°C tiempo de mantenimiento 60min. enfriado a 1°C presenta una mezcla de Ferrita y Martensita.

Grafico N° 98 : Prueba a 850 °C , 60min, 1°C. Aumento 200x.



Fuente : Elaboración Propia del Autor.

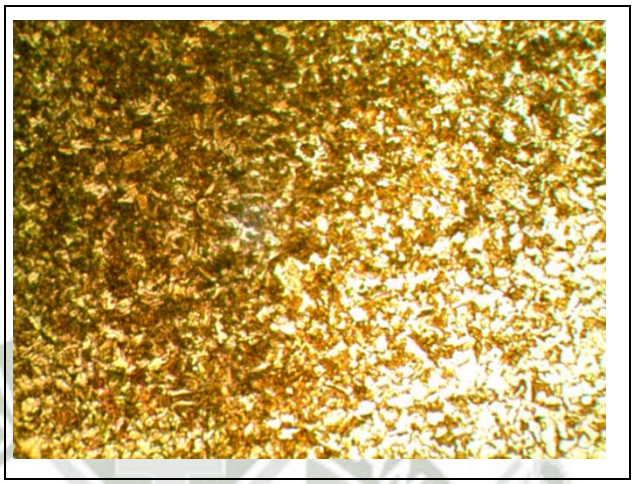
Grafico N° 99 : Prueba a 850 °C , 60min, 1°C. Aumento 1000x.



Fuente : Elaboración Propia del Autor.

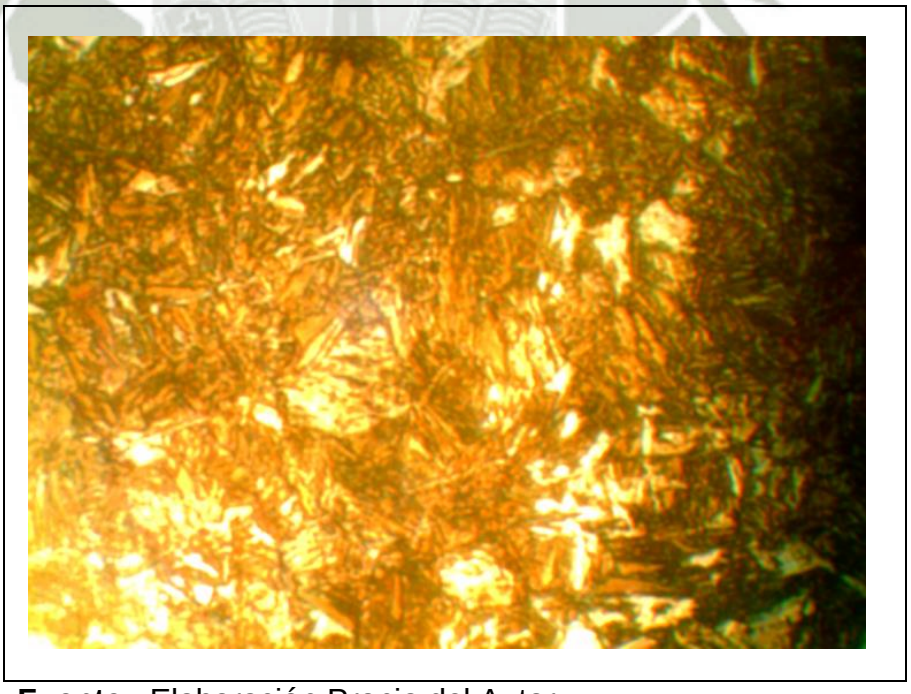
i. Metalografía ensayo a 850°C tiempo de mantenimiento 60min. enfriado a 17°C presenta una mezcla de Ferrita y Martensita.

Grafico N° 100 : Prueba a 850 °C 60min, 17°C. Aumento 200x.



Fuente : Elaboración Propia del Autor.

Grafico N° 101 : Prueba a 850 °C , 60min, 1°C. Aumento 1000x.



Fuente : Elaboración Propia del Autor.

4.3. DISEÑO EXPERIMENTAL

Utilizamos la técnica estadística del diseño experimental factorial porque nos permite identificar , cuantificar la causas del efecto dentro del estudios experimental que elaboramos, también nos permite realizar el menor número de ensayos posibles y poder saber con exactitud cuáles son las condiciones más óptimas del acero A 36 para que pueda obtener las mejores características de una estructura de fase doble . El diseño experimental factorial que consideramos es 2^3 ya que se consideró como tres factores influyentes a la temperatura de calentamiento, tiempo de calentamiento y la temperatura del temple. Para ello se elabora una matriz donde nos indica los factores a considerar, dominio experimental y la matriz del diseño experimental factorial.

Tabla N° 7 : Factores y Dominios Experimentales.

Factores	
T1	Temperatura de calentamiento
T2	Tiempo de mantenimiento
T3	Temepratura de enfriamiento

Dominio Experimental	
Nivel (-)	Nivel (+)
725	850
20	60
1	17

Fuente : Elaboración Propia del Autor

Tabla N° 8 : Matriz de Experimentos para un Diseño Factorial 2^3 y su Plan de Experimentación.

	Matriz de Experimentos			Plan de Experimentación		
	T1	T2	T3	T1	T2	T3
1	-	-	-	725	20	1
2	+	-	-	850	20	1
3	-	+	-	725	60	1
4	+	+	-	850	60	1
5	-	-	+	725	20	17
6	+	-	+	850	20	17
7	-	+	+	725	60	17
8	+	+	+	850	60	17

Fuente : Elaboración Propia del Autor

Las columnas de la matriz no están correlacionadas ya que son ortogonales

Según la matriz realizada ahora se tendrá que codificar los resultados obtenidos de cada ensayo realizado

a. Primero realizaremos el diseño factorial para el ensayo de tracción

Tabla N° 9 : Matriz de Diseño con Valores Codificados / Ensayo de Tracción.

Nro.	Factores							Respuesta Kg/mm^2
	T_1	T_2	T_3	T_1T_2	T_1T_3	T_2T_3	$T_1T_2T_3$	
1	-1	-1	-1	1	1	1	-1	83.25
2	1	-1	-1	1	-1	-1	1	139.48
3	-1	1	-1	-1	1	-1	1	78.49
4	1	1	-1	-1	-1	1	-1	136.05
5	-1	-1	1	-1	-1	1	1	460.78
6	1	-1	1	-1	1	-1	-1	103.70
7	-1	1	1	1	-1	-1	-1	84.39
8	1	1	1	1	1	1	1	120.64

Fuente : Elaboración Propia del Autor

Después de realizar la matriz se procede a realizar el análisis de varianza ANOVA con la ayuda de programas estadísticos podemos determinar que

Tabla N° 10 : Análisis de Error para el Ensayo de Tracción

Factor	SS	Df	MS	Fo	P
T1 (T° calentamiento)	911.8775	1	911.877527	9.93000588	0.016358
T2 (T Tiempo de Man.)	187.4954	1	187.49537	2.04175459	0.164332
T3 (T° enfriamiento)	449.4941	1	449.494109	4.89482306	0.038856
1 y 2	13.54142	1	13.5414222	0.14746103	0.677214
1 y 3	261.7659	1	261.765851	1.41257387	0.198382
2 y 3	185.3113	1	185.311265	2.01797051	0.185325
Error	367.322	4	91.8305123		
Total	2376.808	10			

Fuente : Elaboración Propia del Autor

Para un nivel de significación de a = 0.05; glT = 1; gle = 4 se tiene F (0.05; 1; 4) = 7.7086

La condición de Fo > F (a; glt; gle) se cumple para T1, T2, T3; por lo tanto las variables T1, T3 y las interacciones T1 T2 tienen incidencia significativa en el proceso. Por consiguiente, el modelo matemático será:

$$\hat{Y}=78.7590+9.8312*T1+T2-1.1062*T1T2-3.8012*T1T3+3.9437*T2T3-7.4737$$

El modelo matemático, nos permite evaluar cuan distanciados se encuentran los valores predichos según la técnica experimental . La Tabla, muestra la diferencia entre los valores experimentales y predichos por el modelo matemático para la resistencia a la tracción

Tabla N° 10 : Diferencia de Valores Según Modelo Matemático y Experimentales

Nro.	T1	T2	T3	Yr	$\bar{y}$	R=Yr-$\bar{y}$
1	-1	-1	-1	83.25	97.54768	14.3
2	1	-1	-1	139.48	158.4955	19.02
3	-1	1	-1	78.49	97.41067	18.92
4	1	1	-1	136.05	150.3505	14.3
5	-1	-1	1	460.78	464.8649	4.08
6	1	-1	1	103.70	103.0528	-0.65
7	-1	1	1	84.39	83.73936	-0.65
8	1	1	1	120.64	124.7178	4.08

Fuente : Elaboración Propia del Autor

Se Determina estadísticamente si el modelo matemático hallado representa adecuadamente a los datos experimentales realizando el cálculo de F, Fo 156.63/48.7364 = 3.21

El modelo es adecuado si se cumple que Fo< F (a; glr; gle) ó F (0.05; 8; 4) = 6.04

Estadísticamente el modelo se ajusta adecuadamente a ,los datos experimentales. El modelo decodificado queda de la siguiente manera.

$YD= -184.2506+ 0.3451T_1+2.3489T_2-0.0029T_1T_2-0.016T_1(1)-0.1518T_2(1)+0.002 T_1T_2T_3+10.828$

V. CONCLUCIONES

1. Se puede observar que la dureza del acero A 36 se incrementa notablemente para tratamientos a 850°C, ya que se comienza a la formación de microestructuras martensíticas de bajo contenido de carbono.

2. En los tratamientos a 725 °C, la dureza logra valores moderados que tenemos la presencia de una mezcla de martensita y ferrita (fases dobles). Hay que tener en cuenta que la perlita es sustituida por la fase martensita.

3. La tenacidad resulta ser mayor para microestructura martensíticas que para microestructuras de fases dobles (martensita-ferrita). La muestra para el primer caso, su tipo de fractura corresponde a intergranular - dúctil y para los otros ensayos , presentan un tipo de fractura cuasi-clivaje originado por la disposición discontinua de la martensita en límites de grano que resulta en una baja capacidad para absorber energía.

4. El análisis de la varianza para la resistencia a la tracción, indica que las variables influyentes en el proceso son la temperatura de calentamiento y la temperatura del medio de enfriamiento.

5. Los ensayos a 725°C, evidenciaron la formación de combinaciones micro estructural de martensita y ferrita, teniendo una buena combinación de resistencia y alargamiento.

6. Los ensayos a 850 °C mostraron la formación de fases martensíticas de bajo contenido de carbono, lográndose incrementos máximos de la resistencia a la tracción de cuando se utilizó medios de temple fríos (agua a 1°C)

7. El análisis microscópico revelo la presencia de mezclas de ferrita idiomorfa y martensita cuando se realizó el tratamiento térmico a temperatura intercriticas (725 y 850 °C). La ferrita idiomorfo se forma en un rango de temperaturas que varía desde unas decenas de grados por debajo de la temperatura de inicio de descomposición de la austenita en ferrita, A3, hasta la temperatura donde las transformaciones de origen disfuncional empiezan a ser relativamente lentas y comienzan a tener lugar las trasformaciones de origen no disfuncional tales como la ferrita , la bainita y la martensita

8. Se observó martensita acicular y ferrita en muestras tratadas a 850 °C. La observación al microscopio electrónico de barrido (SEM), confirmo la presencia de martensita del tipo acicular y ferrita.

VI. RECOMENDACIONES

1. Se tiene que realizar una prueba de análisis químico al acero antes de realizar las pruebas porque que el certificado de calidad nos indica el contenido mínimo que tiene el acero así también como sus propiedades mecánicas para ellos recurrimos al apoyo de la norma ASTM A415 – 08, la tesis que ha sido elabora realizo esta prueba en los laboratorios de la PUCP ya que a falta de este equipo se tuvo que efectuar dicha prueba fuera de nuestras instalaciones ANEXO 10 Análisis químico.

2. Para salvaguardad nuestra integridad física recomendamos hacer uso de los protocolos de seguridad en el laboratorio en especial implementar un formato para el análisis del trabajo seguro (ATS) ANEXO 11 cuando estemos realizando labores como las que se efectuaron en este proyecto.

3. Poder contar con una licencia corporativa de las normas ASTM para su visualización y descarga de ellas ya que es de suma importancia considerar normas dentro de proyectos de investigación.

VII. BIBLIOGRAFIA

1. AVIMER Introducción a la metalurgia física.- Segunda edición.- Editorial Calipso S.A. México.- 1987.
2. ANUAL BOOK OF ASTM STANDARDS.- Editorial Staff Copyrigth.- American Society for testing and materials, Philadelphia.-1992.
3. KEYSER.- Materiales y Procesos de Manufactura para ingenieros.- Tercera Edición.- Editorial Limusa, México 1988.
4. GULIAEV.- Metalografía.- Segunda Edición.- Editorial MIR.- Moscú.- 1983
5. GRIMBERG.- Tratamiento Térmico de los Aceros y sus Prácticas de laboratorio.- Editorial Limusa.- México 1989.
6. MONGOMERY Diseño y Análisis de Experimentos.- Editorial Iberoamericana S.A. - México 1991.
7. VALENCIA.- Tecnología 'del Tratamiento térmico de tos metales.- Segunda edición.- Editorial Universidad de Antioquia.- Colombia 1992.
8. ASKELAND.- Ciencia e ingeniería de los Materiales.- International Thomson Editores.- México 1998.
9. CALLISTER.- Introducción a la Ciencia e Ingeniería de los Materiales, Editorial Reverte S.A.- México 1995.
10. CALVO.- Metalografía práctica.- Editorial Alhambra S.A. Madrid 1972.
11. CONTRERAS Metalurgia Física.- Chile.-1985
12. FLIN Y TROJAN.- Materiales de ingeniería y sus Aplicaciones.- Editorial Mac Graw Hill.- Colombia 1989.

13. JQHNSON-WEEKS.- Metalurgia.- Editorial Reverte S.A. México 1961.

14. SARCE Introducción a la Ciencia de Materiales.- Proyecto Multinacional de Materiales.- OEA-CNEA- Argentina 1996.

15. SHACKELFORD Ciencia de Materiales para Ingenieros.- Editorial Prentice Hill Hispanoamericana S.A.- México 1992.

16. SMITH Fundamentos de la Ciencia y la ingeniería, Editorial Mac-Graw-Hill.-México 1993.

17. VAN VLACK Materiales para ingeniería.- Compañía Editorial Continental S.A- México 1991

18. GUY- Fundamentos de Ciencia de Materiales.- Editorial Mc-Graw-Híll.- México 1980.

19. BERNARD-MICHEL- Metalurgia General.- Editorial Hispano Europea.- Paris 1979.

20. BIRCHENALL Physical Metallurgy.- Editorial Mc-Graw-Hill.- Toronto 1969.

21. REED-HILL- Principios de Metalurgia Física.- Tercera Edición.- Editorial G.E.C.S.A.-México 1972.

22. PASCUAL.- Técnica y Práctica del tratamiento Térmico de los Metales- Editorial Blume.- Barcelona 1970.

23. APRAIZ.- Tratamiento térmico de los Aceros.- Editorial Dossat.- Madrid 1961.

24. STURLA Tratamiento termoquímicos de los Aceros y Fundiciones.- Ediciones técnicas internacionales Buenos Aires 1973.

VIII. INDICE DE GRAFICOS

IX. INDICE DE TABLAS

X. INDICE DE ANEXOS – CD ADJUNTO

ANEXO N° 1. NORMA ASTM E 10 - 01 STANDARS TEST METHOD FOR BRINELL HARDNESS OF METALLIC MATERIALS

ANEXO N° 2. NORMA ASTM E 8 STANDARD TEST METHODS FOR TENSION TESTING OF METALLIC MATERIALS

ANEXO N° 3. NORMA ASTM A 370 STANDARD TEST METHODS AND DEFINITIONS FOR MECHANICAL TESTING OF STEEL PRODUCTS

ANEXO N° 4. NORMA ASTM E 23 STANDARD TEST METHODS FOR NOTCHED BAR IMPACT TESTING OF METALLIC MATERIALS

ANEXO N° 5. NORMA ASTM E 3 STANDARD GUIDE FOR PREPARATION OF METALLOGRAPHIC SPECIMENS

ANEXO N° 6. CERTIFICADOS DE CALIDAD DE LOS ACEROS BARRA CUADRADA Y CIRCULAR

ANEXO N° 7. NORMA ASTM A 36 STANDARD SPECIFICATION FOR CARBÓN STRUCTURAL STELL

ANEXO N° 8. NORMA ASTM E 112 STANDARD TEST METHODS FOR DETERMINING AVERAGE GRAIN SIZE

ANEXO N° 9. NORMA ASTM E 7 STANDARD TERMINOLOGY RELATING TO METALLOGRAPH

ANEXO N° 10. ANALISIS QUIMICO

ANEXO N° 11. ANALISIS DE TRABAJO SEGURO (AST)

Designation: E 10 – 01

American Association State Highway and Transportation Officials Standard
AASHTO No.: T70–86
An American National Standard

Standard Test Method for Brinell Hardness of Metallic Materials[1]

This standard is issued under the fixed designation E 10; 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 (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This test method (Test Method A) covers the determination of the Brinell hardness of metallic materials, including methods for the verification of Brinell hardness testing machines (Test Method B) and the calibration of standardized hardness test blocks (Test Method C).

1.2 The values stated in SI units are to be regarded as the standard.

NOTE 1—In common terminology, the equivalent force in kgf is substituted for N.

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:*

E 4 Practices for Force Verification of Testing Machines[2]

E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications[3]

E 74 Practice of Calibration of Force-Measuring Instruments for Verifying the Force Indication of Testing Machines[2]

E 140 Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Rockwell Superficial Hardness, Knoop Hardness, and Scleroscope Hardness[2]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *Brinell hardness number*—a number, which is proportional to the quotient obtained by dividing the test force by the curved surface area of the indentation which is assumed to be spherical and of the diameter of the ball.

$$\text{HBW} = 0.102 \times \frac{2F}{\pi D(D - \sqrt{D^2 - d^2})} \quad \text{(See Table 1)} \qquad (1)$$

where:

D = diameter of the ball, mm,
F = test force, N, and
d = mean diameter of the indentation, mm.

The Brinell hardness is denoted by the symbol: HBW.

3.1.1.1 *Discussion*—In former standards, a steel ball was allowed for hardness values below 450. In cases when a steel ball was used, the Brinell hardness was denoted by HB or HBS.

3.1.1.2 *Discussion*—The symbol HBW is preceded by the hardness value. When conditions other than those specified in 11.1.2 are used, the hardness value is supplemented by an index indicating the test conditions in the order:

(*1*) Diameter of the ball, in mm,
(*2*) A value representing the test force in kg/f (see Table 3), and,
(*3*) Duration of loading, in s.

Examples:
350 HBW 5/750 = Brinell hardness of 350 determined with a ball of 5-mm diameter and with a test force of 7.355 kN (750 kgf) applied for 10 to 15 s.
600 HBW 1/30/20 = Brinell hardness of 600 determined with a ball of 1-mm diameter and with a test force of 294.2 N (30 kgf) applied for 20 s.

3.1.1.3 *Discussion*—Brinell hardness numbers vary with the test force used; however, test results will generally be in agreement when the ratio of the test force to the square of the ball diameter is held constant (see Table 3).

3.1.1.4 *Discussion*—Table 2 lists the Brinell hardness numbers corresponding to various diameters of indentations for 29.4 kN (3000 kgf), 14.7 kN (1500 kgf), and 4.90 kN (500 kgf) test forces making it unnecessary to calculate for each test the value of the Brinell hardness number by the above equation in Table 1 when these forces are used with a 10-mm diameter ball.

3.1.2 *Brinell hardness test*—an indenter (tungsten carbide ball with diameter D) is forced into the surface of a test piece and the diameter of the indentation d left in the surface after removal of the test force, F, is measured. (see Table 1 and Figs. 1 and 2.)

3.1.2.1 *Discussion*—The tungsten carbide ball may be used for materials with a Brinell hardness not exceeding 650.

3.1.3 *calibration*—adjustment of the significant parameters by comparison with values indicated by a reference instrument or by a set of reference standards.

[1] This test method is under the jurisdiction of ASTM Committee E28 on Mechanical Testing and is the direct responsibility of Subcommittee E28.06 on Indentation Hardness Testing.

Current edition approved February 10, 2001. Published April 2001. Originally published as E 10 – 24 T. Last previous edition E 10 – 00a.

[2] *Annual Book of ASTM Standards*, Vol 03.01.

[3] *Annual Book of ASTM Standards*, Vol 14.02.

TABLE 1 Symbols and Designations

NOTE 1— Constant $= \frac{1}{g_n} = \frac{1}{9.806\,65} = 0.102$

Symbol	Designation
D	Diameter of the ball, mm
F	Test force, N
d	Mean diameter of the indentation, mm
h	Depth of the indentation, mm $= \frac{D - \sqrt{D^2 - d^2}}{2}$
HBW	Brinell hardness $= \text{Constant} \times \frac{\text{Test force}}{\text{Surface area of indentation}}$ $= 0.102 \times \frac{2F}{\pi D(D - \sqrt{D^2 - d^2})}$

3.1.4 *verification*—checking or testing to assure conformance with the specification.

4. Significance and Use

4.1 The Brinell hardness test is an empirical indentation hardness test. Brinell hardness tests provide useful information about metallic materials. This information may correlate to tensile strength, wear resistance, ductility, or other physical characteristics of metallic materials, and may be useful in quality control and selection of materials. Brinell hardness testing at the specific location on a part may not represent the physical characteristics of the whole part or end product. Brinell hardness tests are considered satisfactory for acceptance testing of commercial shipments, and they have been used extensively in industry for this purpose.

TEST METHOD A—GENERAL DESCRIPTION AND TEST PROCEDURE FOR BRINELL HARDNESS TESTS

5. Apparatus

5.1 *Testing Machine*—Equipment for Brinell hardness testing usually consists of a testing machine which supports the test specimen and applies an indenting force to a ball in contact with the specimen. The design of the testing machines shall be such that no rocking or lateral movement of the indenter or specimen occurs while the force is being applied. The design of the testing machine shall ensure that the force to the indenter shall be applied smoothly and without impact forces. Precautions shall be taken to prevent a momentary high test force caused by the inertia of the system, hydraulic system overshoot, etc. See equipment manufacturer's instruction manual for a description of the machine's characteristics, limitations, and respective operating procedure.

5.2 *Brinell Balls*:

5.2.1 The standard ball for Brinell hardness testing shall be 10.000 mm in diameter with a deviation from this value of not more than 0.005 mm in any diameter. The ball shall be polished and free of surface defects. Smaller balls having the diameters and tolerances indicated in Table 4 may be used also provided the precautions set forth in 8.1 are observed.

5.2.2 The tungsten carbide ball indenter shall have a minimum hardness of 1500 HV10.

NOTE 2—**Caution:** The Brinell test is not recommended for material having hardness over 650 HBW (see 8.1).

5.2.2.1 The chemical composition of tungsten carbide balls shall be:

Tungsten Carbide (WC)	Balance
Cobalt (Co)	5.0 to 7.0 %
Total other Carbides	2.0 % max

5.2.2.2 The use of hardened steel ball indenters has been eliminated from this test method. Only tungsten carbide balls may now be used for this test method.

5.2.3 If a ball is used to test a specimen which shows a Brinell hardness greater than 650, the result should be considered suspect and the ball inspected for damage. If there is any evidence of damage, the ball shall be replaced.

5.3 *Measuring Device*—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 measuring of the diameter to 0.1 mm and the estimation of the diameter to 0.05 mm.

NOTE 3—This requirement applies to the construction of the device only and is not a requirement for measurement of the indentation.

6. Test Specimen

6.1 There is no standard shape or size for a Brinell test specimen. The specimen upon which the indentation is made shall conform to the following:

6.1.1 *Thickness*—The thickness of the specimen tested shall be such that no bulge or other marking showing the effect of the test force appears on the side of the piece opposite the indentation. As a general rule, the thickness of the specimen shall be at least ten times the depth of the indentation (Table 5).

6.1.2 The minimum width shall conform with the requirements of 8.3.

6.1.3 *Finish*—When necessary, the surface on which the indentation is to be made shall be filed, ground, machined or polished with abrasive material so that the edge of the indentation shall be clearly defined to permit the measurement of the diameter to the specified accuracy (see 9.1). Care should be taken to avoid overheating or cold working the surface.

7. Verification of Testing Machine

7.1 *Verification Methods*—The hardness testing machine shall be verified in accordance with one of the two acceptable methods of verifying Brinell hardness testing machines as given in Test Method B.

7.2 *Test Force Range*—When direct verification is used, the Brinell hardness testing machine is acceptable for use over a test force range within which the error in test force does not exceed ±1 %. When indirect verification is used, the Brinell hardness machine is acceptable for use over a test force range within which the mean hardness value obtained is within ±3 % of the Brinell hardness of the standardized test blocks used.

8. Procedure

8.1 *Magnitude of Test Force*—Typically, the force in the standard Brinell test shall be 29.42 kN (3000 kgf), 14.7 kN (1500 kgf), or 4.90 kN (500 kgf). It is recommended that the diameter of the indentation be between 24 and 60 % of the ball diameter. A lower limit in indentation diameter is necessary

TABLE 2 Brinell Hardness Numbers[A]
(Ball 10 mm in Diameter, Applied Forces of 500, 1500, and 3000 kgf)

NOTE 1—The values given in this table for Brinell hardness numbers are merely solutions of the equation given in the definition in 3.1.1, and include values for impression diameters outside the ranges recommended in 8.1. These values are indicated by italics.

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 Force	1500-kgf Force	3000-kgf Force		500-kgf Force	1500-kgf Force	3000-kgf Force		500-kgf Force	1500-kgf Force	3000-kgf Force		500-kgf Force	1500-kgf Force	3000-kgf Force
2.00	*158*	*473*	*945*	2.60	92.6	278	555	3.20	60.5	182	363	3.80	42.4	127	255
2.01	*156*	*468*	*936*	2.61	91.8	276	551	3.21	60.1	180	361	3.81	42.2	127	253
2.02	*154*	*463*	*926*	2.62	91.1	273	547	3.22	59.8	179	359	3.82	42.0	126	252
2.03	*153*	*459*	*917*	2.63	90.4	271	543	3.23	59.4	178	356	3.83	41.7	125	250
2.04	*151*	*454*	*908*	2.64	89.7	269	538	3.24	59.0	177	354	3.84	41.5	125	249
2.05	*150*	*450*	*899*	2.65	89.0	267	534	3.25	58.6	176	352	3.85	41.3	124	248
2.06	*148*	*445*	*890*	2.66	88.4	265	530	3.26	58.3	175	350	3.86	41.1	123	246
2.07	*147*	*441*	*882*	2.67	87.7	263	526	3.27	57.9	174	347	3.87	40.9	123	245
2.08	*146*	*437*	*873*	2.68	87.0	261	522	3.28	57.5	173	345	3.88	40.6	122	244
2.09	*144*	*432*	*865*	2.69	86.4	259	518	3.29	57.2	172	343	3.89	40.4	121	242
2.10	*143*	*428*	*856*	2.70	85.7	257	514	3.30	56.8	170	341	3.90	40.2	121	241
2.11	*141*	*424*	*848*	2.71	85.1	255	510	3.31	56.5	169	339	3.91	40.0	120	240
2.12	*140*	*420*	*840*	2.72	84.4	253	507	3.32	56.1	168	337	3.92	39.8	119	239
2.13	*139*	*416*	*832*	2.73	83.8	251	503	3.33	55.8	167	335	3.93	39.6	119	237
2.14	*137*	*412*	*824*	2.74	83.2	250	499	3.34	55.4	166	333	3.94	39.4	118	236
2.15	*136*	*408*	*817*	2.75	82.6	248	495	3.35	55.1	165	331	3.95	39.1	117	235
2.16	*135*	*404*	*809*	2.76	81.9	246	492	3.36	54.8	164	329	3.96	38.9	117	234
2.17	*134*	*401*	*802*	2.77	81.3	244	488	3.37	54.4	163	326	3.97	38.7	116	232
2.18	*132*	*397*	*794*	2.78	80.8	242	485	3.38	54.1	162	325	3.98	38.5	116	231
2.19	*131*	*393*	*787*	2.79	80.2	240	481	3.39	53.8	161	323	3.99	38.3	115	230
2.20	*130*	*390*	*780*	2.80	79.6	239	477	3.40	53.4	160	321	4.00	38.1	114	229
2.21	*129*	*386*	*772*	2.81	79.0	237	474	3.41	53.1	159	319	4.01	37.9	114	228
2.22	*128*	*383*	*765*	2.82	78.4	235	471	3.42	52.8	158	317	4.02	37.7	113	226
2.23	*126*	*379*	*758*	2.83	77.9	234	467	3.43	52.5	157	315	4.03	37.5	113	225
2.24	*125*	*376*	*752*	2.84	77.3	232	464	3.44	52.2	156	313	4.04	37.3	112	224
2.25	*124*	*372*	*745*	2.85	76.8	230	461	3.45	51.8	156	311	4.05	37.1	111	223
2.26	*123*	*369*	*738*	2.86	76.2	229	457	3.46	51.5	155	309	4.06	37.0	111	222
2.27	*122*	*366*	*732*	2.87	75.7	227	454	3.47	51.2	154	307	4.07	36.8	110	221
2.28	*121*	*363*	*725*	2.88	75.1	225	451	3.48	50.9	153	306	4.08	36.6	110	219
2.29	*120*	*359*	*719*	2.89	74.6	224	448	3.49	50.6	152	304	4.09	36.4	109	218
2.30	*119*	*356*	*712*	2.90	74.1	222	444	3.50	50.3	151	302	4.10	36.2	109	217
2.31	*118*	*353*	*706*	2.91	73.6	221	441	3.51	50.0	150	300	4.11	36.0	108	216
2.32	*117*	*350*	*700*	2.92	73.0	219	438	3.52	49.7	149	298	4.12	35.8	108	215
2.33	*116*	*347*	*694*	2.93	72.5	218	435	3.53	49.4	148	297	4.13	35.7	107	214
2.34	*115*	*344*	*688*	2.94	72.0	216	432	3.54	49.2	147	295	4.14	35.5	106	213
2.35	*114*	*341*	*682*	2.95	71.5	215	429	3.55	48.9	147	293	4.15	35.3	106	212
2.36	*113*	*338*	*676*	2.96	71.0	213	426	3.56	48.6	146	292	4.16	35.1	105	211
2.37	*112*	*335*	*670*	2.97	70.5	212	423	3.57	48.3	145	290	4.17	34.9	105	210
2.38	*111*	*332*	*665*	2.98	70.1	210	420	3.58	48.0	144	288	4.18	34.8	104	209
2.39	*110*	*330*	*659*	2.99	69.6	209	417	3.59	47.7	143	286	4.19	34.6	104	208
2.40	*109*	*327*	*653*	3.00	69.1	207	415	3.60	47.5	142	285	4.20	34.4	103	207
2.41	108	324	648	3.01	68.6	206	412	3.61	47.2	142	283	4.21	34.2	103	205
2.42	107	322	643	3.02	68.2	205	409	3.62	46.9	141	282	4.22	34.1	102	204
2.43	106	319	637	3.03	67.7	203	406	3.63	46.7	140	280	4.23	33.9	102	203
2.44	105	316	632	3.04	67.3	202	404	3.64	46.4	139	278	4.24	33.7	101	202
2.45	104	313	627	3.05	66.8	200	401	3.65	46.1	138	277	4.25	33.6	101	201
2.46	104	311	621	3.06	66.4	199	398	3.66	45.9	138	275	4.26	33.4	100	200
2.47	103	308	616	3.07	65.9	198	395	3.67	45.6	137	274	4.27	33.2	99.7	199
2.48	102	306	611	3.08	65.5	196	393	3.68	45.4	136	272	4.28	33.1	99.2	198
2.49	101	303	606	3.09	65.0	195	390	3.69	45.1	135	271	4.29	32.9	98.8	198
2.50	100	301	601	3.10	64.6	194	388	3.70	44.9	135	269	4.30	32.8	98.3	197
2.51	99.4	298	597	3.11	64.2	193	385	3.71	44.6	134	268	4.31	32.6	97.8	196
2.52	98.6	296	592	3.12	63.8	191	383	3.72	44.4	133	266	4.32	32.4	97.3	195
2.53	97.8	294	587	3.13	63.3	190	380	3.73	44.1	132	265	4.33	32.3	96.8	194
2.54	97.1	291	582	3.14	62.9	189	378	3.74	43.9	132	263	4.34	32.1	96.4	193
2.55	96.3	289	578	3.15	62.5	188	375	3.75	43.6	131	262	4.35	32.0	95.9	192
2.56	95.5	287	573	3.16	62.1	186	373	3.76	43.4	130	260	4.36	31.8	95.5	191
2.57	94.8	284	569	3.17	61.7	185	370	3.77	43.1	129	259	4.37	31.7	95.0	190
2.58	94.0	282	564	3.18	61.3	184	368	3.78	42.9	129	257	4.38	31.5	94.5	189
2.59	93.3	280	560	3.19	60.9	183	366	3.79	42.7	128	256	4.39	31.4	94.1	188

because of the risk in damaging the ball and difficulty measuring the indentation. The upper limit is necessary because of a reduction in sensitivity as the diameter of the indentation approaches the ball diameter. The thickness and spacing requirements of 6.1.1, 6.1.2, and 8.3 may determine the maximum permissible diameter of indentation for a specific test. Table 6 gives standard test forces and approximate Brinell hardness numbers for the above range of indentation diameters.

TABLE 2 *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 Force	1500-kgf Force	3000-kgf Force		500-kgf Force	1500-kgf Force	3000-kgf Force		500-kgf Force	1500-kgf Force	3000-kgf Force		500-kgf Force	1500-kgf Force	3000-kgf Force
4.40	31.2	93.6	187	5.05	23.3	69.8	140	5.70	17.8	53.5	107	6.35	*14.0*	*42.0*	*84.0*
4.41	31.1	93.2	186	5.06	23.2	69.5	139	5.71	17.8	53.3	107	6.36	*13.9*	*41.8*	*83.7*
4.42	30.9	92.7	185	5.07	23.1	69.2	138	5.72	17.7	53.1	106	6.37	*13.9*	*41.7*	*83.4*
4.43	30.8	92.3	185	5.08	23.0	68.9	138	5.73	17.6	52.9	106	6.38	*13.8*	*41.5*	*83.1*
4.44	30.6	91.8	184	5.09	22.9	68.6	137	5.74	17.6	52.7	105	6.39	*13.8*	*41.4*	*82.8*
4.45	30.5	91.4	183	5.10	22.8	68.3	137	5.75	17.5	52.5	105	6.40	*13.7*	*41.2*	*82.5*
4.46	30.3	91.0	182	5.11	22.7	68.0	136	5.76	17.4	52.3	105	6.41	*13.7*	*41.1*	*82.2*
4.47	30.2	90.5	181	5.12	22.6	67.7	135	5.77	17.4	52.1	104	6.42	*13.6*	*40.9*	*81.9*
4.48	30.0	90.1	180	5.13	22.5	67.4	135	5.78	17.3	51.9	104	6.43	*13.6*	*40.8*	*81.6*
4.49	29.9	89.7	179	5.14	22.4	67.1	134	5.79	17.2	51.7	103	6.44	*13.5*	*40.6*	*81.3*
4.50	29.8	89.3	179	5.15	22.3	66.9	134	5.80	17.2	51.5	103	6.45	*13.5*	*40.5*	*81.0*
4.51	29.6	88.8	178	5.16	22.2	66.6	133	5.81	17.1	51.3	103	6.46	*13.4*	*40.4*	*80.7*
4.52	29.5	88.4	177	5.17	22.1	66.3	133	5.82	17.0	51.1	102	6.47	*13.4*	*40.2*	*80.4*
4.53	29.3	88.0	176	5.18	22.0	66.0	132	5.83	17.0	50.9	102	6.48	*13.4*	*40.1*	*80.1*
4.54	29.2	87.6	175	5.19	21.9	65.8	132	5.84	16.9	50.7	101	6.49	*13.3*	*39.9*	*79.8*
4.55	29.1	87.2	174	5.20	21.8	65.5	131	5.85	16.8	50.5	101	6.50	*13.3*	*39.8*	*79.6*
4.56	28.9	86.8	174	5.21	21.7	65.2	130	5.86	16.8	50.3	101	6.51	*13.2*	*39.6*	*79.3*
4.57	28.8	86.4	173	5.22	21.6	64.9	130	5.87	16.7	50.2	100	6.52	*13.2*	*39.5*	*79.0*
4.58	28.7	86.0	172	5.23	21.6	64.7	129	5.88	16.7	50.0	99.9	6.53	*13.1*	*39.4*	*78.7*
4.59	28.5	85.6	171	5.24	21.5	64.4	129	5.89	16.6	49.8	99.5	6.54	*13.1*	*39.2*	*78.4*
4.60	28.4	85.4	170	5.25	21.4	64.1	128	5.90	16.5	49.6	99.2	6.55	*13.0*	*39.1*	*78.2*
4.61	28.3	84.8	170	5.26	21.3	63.9	128	5.91	16.5	49.4	98.8	6.56	*13.0*	*38.9*	*78.0*
4.62	28.1	84.4	169	5.27	21.2	63.6	127	5.92	16.4	49.2	98.4	6.57	*12.9*	*38.8*	*77.6*
4.63	28.0	84.0	168	5.28	21.1	63.3	127	5.93	16.3	49.0	98.0	6.58	*12.9*	*38.7*	*77.3*
4.64	27.9	83.6	167	5.29	21.0	63.1	126	5.94	16.3	48.8	97.7	6.59	*12.8*	*38.5*	*77.1*
4.65	27.8	83.3	167	5.30	20.9	62.8	126	5.95	16.2	48.7	97.3	6.60	*12.8*	*38.4*	*76.8*
4.66	27.6	82.9	166	5.31	20.9	62.6	125	5.96	16.2	48.5	96.9	6.61	*12.8*	*38.3*	*76.5*
4.67	27.5	82.5	165	5.32	20.8	62.3	125	5.97	16.1	48.3	96.6	6.62	*12.7*	*38.1*	*76.2*
4.68	27.4	82.1	164	5.33	20.7	62.1	124	5.98	16.0	48.1	96.2	6.63	*12.7*	*38.0*	*76.0*
4.69	27.3	81.8	164	5.34	20.6	61.8	124	5.99	16.0	47.9	95.9	6.64	*12.6*	*37.9*	*75.7*
4.70	27.1	81.4	163	5.35	20.5	61.5	123	6.00	*15.9*	*47.7*	*95.5*	6.65	*12.6*	*37.7*	*75.4*
4.71	27.0	81.0	162	5.36	20.4	61.3	123	6.01	*15.9*	*47.6*	*95.1*	6.66	*12.5*	*37.6*	*75.2*
4.72	26.9	80.7	161	5.37	20.3	61.0	122	6.02	*15.8*	*47.4*	*94.8*	6.67	*12.5*	*37.5*	*74.9*
4.73	26.8	80.3	161	5.38	20.3	60.8	122	6.03	*15.7*	*47.2*	*94.4*	6.68	*12.4*	*37.3*	*74.7*
4.74	26.6	79.9	160	5.39	20.2	60.6	121	6.04	*15.7*	*47.0*	*94.1*	6.69	*12.4*	*37.2*	*74.4*
4.75	26.5	79.6	159	5.40	20.1	60.3	121	6.05	*15.6*	*46.8*	*93.7*	6.70	*12.4*	*37.1*	*74.1*
4.76	26.4	79.2	158	5.41	20.0	60.1	120	6.06	*15.6*	*46.7*	*93.4*	6.71	*12.3*	*36.9*	*73.9*
4.77	26.3	78.9	158	5.42	19.9	59.8	120	6.07	*15.5*	*46.5*	*93.0*	6.72	*12.3*	*36.8*	*73.6*
4.78	26.2	78.5	157	5.43	19.9	59.6	119	6.08	*15.4*	*46.3*	*92.7*	6.73	*12.2*	*36.7*	*73.4*
4.79	26.1	78.2	156	5.44	19.8	59.3	119	6.09	*15.4*	*46.2*	*92.3*	6.74	*12.2*	*36.6*	*73.1*
4.80	25.9	77.8	156	5.45	19.7	59.1	118	6.10	*15.3*	*46.0*	*92.0*	6.75	*12.1*	*36.4*	*72.8*
4.81	25.8	77.5	155	5.46	19.6	58.9	118	6.11	*15.3*	*45.8*	*91.7*	6.76	*12.1*	*36.3*	*72.6*
4.82	25.7	77.1	154	5.47	19.5	58.6	117	6.12	*15.2*	*45.7*	*91.3*	6.77	*12.1*	*36.2*	*72.3*
4.83	25.6	76.8	154	5.48	19.5	58.4	117	6.13	*15.2*	*45.5*	*91.0*	6.78	*12.0*	*36.0*	*72.1*
4.84	25.5	76.4	153	5.49	19.4	58.2	116	6.14	*15.1*	*45.3*	*90.6*	6.79	*12.0*	*35.9*	*71.8*
4.85	25.4	76.1	152	5.50	19.3	57.9	116	6.15	*15.1*	*45.2*	*90.3*	6.80	*11.9*	*35.8*	*71.6*
4.86	25.3	75.8	152	5.51	19.2	57.7	115	6.16	*15.0*	*45.0*	*90.0*	6.81	*11.9*	*35.7*	*71.3*
4.87	25.1	75.4	151	5.52	19.2	57.5	115	6.17	*14.9*	*44.8*	*89.6*	6.82	*11.8*	*35.5*	*71.1*
4.88	25.0	75.1	150	5.53	19.1	57.2	114	6.18	*14.9*	*44.7*	*89.3*	6.83	*11.8*	*35.4*	*70.8*
4.89	24.9	74.8	150	5.54	19.0	57.0	114	6.19	*14.8*	*44.5*	*89.0*	6.84	*11.8*	*35.3*	*70.6*
4.90	24.8	74.4	149	5.55	18.9	56.8	114	6.20	*14.7*	*44.3*	*88.7*	6.86	*11.7*	*35.2*	*70.4*
4.91	24.7	74.1	148	5.56	18.9	56.6	113	6.21	*14.7*	*44.2*	*88.3*	6.86	*11.7*	*35.1*	*70.1*
4.92	24.6	73.8	148	5.57	18.8	56.3	113	6.22	*14.7*	*44.0*	*88.0*	6.87	*11.6*	*34.9*	*69.9*
4.93	24.5	73.5	147	5.58	18.7	56.1	112	6.23	*14.6*	*43.8*	*87.7*	6.88	*11.6*	*34.8*	*69.6*
4.94	24.4	73.2	146	5.59	18.6	55.9	112	6.24	*14.6*	*43.7*	*87.4*	6.89	*11.6*	*34.7*	*69.4*
4.95	24.3	72.8	146	5.60	18.6	55.7	111	6.25	*14.5*	*43.5*	*87.1*	6.90	*11.5*	*34.6*	*69.2*
4.96	24.2	72.5	145	5.61	18.5	55.5	111	6.26	*14.5*	*43.4*	*86.7*	6.91	*11.5*	*34.5*	*68.9*
4.97	24.1	72.2	144	5.62	18.4	55.2	110	6.27	*14.4*	*43.2*	*86.4*	6.92	*11.4*	*34.3*	*68.7*
4.98	24.0	71.9	144	5.63	18.3	55.0	110	6.28	*14.4*	*43.1*	*86.1*	6.93	*11.4*	*34.2*	*68.4*
4.99	23.9	71.6	143	5.64	18.3	54.8	110	6.29	*14.3*	*42.9*	*85.8*	6.94	*11.4*	*34.1*	*68.2*
5.00	23.8	71.3	143	5.65	18.2	54.6	109	6.30	*14.2*	*42.7*	*85.5*	6.95	*11.3*	*34.0*	*68.0*
5.01	23.7	71.0	142	5.66	18.1	54.4	109	6.31	*14.2*	*42.6*	*85.2*	6.96	*11.3*	*33.9*	*67.7*
5.02	23.6	70.7	141	5.67	18.1	54.2	108	6.32	*14.1*	*42.4*	*84.9*	6.97	*11.3*	*33.8*	*67.5*
5.03	23.5	70.4	141	5.68	18.0	54.0	108	6.33	*14.1*	*42.3*	*84.6*	6.98	*11.2*	*33.6*	*67.3*
5.04	23.4	70.1	140	5.69	17.9	53.7	107	6.34	*14.0*	*42.1*	*84.3*	6.99	*11.2*	*33.5*	*67.0*

[A] Prepared by the Engineering Mechanics Section, National Bureau of Standards.

It is not mandatory that the Brinell test conform to these hardness ranges, but it should be realized that different Brinell hardness numbers may be obtained for a given material by using different forces on a 10-mm diameter ball. For the purpose of obtaining a continuous scale of values it may be desirable, however, to use a single force to cover the complete

TABLE 3 Test Conditions

Hardness Symbol	Ball Diameter D, mm	0.102 F / D^2	Test Force F Nominal Value	
HBW 10/3000	10	30	29.42	kN − (3000 kgf)
HBW 10/1500	10	15	14.71	kN − (1500 kgf)
HBW 10/1000	10	10	9.807	kN − (1000 kgf)
HBW 10/500	10	5	4.903	kN − (500 kgf)
HBW 10/250	10	2.5	2.452	kN − (250 kgf)
HBW 10/125	10	1.25	1.226	kN − (125 kgf)
HBW 10/100	10	1	980.7	N − (100 kgf)
HBW 5/750	5	30	7.355	kN − (750 kgf)
HBW 5/250	5	10	2.452	kN − (250 kgf)
HBW 5/125	5	5	1.226	kN − (125 kgf)
HBW 5/62.5	5	2.5	612.9	N − (62.5 kgf)
HBW 5/31.25	5	1.25	306.5	N − (31.25 kgf)
HBW 5/25	5	1	245.2	N − (25 kgf)
HBW 2.5/187.5	2.5	30	1.839	kN − (187.5 kgf)
HBW 2.5/62.5	2.5	10	612.9	N − (62.5 kgf)
HBW 2.5/31.25	2.5	5	306.5	N − (31.25 kgf)
HBW 2.5/15.625	2.5	2.5	153.2	N − (15.625 kgf)
HBW 2.5/7.812.5	2.5	1.25	76.61	N − (7.8125 kgf)
HBW 2.5/6.25	2.5	1	61.29	N − (6.25 kgf)
HBW 2/120	2	30	1.177	kN − (120 kgf)
HBW 2/40	2	10	392.3	N − (40 kgf)
HBW 2/20	2	5	196.1	N − (20 kgf)
HBW 2/10	2	2.5	98.07	N − (10 kgf)
HBW 2/5	2	1.25	49.03	N − (5 kgf)
HBW 2/4	2	1	39.23	N − (4 kgf)
HBW 1/30	1	30	294.2	N − (30 kgf)
HBW 1/10	1	10	98.07	N − (10 kgf)
HBW 1/5	1	5	49.03	N − (5 kgf)
HBW 1/2.5	1	2.5	24.52	N − (2.5 kgf)
HBW 1/1.25	1	1.25	12.26	N − (1.25 kgf)
HBW 1/1	1	1	9.807	N − (1 kgf)

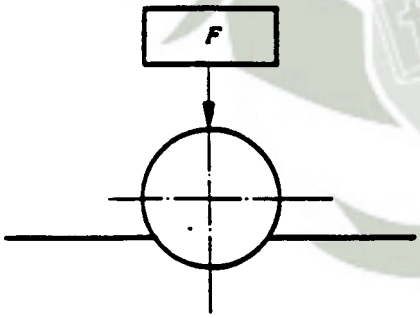


FIG. 1 Principle of Test

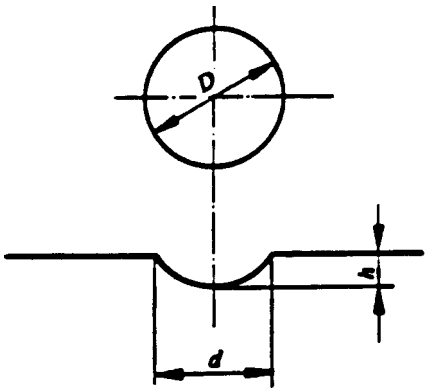


FIG. 2 Principle of Test

TABLE 4 Tolerances for Brinell Hardness Balls

Ball Diameter, mm	Tolerance, mm
10	±0.005
5	±0.004
2.5	±0.003
2	±0.003
1	±0.003

TABLE 5 Minimum Thickness Requirements for Brinell Hardness Tests

Minimum Thickness of Specimen		Minimum Hardness for Which the Brinell Test May Safely Be Made		
in.	mm	3000-kgf Force	1500-kgf Force	500-kgf Force
1/16	1.6	602	301	100
1/8	3.2	301	150	50
3/16	4.8	201	100	33
1/4	6.4	150	75	25
5/16	8.0	120	60	20
3/8	9.6	100	50	17

TABLE 6 Standard Test Forces

Ball Diameter, mm	Force	Recommended Range, HBW
10	29.42 kN (3000 kgf)	96 to 600
10	14.7 kN (1500 kgf)	48 to 300
10	4.90 kN (500 kgf)	16 to 100

range of hardness for a given class of materials. For softer metals, forces of 2.45 kN (250 kgf), 1.23 kN (125 kgf), or 0.981 kN (100 kgf) are sometimes used. The force used shall be specifically stated in the test report (see 11.1.2).

TABLE 7 Hardness Ranges Used By Standard Test Block Method

100 to 200 HBW
300 to 400 HBW
500 to 600 HBW

8.1.1 For testing thin or small specimens, a ball less than 10 mm in diameter is sometimes used. Such tests, which are not to be regarded as standard tests, will approximate the standard tests more closely if the relation between the applied force, *F*, measured in N, and the diameter of the ball, *D*, measured in mm is the same as in the standard tests,

where:

$0.102F/D^2$ = 30 for 29.42 kN (3000 kgf) force and 10-mm ball,

$0.102F/D^2$ = 15 for 14.72 kN (1500 kgf) force and 10-mm ball, and

$0.102F/D^2$ = 5 for 4.90 kN (500 kgf) force and 10-mm ball.

8.1.1.1 *Example*—A 1.23-kN (125-kgf) test force on a 5-mm diameter ball would approximate a standard 4.90-kN (500-kgf) test force on a 10-mm diameter ball.

8.1.2 Tests for soft metals often are made with the following force-diameter ratios:

$$0.102F/D^2 = 2.5 \quad (2)$$

$$0.102F/D^2 = 1.25$$

$$0.102F/D^2 = 1.0$$

8.1.3 When balls smaller than 10 mm in diameter are used, both the test force and ball size shall be specifically stated in the test report (see 3.1.1, 3.1.1.1, and 11.1.2).

8.2 *Radius of Curvature*—When indentations are made on a curved surface, the minimum radius of curvature of the surface shall be not less than 2½ times the diameter of the ball. Indentations made on curved surfaces may be slightly elliptical rather than circular in shape. The measurements of the indentation shall be taken as the mean of the major and minor axes.

8.3 *Spacing of Indentations*—The distance of the center of the indentation from the edge of the specimen or edge of another indentation shall be at least two and one half times the diameter of the indentation.

8.4 *Application of Test Force*—Apply the force to the specimen uniformly taking precautions to prevent a momentary overload of the system. Apply the full test force for 10 to 15 s.

8.4.1 If a duration of test force application other than 10 to 15 s is used, results of the test shall be reported using the nomenclature outlined in 4.2 and 11.1.2.

8.5 *Alignment*—The angle between the indenter force line and the surface of the specimen should be 90 ± 2°. (see 9.1)

9. Measurement of Indentation

9.1 *Diameter*—In the Brinell hardness test, two diameters of the indentation at right angles to each other shall be measured and their mean value used as a basis for calculation of the Brinell hardness number for flat specimens. If the largest and smallest diameters for two readings of the same indentation differ by 0.1 mm or more, refer to the material specifications for further guidance. For routine tests and for tests to determine compliance with a material or product specification, the diameter of the indentation shall be estimated to 0.05 mm (0.0020 in.).

NOTE 4—These measurements are usually made with a low-magnification portable measuring device (approximately 20×) having a fixed scale in the eyepiece. If a more accurate determination is needed, as in referee or standardization tests, a laboratory comparator such as a micrometer measuring device is required.

10. Conversion to Other Hardness Scales or Tensile Strength Values

10.1 There is no general method for accurately converting Brinell hardness numbers to other hardness scales or tensile strength values. Such conversion are, at best, approximations and, therefore, should be avoided except for special cases where a reliable basis for the approximate conversion has been obtained by comparison tests.

NOTE 5—Hardness Conversion Tables E 140 for Metals give approximate hardness conversion values for specific materials such as steel, austenitic stainless steel, nickel and high-nickel alloys, and cartridge brass.

11. Report

11.1 Whenever a Brinell hardness number is used, provide the following information:

11.1.1 The Brinell hardness number, which shall be reported rounded to three significant digits in accordance with rounding method in Practice E 29 (for example, 125 HBW, 99.2 HBW).

11.1.2 The test conditions when the Brinell hardness number is determined from forces other than 29.42 kN (3000 kgf), ball diameters other than 10 mm, and test force applications other than 10 to 15 s (see 3.1.1 and 8.4).

12. Precision and Bias

12.1 *Precision*—An interlaboratory comparison program is now in progress which, when completed, will be the basis of a statement on precision.

12.2 *Bias*—There is no basis for defining the bias for this test method.

TEST METHOD B—VERIFICATION OF BRINELL HARDNESS TESTING MACHINES

13. Scope

13.1 Test Method B covers two procedures for the verification of Brinell hardness testing machines. These are as follows:

13.1.1 *Direct Verification*—Separate verification of force application, indenter, and the measuring device for measuring the diameter of the indentation.

13.1.2 *Indirect Verification*—Verification by the standardized test block method.

13.2 New or rebuilt machines shall be initially checked by the direct verification method (see 13.1.1) before being placed in service.

13.3 Machines used for routine testing may be checked by either verification method.

14. General Requirements

14.1 Before a Brinell hardness testing machine is verified,

the machine shall be examined to ensure that:

14.1.1 The machine is set up properly.

14.1.2 The ball holder, with a new ball whose nominal diameter has been checked (see 15.1.2), is mounted firmly in the plunger.

14.1.3 The force will be applied and removed without shock or vibration.

14.2 If the measuring device is integral with the machine, the machine shall be examined to ensure the following:

14.2.1 The change from test force application to measuring does not influence the readings.

14.2.2 The method of illumination does not affect the readings.

14.2.3 The center of the indentation is in the center of the field of view.

15. Verification

15.1 *Direct Verification*—Separate verification of force application, indenter, and measuring device:

15.1.1 *Force Application*—Brinell hardness testing machines shall be verified at the test force(s) at which it is used. The test forces will be checked periodically with a force measuring device traceable to national standards (in the United States, National Institute of Standards and Technology) in the manner described in Practices E 4. A Brinell hardness testing machine is acceptable for use when the test force error does not exceed ±1 %.

15.1.2 *Indenter*—The indenter to be verified shall be a new ball selected at random from a lot meeting the hardness requirements specified in 5.2. The diameter of each ball shall be verified at not less than three positions and the mean of these readings shall not differ from the nominal diameter by more than the tolerance specified in Table 4.

15.1.3 *Measuring Device*—The measuring device used to determine the diameter of the indentation shall be verified at five intervals over the working range by the use of an accurate scale such as a stage micrometer. The adjustment of the device shall be such that, throughout the range covered, the difference between the scale divisions of the device and of the calibrating scale does not exceed 0.01 mm (0.0004 in.).

15.1.4 The verification is incomplete if a verification report is not issued.

15.2 *Indirect Verification*—Verification by standardized test block method.

15.2.1 A Brinell hardness testing machine also may be checked by making a series of at least five indentations on standardized hardness test blocks (Test Method C).

15.2.2 If the machine is to be used at conditions other than 10/29.42 kN (3000 kgf)/15, the machine also shall be verified at those other conditions.

15.2.3 The testing machine shall be verified for each test force and for each size of ball used. For each test force, standardized blocks within the hardness ranges given in Table 7, shall be used.

NOTE 6—When the hardness test in question makes it impossible to reach the higher hardness range defined in Table 7 (for $0.102/F/D^2 = 5$ or 10), the verification may be carried out with two blocks from the lower hardness range.

15.2.3.1 Verification shall be carried out using a tungsten carbide ball and this verification will be valid for hardnesses ≤ 650 HBW.

15.2.4 *Repeatability*—For each standardized block, let $d_1, d_2, \ldots, d_n$ be the mean values of the measured diameter of the indentations, arranged in increasing order of magnitude. The repeatability of the testing machine under the particular verification conditions is determined by the following quantity:

$$d_n - d_1 \quad (3)$$

The repeatability of the testing machine verified is not considered satisfactory unless it satisfies the conditions given in Table 8.

15.2.5 *Error*—The error of the testing machine under the particular verification conditions is characterized by the following quantity:

$$\bar{H} - H \quad (4)$$

where:

error $= \bar{H} - H$

$$\bar{H} = \frac{H_1 + H_2 \ldots H_n}{n} \quad (5)$$

$H_1, H_2, \ldots, H_n$ = the hardness values corresponding to $d_1, d_2, \ldots, d_n$, and

H = specified hardness of the standardized block.

15.2.6 The Brinell hardness testing machine shall be considered verified if the mean hardness differs by no more than 3 % from the hardness value of the standardized hardness test block.

15.2.7 The verification is incomplete if a verification report is not issued.

15.3 *Verification Report*—The test report shall include the following information:

15.3.1 Reference to this ASTM test method,

15.3.2 Method of verification (direct or indirect),

15.3.3 Identification of the hardness testing machine,

15.3.4 Means of verification (test blocks, elastic proving devices, etc.),

15.3.5 Diameter of indenter ball and test force,

15.3.6 The result obtained,

15.3.7 Date of verification and reference to the calibration institution, and

15.3.8 Identity of person performing the verification.

16. Procedure for Periodic Checks by the User

16.1 Verification by the standardized test block method (15.2) is too lengthy for daily use. Instead, the following is recommended:

TABLE 8 Repeatability of Testing Machine

Hardness of Standardized Block HBW	Repeatability of the Testing Machine, max	HBW	
		H	H_1–H_5, max
<225	0.04 $\bar{d}$	100	9
		200	17
>225	0.02 $\bar{d}$	300	12
		400	17
		500	20
		600	24

16.1.1 Make at least one routine check in accordance with 16.1.2 each day that the testing machine is used.

16.1.2 Consult the machine manufacturer's start-up procedures. Select the force, indenter, and measuring device that will be used for the routine testing. Make at least two indentations on a standardized hardness test block. If the mean of these two values falls within the tolerances required (see 15.2.6), the hardness machine may be regarded as producing satisfactory hardness results. If not, the hardness machine shall be verified as described in 15.2.

TEST METHOD C—CALIBRATION OF STANDARDIZED HARDNESS TEST BLOCKS FOR BRINELL HARDNESS TESTING MACHINES

17. Scope

17.1 This test method covers the calibration of standardized hardness test blocks for the verification of Brinell hardness testing machines as described in Test Method B.

18. Manufacture

18.1 Each metal block to be calibrated shall be not less than 16 mm (⅝ in.) in thickness for 10-mm balls, 12 mm (½ in.) thick for 5-mm balls, and 6 mm (¼in.) thick for smaller balls.

18.1.1 The maximum surface area of the test block shall be 40 cm^2 (6 $in.^2$) for balls less than 5 mm in diameter, and 150 cm^2 (24 $in.^2$) for balls equal to or greater than 5 mm in diameter.

18.2 Each block shall be specially prepared and heat treated to give the necessary homogeneity and stability of structure.

18.3 The maximum error in parallelism shall not exceed 0.0008 mm/mm (in./in.) for blocks when used with balls having a diameter greater than or equal to 5 mm and 0.0002 mm/mm (in./in.) for blocks when used with balls having a diameter less than 5 mm. The maximum deviation in flatness of the block surfaces shall not exceed 0.02 mm (0.0008 in.) and 0.005 mm (0.0002 in.) for balls having diameters equal to or greater than 5 mm and less than 5 mm, respectively.

18.4 The supporting surface of the test block shall have a ground finish and shall have a mean surface roughness height rating that shall not exceed 0.0008-mm (32-µin.) centerline average.

18.5 The test surface shall be free of scratches which would interfere with measurements of the diameters of the indentation.

18.5.1 The mean surface roughness height of the test surface rating shall not exceed 0.0003-mm (12-µin.) center line average for the standard 10-mm ball. For smaller balls a maximum mean test surface roughness height rating of 0.00015 mm (6 µin.) is recommended.

18.6 To permit checking that no material is subsequently removed from the standardized block, its thickness at the time of standardization shall be marked on it to the nearest 0.1 mm (0.004 in.), or an identifying mark shall be made on the test surface. (See Section 24.)

18.7 Each block, if of steel, shall be demagnetized by the manufacturer and maintained demagnetized by the user.

18.8 Each block must be uniquely serialized by the manufacturer for traceability.

19. Standardizing Procedure

19.1 The standardized blocks shall be calibrated on a Brinell hardness testing machine which was verified in accordance with the requirements of 15.1.

19.2 The mechanism that controls the application of the force shall ensure that the speed of approach immediately before the ball touches the specimen and the speed of penetration does not exceed 1 mm/s (0.040 in./s).

19.3 The test force shall be within 0.25 % of the nominal force. Use of a Practice E 74 Class AA device will be required to verify the force.

19.4 The test force shall be applied for 10 to 15 s.

19.5 The standardized blocks shall be calibrated at a temperature of 23 ± 5°C, using the general procedure described in Test Method A.

20. Indenter

20.1 A ball conforming to the requirements of 15.1.2 shall be used for calibrating standardized hardness test blocks.

21. Number of Indentations

21.1 At least five uniformly distributed indentations shall be made on the test surface of the block.

22. Measurement of the Diameters of the Indentation

22.1 The illuminating system of the measuring device shall be adjusted to give uniform intensity over the field of view and maximum contrast between the indentations and the undisturbed surface of the block.

22.2 The measuring device shall be graduated to read 0.002 mm (0.00008 in.) for indentations made with balls of 5-mm diameter or larger and 0.001 mm (0.00004 in.) for indentations made with balls of smaller diameter.

22.3 The measuring device shall be checked by a stage micrometer, or by other suitable means to ensure that the difference between readings corresponding to any two divisions of the instrument is within ±0.001 mm (0.00004 in.) for balls of less than 5-mm diameter and within ±0.002 mm (0.00008 in.) for balls of larger diameter.

23. Uniformity of Hardness

23.1 If d_1, d_2, . . ., d_n are the mean values of the measured diameters as determined by one observer and arranged in increasing order of magnitude, the range of the hardness readings, measured from the last block, is defined as $d_n - d_1$ where n = at least five indentations.

23.2 The range of hardness readings shall be equal to or less than 2 % of the mean diameter for Brinell hardness numbers equal to or less than 225 and 1 % for Brinell hardness number values greater than 225.

24. Marking

24.1 Each standardized block shall be marked with the following:

24.1.1 The arithmetic mean of the hardness values found in the standardizing test and the type of ball used.

24.1.2 The name or mark of the supplier.

24.1.3 The serial number or other unique identification of the block.

24.1.4 Name or mark of the calibrating agency if different from supplier.

24.1.5 The thickness of the block or an official mark on the test surface (see 18.6).

24.1.6 The year of calibration. It is sufficient that the year of calibration be incorporated into the serial number of the block.

24.2 All of the markings except the official mark should be placed outside of the test area or on the side of the block. When the markings are on the side of the block, the markings shall be upright when the test surface is the upper face.

24.3 Each block shall be supplied with a certificate showing the results of the individual standardizing tests and the arithmetic mean of those tests, including the following:

24.3.1 Date of standardization,

24.3.2 Serial number of block, and

24.3.3 Name of manufacturer or mark of supplier.

25. Keywords

25.1 Brinell hardness; metallic

SUMMARY OF CHANGES

Committee E28 has identified the location of selected changes to this standard since the last issue E 10-00a that may impact the use of this standard. The numbering system used in this Summary reflects current numbering of this edition of E 10.

NOTE 7—Most of the changes listed below resulted from the new requirement for using only tungsten-carbide indenter balls and disallowing the use of steel indenter balls (see 5.2.2.2

(1) 2.1 –E 74 title revised.
(2) 3 –definitions alphabetized and new numbering structure used.
(3) 3.1 –new title added.
(4) 3.1.1 (formerly 3.2) - revised
(5) Equation 1– editorial correction
(6) 3.1.1.1 (formerly Note 2) - revised
(7) 3.1.1.2 (formerly Note 3) - revised
(8) 3.1.1.3 (formerly part of Note 3)
(9) 3.1.1.4 (formerly part of Note 3)
(10) 3.1.2 (formerly 3.2) - revised
(11) 3.1.2.1 (formerly Discussion 1) - revised
(12) Former Discussion 2–deleted)
(13) Former Discussion 3 – deleted
(14) Table 1–revised and editorially corrected
(15) 3.1.3 (formerly 3.4)
(16) 3.1.4 (formerly 3.3)
(17) 5.2.2–replaced
(18) Former Note 5–deleted
(19) 5.2.2.2–added
(20) 5.2.3–revised
(21) Table 2–revised
(22) Table 3–revised
(23) Table 5–revised
(24) Table 6 (formerly Table 7) - revised
(25) Table 7 (formerly Table 6) - revised
(26) Former Table 8 - deleted
(27) 8.5-revised
(28) 11.1.1–revised
(29) 15.2.3–revised
(30) 15.2.3.1–revised
(31) 15.3.5- revised
(32) Table 9–renumbered as Table 8 and revised
(33) Summary of Changes added.

Designation: E 8M – 00b
METRIC

An American National Standard

Standard Test Methods for Tension Testing of Metallic Materials [Metric][1]

This standard is issued under the fixed designation E 8M; 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 (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope *

1.1 These test methods cover the tension testing of metallic materials in any form at room temperature, specifically, the methods of determination of yield strength, yield point elongation, tensile strength, elongation, and reduction of area.

NOTE 1—These test methods are the metric companion of Test Methods E 8. Committee E-28 was granted an exception in 1997 by the Committee on Standards to maintain E8 and E8M as separate companion standards rather than combining standards as recommended by the Form and Style manual.

NOTE 2—These metric test methods are essentially the same as those in Test Methods E 8, and are compatible in technical content except that gage lengths are required to be 5D for most round specimens rather than 4D as specified in Test Methods E 8. Test specimens made from powder metallurgy (P/M) materials are exempt from this requirement by industry-wide agreement to keep the pressing of the material to a specific projected area and density.

NOTE 3—Exceptions to the provisions of these test methods may need to be made in individual specifications or test methods for a particular material. For examples, see Test Methods and Definitions A 370 and Test Methods B 557M.

NOTE 4—Room temperature shall be considered to be 10 to 38°C unless otherwise specified.

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:*

A 356/A356M Specification for Steel Castings, Carbon, Low Alloy, and Stainless Steel, Heavy-Walled for Steam Turbines[2]

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[3]

B 557M Test Methods of Tension Testing Wrought and Cast Aluminum- and Magnesium-Alloy Products [Metric][4]

E 4 Practices for Force Verification of Testing Machines[5]

E 6 Terminology Relating to Methods of Mechanical Testing[5]

E 8 Test Methods for Tension Testing of Metallic Materials[5]

E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications[6]

E 83 Practice for Verification and Classification of Extensometers[5]

E 345 Test Methods of Tension Testing of Metallic Foil[5]

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method[6]

E 1012 Practice for Verification of Specimen Alignment Under Tensile Loading[5]

3. Terminology

3.1 *Definitions*—The definitions of terms relating to tension testing appearing in Terminology E 6 shall be considered as applying to the terms used in these test methods of tension testing. Additional terms being defined are as follows:

3.1.1 *discontinuous yielding*—a hesitation or fluctuation of force observed at the onset of plastic deformation, due to localized yielding. (The stress-strain curve need not appear to be discontinuous.)

3.1.2 *lower yield strength, LYS [FL^{-2}]*—the minimum stress recorded during discontinuous yielding, ignoring transient effects.

3.1.3 *upper yield strength, UYS [FL^{-2}]*—the first stress maximum (stress at first zero slope) associated with discontinuous yielding.

3.1.4 *yield point elongation, YPE*—the strain (expressed in percent) separating the stress-strain curve's first point of zero slope from the point of transition from discontinuous yielding to uniform strain hardening. If the transition occurs over a range of strain, the YPE end point is the intersection between (*a*) a horizontal line drawn tangent to the curve at the last zero slope and (*b*) a line drawn tangent to the strain hardening portion of the stress-strain curve at the point of inflection. If there is no point at or near the onset of yielding at which the

[1] These test methods are under the jurisdiction of ASTM Committee E28 on Mechanical Testing and are the direct responsibility of Subcommittee E28.04 on Uniaxial Testing.

Current edition approved Dec. 10, 2000. Published February 2001. Originally published as E 8M – 84. Last previous edition E 8M – 00a.

[2] *Annual Book of ASTM Standards*, Vol 01.02.

[3] *Annual Book of ASTM Standards*, Vol 01.03.

[4] *Annual Book of ASTM Standards*, Vol 02.02.

[5] *Annual Book of ASTM Standards*, Vol 03.01.

[6] *Annual Book of ASTM Standards*, Vol 14.02.

***A Summary of Changes section appears at the end of this standard.**

slope reaches zero, the material has 0 % YPE.

4. Significance and Use

4.1 Tension tests provide information on the strength and ductility of materials under uniaxial tensile stresses. This information may be useful in comparisons of materials, alloy development, quality control, and design under certain circumstances.

4.2 The results of tension tests of specimens machined to standardized dimensions from selected portions of a part or material may not totally represent the strength and ductility properties of the entire end product or its in-service behavior in different environments.

4.3 These test methods are considered satisfactory for acceptance testing of commercial shipments. The test methods have been used extensively in the trade for this purpose.

5. Apparatus

5.1 *Testing Machines*—Machines used for tension testing shall conform to the requirements of Practices E 4. The forces used in determining tensile strength and yield strength shall be within the verified force application range of the testing machine as defined in Practices E 4.

5.2 *Gripping Devices*:

5.2.1 *General*—Various types of gripping devices may be used to transmit the measured force applied by the testing machine to the test specimens. To ensure axial tensile stress within the gage length, the axis of the test specimen should coincide with the center line of the heads of the testing machine. Any departure from this requirement may introduce bending stresses that are not included in the usual stress computation (force divided by cross-sectional area).

NOTE 5—The effect of this eccentric force application may be illustrated by calculating the bending moment and stress thus added. For a standard 12.5-mm diameter specimen, the stress increase is 1.5 % for each 0.025 mm of eccentricity. This error increases to about 2.5 %/0.025 mm for a 9-mm diameter specimen and to about 3.2 %/0.025 mm for a 6-mm diameter specimen.

NOTE 6—Alignment methods are given in Practice E 1012.

5.2.2 *Wedge Grips*—Testing machines usually are equipped with wedge grips. These wedge grips generally furnish a satisfactory means of gripping long specimens of ductile metal and flat plate test specimens such as those shown in Fig. 1. If, however, for any reason, one grip of a pair advances farther than the other as the grips tighten, an undesirable bending stress may be introduced. When liners are used behind the wedges, they must be of the same thickness and their faces must be flat and parallel. For best results, the wedges should be supported over their entire lengths by the heads of the testing machine. This requires that liners of several thicknesses be available to cover the range of specimen thickness. For proper gripping, it is desirable that the entire length of the serrated face of each wedge be in contact with the specimen. Proper alignment of wedge grips and liners is illustrated in Fig. 2. For short specimens and for specimens of many materials, it is generally necessary to use machined test specimens and to use a special means of gripping to ensure that the specimens, when under load, shall be as nearly as possible in uniformly distributed pure axial tension (see 5.2.3, 5.2.4, and 5.2.5).

5.2.3 *Grips for Threaded and Shouldered Specimens and Brittle Materials*—A schematic diagram of a gripping device for threaded-end specimens is shown in Fig. 3, while Fig. 4 shows a device for gripping specimens with shouldered ends. Both of these gripping devices should be attached to the heads of the testing machine through properly lubricated spherical-seated bearings. The distance between spherical bearings should be as great as feasible.

5.2.4 *Grips for Sheet Materials*—The self-adjusting grips shown in Fig. 5 have proved satisfactory for testing sheet materials that cannot be tested satisfactorily in the usual type of wedge grips.

5.2.5 *Grips for Wire*—Grips of either the wedge or snubbing types as shown in Fig. 5 and Fig. 6 or flat wedge grips may be used.

5.3 *Dimension-Measuring Devices*—Micrometers and other devices used for measuring linear dimensions shall be accurate and precise to at least one half the smallest unit to which the individual dimension is required to be measured.

5.4 *Extensometers*—Extensometers used in tension testing shall conform to the requirements of Practice E 83 for the classifications specified by the procedure section of this test method. Extensometers shall be used and verified to include strains corresponding to the yield strength and elongation at fracture (if determined).

5.4.1 Extensometers with gage lengths equal to or shorter than the nominal gage length of the specimen (dimensions shown as “G-Gage Length” in the accompanying figures) may be used to determine the yield behavior. For specimens without a reduced section (for example, full cross sectional area specimens of wire, rod, or bar), the extensometer gage length for the determination of yield behavior shall not exceed 80 % of the distance between grips. For measuring elongation at fracture with an appropriate extensometer the gage length of the extensometer shall be equal to the nominal gage length required for the specimen being tested.

6. Test Specimens

6.1 *General*:

6.1.1 *Specimen Size*—Test specimens shall be either substantially full size or machined, as prescribed in the product specifications for the material being tested.

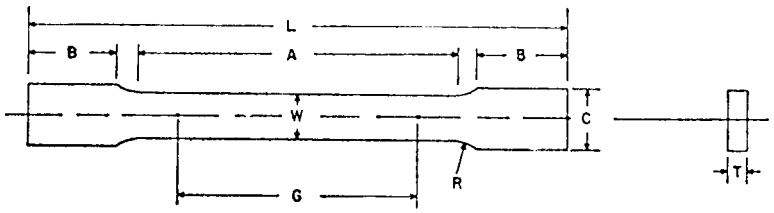
6.1.2 *Location*—Unless otherwise specified, the axis of the test specimen shall be located within the parent material as follows:

6.1.2.1 At the center for products 40 mm or less in thickness, diameter, or distance between flats.

6.1.2.2 Midway from the center to the surface for products over 40 mm in thickness, diameter, or distance between flats.

6.1.3 *Specimen Machining*—Improperly prepared test specimens often are the reason for unsatisfactory and incorrect test results. It is important, therefore, that care be exercised in the preparation of specimens, particularly in the machining, to maximize precision and minimize bias in test results.

6.1.3.1 The reduced sections of prepared specimens should be free of cold work, notches, chatter marks, grooves, gouges, burrs, rough surfaces or edges, overheating, or any other condition which may deleteriously affect the properties to be measured.



Dimensions, mm			
Nominal Width	Standard Specimens		Subsize Specimen
	Plate-Type 40 mm	Sheet-Type 12.5 mm	6 mm
G— Gage length (Note 1 and Note 2)	200.0 ± 0.2	50.0 ± 0.1	25.0 ± 0.1
W— Width (Note 3 and Note 4)	40.0 ± 2.0	12.5 ± 0.2	6.0 ± 0.1
T— Thickness (Note 5)		thickness of material	
R— Radius of fillet, min (Note 6)	25	12.5	6
L— Overall length, (Note 2, Note 7 and Note 8)	450	200	100
A— Length of reduced section, min	225	57	32
B— Length of grip section, (Note 8)	75	50	30
C— Width of grip section, approximate (Note 4 and Note 9)	50	20	10

NOTE 1—For the 40-mm wide specimen, 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. Either a set of nine or more punch marks 25 mm apart, or one or more pairs of punch marks 200 mm apart, may be used.

NOTE 2—When elongation measurements of 40-mm wide specimens are not required, a minimum length of reduced section (*A*) of 75 mm may be used with all other dimensions similar to the plate-type specimen.

NOTE 3—For the three sizes of specimens, the ends of the reduced section shall not differ in width by more than 0.10, 0.05 or 0.02 mm, respectively. Also, there may be a gradual decrease in width from the ends to the center, but the width at each end shall not be more than 1 % larger than the width at the center.

NOTE 4—For each of the three 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.

NOTE 5—The dimension *T* is the thickness of the test specimen as provided for in the applicable material specifications. Minimum thickness of 40-mm wide specimens shall be 5 mm. Maximum thickness of 12.5-mm and 6-mm wide specimens shall be 19 mm and 6 mm, respectively.

NOTE 6—For the 40-mm wide specimen, a 13-mm minimum radius at the ends of the reduced section is permitted for steel specimens under 690 MPa in tensile strength when a profile cutter is used to machine the reduced section.

NOTE 7—The dimension shown is suggested as a minimum. In determining the minimum length, the grips must not extend in to the transition section between Dimensions A and B, see Note 9.

NOTE 8—To aid in obtaining axial force application during testing of 6-mm wide specimens, the overall length should be as large as the material will permit, up to 200 mm.

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 12.5-mm wide specimens is over 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 the three sizes of specimens, the ends of the specimen shall be symmetrical in width with the center line of the reduced section within 2.5, 0.25, and 0.13 mm, respectively. However, for referee testing and when required by product specifications, the ends of the 12.5-mm wide specimen shall be symmetrical within 0.2 mm.

NOTE 11—For each specimen type, the radii of all fillets shall be equal to each other within a tolerance of 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 2.5 mm.

NOTE 12—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 2*W* from the edge of the gripping device, the tensile properties determined may not be representative of the material. In acceptance testing, 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.

FIG. 1 Rectangular Tension Test Specimens

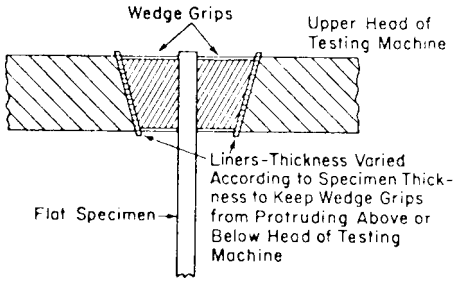


FIG. 2 Wedge Grips with Liners for Flat Specimens

NOTE 7—Punching or blanking of reduced section may produce significant cold work or shear burrs, or both, along the edges which should be removed by machining.

6.1.3.2 Within the reduced section of rectangular specimens, edges or corners should not be ground or abraded in a manner which could cause the actual cross-sectional area of the specimen to be significantly different from the calculated area.

6.1.3.3 For brittle materials, large radius fillets at the ends of the gage length should be used.

6.1.3.4 The cross-sectional area of the specimen should be smallest at the center of the reduced section to ensure fracture

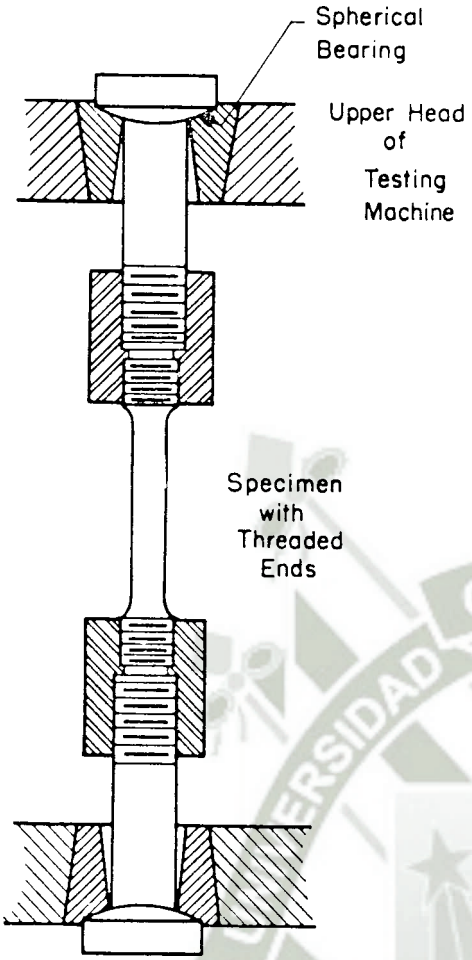


FIG. 3 Gripping Device for Threaded-End Specimens

within the gage length. For this reason, a small taper is permitted in the reduced section of each of the specimens described in the following sections.

6.1.4 *Specimen Surface Finish*—When materials are tested with surface conditions other than as manufactured, the surface finish of the test specimens shall be as provided in the applicable product specifications.

NOTE 8—Particular attention should be given to the uniformity and quality of surface finish of specimens for high strength and very low ductility materials, since this has been shown to be a factor in the variability of test results.

6.2 *Plate-Type Specimens*—The standard plate-type specimen is shown in Fig. 1. This specimen is used for testing metallic materials in the form of plate, shapes, and flat material having a nominal thickness of 5 mm or over. When product specifications so permit, other types of specimens may be used, as provided in 6.3, 6.4, and 6.5.

6.3 *Sheet-Type Specimens*:

6.3.1 The standard sheet-type test specimen is shown in Fig. 1. This specimen is used for testing metallic materials in the form of sheet, plate, flat wire, strip, band, hoop, rectangles, and shapes ranging in nominal thickness from 0.13 to 19 mm. When product specifications so permit, other types of specimens may be used as provided in 6.2, 6.4, and 6.5.

NOTE 9—Test Methods E 345 may be used for tension testing of

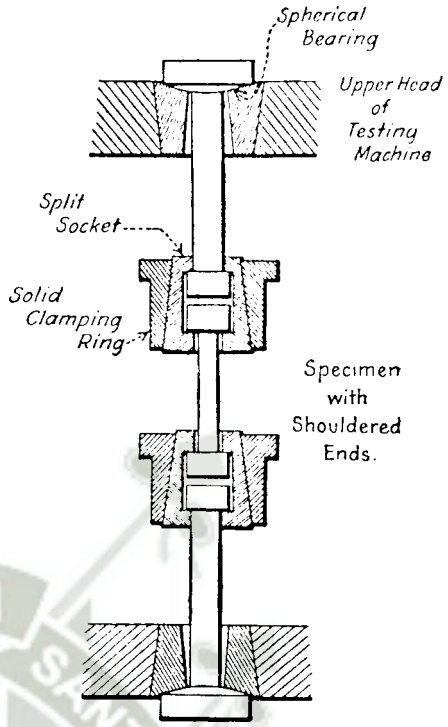


FIG. 4 Gripping Device for Shouldered-End Specimens

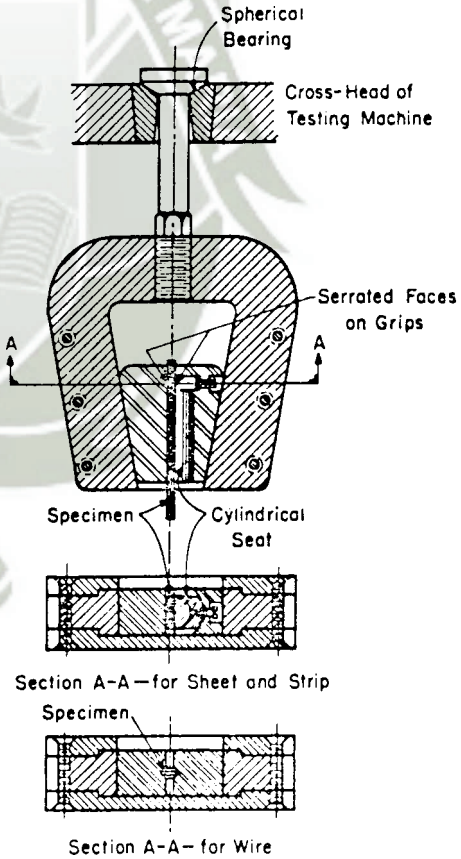


FIG. 5 Gripping Devices for Sheet and Wire Specimens

materials in thicknesses up to 0.150 mm.

6.3.2 Pin ends as shown in Fig. 7 may be used. In order to avoid buckling in tests of thin- and high-strength materials, it

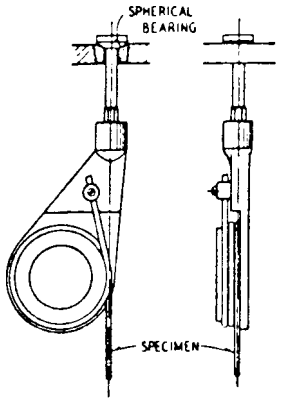


FIG. 6 Snubbing Device for Testing Wire

may be necessary to use stiffening plates at the grip ends.

6.4 *Round Specimens*:

6.4.1 The standard 12.5-mm diameter round test specimen shown in Fig. 8 is used quite generally for testing metallic materials, both cast and wrought.

6.4.2 Fig. 8 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. 1 cannot be prepared. Other sizes of small, round specimens may be used. In any such small-size specimen, it is important that the gage length for measurement of elongation be five times the diameter of the specimen.

6.4.3 The shape of the ends of the specimen outside of the gage length shall be suitable to the material and of a shape to fit the holders or grips of the testing machine so that the forces may be applied axially. Fig. 9 shows specimens with various types of ends that have given satisfactory results.

6.5 *Specimens for Sheet, Plate, Flat Wire, and Strip*—In testing sheet, plate, flat wire, and strip one of the following types of specimens shall be used:

6.5.1 For material ranging in nominal thickness from 0.13 to 19 mm, use the sheet-type specimen described in 6.3.

NOTE 10—Attention is called to the fact that either of the flat specimens described in 6.2 and 6.3 may be used for material from 5 to 19 mm in thickness, and one of the round specimens described in 6.4 may also be used for material 12.5 mm or more in thickness.

6.5.2 For material having a nominal thickness of 5 mm or over (Note 10), use the plate-type specimen described in 6.2.

6.5.3 For material having a nominal thickness of ½ in. or over (Note 10), use the largest practical size of specimen described in 6.4. When product specifications so permit, a sheet-type ½ in. wide specimen conforming to the geometry of Fig. 1 is appropriate, provide the T-Thickness dimension is machined to .400 in., ± .020 in. and this machined thickness is uniform within .004 in. throughout the reduced section. In the event of disagreement, referee specimens shall be the round specimen.

6.6 *Specimens for Wire, Rod, and Bar*:

6.6.1 For round wire, rod, and bar, test specimens having the full cross-sectional area of the wire, rod, or bar shall be used wherever practicable. The gage length for the measurement of elongation of wire less than 4 mm in diameter shall be as prescribed in product specifications. In testing wire, rod, or bar that has a 4 mm or larger diameter, unless otherwise specified, a gage length equal to five times the diameter shall be used. The total length of the specimens shall be at least equal to the gage length plus the length of material required for the full use of the grips employed.

6.6.2 For wire of octagonal, hexagonal, or square cross section, for rod or bar of round cross section where the specimen required in 6.6.1 is not practicable, and for rod or bar of octagonal, hexagonal, or square cross section, one of the following types of specimens shall be used:

6.6.2.1 *Full Cross Section* (Note 11)—It is permissible to reduce the test section slightly with abrasive cloth or paper, or machine it sufficiently to ensure fracture within the gage marks. For material not exceeding 5 mm in diameter or distance between flats, the cross-sectional area may be reduced to not less than 90 % of the original area without changing the shape of the cross section. For material over 5 mm in diameter or distance between flats, the diameter or distance between flats may be reduced by not more than 0.25 mm without changing the shape of the cross section. Square, hexagonal, or octagonal wire or rod not exceeding 5 mm between flats may be turned to a round having a cross-sectional area not smaller than 90 % of the area of the maximum inscribed circle. Fillets, preferably with a radius of 10 mm, but not less than 3 mm, shall be used at the ends of the reduced sections. Square, hexagonal, or octagonal rod over 5 mm between flats may be turned to a round having a diameter no smaller than 0.25 mm less than the original distance between flats.

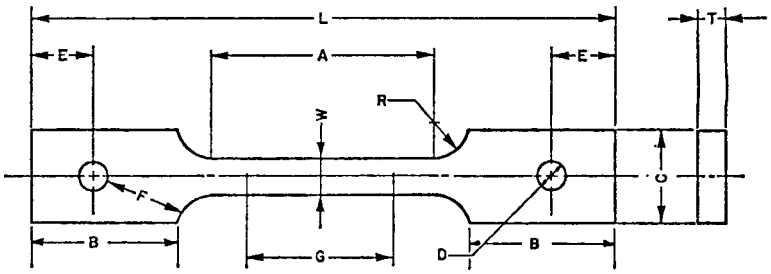
NOTE 11—The ends of copper or copper alloy specimens may be flattened 10 to 50 % from the original dimension in a jig similar to that shown in Fig. 10, to facilitate fracture within the gage marks. In flattening the opposite ends of the test specimen, care shall be taken to ensure that the four flattened surfaces are parallel and that the two parallel surfaces on the same side of the axis of the test specimen lie in the same plane.

6.6.2.2 For rod and bar, the largest practical size of round specimen as described in 6.4 may be used in place of a test specimen of full cross section. Unless otherwise specified in the product specification, specimens shall be parallel to the direction of rolling or extrusion.

6.7 *Specimens for Rectangular Bar*— In testing rectangular bar one of the following types of specimens shall be used:

6.7.1 *Full Cross Section*—It is permissible to reduce the width of the specimen throughout the test section with abrasive cloth or paper, or by machining sufficiently to facilitate fracture within the gage marks, but in no case shall the reduced width be less than 90 % of the original. The edges of the midlength of the reduced section not less than 20 mm in length shall be parallel to each other and to the longitudinal axis of the specimen within 0.05 mm. Fillets, preferably with a radius of 10 mm but not less than 3 mm, shall be used at the ends of the reduced sections.

6.7.2 Rectangular bars of thickness small enough to fit the grips of the testing machine but of too great width may be reduced in width by cutting to fit the grips, after which the cut surfaces shall be machined or cut and smoothed to ensure failure within the desired section. The reduced width shall be not less than the original bar thickness. Also, one of the types of specimens described in 6.2, 6.3, and 6.4 may be used.



Dimensions, mm	
G— Gage length	50.0 ± 0.1
W— Width (Note 1)	12.5 ± 0.2
T— Thickness, max (Note 2)	12.5
R— Radius of fillet, min (Note 3)	13
L— Overall length, min	200
A— Length of reduced section, min	57
B— Length of grip section, min	50
C— Width of grip section, approximate	50
D— Diameter of hole for pin, min (Note 4)	13
E— Edge distance from pin, approximate	40
F— Distance from hole to fillet, min	15

NOTE 1—The ends of the reduced section shall differ in width by not more than 0.1 mm. There may be a gradual taper in width from the ends to the center, but the width at each end shall be not more than 1 % greater than the width at the center.

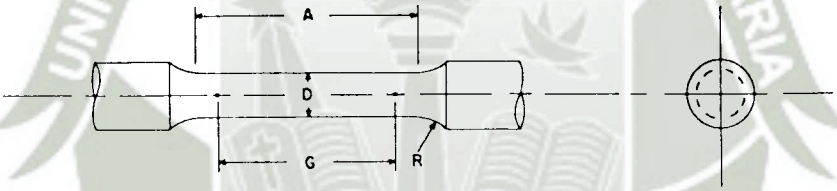
NOTE 2—The dimension *T* is the thickness of the test specimen as stated in the applicable product specifications.

NOTE 3—For some materials, a fillet radius *R* larger than 13 mm may be needed.

NOTE 4—Holes must be on center line of reduced section, within ± 0.1 mm.

NOTE 5—Variations of dimensions *C*, *D*, *E*, *F*, and *L* may be used that will permit failure within the gage length.

FIG. 7 Pin-Loaded Tension Test Specimen with 50-mm Gage Length



	Dimensions, mm				
	Standard Specimen	Small-Size Specimens Proportional To Standard			
	12.5	9	6	4	2.5
G—Gage length	62.5 ± 0.1	45.0± 0.1	30.0 ± 0.1	20.0± 0.1	12.5 ± 0.1
D—Diameter (Note 1)	12.5 ± 0.2	9.0 ± 0.1	6.0 ± 0.1	4.0 ± 0.1	2.5 ± 0.1
R—Radius of fillet, min	10	8	6	4	2
A—Length of reduced section, min (Note 2)	75	54	36	24	20

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 gage length. Reference marks for the measurement of elongation should, nevertheless, be spaced at the indicated gage length.

NOTE 3—The gage length and fillets shall 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 may 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 Figs. 8 and 9, the gage lengths are equal to five times the nominal diameter. In some product specifications other specimens may be provided for, but the 5-to-1 ratio is maintained within dimensional tolerances, the elongation values may not be comparable with those obtained from the standard test specimen.

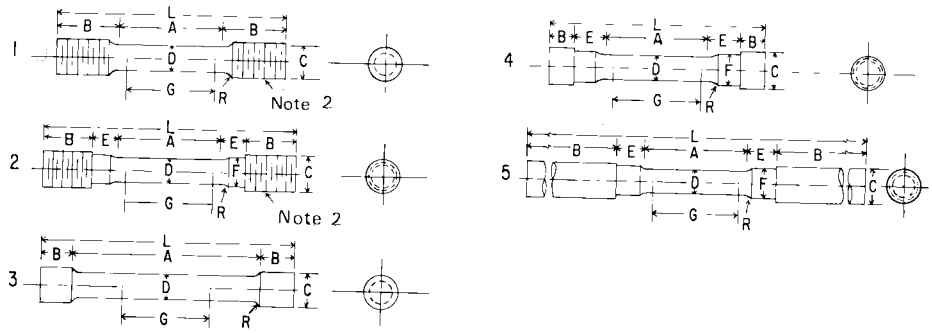
NOTE 5—The use of specimens smaller than 6 mm in diameter shall be restricted to cases when the material to be tested is of insufficient size to obtain larger specimens or when all parties agree to their use for acceptance testing. Smaller specimens require suitable equipment and greater skill in both machining and testing.

FIG. 8 Standard 12.5-mm Round Tension Test Specimen with Gage Lengths Five Times the Diameters (5D), and Examples of Small-Size Specimens Proportional to the Standard Specimen

6.8 *Shapes, Structural and Other*—In testing shapes other than those covered by the preceding sections, one of the types of specimens described in 6.2, 6.3, and 6.4 shall be used.

6.9 *Specimens for Pipe and Tube* (Note 12):

6.9.1 For all small tube (Note 12), particularly sizes 25 mm and under in nominal outside diameter, and frequently for



	Dimensions, mm				
	Specimen 1	Specimen 2	Specimen 3	Specimen 4	Specimen 5
G—Gage length	62.5 ± 0.1	62.5± 0.1	62.5 ± 0.1	62.5 ± 0.1	62.5 ± 0.1
D—Diameter (Note 1)	12.5 ± 0.2	12.5 ± 0.2	12.5 ± 0.2	12.5± 0.2	12.5 ± 0.2
R—Radius of fillet, min	10	10	2	10	10
A—Length of reduced section	75, min	75, min	100, approximately	75, min	75, min
L—Overall length, approximate	145	155	140	140	255
B—Length of end section (Note 3)	35, approximately	25, approximately	20, approximately	15, approximately	75, min
C—Diameter of end section	20	20	20	22	20
E—Length of shoulder and fillet section, approximate	... .	15	... .	20	15
F—Diameter of shoulder	... .	15	... .	15	15

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.

NOTE 2—On Specimens 1 and 2, any standard thread is permissible that provides for proper alignment and aids in assuring that the specimen will break within the reduced section.

NOTE 3—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.

FIG. 9 Various Types of Ends for Standard Round Tension Test Specimens

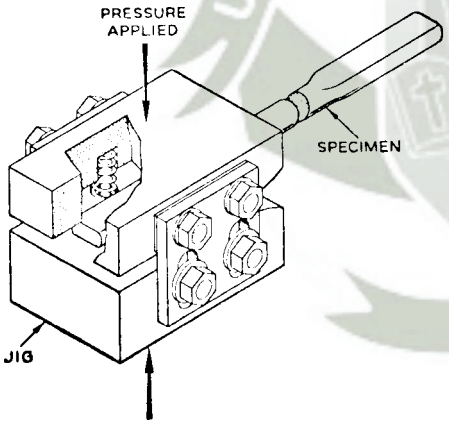
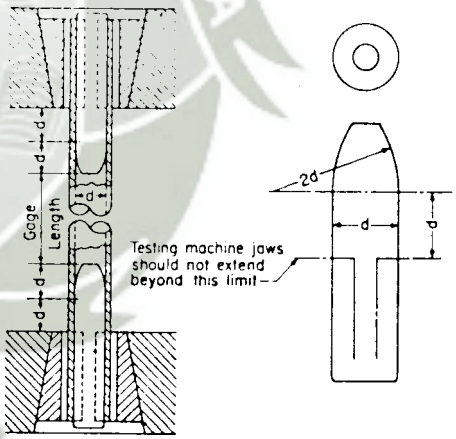


FIG. 10 Squeezing Jig for Flattening Ends of Full-Size Tension Test Specimens



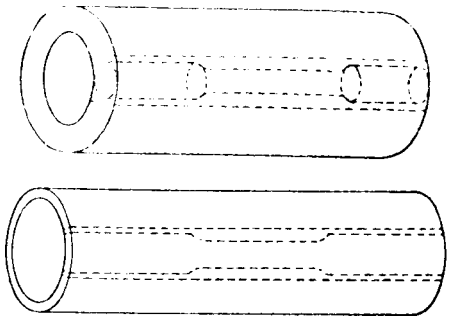
NOTE 1—The diameter of the plug shall have a slight taper from the line limiting the testing machine jaws to the curved section.

FIG. 11 Metal Plugs for Testing Tubular Specimens, Proper Location of Plugs in Specimen and of Specimen in Heads of Testing Machine

larger sizes, except as limited by the testing equipment, it is standard practice to use tension test specimens of full-size tubular sections. Snug-fitting metal plugs shall be inserted far enough into the ends of such tubular specimens to permit the testing machine jaws to grip the specimens properly. The plugs shall not extend into that part of the specimen on which the elongation is measured. Elongation is measured over a length of 5D unless otherwise stated in the product specification. Fig. 11 shows a suitable form of plug, the location of the plugs in the specimen, and the location of the specimen in the grips of the testing machine.

NOTE 12—The term "tube" is used to indicate tubular products in general, and includes pipe, tube, and tubing.

6.9.2 For large-diameter tube that cannot be tested in full section, longitudinal tension test specimens shall be cut as indicated in Fig. 12. Specimens from welded tube shall be located approximately 90° from the weld. If the tube-wall thickness is under 20 mm, either a specimen of the form and dimensions shown in Fig. 13 or one of the small-size specimens proportional to the standard 12.5-mm specimen, as



NOTE 1—The edges of the blank for the specimen shall be cut parallel to each other.

FIG. 12 Location from Which Longitudinal Tension Test Specimens Are to Be Cut from Large-Diameter Tube

mentioned in 6.4.2 and shown in Fig. 8, shall be used. Specimens of the type shown in Fig. 13 may be tested with grips having a surface contour corresponding to the curvature of the tube. When grips with curved faces are not available, the ends of the specimens may be flattened without heating. If the tube-wall thickness is 20 mm or over, the standard specimen shown in Fig. 8 shall be used.

NOTE 13—In clamping of specimens from pipe and tube (as may be done during machining) or in flattening specimen ends (for gripping), care must be taken so as not to subject the reduced section to any deformation or cold work, as this would alter the mechanical properties.

6.9.3 Transverse tension test specimens for tube may be taken from rings cut from the ends of the tube as shown in Fig. 14. Flattening of the specimen may be either after separating as in *A*, or before separating as in *B*. Transverse tension test specimens for large tube under 20 mm in wall thickness shall be either of the small-size specimens shown in Fig. 8 or of the form and dimensions shown for Specimen 2 in Fig. 13. When using the latter specimen, either or both surfaces of the specimen may be machined to secure a uniform thickness, provided not more than 15 % of the normal wall thickness is removed from each surface. For large tube 20 mm and over in wall thickness, the standard specimen shown in Fig. 8 shall be used for transverse tension tests. Specimens for transverse tension tests on large welded tube to determine the strength of welds shall be located perpendicular to the welded seams, with the welds at about the middle of their lengths.

6.10 *Specimens for Forgings*—For testing forgings, the largest round specimen described in 6.4 shall be used. If round specimens are not feasible, then the largest specimen described in 6.5 shall be used.

6.10.1 For forgings, specimens shall be taken as provided in the applicable product specifications, either from the predominant or thickest part of the forging from which a coupon can be obtained, or from a prolongation of the forging, or from separately forged coupons representative of the forging. When not otherwise specified, the axis of the specimen shall be parallel to the direction of grain flow.

6.11 *Specimens for Castings*—In testing castings either the standard specimen shown in Fig. 8 or the specimen shown in Fig. 15 shall be used unless otherwise provided in the product specifications.

6.11.1 Test coupons for castings shall be made as shown in Fig. 16 and Table 1.

6.12 *Specimen for Malleable Iron*—For testing malleable iron the test specimen shown in Fig. 17 shall be used, unless otherwise provided in the product specifications.

6.13 *Specimen for Die Castings*—For testing die castings the test specimen shown in Fig. 18 shall be used unless otherwise provided in the product specifications.

6.14 *Specimens for Powder Metallurgy (P/M) Materials*—For testing powder metallurgy (P/M) materials the test specimens shown in Fig. 19 and Fig. 20 shall be used, unless otherwise provided in the product specifications. When making test specimens in accordance with Fig. 19, shallow transverse grooves, or ridges, may be pressed in the ends to allow gripping by jaws machined to fit the grooves or ridges. Because of shape and other factors, the flat unmachined tensile test specimen (Fig. 19) in the heat-treated condition will have an ultimate tensile strength of 50 % to 85 % of that determined in a machined round tensile test specimen (Fig. 20) of like composition and processing.

7. Procedures

7.1 *Preparation of the Test Machine*— Upon startup or following a prolonged period of machine inactivity, the test machine should be exercised or warmed up to normal operating temperatures to minimize errors that may result from transient conditions.

7.2 *Measurement of Dimensions of Test Specimens*:

7.2.1 To determine the cross-sectional area of a test specimen, measure the dimensions of the cross section at the center of the reduced section. For referee testing of specimens under 5 mm in their least dimension, measure the dimensions where the least cross-sectional area is found. Measure and record the cross-sectional dimensions of tension test specimens 5 mm and over to the nearest 0.02 mm; the cross-sectional dimensions less than 5 mm and not less than 2.5 mm to the nearest 0.01 mm; the cross-sectional dimensions less than 2.5 mm and not less than 0.50 mm to the nearest 0.002 mm; and when practical, the cross-sectional dimensions less than 0.50 mm to at least the nearest 1 % but in all cases to at least the nearest 0.002 mm.

NOTE 14—Accurate and precise measurement of specimen dimensions can be one of the most critical aspects of tension testing, depending on specimen geometry. See Appendix X2 for additional information.

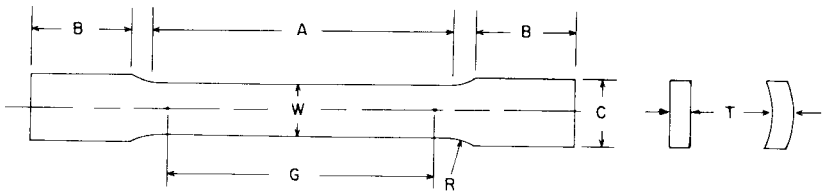
NOTE 15—Rough surfaces due to the manufacturing process such as hot rolling, metallic coating, etc., may lead to inaccuracy of the computed areas greater than the measured dimensions would indicate. Therefore, cross-sectional dimensions of tension test specimens with rough surfaces due to processing may be measured and recorded to the nearest 0.02 mm.

NOTE 16—See X2.9 for cautionary information on measurements taken from coated metal products.

7.2.2 Determine cross-sectional areas of full-size test specimens of nonsymmetrical cross sections by weighing a length not less than 20 times the largest cross-sectional dimension and using the value of density of the material. Determine the weight to the nearest 0.5 % or less.

7.2.3 For materials where the specified elongation is 3 % or less, measure the original gage length to the nearest 0.05 mm prior to testing.

7.2.4 When using specimens of the type shown in Fig. 13



Dimensions, mm							
Nominal Width	Specimen 1	Specimen 2	Specimen 3	Specimen 4	Specimen 5	Specimen 6	Specimen 7
	12.5	40	40	20	20	25	25
G—Gage length	50.0 ± 0.1	50.0 ± 0.1	200.0 ± 0.2	50.0 ± 0.1	100.0 ± 0.1	50.0 ± 0.1	100.0 ± 0.1
W—Width (Note 1)	12.5 ± 0.2	40.0± 2.0	40.0 ± 2.0	20.0 ± 0.7	20.0 ± 0.7	25.0 ± 1.5	25.0 ± 1.5
T—Thickness	measured thickness of specimen						
R—Radius of fillet, min	12.5	25	25	25	25	25	25
A—Length of reduced section, min	60	60	230	60	120	60	120
B—Length of grip section, min (Note 2)	75	75	75	75	75	75	75
C—Width of grip section, approximate (Note 3)	20	50	50	25	25	40	40

NOTE 1—The ends of the reduced section shall not differ in width by more than 0.1 mm for specimens 1–7. There may be a gradual taper in width from the ends to the center, but the width at each end shall be not more than 1 % greater than the width at the center.

NOTE 2—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 ends of the specimen shall be symmetrical with the center line of the reduced section within 1.0 mm for specimens 1, 4, and 5 and 2.5 mm for specimens 2, 3, 6, and 7.

NOTE 4—For circular segments, the cross-sectional area may be calculated by multiplying W and *T*. If the ratio of the dimension *W* to the diameter of the tubular section is larger than about ⅙, the error in using this method to calculate cross-sectional area may be appreciable. In this case, the exact equaton (see 7.2.3) must be used to determine the area.

NOTE 5—For each specimen type, the radii of all fillets shall be equal to each other within a tolerance of 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 2.5 mm.

NOTE 6—Specimens with sides parallel throughout their length are permitted, except for referee testing and where prohibited by product specification, 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 2*W* 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.

FIG. 13 Tension Test Specimens for Large-Diameter Tubular Products

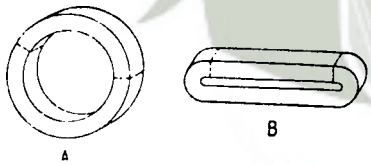


FIG. 14 Location of Transverse Tension Test Specimen in Ring Cut from Tubular Products

taken from tubes, the cross-sectional area shall be determined as follows:

If $D/W \leq 6$:

$$A = [(W/4) \times (D^2 - W^2)^{1/2}] + [(D^2/4) \times \arcsin (W/D)] - [(W/4) \times ((D - 2T)^2 - W^2)^{1/2}] - [((D - 2T)/2)^2 \times \arcsin (W/(D - 2T))] \quad (1)$$

where:

A = exact cross-sectional area, mm^2,
W = width of the specimen in the reduced section, mm,
D = measured outside diameter of the tube, mm, and
T = measured wall thickness of the specimen, mm.

arcsin values to be in radians

If $D/W > 6$, the exact equation or the following equation may be used:

$$A = W \times T \quad (2)$$

where:

A = approximate cross-sectional area, mm^2,
W = width of the specimen in the reduced section, mm, and
T = measured wall thickness of the specimen, mm.

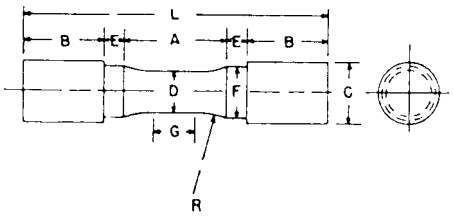
NOTE 17—See X2.8 for cautionary information on measurements and calculations for specimens taken from large-diameter tubing.

7.3 *Gage Length Marking of Test Specimens*:

7.3.1 The gage length for the determination of elongation shall be in accordance with the product specifications for the material being tested. Gage marks shall be stamped lightly with a punch, scribed lightly with dividers or drawn with ink as preferred. For material that is sensitive to the effect of slight notches and for small specimens, the use of layout ink will aid in locating the original gage marks after fracture.

7.4 *Zeroing of the Testing Machine*:

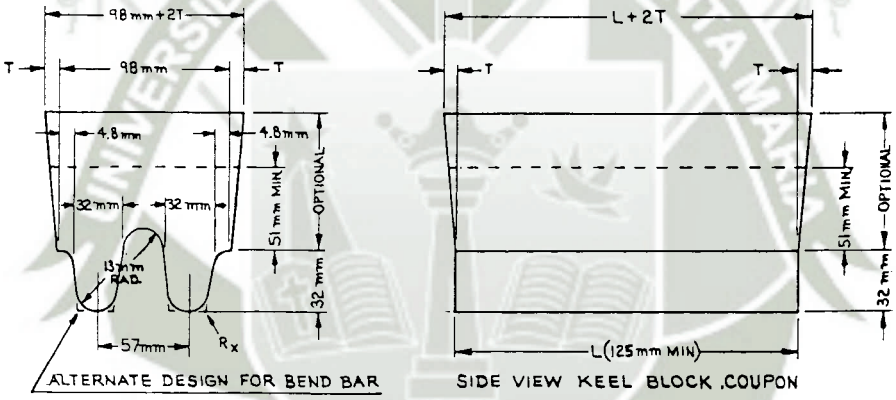
7.4.1 The testing machine shall be set up in such a manner that zero force indication signifies a state of zero force on the specimen. Any force (or preload) imparted by the gripping of the specimen (see Note 18) must be indicated by the force measuring system unless the preload is physically removed prior to testing. Artificial methods of removing the preload on the specimen, such as taring it out by a zero adjust pot or removing it mathematically by software, are prohibited because these would affect the accuracy of the test results.



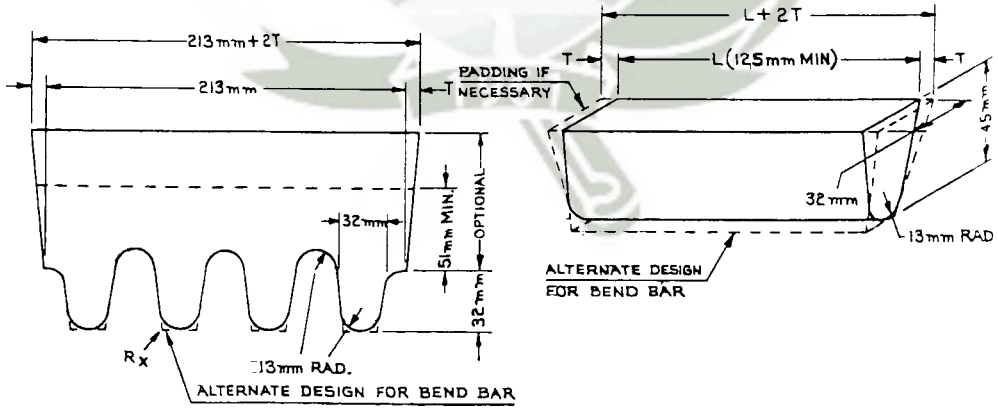
Nominal Diameter	Dimensions, mm		
	Specimen 1	Specimen 2	Specimen 3
	12.5	20	30
G—Length of parallel	Shall be equal to or greater than diameter *D*		
D—Diameter	12.5 ± 0.2	20.0 ± 0.4	30.0 ± 0.6
R—Radius of fillet, min	25	25	50
A—Length of reduced section, min	32	38	60
L—Overall length, min	95	100	160
B—Length of end section, approximate	25	25	45
C—Diameter of end section, approximate	20	30	48
E—Length of shoulder, min	6	6	8
F—Diameter of shoulder	16.0 ± 0.4	24.0± 0.4	36.5 ± 0.4

NOTE 1—The reduced section and shoulders (dimensions *A*, *D*, *E*, *F*, *G*, and *R*) shall 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 force shall be axial. Commonly the ends are threaded and have the dimensions *B* and *C* given above.

FIG. 15 Standard Tension Test Specimen for Cast Iron



(*a*) **Design for Double Keel Block Coupon**



(*b*) **Design for Multiple Keel Block Coupon (4 Legs)** (*c*) **Design for "Attached" Coupon**

FIG. 16 Test Coupons for Castings (see Table 1 for Details of Design)

NOTE 18—Preloads generated by gripping of specimens may be either tensile or compressive in nature and may be the result of such things as:

— grip design
— malfunction of gripping apparatus (sticking, binding, etc.)
— excessive gripping force
— sensitivity of the control loop

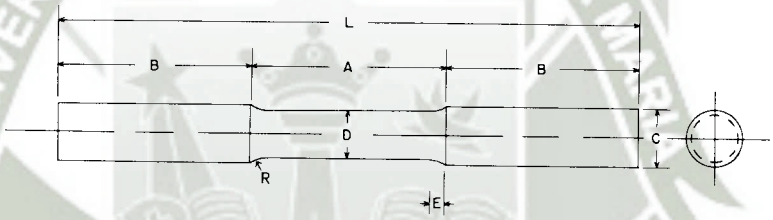
NOTE 19—It is the operator's responsibility to verify that an observed preload is acceptable and to ensure that grips operate in a smooth manner.

TABLE 1 Details of Test Coupon Design for Castings (See Fig. 16)

NOTE 1—*Test Coupons for Large and Heavy Steel Castings:* The test coupons in Fig. 16 are to be used for large and heavy steel castings. However, at the option of the foundry the cross-sectional area and length of the standard coupon may be increased as desired. This provision does not apply to Specification A 356/A 356M.

NOTE 2—*Bend Bar:* If a bend bar is required, an alternate design (as shown by dotted lines in Fig. 16) is indicated.

	Log Design (125 mm)		Riser Design
1. *L* (length)	A 125-mm minimum length will be used. This length may be increased at the option of the foundry to accommodate additional test bars (see Note 1).	1. *L* (length)	The length of the riser at the base will be the same as the top length of the leg. The length of the riser at the top therefore depends on the amount of taper added to the riser.
2. End taper	Use of and size of end taper is at the option of the foundry.	2. Width	The width of the riser at the base of a multiple-leg coupon shall be *n* (57 mm) − 16 mm where *n* equals the number of legs attached to the coupon. The width of the riser at the top is therefore dependent on the amount of taper added to the riser.
3. Height	32 mm		
4. Width (at top)	32 mm (see Note 1).		
5. Radius (at bottom)	13 mm max		
6. Spacing between legs	A 13-mm radius will be used between the legs.		
7. Location of test bars	The tensile, bend, and impact bars will be taken from the lower portion of the leg (see Note 2).		
8. Number of legs	The number of legs attached to the coupon is at the option of the foundry providing they are equispaced according to Item 6.	3. *T* (riser taper) Height	Use of and size is at the option of the foundry. The minimum height of the riser shall be 51 mm. The maximum height is at the option of the foundry for the following reasons: (*a*) many risers are cast open, (*b*) different compositions may require variation in risering for soundness, or (*c*) different pouring temperatures may require variation in risering for soundness.
9. R_s	Radius from 0 to approximately 2 mm		



Dimensions, mm	
D—Diameter	16
R—Radius of fillet	8
A—Length of reduced section	64
L—Overall length	190
B—Length of end section	64
C—Diameter of end section	20
E—Length of fillet	5

FIG. 17 Standard Tension Test Specimen for Malleable Iron

Unless otherwise specified, it is recommended that momentary (dynamic) forces due to gripping not exceed 20 % of the material's nominal yield strength and that static preloads not exceed 10 % of the material's nominal yield strength.

7.5 *Gripping of the Test Specimen*:

7.5.1 For specimens with reduced sections, gripping of the specimen shall be restricted to the grip section, because gripping in the reduced section or in the fillet can significantly affect test results.

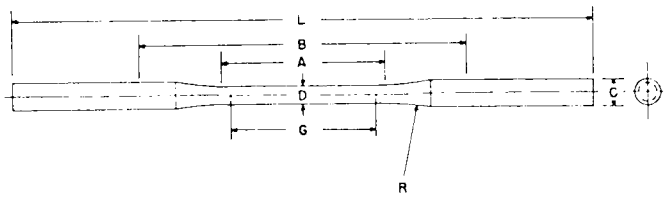
7.6 *Speed of Testing*:

7.6.1 Speed of testing may be defined in terms of (*a*) rate of straining of the specimen, (*b*) rate of stressing of the specimen, (*c*) rate of separation of the two heads of the testing machine during a test, (*d*) the elapsed time for completing part or all of the test, or (*e*) free-running crosshead speed (rate of movement of the crosshead of the testing machine when not under load).

7.6.2 Specifying suitable numerical limits for speed and selection of the method are the responsibilities of the product committees. Suitable limits for speed of testing should be specified for materials for which the differences resulting from the use of different speeds are of such magnitude that the test results are unsatisfactory for determining the acceptability of the material. In such instances, depending upon the material and the use for which the test results are intended, one or more of the methods described in the following paragraphs is recommended for specifying speed of testing.

NOTE 20—Speed of testing can affect test values because of the rate sensitivity of materials and the temperature-time effects.

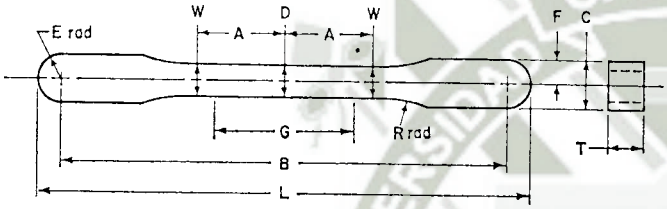
7.6.2.1 *Rate of Straining*—The allowable limits for rate of straining shall be specified in metres per metre per second. Some testing machines are equipped with pacing or indicating



Dimensions, mm	
G—Gage length	50.0 ± 0.1
D—Diameter (see Note)	6.4 ± 0.1
R—Radius of fillet, min	75
A—Length of reduced section, min	60
L—Overall length, min	230
B—Distance between grips, min	115
C—Diameter of end section, approximate	10

NOTE 1—The reduced section may have a gradual taper from the ends toward the center, with the ends not more than 0.1 mm larger in diameter than the center.

FIG. 18 Standard Tension Test Specimen for Die Castings

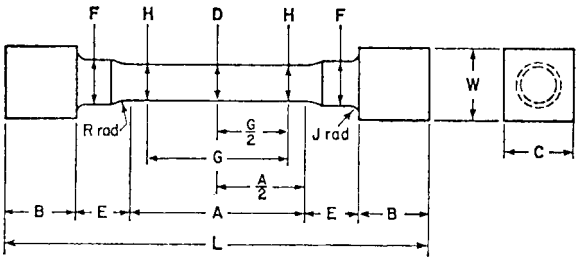


Pressing Area = 645 mm^2

NOTE 1—Dimensions specified, except *G* and *T*, are those of the die.

Dimensions, mm	
G—Gage length	25.40 ± 0.8
D—Width at center	5.72 ± 0.03
W—Width at end of reduced section	5.97 ± 0.03
T—Compact to this thickness	3.56 to 6.35
R—Radius of fillet	25.4
A—Half-length of reduced section	15.88
B—Grip length	80.95 ± 0.03
L—Overall length	89.64 ± 0.03
C—Width of grip section	8.71 ± 0.03
F—Half-width of grip section	4.34 ± 0.03
E—End radius	4.34 ± 0.03

FIG. 19 Standard Flat Unmachined Tension Test Specimen for Powder Metallurgy (P/M) Products



Approximate Pressing Area of Unmachined Compact = 752 mm^2

Machining Recommendations

1. Rough machine reduced section to 6.35 mm diameter
2. Finish turn 4.75/4.85 mm diameter with radii and taper
3. Polish with 00 emery cloth
4. Lap with crocus cloth

Dimensions, mm	
G—Gage length	25.40 ± 0.8
D—Diameter at center of reduced section	4.75± 0.03
H—Diameter at ends of gage length	4.85± 0.03
R—Radius of fillet	6.35 ± 0.13
A—Length of reduced section	47.63 ± 0.13
L—Overall length (die cavity length)	75, nominal
B—Length of end section	7.88 ± 0.13
C—Compact to this end thickness	10.03 ± 0.13
W—Die cavity width	10.03 ± 0.08
E—Length of shoulder	6.35 ± 0.13
F—Diameter of shoulder	7.88 ± 0.03
J—End fillet radius	1.27 ± 0.13

NOTE 1—The gage length and fillets of the specimen shall be as shown. The ends as shown are designed to provide a practical minimum pressing area. Other end designs are acceptable, and in some cases are required for high-strength sintered materials.

NOTE 2—It is recommended that the test specimen be gripped with a split collet and supported under the shoulders. The radius of the collet support circular edge is to be not less than the end fillet radius of the test specimen.

NOTE 3—Diameters *D* and *H* are to be concentric within 0.03 mm total indicator runout (T.I.R.), and free of scratches and tool marks.

FIG. 20 Standard Round Machined Tension Test Specimen for Powder Metallurgy (P/M) Products

devices for the measurement and control of rate of straining, but in the absence of such a device the average rate of straining can be determined with a timing device by observing the time required to effect a known increment of strain.

7.6.2.2 *Rate of Stressing*—The allowable limits for rate of stressing shall be specified in megapascals per second. Many testing machines are equipped with pacing or indicating devices for the measurement and control of the rate of stressing, but in the absence of such a device the average rate of stressing can be determined with a timing device by observing the time required to apply a known increment of stress.

7.6.2.3 *Rate of Separation of Heads During Tests*—The allowable limits for rate of separation of the heads of the testing machine, during a test, shall be specified in metres per metre of length of reduced section (or distance between grips for specimens not having reduced sections) per second. The limits for the rate of separation may be further qualified by specifying different limits for various types and sizes of specimens. Many testing machines are equipped with pacing or indicating devices for the measurement and control of the rate of separation of the heads of the machine during a test, but in the absence of such a device the average rate of separation of the heads can be experimentally determined by using suitable length-measuring and timing devices.

7.6.2.4 *Elapsed Time*—The allowable limits for the elapsed time from the beginning of force application (or from some specified stress) to the instant of fracture, to the maximum force, or to some other stated stress, shall be specified in minutes or seconds. The elapsed time can be determined with a timing device.

7.6.2.5 *Free-Running Crosshead Speed*—The allowable limits for the rate of movement of the crosshead of the testing machine, with no force applied by the testing machine, shall be specified in metres per metre of length of reduced section (or distance between grips for specimens not having reduced sections) per second. The limits for the crosshead speed may be further qualified by specifying different limits for various types and sizes of specimens. The average crosshead speed can be

experimentally determined by using suitable length-measuring and timing devices.

NOTE 21—For machines not having crossheads or having stationary crossheads, the phrase "free-running crosshead speed" may be interpreted to mean the free-running rate of grip separation.

7.6.3 *Speed of Testing When Determining Yield Properties*—Unless otherwise specified, any convenient speed of testing may be used up to one half the specified yield strength or up to one quarter the specified tensile strength, whichever is smaller. The speed above this point shall be within the limits specified. If different speed limitations are required for use in determining yield strength, yield point elongation, tensile strength, elongation, and reduction of area, they should be stated in the product specifications. In the absence of any specified limitations on speed of testing, the following general rules shall apply:

NOTE 22—In the previous and following paragraphs, the yield properties referred to include yield strength and yield point elongation.

7.6.3.1 The speed of testing shall be such that the forces and strains used in obtaining the test results are accurately indicated.

7.6.3.2 When performing a test to determine yield properties, the rate of stress application shall be between 1.15 and 11.5 MPa/s.

NOTE 23—When a specimen being tested begins to yield, the stressing rate decreases and may even become negative in the case of a specimen with discontinuous yielding. To maintain a constant stressing rate in this case would require the testing machine to operate at extremely high speeds and, in many cases, this is not practical. The speed of the testing machine shall not be increased in order to maintain a stressing rate when the specimen begins to yield. In practice, it is simpler to use either a strain rate, a rate of separation of the heads, or a free-running crosshead speed which approximates the desired stressing rate. As an example, use a strain rate that is less than 11.5 MPa/s divided by the nominal Young's Modulus of the material being tested. As another example, find a rate of separation of the heads through experimentation which would approximate the desired stressing rate prior to the onset of yielding, and maintain that rate of separation of the heads through the region that yield properties are determined. While both of these methods will provide similar rates of stressing and straining prior to the onset of yielding, the rates of stressing and straining may be different in the region where yield properties are determined. This difference is due to the change in the rate of elastic deformation of the testing machine, before and after the onset of yielding. In addition, the use of any of the methods other than rate of straining may result in different stressing and straining rates when using different testing machines, due to differences in the stiffness of the testing machines used.

7.6.4 *Speed of Testing When Determining Tensile Strength*—In the absence of any specified limitations on speed of testing, the following general rules shall apply for materials with expected elongations greater than 5 %. When determining only the tensile strength, or after the yield behavior has been recorded, the speed of the testing machine shall be set between 0.05 and 0.5 m/m of the length of the reduced section (or distance between the grips for specimens not having reduced sections) per minute. Alternatively, an extensometer and strain rate indicator may be used to set the strain between 0.05 and 0.5 m/m/min.

NOTE 24—For materials with expected elongations less than or equal to 5 %, the speed of the testing machine may be maintained throughout the test at the speed used to determine yield properties.

NOTE 25—Tensile strength and elongation are sensitive to test speed for many materials (see Appendix XI) to the extent that variations within the range of test speeds given above can significantly affect results.

7.7 *Determination of Yield Strength*— Determine yield strength by any of the methods described in 7.7.1 to 7.7.4. Where extensometers are employed, use only those which are verified over a strain range in which the yield strength will be determined (see 5.4).

NOTE 26—For example, a verified strain range of 0.2 to 2.0 % is appropriate for use in determining the yield strengths of many metals.

NOTE 27—Determination of yield behavior on materials which cannot support an appropriate extensometer (thin wire, for example) is problematic and outside the scope of this standard.

7.7.1 *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 may be drawn. Then on the stress-strain diagram (Fig. 21) 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 diagram (Note 33). In reporting values of yield strength obtained by this method, the specified value of offset used should be stated in parentheses after the term yield strength, as follows:

$$\text{yield strength (offset} = 0.2\ \%) = 360\ \text{MPa} \quad (3)$$

In using this method, a Class B2 or better extensometer (see Practice E 83) shall be used.

NOTE 28—There are two general types of extensometers, averaging and non-averaging, the use of which is dependent on the product tested. For most machined specimens, there are minimal differences. However, for some forgings and tube sections, significant differences in measured yield strength can occur. For these cases, it is recommended that the averaging type be used.

NOTE 29—When there is a disagreement over yield properties, the

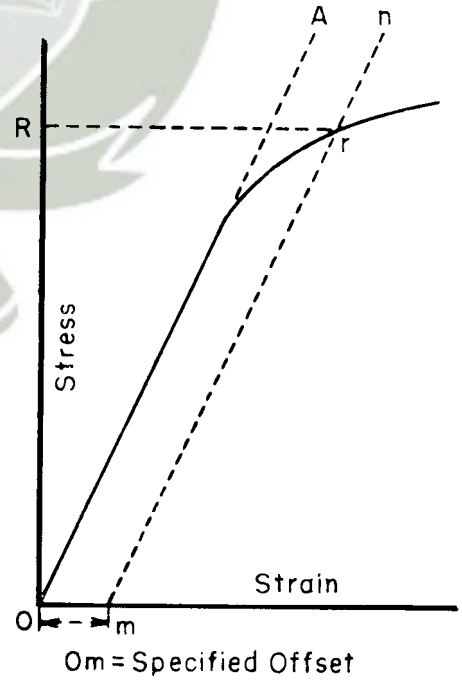


FIG. 21 Stress-Strain Diagram for Determination of Yield Strength by the Offset Method

offset method for determining yield strength is recommended as the referee method.

7.7.2 *Extension-Under-Load Method*—Yield strength by the extension-under-load method may be determined by: (*1*) using autographic or numerical devices to secure stress-strain data, and then analyzing this data (graphically or using automated methods) to determine the stress value at the specified value of extension, or (*2*) using devices that indicate when the specified extension occurs, so that the stress then occurring may be ascertained (Note 31). Any of these devices may be automatic. This method is illustrated in Fig. 22. The stress at the specified extension shall be reported as follows:

$$\text{yield strength (EUL} = 0.5\ \%) = 360\ \text{MPa} \quad (4)$$

Extensometers and other devices used in determination of the extension shall meet Class B2 requirements (see Practice E 83) at the strain of interest, except where use of low-magnification Class C devices is helpful, such as in facilitating measurement of YPE if observed. If Class C devices are used, this must be reported along with the results.

NOTE 30—The appropriate value of the total extension must be specified. For steels with nominal yield strengths of less than 550 MPa, an appropriate value is 0.005 mm/mm (0.5 %) of the gage length. For higher strength steels, a greater extension or the offset method should be used.

NOTE 31—When no other means of measuring elongation are available, a pair of dividers or similar device can be used to determine a point of detectable elongation between two gage marks on the specimen. The gage length shall be 50 mm. The stress corresponding to the load at the instant of detectable elongation may be recorded as the *approximate* extension-under-load yield strength.

7.7.3 *Autographic Diagram Method (for materials exhibiting discontinuous yielding)*—Obtain stress-strain (or force-elongation) data or construct a stress-strain (or load-elongation) diagram using an autographic device. Determine the upper or lower yield strength as follows:

7.7.3.1 Record the stress corresponding to the maximum force at the onset of discontinuous yielding as the upper yield strength. This is illustrated in Fig. 23 and Fig. 24.

NOTE 32—If multiple peaks are observed at the onset of discontinuous yielding, the first is considered the upper yield strength. (See Fig. 24.)

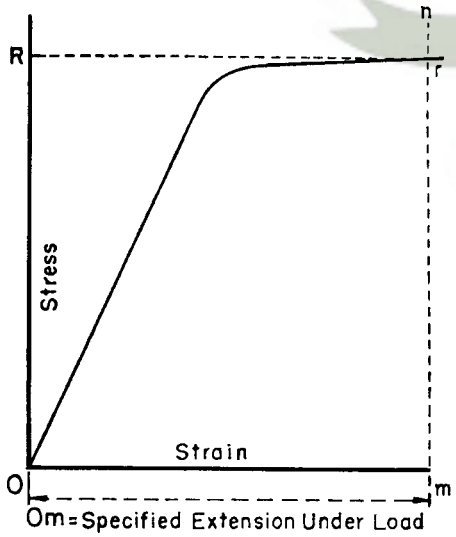


FIG. 22 Stress-Strain Diagram for Determination of Yield Strength by the Extension-Under-Load Method

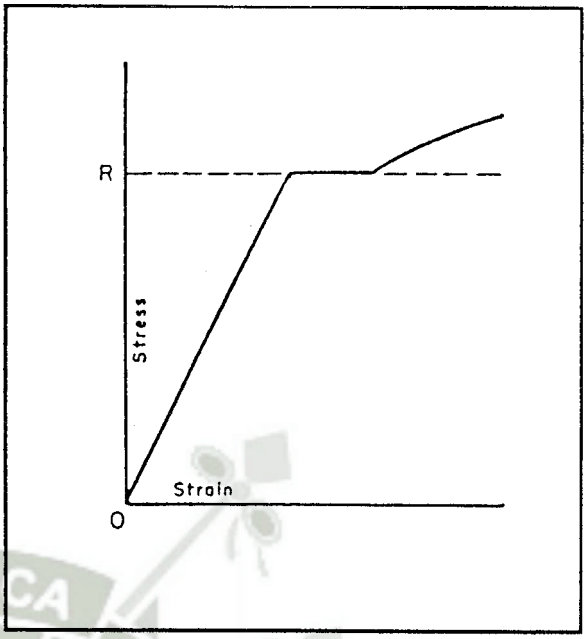


FIG. 23 Stress-Strain Diagram Showing Upper Yield Strength Corresponding with Top of Knee

7.7.3.2 Record the minimum stress observed during discontinuous yielding (ignoring transient effects) as the lower yield strength. This is illustrated in Fig. 24.

NOTE 33—Yield properties of materials exhibiting yield point elongation are often less repeatable and less reproducible than those of similar materials having no YPE. Offset and EUL yield strengths may be significantly affected by force fluctuations occurring in the region where the offset or extension intersects the stress-strain curve. Determination of upper or lower yield strengths (or both) may therefore be preferable for such materials, although these properties are dependent on variables such as test machine stiffness and alignment. Speed of testing may also have a significant effect, regardless of the method employed.

NOTE 34—Where low-magnification autographic recordings are needed to facilitate measurement of yield point elongation for materials which may have discontinuous yielding, Class C extensometers may be employed. When this is done but the material exhibits no discontinuous yielding, the extension-under-load yield strength may be determined instead, using the autographic recording (see Extension-Under-Load Method).

7.7.4 *Halt-of-the-Force Method (for materials exhibiting discontinuous yielding)*—Apply an increasing force to the specimen at a uniform deformation rate. When the force hesitates, record the corresponding stress as the upper yield strength.

NOTE 35—The Halt-of-the-Force Method was formerly known as the Halt-of-the-Pointer Method, the Drop-of-the-Beam Method, and the Halt-of-the-Load Method.

7.8 *Yield Point Elongation*—Calculate the yield point elongation from the stress-strain diagram or data by determining the difference in strain between the upper yield strength (first zero slope) and the onset of uniform strain hardening (see definition of YPE and Fig. 24).

NOTE 36—The stress-strain curve of a material exhibiting only a hint of the behavior causing YPE may have an inflection at the onset of yielding

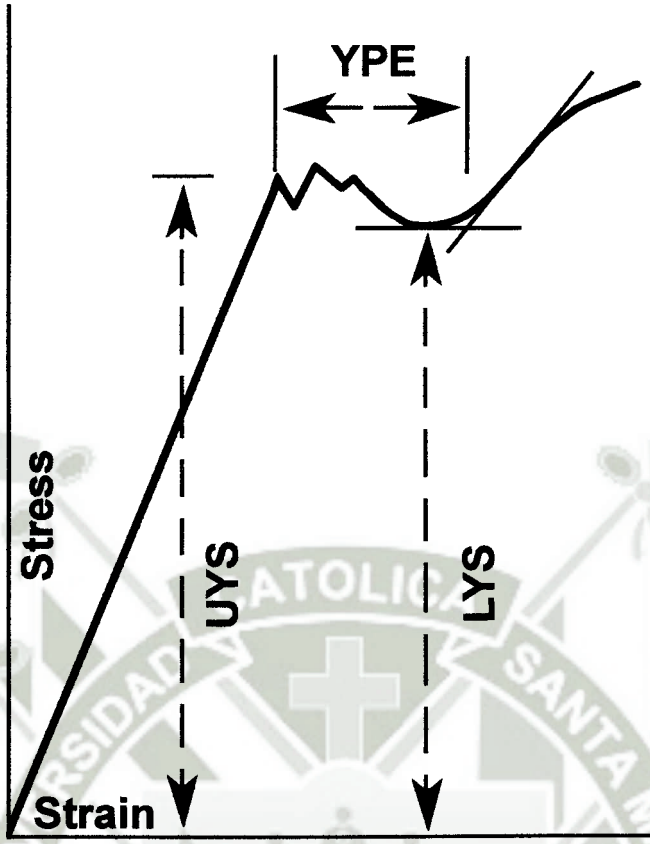


FIG. 24 Stress-Strain Diagram Showing Yield Point Elongation and Upper and Lower Yield Strengths

with no point where the slope reaches zero (Fig. 25). Such a material has no YPE, but may be characterized as exhibiting an *inflection*. Materials exhibiting inflections, like those with measurable YPE, may, in certain applications, acquire an unacceptable surface appearance during forming.

7.9 *Tensile Strength*—Calculate the tensile strength by dividing the maximum force carried by the specimen during the tension test by the original cross-sectional area of the specimen.

NOTE 37—If the upper yield strength is the maximum stress recorded, and if the stress-strain curve resembles that of Fig. 26, it is recommended that the maximum stress *after discontinuous yielding* be reported as the tensile strength. Where this may occur, determination of the tensile strength should be in accordance with the agreement between the parties involved.

7.10 *Elongation*:

7.10.1 In reporting values of elongation, give both the original gage length and the percentage increase. If any device other than an extensometer is placed in contact with the specimen's reduced section during the test, this shall also be noted.

Example: elongation = 30 % increase (50−mm gage length) (5)

NOTE 38—Elongation results are very sensitive to variables such as: (*a*) speed of testing, (*b*) specimen geometry (gage length, diameter, width, and thickness), (*c*) heat dissipation (through grips, extensometers, or other devices in contact with the reduced section), (*d*) surface finish in reduced section (especially burrs or notches), (*e*) alignment, and (*f*) fillets and tapers. Parties involved in comparison or conformance testing should standardize the above items, and it is recommended that use of ancillary devices (such as extensometer supports) which may remove heat from specimens be avoided. See Appendix X1. for additional information on the effects of these variables.

7.10.2 When the specified elongation is greater than 3 %, fit ends of the fractured specimen together carefully and measure the distance between the gage marks to the nearest 0.25 mm for gage lengths of 50 mm and under, and to at least the nearest 0.5 % of the gage length for gage lengths over 50 mm. A percentage scale reading to 0.5 % of the gage length may be used.

7.10.3 When the *specified* elongation is 3 % or less, determine the elongation of the specimen using the following procedure, except that the procedure given in 7.10.2 may be used instead when the *measured* elongation is greater than 3 %.

7.10.3.1 Prior to testing, measure the original gage length of the specimen to the nearest 0.05 mm.

7.10.3.2 Remove partly torn fragments that will interfere with fitting together the ends of the fractured specimen or with making the final measurement.

7.10.3.3 Fit the fractured ends together with matched surfaces and apply a force along the axis of the specimen sufficient to close the fractured ends together. If desired, this force may then be removed carefully, provided the specimen remains intact.

NOTE 39—The use of a force of approximately 15 MPa has been found to give satisfactory results on test specimens of aluminum alloy.

7.10.3.4 Measure the final gage length to the nearest 0.05 mm and report the elongation to the nearest 0.2 %.

7.10.4 Elongation measured per paragraph 7.10.2 or 7.10.3

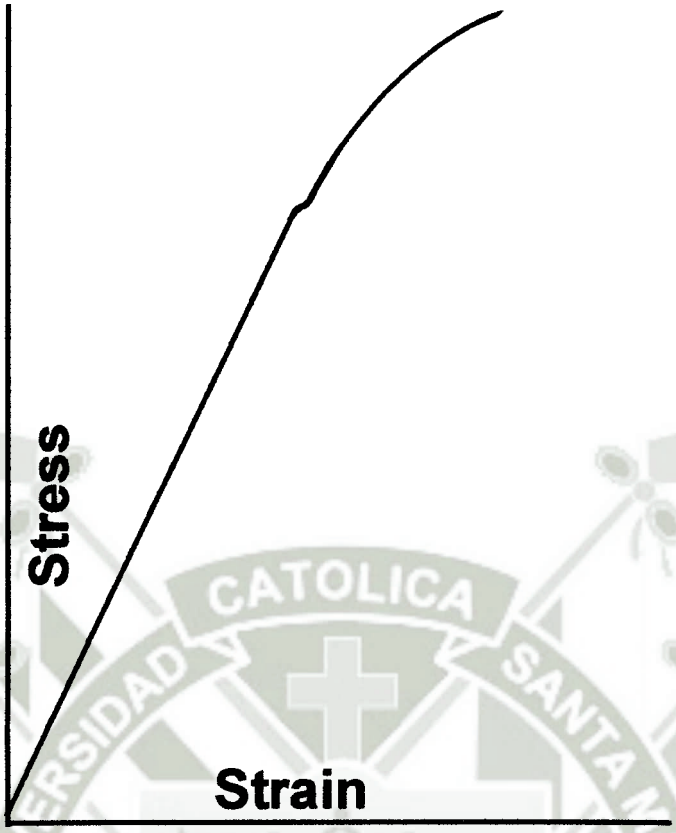


FIG. 25 Stress-Strain Diagram With an Inflection, But No YPE

may be affected by location of the fracture, relative to the marked gage length. If any part of the fracture occurs outside the gage marks or is located less than 25 % of the elongated gage length from either gage mark, the elongation value obtained using that pair of gage marks may be abnormally low and non-representative of the material. If such an elongation measure is obtained in acceptance testing involving only a minimum requirement and meets the requirement, no further testing need be done. Otherwise, discard the test and retest the material.

7.10.5 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.

7.10.5.1 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 (see 5.4). 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 gage length shall be the nominal gage 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.

7.10.5.2 Percent elongation at fracture may be calculated directly from elongation at fracture data and be reported instead of percent elongation as calculated in paragraphs 7.10.2 to 7.10.3. However, these two parameters are not interchangeable. Use of the elongation at fracture method generally provides more repeatable results.

NOTE 40—When disagreements arise over the percent elongation results, agreement must be reached on which method to use to obtain the results.

7.11 *Reduction of Area*:

7.11.1 The reduced area used to calculate reduction of area (see 7.11.2 and 7.11.3) shall be the minimum cross section at the location of fracture.

7.11.2 *Specimens With Originally Circular Cross Sections*—Fit the ends of the fractured specimen together and measure the reduced diameter to the same accuracy as the original measurement.

NOTE 41—Because of anisotropy, circular cross sections often do not remain circular during straining in tension. The shape is usually elliptical, thus, the area may be calculated by $\pi \cdot d_1 \cdot d_2/4$, where d_1 and d_2 are the major and minor diameters, respectively.

7.11.3 *Specimens With Originally Rectangular Cross Sections*—Fit the ends of the fractured specimen together and measure the thickness and width at the minimum cross section to the same accuracy as the original measurements.

NOTE 42—Because of the constraint to deformation that occurs at the corners of rectangular specimens, the dimensions at the center of the original flat surfaces are less than those at the corners. The shapes of these surfaces are often assumed to be parabolic. When this assumption is made,

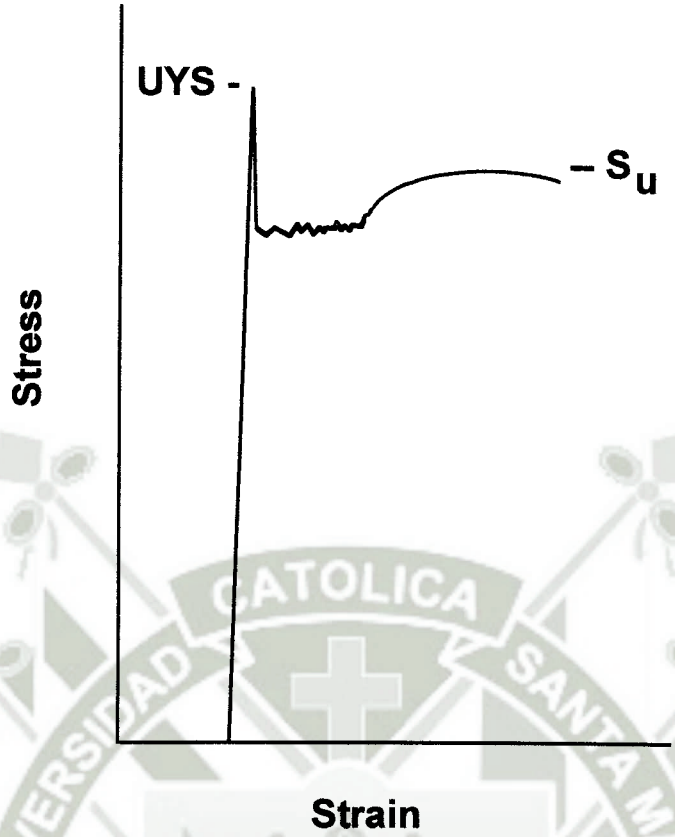


FIG. 26 Stress-Strain Diagram in Which the Upper Yield Strength is the Maximum Stress Recorded

an effective thickness, t_e, may be calculated by: $(t_1 + 4t_2 + t_3)/6$, where t_1 and t_3 are the thicknesses at the corners, and t_2 is the thickness at the mid-width. An effective width may be similarly calculated.

7.11.4 Calculate the reduced area based upon the dimensions determined in 7.11.2 or 7.11.3. 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.

7.11.5 If any part of the fracture takes place outside the middle half of the reduced section or in a punched or scribed gage mark within the reduced section, the reduction of area value obtained may not be representative of the material. In acceptance testing, if the reduction of area so calculated meets the minimum requirements specified, no further testing is required, but if the reduction of area is less than the minimum requirements, discard the test results and retest.

7.11.6 Results of measurements of reduction of area shall be rounded using the procedures of Practice E 29 and any specific procedures in the product specifications. In the absence of a specified procedure, it is recommended that reduction of area test values in the range from 0 to 10 % be rounded to the nearest 0.5 % and test values of 10 % and greater to the nearest 1 %.

7.12 *Rounding Reported Test Data for Yield Strength and Tensile Strength*—Test data should be rounded using the procedures of Practice E 29 and the specific procedures in the product specifications. In the absence of a specified procedure for rounding the test data, one of the procedures described in the following paragraphs is recommended.

7.12.1 For test values up to 500 MPa, round to the nearest 1 MPa; for test values of 500 MPa and up to 1000 MPa, round to the nearest 5 MPa; for test values of 1000 MPa and greater, round to the nearest 10 MPa.

NOTE 43—For steel products, see Test Methods and Definitions A 370.

7.12.2 For all test values, round to the nearest 1 MPa.

NOTE 44—For aluminum- and magnesium-alloy products, see Methods B 557M.

7.12.3 For all test values, round to the nearest 5 MPa.

7.13 *Replacement of Specimens*—A test specimen may be discarded and a replacement specimen selected from the same lot of material in the following cases:

7.13.1 The original specimen had a poorly machined surface,

7.13.2 The original specimen had the wrong dimensions,

7.13.3 The specimen's properties were changed because of poor machining practice,

7.13.4 The test procedure was incorrect,

7.13.5 The fracture was outside the gage length,

7.13.6 For elongation determinations, the fracture was outside the middle half of the gage length, or

7.13.7 There was a malfunction of the testing equipment.

NOTE 45—The tension specimen is inappropriate for assessing some types of imperfections in a material. Other methods and specimens employing ultrasonics, dye penetrants, radiography, etc., may be considered when flaws such as cracks, flakes, porosity, etc., are revealed during a test and soundness is a condition of acceptance.

8. Report

8.1 Test information on materials not covered by a product specification should be reported in accordance with 8.2 or both 8.2 and 8.3.

8.2 Test information to be reported shall include the following when applicable:

8.2.1 Material and sample identification.

8.2.2 Specimen type (Section 6).

8.2.3 Yield strength and the method used to determine yield strength (see 7.7).

8.2.4 Yield point elongation (see 7.8).

8.2.5 Tensile strength (see 7.9).

8.2.6 Elongation (report original gage length, percentage increase, and method used to determine elongation) (see 7.10).

8.2.7 Reduction of area (see 7.11).

8.3 Test information to be available on request shall include:

8.3.1 Specimen test section dimension(s).

8.3.2 Formula used to calculate cross-sectional area of specimens taken from large-diameter tubular products.

8.3.3 Speed and method used to determine speed of testing (see 7.6).

8.3.4 Method used for rounding of test results (see 7.12).

8.3.5 Reasons for replacement specimens (see 7.13).

9. Precision and Bias [7]

9.1 *Precision*—An interlaboratory test program gave the following values for coefficients of variation for the most commonly measured tensile properties:

Coefficient of Variation, %

	Tensile Strength	Yield Strength Offset = 0.02 %	Yield Strength Offset = 0.2 %	Elongation Gage Length = 5 Diameters	Reduction of Area
$CV\%_r$	0.9	2.7	1.4	3.0	2.8
$CV\%_R$	1.3	4.5	2.3	6.4	4.6

$CV\%_r$ = repeatability coefficient of variation in percent within a laboratory
$CV\%_R$ = repeatability coefficient of variation in percent between laboratories

9.1.1 The values shown are the averages from tests on six frequently tested metals, selected to include most of the normal range for each property listed above. When these materials are compared, a large difference in coefficient of variation is found. Therefore, the values above should not be tightness; width; workmanship used to judge whether the difference between duplicate tests of a specific material is larger than expected. The values are provided to allow potential users of this test method to assess, in general terms, its usefulness for a proposed application.

9.2 *Bias*—The procedures in Test Methods E 8M for measuring tensile properties have no bias because these properties can only be defined in terms of a test method.

10. Keywords

10.1 accuracy; bending stress; discontinuous yielding; drop-of-the-beam; eccentric force application; elastic extension; elongation; extension-under-load; extensometer; force; free-running crosshead speed; gage length; halt-of-the force; percent elongation; plastic extension; preload; rate of stressing; rate of straining; reduced section; reduction of area; sensitivity; strain; stress; taring; tensile strength; tension testing; yield point elongation; yield strength

[7] Supporting data can be found in Appendix I and additional data are available from ASTM Headquarters. Request RR: E28-1004 and E28-1006.

APPENDIXES

(Nonmandatory Information)

X1. FACTORS AFFECTING TENSION TEST RESULTS

X1.1 The precision and bias of tension test strength and ductility measurements depend on strict adherence to the stated test procedure and are influenced by instrumental and material factors, specimen preparation, and measurement/testing errors.

X1.2 The consistency of agreement for repeated tests of the same material is dependent on the homogeneity of the material, and the repeatability of specimen preparation, test conditions, and measurements of the tension test parameters.

X1.3 Instrumental factors that can affect test results include: the stiffness, damping capacity, natural frequency, and mass of moving parts of the tensile test machine; accuracy of force indication and use of forces within the verified range of the machine; rate of force application, alignment of the test specimen with the applied force, parallelness of the grips, grip pressure, nature of the force control used, appropriateness and calibration of extensometers, heat dissipation (by grips, extensometers, or ancillary devices), and so forth.

X1.4 Material factors that can affect test results include: representativeness and homogeneity of the test material, sampling scheme, and specimen preparation (surface finish, dimensional accuracy, fillets at the ends of the gage length, taper in the gage length, bent specimens, thread quality, and so forth).

X1.4.1 Some materials are very sensitive to the quality of the surface finish of the test specimen (see Note 8) and must be ground to a fine finish, or polished to obtain correct results.

X1.4.2 Test results for specimens with as-cast, as-rolled, as-forged, or other non-machined surface conditions can be affected by the nature of the surface (see Note 15).

X1.4.3 Test specimens taken from appendages to the part or component, such as prolongs or risers, or from separately produced castings (for example, keel blocks) may produce test results that are not representative of the part or component.

X1.4.4 Test specimen dimensions can influence test results. For cylindrical or rectangular specimens, changing the test specimen size generally has a negligible effect on the yield and tensile strength but may influence the upper yield strength, if one is present, and elongation and reduction of area values. Comparison of elongation values determined using different specimens requires that the following ratio be controlled:

$$L_0/(A_0)^{1/2} \quad \text{(X1.1)}$$

where:
L_0 = original gage length of specimen, and
A_0 = original cross-sectional area of specimen.

X1.4.4.1 Specimens with smaller $L_0/(A_0)^{1/2}$ ratios generally give greater elongation and reduction in area values. This is the case, for example, when the width or thickness of a rectangular tensile test specimen is increased.

X1.4.4.2 Holding the $L_0/(A_0)^{1/2}$ ratio constant minimizes, but does not necessarily eliminate, differences. Depending on material and test conditions, increasing the size of the proportional specimen of Fig. 8 may be found to increase or decrease elongation and reduction in area values somewhat.

X1.4.5 Use of a taper in the gage length, up to the allowed 1 % limit, can result in lower elongation values. Reductions of as much as 15 % have been reported for a 1 % taper.

X1.4.6 Changes in the strain rate can affect the yield strength, tensile strength, and elongation values, especially for materials which are highly strain rate sensitive. In general, the yield strength and tensile strength will increase with increasing strain rate, although the effect on tensile strength is generally less pronounced. Elongation values generally decrease as the strain rate increases.

X1.4.7 Brittle materials require careful specimen preparation, high quality surface finishes, large fillets at the ends of the gage length, oversize threaded grip sections, and cannot tolerate punch or scribe marks as gage length indicators.

X1.4.8 Flattening of tubular products to permit testing does alter the material properties, generally nonuniformity, in the flattened region which may affect test results.

X1.5 Measurement errors that can affect test results include: verification of the test force, extensometers, micrometers, dividers, and other measurement devices, alignment and zeroing of chart recording devices, and so forth.

X1.5.1 Measurement of the dimensions of as-cast, as-rolled, as-forged, and other test specimens with non-machined surfaces may be imprecise due to the irregularity of the surface flatness.

X1.5.2 Materials with anisotropic flow characteristics may exhibit non-circular cross sections after fracture and measurement precision may be affected, as a result (see Note 37).

X1.5.3 The corners of rectangular test specimens are subject to constraint during deformation and the originally flat surfaces may be parabolic in shape after testing which will affect the precision of final cross-sectional area measurements (see Note 42).

X1.5.4 If any portion of the fracture occurs outside of the middle of the gage length, or in a punch or scribe mark within the gage length, the elongation and reduction of area values may not be representative of the material. Wire specimens that break at or within the grips may not produce test results representative of the material.

X1.5.5 Use of specimens with shouldered ends (“button-head” tensiles) will produce lower 0.02 % offset yield strength values than threaded specimens.

X1.6 Because standard reference materials with certified tensile property values are not available, it is not possible to rigorously define the bias of tension tests. However, by the use of carefully designed and controlled interlaboratory studies, a reasonable definition of the precision of tension test results can be obtained.

X1.6.1 An interlaboratory test program[7] was conducted in which six specimens each, of six different materials were prepared and tested by each of six different laboratories. Tables X1.1-X1.5 present the precision statistics, as defined in Practice E 691, for: tensile strength, 0.02 % yield strength, 0.2 % yield strength, % elongation in 5D, and % reduction in area. In each table, the first column lists the six materials tested, the second column lists the average of the average results obtained by the laboratories, the third and fifth columns list the repeatability and reproducibility standard deviations, the fourth and sixth columns list the coefficients of variation for these standard deviations, and the seventh and eighth columns list the 95 % repeatability and reproducibility limits.

X1.6.2 The averages (below columns four and six in each

TABLE X1.1 Precision Statistics—Tensile Strength, MPa

NOTE 1— X is the average of the cell averages, that is, the grand mean for the test parameter,
s_r is the repeatability standard deviation (within-laboratory precision),
s_r/X is the coefficient of variation in %,
s_R is the reproducibility standard deviation (between-laboratory precision),
s_R/X is the coefficient of variation, %,
r is the 95 % repeatability limits,
R is the 95 % reproducibility limits.

Material	X	s_r	s_r/X,%	s_R	s_R/X, %	r	R
EC-H19	176.9	4.3	2.45	4.3	2.45	12.1	12.1
2024-T351	491.3	6.1	1.24	6.6	1.34	17.0	18.5
ASTM A105	596.9	4.1	0.69	8.7	1.47	11.6	24.5
AISI 316	694.6	2.7	0.39	8.4	1.21	7.5	23.4
Inconel 600	685.9	2.9	0.43	5.0	0.72	8.2	13.9
SAE 51410	1253.0	3.2	0.25	7.9	0.63	8.9	22.1
		Averages:	0.91		1.30		

TABLE X1.2 Precision Statistics—0.02 % Yield Strength, MPa

Material	X	s_r	s_r/X,%	s_R	s_R/X, %	r	R
EC-H19	111.4	4.5	4.00	8.2	7.37	12.5	23.0
2024-T351	354.2	5.8	1.64	6.1	1.73	16.3	17.2
ASTM A105	411.4	8.3	2.02	13.1	3.18	23.2	36.6
AISI 316	336.1	16.7	4.97	31.9	9.49	46.1	89.0
Inconel 600	267.1	3.2	1.18	5.2	1.96	8.8	14.7
SAE 51410	723.2	16.6	2.29	21.9	3.02	46.4	61.2
		Averages:	2.68		4.46		

TABLE X1.3 Precision Statistics—0.2 % Yield Strength, MPa

Material	X	s_r	s_r/X,%	s_R	s_R/X, %	r	R
EC-H19	158.4	3.3	2.06	3.3	2.07	9.2	9.2
2024-T351	362.9	5.1	1.41	5.4	1.49	14.3	15.2
ASTM A105	402.4	5.7	1.42	9.9	2.47	15.9	27.8
AISI 316	481.1	6.6	1.36	19.5	4.06	18.1	54.7
Inconel 600	268.3	2.5	0.93	5.8	2.17	7.0	16.3
SAE 51410	967.5	8.9	0.92	15.9	1.64	24.8	44.5
		Averages:	1.35		2.32		

TABLE X1.4 Precision Statistics— % Elongation in 5D

NOTE 1—Length of reduced section = 6D.

Material	X	s_r	s_r/X,%	s_R	s_R/X, %	r	R
EC-H19	14.60	0.59	4.07	0.66	4.54	1.65	1.85
2024-T351	17.99	0.63	3.48	1.71	9.51	1.81	4.81
ASTM A105	25.63	0.77	2.99	1.30	5.06	2.15	3.63
AISI 316	35.93	0.71	1.98	2.68	7.45	2.00	7.49
Inconel 600	41.58	0.67	1.61	1.60	3.86	1.88	4.49
SAE 51410	12.39	0.45	3.61	0.96	7.75	1.25	2.69
		Averages:	2.96		6.36		

TABLE X1.5 Precision Statistics— % Reduction in Area

Material	X	s_r	s_r/X,%	s_R	s_R/X, %	r	R
EC-H19	79.15	1.93	2.43	2.01	2.54	5.44	5.67
2024-T351	30.41	2.09	6.87	3.59	11.79	5.79	10.01
ASTM A105	65.59	0.84	1.28	1.26	1.92	2.35	3.53
AISI 316	71.49	0.99	1.39	1.60	2.25	2.78	4.50
Inconel 600	59.34	0.67	1.14	0.70	1.18	1.89	1.97
SAE 51410	50.49	1.86	3.69	3.95	7.81	5.21	11.05
		Averages:	2.80		4.58		

table) of the coefficients of variation permit a relative comparison of the repeatability (within-laboratory precision) and reproducibility (between-laboratory precision) of the tension test parameters. This shows that the ductility measurements exhibit less repeatability and reproducibility than the strength measurements. The overall ranking from the least to the most repeatable and reproducible is: % elongation in 5D, % reduction in area, 0.02 % offset yield strength, 0.2 % offset yield strength, and tensile strength. Note that the rankings are in the same order for the repeatability and reproducibility average coefficients of variation and that the reproducibility (between-laboratory precision) is poorer than the repeatability (within-laboratory precision), as would be expected.

X1.6.3 No comments about bias can be made for the interlaboratory study due to the lack of certified test results for these specimens. However, examination of the test results showed that one laboratory consistently exhibited higher than average strength values and lower than average ductility values for most of the specimens. One other laboratory had consistently lower than average tensile strength results for all specimens.

X2. MEASUREMENT OF SPECIMEN DIMENSIONS

X2.1 Measurement of specimen dimensions is critical in tension testing, and it becomes more critical with decreasing specimen size, as a given absolute error becomes a larger relative (percent) error. Measuring devices and procedures should be selected carefully, so as to minimize measurement error and provide good repeatability and reproducibility.

X2.2 Relative measurement error should be kept at or below 1 %, where possible. Ideally, this 1 % error should include not only the resolution of the measuring device but also the variability commonly referred to as repeatability and reproducibility. (Repeatability is the ability of any operator to obtain similar measurements in repeated trials. Reproducibility is the ability of multiple operators to obtain similar measurements.)

X2.3 Formal evaluation of gage repeatability and reproducibility (GR and R) by way of a GR and R study is highly recommended. A GR and R study involves having multiple operators each take two or three measurements of a number of parts—in this case, test specimens. Analysis, usually done by computer, involves comparing the observed measurement variations to a tolerance the procedure is to determine conformance to. High GR and R percentages (more than 20 %) indicate much variability relative to the tolerance, whereas low percentages (10 % or lower) indicate the opposite. The analysis also estimates, independently, the repeatability and reproducibility.

X2.4 GR and R studies in which nontechnical personnel used different brands and models of hand-held micrometers have given results varying from about 10 % (excellent) to nearly 100 % (essentially useless), relative to a dimensional tolerance of 0.075 mm. The user is, therefore, advised to be very careful in selecting devices, setting up measurement procedures, and training personnel.

X2.5 With a 0.075 mm tolerance, a 10 % GR and R result (exceptionally good, even for digital hand-held micrometers reading to 0.001 mm) indicates that the total variation due to repeatability and reproducibility is around 0.0075 mm. This is less than or equal to 1 %, only if all dimensions to be measured are greater than or equal to 0.75 mm. The relative error in using this device to measure thickness of a 0.25 mm flat tensile specimen would be 3 %, which is considerably more than that allowed for load or strain measurement.

X2.6 Dimensional measurement errors can be identified as the cause of many *out-of-control* signals, as indicated by statistical process control (SPC) charts used to monitor tension testing procedures. This has been the experience of a production laboratory employing SPC methodology and the best hand-held micrometers available (from a GR and R standpoint) in testing of 0.45 mm to 6.35 mm flat-rolled steel products.

X2.7 Factors which affect GR and R, sometimes dramatically, and which should be considered in the selection and evaluation of hardware and procedures include:

X2.7.1 Resolution,
X2.7.2 Verification,
X2.7.3 Zeroing,
X2.7.4 Type of anvil (flat, rounded, or pointed),
X2.7.5 Cleanliness of part and anvil surfaces,
X2.7.6 User-friendliness of measuring device,
X2.7.7 Stability/temperature variations,
X2.7.8 Coating removal,
X2.7.9 Operator techique, and
X2.7.10 Ratchets or other features used to regulate the clamping force.

X2.8 Flat anvils are generally preferred for measuring the dimensions of round or flat specimens which have relatively smooth surfaces. One exception is that rounded or pointed anvils must be used in measuring the thickness of curved specimens taken from large-diameter tubing (see Fig. 13), to prevent overstating the thickness. (Another concern for these curved specimens is the error that can be introduced through use of the equation $A = W \times T$; see 7.2.4.)

X2.9 Heavy coatings should generally be removed from at least one grip end of flat specimens taken from coated products to permit accurate measurement of base metal thickness, assuming (*a*) the base metal properties are what are desired, (*b*) the coating does not contribute significantly to the strength of the product, and (*c*) coating removal can be easily accomplished (some coatings may be easily removed by chemical stripping). Otherwise, it may be advisable to leave the coating intact and determine the base metal thickness by an alternate method. Where this issue may arise, all parties involved in comparison or conformance testing should agree as to whether or not coatings are to be removed before measurement.

X2.10 As an example of how the considerations identified above affect dimensional measurement procedures, consider the case of measuring the thickness of 0.40 mm painted, flat rolled steel specimens. The paint should be removed prior to measurement, if possible. The measurement device used should have flat anvils, must read to 0.001 mm or better, and must have excellent repeatability and reproducibility. Since GR and R is a significant concern, it will be best to use a device which has a feature for regulating the clamping force used, and devices without digital displays should be avoided to prevent reading errors. Before use of the device, and periodically during use, the anvils should be cleaned, and the device should be verified or zeroed (if an electronic display is used) or both. Finally, personnel should be trained and audited periodically to ensure that the measuring device is being used correctly and consistently by all.

SUMMARY OF CHANGES

This section identifies the principal changes to this standard that have been incorporated since the last issue.

(1) Note 16 was inserted, susequent notes renumbered.
(2) X2.9 was revised.
(3) 7.10.4 was revised.
(4) 6.5.3 was revised.
(5) In Fig. 1, Note 7 was added and subsequent notes of this figure were renumbered. The new note was to eliminate a minimum requirement for the length of the test specimen.

Designation: A 370 – 97a

An American National Standard

Standard Test Methods and Definitions for Mechanical Testing of Steel Products[1]

This standard is issued under the fixed designation A 370; 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 (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 These test methods[2] cover procedures and definitions for the mechanical testing of wrought and cast steel products. 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 where 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	5 to 13
Bend	14
Hardness	15
Brinell	16
Rockwell	17
Portable	18
Impact	19 to 28
Keywords	29

1.3 Annexes covering details peculiar to certain products are appended to these test methods as follows:

	Annex
Bar Products	1
Tubular Products	2
Fasteners	3
Round Wire Products	4
Significance of Notched-Bar Impact Testing	5
Converting Percentage Elongation of Round Specimens to Equivalents for Flat Specimens	6
Testing Multi-Wire Strand	7
Rounding of Test Data	8
Methods for Testing Steel Reinforcing Bars	9
Procedure for Use and Control of Heat-Cycle Simulation	10

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 gage lengths of 2 or 8 in. may be reported in SI unit gage 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 gage lengths of 50 or 200 mm may be reported in inch-pound gage lengths of 2 or 8 in., respectively, as applicable.

1.6 Attention is directed to Practices A 880 and E 1595 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 and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

A 703/A 703M Specification for Steel Castings, General Requirements, for Pressure-Containing Parts[3]

A 781/A 781M Specification for Castings, Steel and Alloy, Common Requirements, for General Industrial Use[3]

A 833 Practice for Indentation Hardness of Metallic Materials by Comparison Hardness Testers[4]

A 880 Practice for Criteria for Use in Evaluation of Testing Laboratories and Organizations for Examination and Inspection of Steel, Stainless Steel, and Related Alloys[5]

E 4 Practices for Force Verification of Testing Machines[6]

E 6 Terminology Relating to Methods of Mechanical Testing[6]

E 8 Test Methods for Tension Testing of Metallic Materials[6]

E 8M Test Methods for Tension Testing of Metallic Materials [Metric][6]

E 10 Test Method for Brinell Hardness of Metallic Materials[6]

E 18 Test Methods for Rockwell Hardness and Rockwell

[1] These test methods and definitions are under the jurisdiction of ASTM Committee A-1 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 Jan. 10 and March 10, 1997. Published November 1997. Originally published as A 370 – 53 T. Last previous edition A 370 – 96.

[2] For *ASME Boiler and Pressure Vessel Code* applications see related Specification SA-370 in Section II of that Code.

[3] *Annual Book of ASTM Standards*, Vol 01.02.

[4] *Annual Book of ASTM Standards*, Vol 01.05.

[5] *Annual Book of ASTM Standards*, Vol 01.03.

[6] *Annual Book of ASTM Standards*, Vol 03.01.

Superficial Hardness of Metallic Materials[6]
E 23 Test Methods for Notched Bar Impact Testing of Metallic Materials[6]
E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications[7]
E 83 Practice for Verification and Classification of Extensometers[6]
E 110 Test Method for Indentation Hardness of Metallic Materials by Portable Hardness Testers[6]
E 190 Method for Guided Bend Test for Ductility of Welds[6]
E 208 Test Method for Conducting Drop-Weight Test to Determine Nil-Ductility Transition Temperature of Ferritic Steels[6]
E 290 Test Method for Semi-Guided Bend Test for Ductility of Metallic Materials[6]
E 1595 Practice for Evaluating the Performance of Mechanical Testing Laboratories[6]

2.2 *Other Document:*

ASME Boiler and Pressure Vessel Code, Section VIII, Division I, Part UG-84[8]

3. General Precautions

3.1 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.

3.2 Improper machining or preparation of test specimens may give erroneous results. Care should be exercised to assure good workmanship in machining. Improperly machined specimens should be discarded and other specimens substituted.

3.3 Flaws in the specimen may also affect results. If any test specimen develops flaws, the retest provision of the applicable product specification shall govern.

3.4 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.

4. Orientation of Test Specimens

4.1 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:

4.1.1 *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. 2(*a*), and 2(*b*)).

4.1.2 *Transverse Test*, unless specifically defined otherwise, signifies that the lengthwise axis of the specimen is at right 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).

4.2 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:

4.2.1 *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. 2(*a*)).

4.2.2 *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. 2(*a*), 2(*b*), 2(*c*), and 2(*d*)).

TENSION TEST

5. Description

5.1 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 E 6.

5.2 In general the testing equipment and methods are given in Test Methods E 8. However, there are certain exceptions to Test Methods E 8 practices in the testing of steel, and these are covered in these test methods.

6. Terminology

6.1 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 E 6.

7. Testing Apparatus and Operations

7.1 *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.

7.2 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 E 4.

NOTE 1—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.

7.3 *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

[7] *Annual Book of ASTM Standards*, Vol 14.02.
[8] Available from American Society of Mechanical Engineers, 345 E. 47th Street, New York, NY 10017.

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.

7.4 *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), or (*2*) in terms of rate of separation of the two heads of the testing machine under load, or (*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 2—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.

7.4.1 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 separation of the heads shall not exceed ½ 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 1/10 the specified maximum rates for determining yield point or yield strength and tensile strength.

7.4.2 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 specfied values of free running crosshead speed.

7.4.3 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.

8. Test Specimen Parameters

8.1 *Selection*—Test coupons shall be selected in accordance with the applicable product specifications.

8.1.1 *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 Fig. 1 and Fig. 2).

8.1.2 *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.

8.1.3 *Cast Steels*— Test coupons for castings from which tension test specimens are prepared shall be in accordance with the requirements of Specifications A 703/A 703M or A781/A 781M, as applicable.

8.2 *Size and Tolerances*—Test specimens shall be the full thickness or section of material as-rolled, or may be machined to the form and dimensions shown in Figs. 3-6, inclusive. The selection of size and type of specimen is prescribed by the applicable product specification. Full section specimens shall be tested in 8-in. (200-mm) gage length unless otherwise specified in the product specification.

8.3 *Procurement of Test Specimens*—Specimens shall be sheared, blanked, sawed, trepanned, or oxygen-cut from portions of the material. They are usually machined so as to have a reduced cross section at mid-length in order to obtain uniform distribution of the stress over the cross section and to localize the zone of fracture. When test coupons are sheared, blanked, sawed, or oxygen-cut, care shall be taken to remove by machining all distorted, cold-worked, or heat-affected areas from the edges of the section used in evaluating the test.

8.4 *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.

8.5 *Measurement of Dimensions of Test Specimens*:

8.5.1 *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) gage length specimen and 0.001 in. (0.025 mm) for the 2-in. (50-mm) gage length specimen in Fig. 3. The center thickness dimension shall be measured to the nearest 0.001 in. for both specimens.

8.5.2 *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 gage length to the nearest 0.001 in. (0.025 mm). (See Table 1.)

8.6 *General*—Test specimens shall be either substantially

full size or machined, as prescribed in the product specifications for the material being tested.

8.6.1 Improperly prepared test specimens often cause unsatisfactory test results. It is important, therefore, that care be exercised in the preparation of specimens, particularly in the machining, to assure good workmanship.

8.6.2 It is desirable to have the cross-sectional area of the specimen smallest at the center of the gage length to ensure fracture within the gage length. This is provided for by the taper in the gage length permitted for each of the specimens described in the following sections.

8.6.3 For brittle materials it is desirable to have fillets of large radius at the ends of the gage length.

9. Plate-Type Specimen

9.1 The standard plate-type test specimen is shown in Fig. 3. This specimen is used for testing metallic materials in the form of plate, structural and bar-size shapes, and flat material having a nominal thickness of 3/16 in. (5 mm) or over. When product specifications so permit, other types of specimens may be used.

NOTE 3—When called for in the product specification, the 8-in. gage length specimen of Fig. 3 may be used for sheet and strip material.

10. Sheet-Type Specimen

10.1 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 ¾in. (0.13 to 19 mm). When product specifications so permit, other types of specimens may be used, as provided in Section 9 (see Note 3).

11. Round Specimens

11.1 The standard 0.500-in. (12.5-mm) diameter round test specimen shown in Fig. 4 is used quite generally for testing metallic materials, both cast and wrought.

11.2 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 gage length for measurement of elongation be four times the diameter of the specimen (see Note 4, Fig. 4).

11.3 The shape of the ends of the specimens outside of the gage length shall be suitable to the material and of a shape to fit the holders or grips of the testing machine so that the loads are applied axially. Fig. 5 shows specimens with various types of ends that have given satisfactory results.

12. Gage Marks

12.1 The specimens shown in Figs. 3-6 shall be gage marked with a center punch, scribe marks, multiple device, or drawn with ink. The purpose of these gage 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 gage 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. gage length specimen, Fig. 3, one or more sets of 8-in. gage marks may be used, intermediate marks within the gage length being optional. Rectangular 2-in. gage length specimens, Fig. 3, and round specimens, Fig. 4, are gage marked with a double-pointed center punch or scribe marks. One or more sets of gage 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.

13. Determination of Tensile Properties

13.1 *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:

13.1.1 *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.

13.1.2 *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.

13.1.3 *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 13.1.1 and 13.1.2, 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 (Note 4 and Note 5) to the specimen. When the load producing a specified extension (Note 6) is reached record the stress corresponding to the load as the yield point (Fig. 8).

NOTE 4—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 5—Reference should be made to Practice E 83.

NOTE 6—For steel with a yield point specified not over 80 000 psi (550 MPa), an appropriate value is 0.005 in./in. of gage length. For values above 80 000 psi, this method is not valid unless the limiting total extension is increased.

NOTE 7—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 7.4.1. Generally, the abberations 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.

13.2 *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, etc. Determine yield strength by one of the following methods:

13.2.1 *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 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 off set specified or used, 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 8 for automatic devices.

13.2.2 *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 Note 8 and Note 9) 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:

$$\text{Yield strength (0.5 \% } EUL\text{)} = 52\,000 \text{ psi (360 MPa)} \quad (2)$$

The total strain can be obtained satisfactorily by use of a Class B1 extensometer (Note 4, Note 5, and Note 7).

NOTE 8—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 9—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:

$$\text{Extension under load, in./in. of gage length} = (YS/E) + r \quad (3)$$

where:

YS = specified yield strength, psi or MPa,
E = modulus of elasticity, psi or MPa, and
r = limiting plastic strain, in./in.

13.3 *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.

13.4 *Elongation*:

13.4.1 Fit the ends of the fractured specimen together carefully and measure the distance between the gage marks to the nearest 0.01 in. (0.25 mm) for gage lengths of 2 in. and under, and to the nearest 0.5 % of the gage length for gage lengths over 2 in. A percentage scale reading to 0.5 % of the gage length may be used. The elongation is the increase in length of the gage length, expressed as a percentage of the original gage length. In recording elongation values, give both the percentage increase and the original gage length.

13.4.2 If any part of the fracture takes place outside of the middle half of the gage 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.

13.5 *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

14. Description

14.1 The bend test is one method for evaluating ductility, but it cannot be considered as a quantitative means of predicting service performance in bending operations. The severity of the bend test is primarily a function of the angle of bend and 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. Method E 190 and Test Method E 290 may be consulted for methods of performing the test.

14.2 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, heating in oil, or in an oven.

14.3 Bend the test specimen at room temperature to an inside diameter, as designated by the applicable product specifications, to the extent specified without major cracking on the outside of the bent portion. The speed of bending is ordinarily not an important factor.

HARDNESS TEST

15. General

15.1 A hardness test is a means of determining resistance to penetration and is occasionally employed to obtain a quick approximation of tensile strength. Table 2, Table 3, Table 4, and Table 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. Since all converted hardness values must be considered approximate, however, all converted Rockwell hardness numbers shall be rounded to the nearest whole number.

15.2 *Hardness Testing*:

15.2.1 If the product specification permits alternative hardness testing to determine conformance to a specified hardness requirement, the conversions listed in Table 2, Table 3, Table 4, and Table 5 shall be used.

15.2.2 When recording converted hardness numbers, the measured hardness and test scale shall be indicated in parentheses, for example: 353 HB (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.

16. Brinell Test

16.1 *Description*:

16.1.1 A specified load is applied to a flat surface of the specimen to be tested, through a hard 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 (HB) in accordance with the following equation:

$$HB = P/[(\pi D/2)(D - \sqrt{D^2 - d^2})] \quad (4)$$

where:

HB = Brinell hardness number,
P = applied load, kgf,
D = diameter of the steel ball, mm, and
d = average diameter of the indentation, mm.

NOTE 10—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 11—In Test Method E 10, the values are stated in SI units whereas in this section, kg/m units are used.

16.1.2 The standard Brinell test using a 10-mm ball employs a 3000-kgf load for hard materials and a 1500 or 500-kgf load for thin sections or soft materials (see Annex on Steel Tubular Products). Other loads and different size indentors may be used when specified. In recording 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.

16.1.3 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.

16.1.4 Brinell hardness may be required when tensile properties are not specified.

16.2 *Apparatus*—Equipment shall meet the following requirements:

16.2.1 *Testing Machine*— A Brinell hardness testing machine is acceptable for use over a loading range within which its load measuring device is accurate to ±1 %.

16.2.2 *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 12—This requirement applies to the construction of the microscope only and is not a requirement for measurement of the indentation, see 16.4.3.

16.2.3 *Standard Ball*— The standard 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 (0.0004 in.) in any diameter. A 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 3000 kgf against the test specimen.

16.3 *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.

16.4 *Procedure*:

16.4.1 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.

16.4.2 Apply the load for a minimum of 15 s.

16.4.3 Measure two diameters of the indentation at right angles to the nearest 0.1 mm, estimate to the nearest 0.05 mm, and average to the nearest 0.05 mm. If the two diameters differ by more than 0.1 mm, discard the readings and make a new indentation.

16.4.4 Do not use a steel ball on steels having a hardness over 450 HB nor a carbide ball on steels having a hardness over 650 HB. The Brinell hardness test is not recommended for materials having a hardness over 650 HB.

16.4.4.1 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 16.4.4, the ball shall be either discarded and replaced with a new ball or remeasured to ensure conformance with the requirements of Test Method E 10.

16.5 *Detailed Procedure*—For detailed requirements of this test, reference shall be made to the latest revision of Test Method E 10.

17. Rockwell Test

17.1 *Description*:

17.1.1 In this test a hardness value is obtained by determining the depth of penetration of a diamond point or a steel 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:

Scale Symbol	Penetrator	Major Load, kgf	Minor Load, kgf
B	1/16-in. steel ball	100	10
C	Diamond brale	150	10

17.1.2 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 hardened steel ball or diamond penetrator, to cover the same range of hardness values as for the heavier loads. The superficial hardness scales are as follows:

Scale Symbol	Penetrator	Major Load, kgf	Minor Load, kgf
15T	1/16-in. steel ball	15	3
30T	1/16-in. steel ball	30	3
45T	1/16-in. steel ball	45	3
15N	Diamond brale	15	3
30N	Diamond brale	30	3
45N	Diamond brale	45	3

17.2 *Reporting Hardness*—In recording hardness values, the hardness number shall always precede the scale symbol, for example: 96 HRB, 40 HRC, 75 HR15N, or 77 HR30T.

17.3 *Test Blocks*— Machines should be checked to make certain they are in good order by means of standardized Rockwell test blocks.

17.4 *Detailed Procedure*—For detailed requirements of this test, reference shall be made to the latest revision of Test Methods E 18.

18. Portable Hardness Test

18.1 Although the use of the standard, stationary Brinell or Rockwell hardness tester is generally preferred, it is not always possible to perform the hardness test using such equipment due to the part size or location. In this event, hardness testing using portable equipment as described in Practice A 833 or Test Method E 110 shall be used.

CHARPY IMPACT TESTING

19. Summary

19.1 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.

19.2 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.

20. Significance and Use

20.1 *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 less energy. Within the transition range, the fracture will generally be a mixture of areas of ductile fracture and brittle fracture.

20.2 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.

20.2.1 The specification may require a minimum test result for absorbed energy, fracture appearance, lateral expansion, or

a combination thereof, at a specified test temperature.

20.2.2 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.

20.3 Further information on the significance of impact testing appears in Annex A5.

21. Apparatus

21.1 *Testing Machines*:

21.1.1 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.

21.1.2 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.

21.1.3 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 E 23). 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).

21.2 *Temperature Media*:

21.2.1 For testing at other than room temperature, it is necessary to condition the Charpy specimens in media at controlled temperatures.

21.2.2 Low temperature media usually are chilled fluids (such as water, ice plus water, dry ice plus organic solvents, or liquid nitrogen) or chilled gases.

21.2.3 Elevated temperature media are usually heated liquids such as mineral or silicone oils. Circulating air ovens may be used.

21.3 *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 E 23). 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.

22. Sampling and Number of Specimens

22.1 *Sampling*:

22.1.1 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.

22.1.2 *Number of Specimens*.

22.1.2.1 A Charpy impact test consists of all specimens taken from a single test coupon or test location.

22.1.2.2 When the specification calls for a minimum average test result, three specimens shall be tested.

22.1.2.3 When the specification requires determination of a transition temperature, eight to twelve specimens are usually needed.

22.2 *Type and Size*:

22.2.1 Use a standard full size Charpy V-notch specimen (Type A) as shown in Fig. 11, except as allowed in 22.2.2.

22.2.2 *Subsized Specimens*.

22.2.2.1 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.

22.2.2.2 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 13—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.

22.2.2.3 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).

22.2.2.4 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.

22.2.2.5 Notch the narrow face of the standard subsize specimens so that the notch is perpendicular to the 10 mm wide face.

22.3 *Notch Preparation*—The machining of the notch is critical, as it has been demonstrated that extremely minor variations in notch radius and profile, or tool marks at the bottom of the notch may result in erratic test data. (See Annex A5).

23. Calibration

23.1 *Accuracy and Sensitivity*—Calibrate and adjust Charpy impact machines in accordance with the requirements of Test Methods E 23.

24. Conditioning—Temperature Control

24.1 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) because the effect of variations in temperature on Charpy test results can be very great.

NOTE 14—For some steels there may not be a need for this restricted temperature, for example, austenitic steels.

NOTE 15—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.

25. Procedure

25.1 *Temperature*:

25.1.1 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.

25.1.2 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.

25.2 *Positioning and Breaking Specimens*:

25.2.1 Carefully center the test specimen in the anvil and release the pendulum to break the specimen.

25.2.2 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 25.1.1.

25.3 *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.

25.4 *Individual Test Values*:

25.4.1 *Impact energy*— Record the impact energy absorbed to the nearest ft·lbf (J).

25.4.2 *Fracture Appearance*:

25.4.2.1 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.

25.4.2.2 Determine the individual fracture appearance values to the nearest 5 % shear fracture and record the value.

25.4.3 *Lateral Expansion*:

25.4.3.1 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.

25.4.3.2 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.

25.4.3.3 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.

25.4.3.4 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 gage similar to that shown in Fig. 16 and Fig. 17.

25.4.3.5 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 gage, 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.

25.4.3.6 Measure the individual lateral expansion values to the nearest mil (0.025 mm) and record the values.

26. Interpretation of Test Result

26.1 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) of the individual test values of three specimens from one test location.

26.1.1 When a minimum average test result is specified:

26.1.1.1 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.

26.1.1.2 If the acceptance requirements of 26.1.1.1 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.

26.2 *Test Specifying a Minimum Transition Temperature*:

26.2.1 *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.

26.2.2 *Determination of Transition Temperature*:

26.2.2.1 Break one specimen at each of a series of temperatures above and below the anticipated transition temperature using the procedures in Section 25. Record each test temperature to the nearest 1°F (0.5°C).

26.2.2.2 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.

26.2.2.3 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 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.

26.2.2.4 Accept the test result if the determined transition

temperature is equal to or lower than the specified value.

26.2.2.5 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 25 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.

26.3 When subsize specimens are permitted or necessary, or both, modify the specified test requirement according to Table 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.

27. Records

27.1 The test record should contain the following information as appropriate:

27.1.1 Full description of material tested (that is, specification number, grade, class or type, size, heat number).

27.1.2 Specimen orientation with respect to the material axis.

27.1.3 Specimen size.

27.1.4 Test temperature and individual test value for each specimen broken, including initial tests and retests.

27.1.5 Test results.

27.1.6 Transition temperature and criterion for its determination, including initial tests and retests.

28. Report

28.1 The specification should designate the information to be reported.

29. Keywords

29.1 bend test; Brinell hardness; charpy impact test; elongation; FATT (Fracture Appearance Transition Temperature); hardness 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 supplement delineates only those details which are peculiar to hot-rolled and cold-finished steel bars and are not covered in the general section of these test methods.

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 condition 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.^{2} (645 mm^2) 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.

A2. STEEL TUBULAR PRODUCTS

A2.1 Scope

A2.1.1 This supplement covers definitions and methods of testing peculiar to tubular products which are not covered in the general section of these methods.

A2.1.2 Tubular shapes covered by this specification shall not be limited to products with circular cross sections but include shapes such as rectangular structural tubing.

A2.2 Tension Test

A2.2.1 *Full-Size Longitudinal Test Specimens*:

A2.2.1.1 It is standard practice to use tension test specimens of full-size tubular sections within the limit of the testing equipment. 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 gage length prescribed for measuring the elongation.

A2.2.1.2 Unless otherwise required by the individual product specification, the gage length for furnace-welded pipe is normally 8 in. (200 mm), except that for nominal sizes ¾in. and smaller, the gage length shall be as follows:

Nominal Size, in.	Gage Length, in. (mm)
¾ and ½	6 (150)
⅜ and ¼	4 (100)
⅛	2 (50)

A2.2.1.3 For seamless and electric-welded pipe and tubes the gage length is 2 in. However, for tubing having an outside diameter of ⅜ in. (10 mm) or less, it is customary to use a gage length equal to four times the outside diameter when elongation values comparable to larger specimens are required.

A2.2.1.4 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:

$$A = 3.1416t\,(D - t) \qquad \text{(A2.1)}$$

where:
A = sectional area, in.^{2}
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 For larger sizes of tubular products which cannot be tested in full-section, longitudinal test specimens are obtained from strips cut from the tube or pipe as indicated in Fig. A2.2 and machined to the dimensions shown in Fig. A2.3. For furnace-welded tubes or pipe the 8-in. gage length specimen as shown in Fig. A2.3 is standard, the specimen being located at approximately 90° from the weld. For seamless and electric-welded tubes or pipe, the 2-in. gage length specimen as shown in Fig. A2.3 (1) is standard, the specimen being located approximately 90° from the weld in the case of electric-welded tubes. Specimens of the type shown in Fig. A2.3 may be tested with grips having a surface contour corresponding to the curvature of the tubes. When grips with curved faces are not available, the ends of the specimens may be flattened without heating. Standard tension test specimens, as shown in specimen No. 4 of Fig. A2.3, are nominally 1½in. (38 mm) wide in the gage length section. When sub-size specimens are necessary due to the dimensions and character of the material to be tested, specimens 1, 2, or 3 shown in Fig. A2.3 where applicable, are considered standard.

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 given in Test Methods E 8 or E 8M.

A2.2.2.2 The width should be measured at each end of the gage 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 gage 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.

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 gage length for measurement of elongation be four times the diameter of the specimen (see Note 4, Fig. 4). The elongation requirements for the round specimen 2-in. gage 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.

A2.3 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 through A2.3.5.

A2.3.3 A diagrammatic vertical cross-sectional sketch of the testing machine is shown in Fig. A2.6.

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 gage 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 gage 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:

$$(1)\quad P = 2St/D \qquad \text{(A2.2)}$$

$$(2)\quad S = PD/2t \qquad \text{(A2.3)}$$

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 Fig. A2.7 and Fig. 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 gage, 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.

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 5⁄16 in. (7.9 mm) in outside diameter, nor are they performed on the inside surface of tubes with less than ¼ 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 ¼in. (6.4 mm). The wall thickness limitations for the Superficial Rockwell hardness test are given in Table A2.1 and Table 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 proper-ties 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 2½ 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 2½ 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 1½ in. (38 mm) wide, at 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.

A3. STEEL FASTENERS

A3.1 Scope

A3.1.1 This supplement covers definitions and methods of testing peculiar to steel fasteners which are not covered in the general section of Test Methods and Definitions A 370. Standard tests required by the individual product specifications are to be performed as outlined in the general section of these methods.

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-A3.2.1.3 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 full size tests are required, proof load Method 1 is to be limited in application to bolts whose length does not exceed 8 in. (203 mm) or 8 times the nominal diameter, whichever is greater. For bolts longer than 8 in. or 8 times the nominal diameter, whichever is greater, proof load Method 2 shall be used.

(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 ±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 percent 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.

(a) *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 percent of the length of bolt occupied by 6 full threads shall be determined by the method described in 13.2.1 of these methods, A 370. 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. 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:

$$A_s = 0.7854[D - (0.9743/n)]^2 \quad \text{(A3.1)}$$

where:
A_s = stress area, in.^{2},
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 of 10° between its faces 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)
9⁄16 to ¾	0.050 (1.3)	0.060 (1.5)
⅞ to 1	0.063 (1.5)	0.060 (1.5)
1⅛ to 1¼	0.063 (1.5)	0.125 (3.2)
1⅜ to 1½	0.094 (2.4)	0.125 (3.2)

A3.2.1.6 *Wedge Testing of HT Bolts Threaded to Head*—For heat-treated bolts over 100 000 psi (690 MPa) minimum tensile strength and that are threaded 1 diameter and closer to the underside of the head, the wedge angle shall be 6° for sizes ¼ through ¾ in. (6.35 to 19.0 mm) and 4° for sizes over ¾ in.

A3.2.1.7 *Tension Testing of Bolts Machined to Round Test Specimens*:

(a) (a) Bolts under 1½in. (38 mm) in diameter which require machined tests shall preferably use a standard ½-in., (13-mm) round 2-in. (50-mm) gage 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 gage length for measuring the elongation shall be four times the diameter of the specimen.

(b) (b) For bolts 1½ in. and over in diameter, a standard ½-in. round 2-in. gage 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.

(c) (c) 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 13 of these test methods.

A3.3 Speed of Testing

A3.3.1 Speed of testing shall be as prescribed in the individual product specifications.

A3.4 Hardness Tests for Externally Threaded Fasteners

A3.4.1 When specified, externally threaded fasteners shall be hardness tested. Fasteners with hexagonal or square heads shall be Brinell or Rockwell hardness tested on the side or top of the head. Externally threaded fasteners with other type of heads and those without heads shall be Brinell or Rockwell hardness tested on one end. Due to possible distortion from the Brinell load, care should be taken that this test meets the requirements of Section 16 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.

A3.4.2 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.

A3.5 Testing of Nuts

A3.5.1 *Proof Load*— A sample nut shall be assembled on a hardened threaded mandrel or on a bolt conforming to the particular specification. A load axial with the mandrel or bolt and equal to the specified proof load of the nut shall be applied. The nut shall resist this load without stripping or rupture. If the threads of the mandrel are damaged during the test the individual test shall be discarded. The mandrel shall be threaded to American National Standard Class 3 tolerance, except that the major diameter shall be the minimum major diameter with a tolerance of + 0.002 in. (0.051 mm).

A3.5.2 *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.

A3.6 Bars Heat Treated or Cold Drawn for Use in the Manufacture of Studs, Nuts or Other Bolting Material

A3.6.1 When the bars, as received by the manufacturer, have been processed and proved to meet certain specified properties, it is not necessary to test the finished product when these properties have not been changed by the process of manufacture employed for the finished product.

A4. ROUND WIRE PRODUCTS

A4.1 Scope

A4.1.1 This supplement covers the apparatus, specimens and methods of testing peculiar to steel wire products which are not covered in the general section of Test Methods A 370.

A4.2 Apparatus

A4.2.1 *Gripping Devices*—Grips of either the wedge or snubbing types as shown in Fig. A4.1 and Fig. 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 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 non-axial 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 gage length of the specimens shall be 10 in. (254 mm). However, if the determination of elongation values is not required, any convenient gage length is permissible. The total length of the specimens shall be at least equal to the gage 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. gage length specimen.

A4.3.2 Any specimen breaking in the grips shall be discarded and a new specimen tested.

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 gage 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 gage length, expressed as a percentage of the original gage length. In recording elongation values, both the percentage increase and the original gage 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 gage 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 suceptibility 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 E 4340 steel specimens[9] 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 E 23) are based on the Type A specimen of Fig. 4 of Test Methods E 23.

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 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 E 23 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

[9] Fahey, N. H., "Effects of Variables in Charpy Impact Testing," *Materials Research & Standards*, Vol 1, No. 11, November, 1961, p. 872.

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) gage 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,[10] and used by Oliver[11] 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:

$$e = e_o\,[4.47\,(\sqrt{A})/L]^a \qquad \text{(A6.1)}$$

where:

e_o = percentage elongation after fracture on a standard test specimen having a 2-in. gage length and 0.500-in. diameter,

e = percentage elongation after fracture on a standard test specimen having a gage 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) gage 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) gage length, and 0.250-in. (6.35- mm) diameter by 1.0-in. (25.4-mm) gage length the factor in the equation is 4.51 instead of 4.47. The small error introduced by using Table A6.1 for the subsized 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. gage length test specimen as the reference specimen.

A6.3.3 Elongation given for a standard 0.500-in. diameter by 2-in. gage 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.

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 A 370, consideration must be given to the metallurgical effects dependent on the thickness of the material as processed.

[10] Bertella, C. A., *Giornale del Genio Civile*, Vol 60, 1922, p. 343.

[11] Oliver, D. A., *Proceedings of the Institution of Mechanical Engineers*, 1928, p. 827.

A7. METHOD OF TESTING MULTI-WIRE STRAND FOR PRESTRESSED CONCRETE

A7.1 Scope

A7.1.1 This method provides procedures for the tension testing of multi-wire strand for prestressed concrete. This method is intended for use in evaluating the strand properties prescribed in specifications for“ prestressing steel strands.”

A7.2 General Precautions

A7.2.1 Premature failure of the test specimens may result if there is any appreciable notching, cutting, or bending of the specimen by the gripping devices of the testing machine.

A7.2.2 Errors in testing may result if the seven wires constituting the strand are not loaded uniformly.

A7.2.3 The mechanical properties of the strand may be materially affected by excessive heating during specimen preparation.

A7.2.4 These difficulties may be minimized by following the suggested methods of gripping described in A7.4.

A7.3 Gripping Devices

A7.3.1 The true mechanical properties of the strand are determined by a test in which fracture of the specimen occurs in the free span between the jaws of the testing machine. Therefore, it is desirable to establish a test procedure with suitable apparatus which will consistently produce such results.

Due to inherent physical characteristics of individual machines, it is not practical to recommend a universal gripping procedure that is suitable for all testing machines. Therefore, it is necessary to determine which of the methods of gripping described in A7.3.2 to A7.3.8 is most suitable for the testing equipment available.

A7.3.2 *Standard V-Grips with Serrated Teeth (Note A7.1).*

A7.3.3 *Standard V-Grips with Serrated Teeth (Note A7.1), Using Cushioning Material*—In this method, some material is placed between the grips and the specimen to minimize the notching effect of the teeth. Among the materials which have been used are lead foil, aluminum foil, carborundum cloth, bra shims, etc. The type and thickness of material required is dependent on the shape, condition, and coarseness of the teeth.

A7.3.4 *Standard V-Grips with Serrated Teeth (Note A7.1), Using Special Preparation of the Gripped Portions of the Specimen*—One of the methods used is tinning, in which the gripped portions are cleaned, fluxed, and coated by multiple dips in molten tin alloy held just above the melting point. Another method of preparation is encasing the gripped portions in metal tubing or flexible conduit, using epoxy resin as the bonding agent. The encased portion should be approximately twice the length of lay of the strand.

A7.3.5 *Special Grips with Smooth, Semi-Cylindrical Grooves (Note A7.2)*—The grooves and the gripped portions of the specimen are coated with an abrasive slurry which holds the specimen in the smooth grooves, preventing slippage. The slurry consists of abrasive such as Grade 3-F aluminum oxide and a carrier such as water or glycerin.

A7.3.6 *Standard Sockets of the Type Used for Wire Rope*—The gripped portions of the specimen are anchored in the sockets with zinc. The special procedures for socketing usually employed in the wire rope industry must be followed.

A7.3.7 *Dead-End Eye Splices*—These devices are available in sizes designed to fit each size of strand to be tested.

A7.3.8 *Chucking Devices*—Use of chucking devices of the type generally employed for applying tension to strands in casting beds is not recommended for testing purposes.

NOTE A7.1—The number of teeth should be approximately 15 to 30 per in., and the minimum effective gripping length should be approximately 4 in. (102 mm).

NOTE A7.2—The radius of curvature of the grooves is approximately the same as the radius of the strand being tested, and is located 1/32 in. (0.79 mm) above the flat face of the grip. This prevents the two grips from closing tightly when the specimen is in place.

A7.4 Specimen Preparation

A7.4.1 If the molten-metal temperatures employed during hot-dip tinning or socketing with metallic material are too high, over approximately 700°F (370°C), the specimen may be heat affected with a subsequent loss of strength and ductility. Careful temperature controls should be maintained if such methods of specimen preparation are used.

A7.5 Procedure

A7.5.1 *Yield Strength*— For determining the yield strength use a Class B-1 extensometer (Note A7.3) as described in Practice E 83. Apply an initial load of 10 % of the expected minimum breaking strength to the specimen, then attach the extensometer and adjust it to a reading of 0.001 in./in. of gage length. Then increase the load until the extensometer indicates an extension of 1 %. Record the load for this extension as the yield strength. The extensometer may be removed from the specimen after the yield strength has been determined.

A7.5.2 *Elongation*— For determining the elongation use a Class D extensometer (Note A7.3), as described in Practice E 83, having a gage length of not less than 24 in. (610 mm) (Note A7.4). Apply an initial load of 10 % of the required minimum breaking strength to the specimen, then attach the extensometer (Note A7.3) and adjust it to a zero reading. The extensometer may be removed from the specimen prior to rupture after the specified minimum elongation has been exceeded. It is not necessary to determine the final elongation value.

A7.5.3 *Breaking Strength*—Determine the maximum load at which one or more wires of the strand are fractured. Record this load as the breaking strength of the strand.

NOTE A7.3—The yield-strength extensometer and the elongation extensometer may be the same instrument or two separate instruments. Two separate instruments are advisable since the more sensitive yield-strength extensometer, which could be damaged when the strand fractures, may be removed following the determination of yield strength. The elongation extensometer may be constructed with less sensitive parts or be constructed in such a way that little damage would result if fracture occurs while the extensometer is attached to the specimen.

NOTE A7.4—Specimens that break outside the extensometer or in the jaws and yet meet the minimum specified values are considered as meeting the mechanical property requirements of the product specification, regardless of what procedure of gripping has been used. Specimens that break outside of the extensometer or in the jaws and do not meet the minimum specified values are subject to retest. Specimens that break between the jaws and the extensometer and do not meet the minimum specified values are subject to retest as provided in the applicable specification.

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 E 29 shall be used.

A8.1.1.1 Values shall be rounded up or rounded down as determined by the rules of Practice E 29.

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 E 29 would cause rejection ofmaterial.

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.

A9. METHODS FOR TESTING STEEL REINFORCING BARS

A9.1 Scope

A9.1.1 This annex covers additional details specific to testing steel reinforcing bars for use in concrete reinforcement.

A9.2 Test Specimens

A9.2.1 All test specimens shall be the full section of the bar as rolled.

A9.3 Tension Testing

A9.3.1 *Test Specimen*— Specimens for tension tests shall be long enough to provide for an 8-in. (200-mm) gage length, a distance of at least two bar diameters between each gage mark and the grips, plus sufficient additional length to fill the grips completely leaving some excess length protruding beyond each grip.

A9.3.2 *Gripping Device*— The grips shall be shimmed so that no more than ½ in. (13 mm) of a grip protrudes from the head of the testing machine.

A9.3.3 *Gage Marks*— The 8-in. (200-mm) gage length shall be marked on the specimen using a preset 8-in. (200-mm) punch or, alternately, may be punch marked every 2 in. (50 mm) along the 8-in. (200-mm) gage length, on one of the longitudinal ribs, if present, or in clear spaces of the deformation pattern. The punch marks shall not be put on a transverse deformation. Light punch marks are desirable because deep marks severely indent the bar and may affect the results. A bullet-nose punch is desirable.

A9.3.4 The yield strength or yield point shall be determined by one of the following methods:

A9.3.4.1 Extension under load using an autographic diagram method or an extensometer as described in 13.1.2 and 13.1.3,

A9.3.4.2 By the drop of the beam or halt in the gage of the testing machine as described in 13.1.1 where the steel tested as a sharp-kneed or well-defined type of yield point.

A9.3.5 The unit stress determinations for yield and tensile strength on full-size specimens shall be based on the nominal bar area.

A9.4 Bend Testing

A9.4.1 Bend tests shall be made on specimens of sufficient length to ensure free bending and with apparatus which provides:

A9.4.1.1 Continuous and uniform application of force throughout the duration of the bending operation,

A9.4.1.2 Unrestricted movement of the specimen at points of contact with the apparatus and bending around a pin free to rotate, and

A9.4.1.3 Close wrapping of the specimen around the pin during the bending operation.

A9.4.2 Other acceptable more severe methods of bend testing, such as placing a specimen across two pins free to rotate and applying the bending force with a fix pin, may be used.

A9.4.3 When re-testing is permitted by the product specification, the following shall apply:

A9.4.3.1 Sections of bar containing identifying roll marking shall not be used.

A9.4.3.2 Bars shall be so placed that longitudinal ribs lie in a plane at right angles to the plane of bending.

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*[12]:

ASME Boiler and Pressure Vessel Code Section III, latest edition.

[12] Available from American Society of Mechanical Engineers, 345 E. 47th St., New York, NY 10017

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 deg apart if the material specification requires test locations 180 deg 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 deg 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.

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 ±25°F (±14°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) (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) (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°F (14°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) (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 infra red 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 10 years or as designed by the customer. Information shall be so organized that all practices can be verified by adequate documented records.

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.^{2}	Multiplying Factor	Actual Diameter, in.	Area, in.^{2}	Multiplying Factor	Actual Diameter, in.	Area, in.^{2}	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
							(0.05)[A]	(20.0)[A]
0.497	0.1940	5.15	0.350	0.0962	10.39	0.252	0.0499	20.05
							(0.05)[A]	(20.0)[A]
0.498	0.1948	5.13	0.351	0.0968	10.33	0.253	0.0503	19.89
							(0.05)[A]	(20.0)[A]
0.499	0.1956	5.11	0.352	0.0973	10.28	0.254	0.0507	19.74
0.500	0.1963	5.09	0.353	0.0979	10.22	0.255	0.0511	19.58
0.501	0.1971	5.07	0.354	0.0984	10.16			
0.502	0.1979	5.05	0.355	0.0990	10.10			
0.503	0.1987	5.03	0.356	0.0995	10.05			
				(0.1)[A]	(10.0)[A]			
0.504	0.1995	5.01	0.357	0.1001	9.99			
	(0.2)[A]	(5.0)[A]		(0.1)[A]	(10.0)[A]			
0.505	0.2003	4.99						
	(0.2)[A]	(5.0)[A]						
0.506	0.2011	4.97						
	(0.2)[A]	(5.0)[A]						
0.507	0.2019	4.95						
0.508	0.2027	4.93						
0.509	0.2035	4.91						
0.510	0.2043	4.90						

[A] 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.

TABLE 2 Approximate Hardness Conversion Numbers for Nonaustenitic Steels[A] (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			
					15N Scale, 15-kgf Load, Diamond Penetrator	30N Scale 30-kgf Load, Diamond Penetrator	45N Scale, 45-kgf Load, Diamond Penetrator	Approximate Tensile Strength, ksi (MPa)
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)

[A] 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 3 Approximate Hardness Conversion Numbers for Nonaustenitic Steels[A] (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 and 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	...

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 and 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	
32	...	...	89	27.4	75.2	71.0	37.6	4.6	...
31	...	...	88	27.0	74.6	70.7	37.0	3.6	...
30	...	...	87	26.6	74.0	70.4	36.3	2.6	...

[A] 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

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

TABLE 6 Brinell Hardness Numbers[A]

(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*	2.60	92.6	278	555	3.20	60.5	182	363	3.80	42.4	127	255
2.01	*156*	*468*	*936*	2.61	91.8	276	551	3.21	60.1	180	361	3.81	42.2	127	253
2.02	*154*	*463*	*926*	2.62	91.1	273	547	3.22	59.8	179	359	3.82	42.0	126	252
2.03	*153*	*459*	*917*	2.63	90.4	271	543	3.23	59.4	178	356	3.83	41.7	125	250
2.04	*151*	*454*	*908*	2.64	89.7	269	538	3.24	59.0	177	354	3.84	41.5	125	249
2.05	*150*	*450*	*899*	2.65	89.0	267	534	3.25	58.6	176	352	3.85	41.3	124	248
2.06	*148*	*445*	*890*	2.66	88.4	265	530	3.26	58.3	175	350	3.86	41.1	123	246
2.07	*147*	*441*	*882*	2.67	87.7	263	526	3.27	57.9	174	347	3.87	40.9	123	245
2.08	*146*	*437*	*873*	2.68	87.0	261	522	3.28	57.5	173	345	3.88	40.6	122	244
2.09	*144*	*432*	*865*	2.69	86.4	259	518	3.29	57.2	172	343	3.89	40.4	121	242
2.10	*143*	*428*	*856*	2.70	85.7	257	514	3.30	56.8	170	341	3.90	40.2	121	241
2.11	*141*	*424*	*848*	2.71	85.1	255	510	3.31	56.5	169	339	3.91	40.0	120	240
2.12	*140*	*420*	*840*	2.72	84.4	253	507	3.32	56.1	168	337	3.92	39.8	119	239
2.13	*139*	*416*	*832*	2.73	83.8	251	503	3.33	55.8	167	335	3.93	39.6	119	237
2.14	*137*	*412*	*824*	2.74	83.2	250	499	3.34	55.4	166	333	3.94	39.4	118	236
2.15	*136*	*408*	*817*	2.75	82.6	248	495	3.35	55.1	165	331	3.95	39.1	117	235
2.16	*135*	*404*	*809*	2.76	81.9	246	492	3.36	54.8	164	329	3.96	38.9	117	234
2.17	*134*	*401*	*802*	2.77	81.3	244	488	3.37	54.4	163	326	3.97	38.7	116	232
2.18	*132*	*397*	*794*	2.78	80.8	242	485	3.38	54.1	162	325	3.98	38.5	116	231
2.19	*131*	*393*	*787*	2.79	80.2	240	481	3.39	53.8	161	323	3.99	38.3	115	230
2.20	*130*	*390*	*780*	2.80	79.6	239	477	3.40	53.4	160	321	4.00	38.1	114	229
2.21	*129*	*386*	*772*	2.81	79.0	237	474	3.41	53.1	159	319	4.01	37.9	114	228
2.22	*128*	*383*	*765*	2.82	78.4	235	471	3.42	52.8	158	317	4.02	37.7	113	226
2.23	*126*	*379*	*758*	2.83	77.9	234	467	3.43	52.5	157	315	4.03	37.5	113	225
2.24	*125*	*376*	*752*	2.84	77.3	232	464	344	52.2	156	313	4.04	37.3	112	224
2.25	*124*	*372*	*745*	2.85	76.8	230	461	3.45	51.8	156	311	4.05	37.1	111	223
2.26	*123*	*369*	*738*	2.86	76.2	229	457	3.46	51.5	155	309	4.06	37.0	111	222
2.27	*122*	*366*	*732*	2.87	75.7	227	454	3.47	51.2	154	307	4.07	36.8	110	221
2.28	*121*	*363*	*725*	2.88	75.1	225	451	3.48	50.9	153	306	4.08	36.6	110	219
2.29	*120*	*359*	*719*	2.89	74.6	224	448	3.49	50.6	152	304	4.09	36.4	109	218
2.30	*119*	*356*	*712*	2.90	74.1	222	444	3.50	50.3	151	302	4.10	36.2	109	217
2.31	*118*	*353*	*706*	2.91	73.6	221	441	3.51	50.0	150	300	4.11	36.0	108	216
2.32	*117*	*350*	*700*	2.92	73.0	219	438	3.52	49.7	149	298	4.12	35.8	108	215
2.33	*116*	*347*	*694*	2.93	72.5	218	435	3.53	49.4	148	297	4.13	35.7	107	214
2.34	*115*	*344*	*688*	2.94	72.0	216	432	3.54	49.2	147	295	4.14	35.5	106	213
2.35	*114*	*341*	*682*	2.95	71.5	215	429	3.55	48.9	147	293	4.15	35.3	106	212
2.36	*113*	*338*	*676*	2.96	71.0	213	426	3.56	48.6	146	292	4.16	35.1	105	211
2.37	*112*	*335*	*670*	2.97	70.5	212	423	3.57	48.3	145	290	4.17	34.9	105	210
2.38	*111*	*332*	*665*	2.98	70.1	210	420	3.58	48.0	144	288	4.18	34.8	104	209
2.39	*110*	*330*	*659*	2.99	69.6	209	417	3.59	47.7	143	286	4.19	34.6	104	208
2.40	*109*	*327*	*653*	3.00	69.1	207	415	3.60	47.5	142	285	4.20	34.4	103	207
2.41	*108*	*324*	*648*	3.01	68.6	206	412	3.61	47.2	142	283	4.21	34.2	103	205
2.42	*107*	*322*	*643*	3.02	68.2	205	409	3.62	46.9	141	282	4.22	34.1	102	204
2.43	*106*	*319*	*637*	3.03	67.7	203	406	3.63	46.7	140	280	4.23	33.9	102	203
2.44	*105*	*316*	*632*	3.04	67.3	202	404	3.64	46.4	139	278	4.24	33.7	101	202
2.45	*104*	*313*	*627*	3.05	66.8	200	401	3.65	46.1	138	277	4.25	33.6	101	201
2.46	*104*	*311*	*621*	3.06	66.4	199	398	3.66	45.9	138	275	4.26	33.4	100	200
2.47	*103*	*308*	*616*	3.07	65.9	198	395	3.67	45.6	137	274	4.27	33.2	99.7	199
2.48	*102*	*306*	*611*	3.08	65.5	196	393	3.68	45.4	136	272	4.28	33.1	99.2	198
2.49	*101*	*303*	*606*	3.09	65.0	195	390	3.69	45.1	135	271	4.29	32.9	98.8	198
2.50	100	301	601	3.10	64.6	194	388	3.70	44.9	135	269	4.30	32.8	98.3	197
2.51	99.4	298	597	3.11	64.2	193	385	3.71	44.6	134	268	4.31	32.6	97.8	196
2.52	98.6	296	592	3.12	63.8	191	383	3.72	44.4	133	266	4.32	32.4	97.3	195
2.53	97.8	294	587	3.13	63.3	190	380	3.73	44.1	132	265	4.33	32.3	96.8	194
2.54	97.1	291	582	3.14	62.9	189	378	3.74	43.9	132	263	4.34	32.1	96.4	193
2.55	96.3	289	578	3.15	62.5	188	375	3.75	43.6	131	262	4.35	32.0	95.9	192
2.56	95.5	287	573	3.16	62.1	186	373	3.76	43.4	130	260	4.36	31.8	95.5	191
2.57	94.8	284	569	3.17	61.7	185	370	3.77	43.1	129	259	4.37	31.7	95.0	190
2.58	94.0	282	564	3.18	61.3	184	368	3.78	42.9	129	257	4.38	31.5	94.5	189
2.59	93.3	280	560	3.19	60.9	183	366	3.79	42.7	128	256	4.39	31.4	94.1	188
4.40	31.2	93.6	187	5.05	23.3	69.8	140	5.70	17.8	53.5	107	6.35	*14.0*	*42.0*	*84.0*
4.41	31.1	93.2	186	5.06	23.2	69.5	139	5.71	17.8	53.3	107	6.36	*13.9*	*41.8*	*83.7*
4.42	30.9	92.7	185	5.07	23.1	69.2	138	5.72	17.7	53.1	106	6.37	*13.9*	*41.7*	*83.4*
4.43	30.8	92.3	185	5.08	23.0	68.9	138	5.73	17.6	52.9	106	6.38	*13.8*	*41.5*	*83.1*
4.44	30.6	91.8	184	5.09	22.9	68.6	137	5.74	17.6	52.7	105	6.39	*13.8*	*41.4*	*82.8*
4.45	30.5	91.4	183	5.10	22.8	68.3	137	5.75	17.5	52.5	105	6.40	*13.7*	*41.2*	*82.5*
4.46	30.3	91.0	182	5.11	22.7	68.0	136	5.76	17.4	52.3	105	6.41	*13.7*	*41.1*	*82.2*
4.47	30.2	90.5	181	5.12	22.6	67.7	135	5.77	17.4	52.1	104	6.42	*13.6*	*40.9*	*81.9*
4.48	30.0	90.1	180	5.13	22.5	67.4	135	5.78	17.3	51.9	104	6.43	*13.6*	*40.8*	*81.6*

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
4.49	29.9	89.7	179	5.14	22.4	67.1	134	5.79	17.2	51.7	103	6.44	*13.5*	*40.6*	*81.3*
4.50	29.8	89.3	179	5.15	22.3	66.9	134	5.80	17.2	51.5	103	6.45	*13.5*	*40.5*	*81.0*
4.51	29.6	88.8	178	5.16	22.2	66.6	133	5.81	17.1	51.3	103	6.46	*13.4*	*40.4*	*80.7*
4.52	29.5	88.4	177	5.17	22.1	66.3	133	5.82	17.0	51.1	102	6.47	*13.4*	*40.2*	*80.4*
4.53	29.3	88.0	176	5.18	22.0	66.0	132	5.83	17.0	50.9	102	6.48	*13.4*	*40.1*	*80.1*
4.54	29.2	87.6	175	5.19	21.9	65.8	132	5.84	16.9	50.7	101	6.49	*13.3*	*39.9*	*79.8*
4.55	29.1	87.2	174	5.20	21.8	65.5	131	5.85	16.8	50.5	101	6.50	*13.3*	*39.8*	*79.6*
4.56	28.9	86.8	174	5.21	21.7	65.2	130	5.86	16.8	50.3	101	6.51	*13.2*	*39.6*	*79.3*
4.57	28.8	86.4	173	5.22	21.6	64.9	130	5.87	16.7	50.2	100	6.52	*13.2*	*39.5*	*79.0*
4.58	28.7	86.0	172	5.23	21.6	64.7	129	5.88	16.7	50.0	99.9	6.53	*13.1*	*39.4*	*78.7*
4.59	28.5	85.6	171	5.24	21.5	64.4	129	5.89	16.6	49.8	99.5	6.54	*13.1*	*39.2*	*78.4*
4.60	28.4	85.4	170	5.25	21.4	64.1	128	5.90	16.5	49.6	99.2	6.55	*13.0*	*39.1*	*78.2*
4.61	28.3	84.8	170	5.26	21.3	63.9	128	5.91	16.5	49.4	98.8	6.56	*13.0*	*38.9*	*78.0*
4.62	28.1	84.4	169	5.27	21.2	63.6	127	5.92	16.4	49.2	98.4	6.57	*12.9*	*38.8*	*77.6*
4.63	28.0	84.0	168	5.28	21.1	63.3	127	5.93	16.3	49.0	98.0	6.58	*12.9*	*38.7*	*77.3*
4.64	27.9	83.6	167	5.29	21.0	63.1	126	5.94	16.3	48.8	97.7	6.59	*12.8*	*38.5*	*77.1*
4.65	27.8	83.3	167	5.30	20.9	62.8	126	5.95	16.2	48.7	97.3	6.60	*12.8*	*38.4*	*76.8*
4.66	27.6	82.9	166	5.31	20.9	62.6	125	5.96	16.2	48.5	96.9	6.61	*12.8*	*38.3*	*76.5*
4.67	27.5	82.5	165	5.32	20.8	62.3	125	5.97	16.1	48.3	96.6	6.62	*12.7*	*38.1*	*76.2*
4.68	27.4	82.1	164	5.33	20.7	62.1	124	5.98	16.0	48.1	96.2	6.63	*12.7*	*38.0*	*76.0*
4.69	27.3	81.8	164	5.34	20.6	61.8	124	5.99	16.0	47.9	95.9	6.64	*12.6*	*37.9*	*75.7*
4.70	27.1	81.4	163	5.35	20.5	61.5	123	6.00	*15.9*	47.7	95.5	6.65	*12.6*	*37.7*	*75.4*
4.71	27.0	81.0	162	5.36	20.4	61.3	123	6.01	*15.9*	47.6	95.1	6.66	*12.5*	*37.6*	*75.2*
4.72	26.9	80.7	161	5.37	20.3	61.0	122	6.02	*15.8*	47.4	94.8	6.67	*12.5*	*37.5*	*74.9*
4.73	26.8	80.3	161	5.38	20.3	60.8	122	6.03	*15.7*	47.2	94.4	6.68	*12.4*	*37.3*	*74.7*
4.74	26.6	79.9	160	5.39	20.2	60.6	121	6.04	*15.7*	47.0	94.1	6.69	*12.4*	*37.2*	*74.4*
4.75	26.5	79.6	159	5.40	20.1	60.3	121	6.05	*15.6*	46.8	93.7	6.70	*12.4*	*37.1*	*74.1*
4.76	26.4	79.2	158	5.41	20.0	60.1	120	6.06	*15.6*	46.7	93.4	6.71	*12.3*	*36.9*	*73.9*
4.77	26.3	78.9	158	5.42	19.9	59.8	120	6.07	*15.5*	46.5	93.0	6.72	*12.3*	*36.8*	*73.6*
4.78	26.2	78.5	157	5.43	19.9	59.6	119	6.08	*15.4*	46.3	92.7	6.73	*12.2*	*36.7*	*73.4*
4.79	26.1	78.2	156	5.44	19.8	59.3	119	6.09	*15.4*	46.2	92.3	6.74	*12.2*	*36.6*	*73.1*
4.80	25.9	77.8	156	5.45	19.7	59.1	118	6.10	*15.3*	46.0	92.0	6.75	*12.1*	*36.4*	*72.8*
4.81	25.8	77.5	155	5.46	19.6	58.9	118	6.11	*15.3*	45.8	91.7	6.76	*12.1*	*36.3*	*72.6*
4.82	25.7	77.1	154	5.47	19.5	58.6	117	6.12	*15.2*	45.7	91.3	6.77	*12.1*	*36.2*	*72.3*
4.83	25.6	76.8	154	5.48	19.5	58.4	117	6.13	*15.2*	45.5	91.0	6.78	*12.0*	*36.0*	*72.1*
4.84	25.5	76.4	153	5.49	19.4	58.2	116	6.14	*15.1*	45.3	90.6	6.79	*12.0*	*35.9*	*71.8*
4.85	25.4	76.1	152	5.50	19.3	57.9	116	6.15	*15.1*	45.2	90.3	6.80	*11.9*	*35.8*	*71.6*
4.86	25.3	75.8	152	5.51	19.2	57.7	115	6.16	*15.0*	45.0	90.0	6.81	*11.9*	*35.7*	*71.3*
4.87	25.1	75.4	151	5.52	19.2	57.5	115	6.17	*14.9*	44.8	89.6	6.82	*11.8*	*35.5*	*71.1*
4.88	25.0	75.1	150	5.53	19.1	57.2	114	6.18	*14.9*	44.7	89.3	6.83	*11.8*	*35.4*	*70.8*
4.89	24.9	74.8	150	5.54	19.0	57.0	114	6.19	*14.8*	44.5	89.0	6.84	*11.8*	*35.3*	*70.6*
4.90	24.8	74.4	149	5.55	18.9	56.8	114	6.20	*14.7*	44.3	88.7	6.86	*11.7*	*35.2*	*70.4*
4.91	24.7	74.1	148	5.56	18.9	56.6	113	6.21	*14.7*	44.2	88.3	6.86	*11.7*	*35.1*	*70.1*
4.92	24.6	73.8	148	5.57	18.8	56.3	113	6.22	*14.7*	44.0	88.0	6.87	*11.6*	*34.9*	*69.9*
4.93	24.5	73.5	147	5.58	18.7	56.1	112	6.23	*14.6*	43.8	87.7	6.88	*11.6*	*34.8*	*69.6*
4.94	24.4	73.2	146	5.59	18.6	55.9	112	6.24	*14.6*	43.7	87.4	6.89	*11.6*	*34.7*	*69.4*
4.95	24.3	72.8	146	5.60	18.6	55.7	111	6.25	*14.5*	43.5	87.1	6.90	*11.5*	*34.6*	*69.2*
4.96	24.2	72.5	145	5.61	18.5	55.5	111	6.26	*14.5*	43.4	86.7	6.91	*11.5*	*34.5*	*68.9*
4.97	24.1	72.2	144	5.62	18.4	55.2	110	6.27	*14.4*	43.2	86.4	6.92	*11.4*	*34.3*	*68.7*
4.98	24.0	71.9	144	5.63	18.3	55.0	110	6.28	*14.4*	43.1	86.1	6.93	*11.4*	*34.2*	*68.4*
4.99	23.9	71.6	143	5.64	18.3	54.8	110	6.29	*14.3*	42.9	85.8	6.94	*11.4*	*34.1*	*68.2*
5.00	23.8	71.3	143	5.65	18.2	54.6	109	6.30	*14.2*	42.7	85.5	6.95	*11.3*	*34.0*	*68.0*
5.01	23.7	71.0	142	5.66	18.1	54.4	109	6.31	*14.2*	42.6	85.2	6.96	*11.3*	*33.9*	*67.7*
5.02	23.6	70.7	141	5.67	18.1	54.2	108	6.32	*14.1*	42.4	84.9	6.97	*11.3*	*33.8*	*67.5*
5.03	23.5	70.4	141	5.68	18.0	54.0	108	6.33	*14.1*	42.3	84.6	6.98	*11.2*	*33.6*	*67.3*
5.04	23.4	70.1	140	5.69	17.9	53.7	107	6.34	*14.0*	42.1	84.3	6.99	*11.2*	*33.5*	*67.0*

[A] Prepared by the Engineering Mechanics Section, Institute for Standards Technology.

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 *B*, in.	Dimension *A*, 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 *B*, mm	Dimension *A*, 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

TABLE 9 Charpy V-Notch Test Acceptance Criteria for Various Sub-Size Specimens

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		⅓Size, 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]
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]

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.^{3} 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 ⅝ (16)	Up to 1½(38), incl	Full section by 8-in. (203-mm) gage length (Fig. 4).	Mill reduced section to 2-in. (51-mm) gage 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. (203-mm) gage length (Fig. 4).	Mill reduced section to 2-in. gage length and 1½ in. wide.
⅝ to 1½ (16 to 38), excl	Up to 1½ (38), incl	Full section by 8-in. gage length or machine standard ½ by 2-in. (13 by 51-mm) gage length specimen from center of section (Fig. 5).	Mill reduced section to 2-in. (51-mm) gage length and approximately 25% less than test specimen width or machine standard ½ by 2-in. (13 by 51-mm) gage length specimen from center of section (Fig. 5).
	Over 1½ (38)	Full section, or mill 1½ in. (38 mm) width by 8-in. (203-mm) gage length (Fig. 4) or machine standard ½by 2-in. gage (13 by 51-mm) gage length specimen from midway between edge and center of section (Fig. 5).	Mill reduced section to 2-in. gage length and 1½ in. wide or machine standard ½ by 2-in. gage length specimen from midway between edge and center of section (Fig. 5).
1½ (38) and over		Full section by 8-in. (203-mm) gage length, or machine standard ½ by 2-in. (13 by 51-mm) gage length specimen from midway between surface and center (Fig. 5).	Machine standard ½ by 2-in. (13 by 51-mm) gage length specimen from midway between surface and center (Fig. 5).

Diameter or Distance Between Parallel Faces, in. (mm)	Hot-Rolled Bars	Cold-Finished Bars
	Rounds, Squares, Hexagons, and Octagons	
Under ⅝	Full section by 8-in. (203-mm) gage length on machine to sub-size specimen (Fig. 5).	Machine to sub-size specimen (Fig. 5).
⅝ to 1½ (16 to 38), excl	Full section by 8-in. (203-mm) gage length or machine standard ½in. by 2-in. (13 by 51-mm) gage length specimen from center of section (Fig. 5).	Machine standard ½ in. by 2-in. gage length specimen from center of section (Fig. 5).
1½ (38) and over	Full section by 8-in. (203-mm) gage length or machine standard ½ in. by 2-in. (13 by 51-mm) gage length specimen from midway between surface and center of section (Fig. 5).	Machine standard ½ in. by 2-in. (13 by 51-mm gage length specimen from midway between surface and center of section (Fig. 5)).
	Other Bar-Size Sections	
All sizes	Full section by 8-in. (203-mm) gage length or prepare test specimen 1½ in. (38 mm) wide (if possible) by 8-in. (203-mm) gage length.	Mill reduced section to 2-in. (51-mm) gage 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 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.

TABLE A2.1 Wall Thickness Limitations of Superficial Hardness Test on Annealed or Ductile Materials for Steel Tubular Products[A]
("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

[A] 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[A]
("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

[A] The heaviest load recommended for a given wall thickness is generally used.

TABLE A5.1 Effect of Varying Notch Dimensions on Standard Specimens

	High-Energy Specimens, ft·lbf (J)	High-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)[A]	72.2 (97.9)	41.3 (56.0)	11.4 (15.5)
Depth of notch, 0.0805 in. (2.04 mm)[A]	75.1 (101.8)	42.2 (57.2)	12.4 (16.8)
Depth of notch, 0.0775 in. (1.77 mm)[A]	76.8 (104.1)	45.3 (61.4)	12.7 (17.2)
Depth of notch, 0.074 in. (1.57 mm)[A]	79.6 (107.9)	46.0 (62.4)	12.8 (17.3)
Radius at base of notch, 0.005 in. (0.127 mm)[B]	72.3 (98.0)	41.7 (56.5)	10.8 (14.6)
Radius at base of notch, 0.015 in. (0.381 mm)[B]	80.0 (108.5)	47.4 (64.3)	15.8 (21.4)

[A] Standard 0.079 ± 0.002 in. (2.00 ± 0.05 mm).
[B] Standard 0.010 ± 0.001 in. (0.25 ± 0.025 mm).

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. Gage Length Standard Tension Test Specimen to Standard ½ by 2-in. and 1½ by 8-in. Flat Specimens

Thickness, in.	½by 2-in. Specimen	1½by 8-in. Specimen	Thickness in.	1½by 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	...	...

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. Gage Length Standard Tension Test Specimen to Standard ½ by 2-in. and 1½ by 8-in. Flat Specimens

Thickness, in.	½by 2-in. Specimen	1½by 8-in. Specimen	Thickness, in.	1½by 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	...	...

TABLE A8.1 Recommended Values for Rounding Test Data

Test Quantity	Test Data Range	Rounded Value[A]
Yield Point, Yield Strength, Tensile Strength	up to 50 000 psi, excl (up to 50 ksi) 50 000 to 100 000 psi, excl (50 to 100 ksi) 100 000 psi and above (100 ksi and above)	100 psi (0.1 ksi) 500 psi (0.5 ksi) 1000 psi (1.0 ksi)
	up to 500 MPa, excl 500 to 1000 MPa, excl 1000 MPa and above	1 MPa 5 MPa 10 MPa
Elongation	0 to 10 %, excl 10 % and above	0.5 % 1 %
Reduction of Area	0 to 10 %, excl 10 % and above	0.5 % 1 %
Impact Energy	0 to 240 ft·lbf (or 0 to 325 J)	1 ft·lbf (or 1 J)[B]
Brinell Hardness	all values	tabular value[C]
Rockwell Hardness	all scales	1 Rockwell Number

[A] 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.

[B] These units are not equivalent but the rounding occurs in the same numerical ranges for each. (1 ft·lbf = 1.356 J.)

[C] 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.

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						

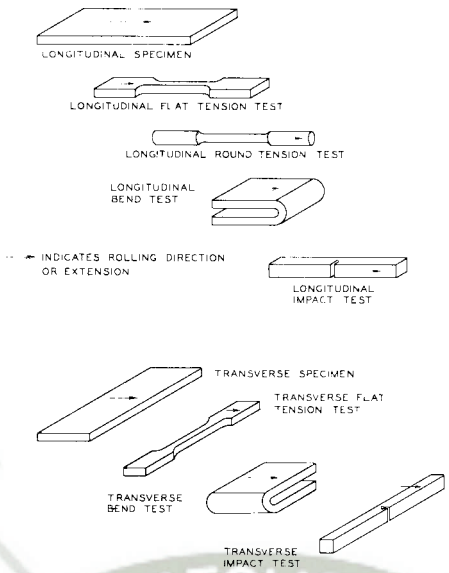
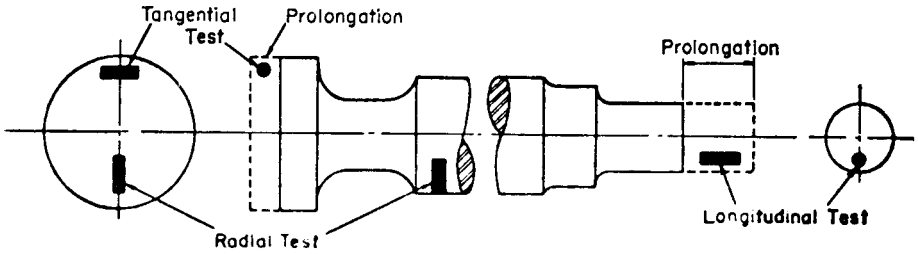
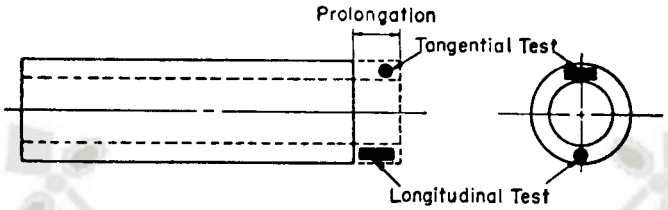


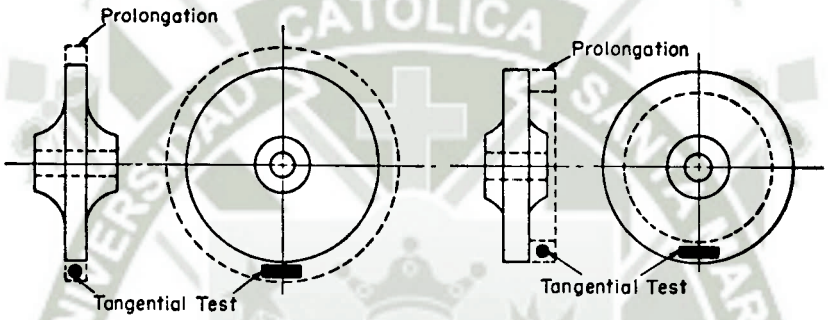
FIG. 1 The Relation of Test Coupons and Test Specimens to Rolling Direction or Extension (Applicable to General Wrought Products)



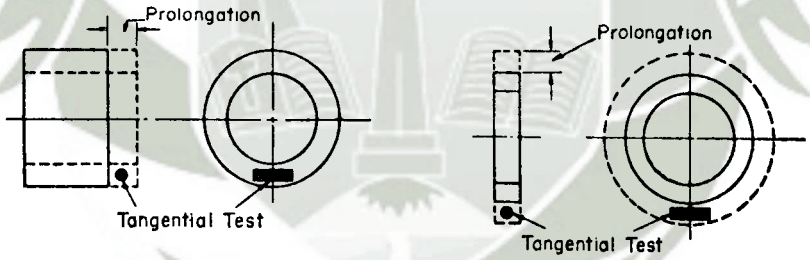
(a) Shafts and Rotors



(b) Hollow Forgings.

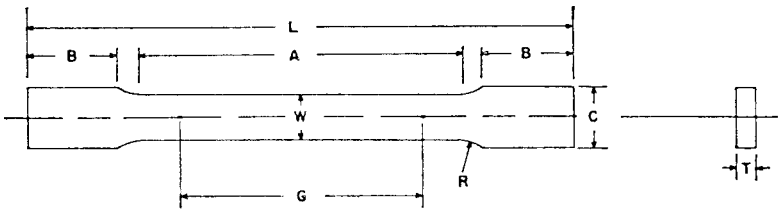


(c) Disk Forgings



(d) Ring Forgings.

FIG. 2 Locations of Test Specimens for Various Types of Forgings



DIMENSIONS

	Standard Specimens				Subsize Specimen	
	Plate-Type, 1½-in. Wide		Sheet-Type, ½-in. Wide		¼-in. Wide	
	in.	mm	in.	mm	in.	mm
G—Gage length (Notes 1 and 2)	8.00 ± 0.01	200 ± 0.25	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	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	¼	6
L—Over-all length, min (Notes 2 and 8)	18	450	8	200	4	100
A—Length of reduced section, min	9	225	2¼	60	1¼	32
B—Length of grip section, min (Note 9)	3	75	2	50	1¼	32
C—Width of grip section, approximate (Notes 4, 10, and 11)	2	50	¾	20	⅜	10

NOTE 1—For the 1½-in. (40-mm) wide specimen, 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. Either 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.

NOTE 2—For the ½-in. (12.5-mm) wide specimen, gage marks for measuring the elongation after fracture shall be made on the ½-inch (12.5-mm) face or on the edge of the specimen and within the reduced section. Either a set of three or more marks 1.0 in. (25 mm) apart or one or more pairs of marks 2 in. (50 mm) apart may be used.

NOTE 3—For the three sizes of specimens, the ends of the reduced section shall not differ in width by more than 0.004, 0.002 or 0.001 in. (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., 0.005 in., or 0.003 in. (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 three 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 material specifications. Minimum nominal thickness of 1½-in. (40-mm) wide specimens shall be 3⁄16 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 ¾in. (19 mm) and ¼ in. (6 mm), respectively.

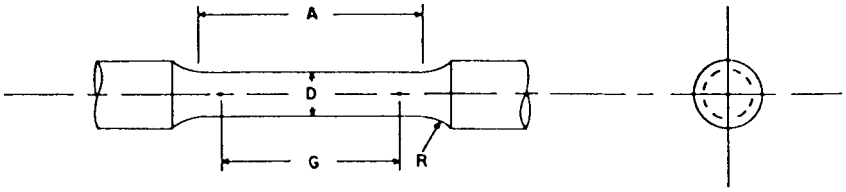
NOTE 8—To aid in obtaining axial loading during testing of ¼-in. (6-mm) wide specimens, the over-all length should be as the material will permit.

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. However, 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—Gage 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	⅜	10	¼	6	3/16	5	5/32	4	3/32	2
A—Length of reduced section, min (Note 2)	2¼	60	1¾	45	1¼	32	¾	20	⅝	16

NOTE 1—The reduced section may have a gradual taper from the ends toward the center, with the ends not more than 1 percent 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 gage length. Reference marks for the measurement of elongation should, nevertheless, be spaced at the indicated gage length.

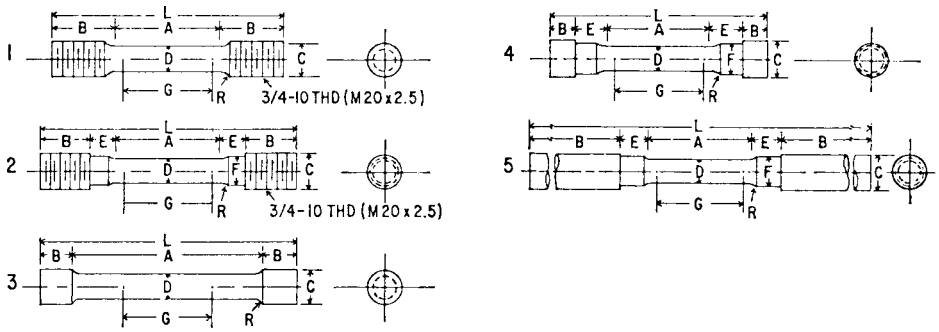
NOTE 3—The gage length and fillets shall be as shown, but the ends may be of any form to fit the holders of the testing machine in such a way that the load shall be axial (see Fig. 9). If the ends are to be held in wedge grips it is desirable, if possible, to make the length of the grip section great 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 gage 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 $in.^2$, 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) Gage Length and Examples of Small-Size Specimens Proportional to the Standard Specimens



DIMENSIONS

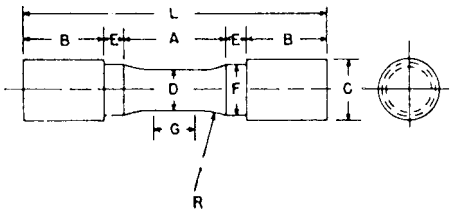
	Specimen 1		Specimen 2		Specimen 3		Specimen 4		Specimen 5	
	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm
G—Gage length	2.000± 0.005	50.0 ± 0.10	2.000± 0.005	50.0 ± 0.10	2.000± 0.005	50.0 ± 0.10	2.000± 0.005	50.0 ± 0.10	2.00± 0.005	50.0 ± 0.10
D—Diameter (Note 1)	0.500 ± 0.010	12.5± 0.25	0.500 ± 0.010	12.5± 0.25	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	⅜	10	⅜	10	1/16	2	⅜	10	⅜	10
A—Length of reduced section	2¼, min	60, min	2¼, min	60, min	4, approximately	100, approximately	2¼, min	60, min	2¼, min	60, min
L—Over-all length, approximate	5	125	5½	140	5½	140	4¾	120	9½	240
B—Grip section (Note 2)	1⅜, approximately	35, approximately	1, approximately	25, approximately	¾, approximately	20, approximately	½, approximately	13, approximately	3, min	75, min
C—Diameter of end section	¾	20	¾	20	23/32	18	⅞	22	¾	20
E—Length of shoulder and fillet section, approximate	...	...	⅝	16	...	...	¾	20	⅝	16
F—Diameter of shoulder	...	...	⅝	16	...	...	⅝	16	19/32	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 (¾by 16, ½ by 20, ⅜ by 24, and ¼ 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 *D*					
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	1¼	32	1½	38	2¼	60
L—Over-all length, min	3¾	95	4	100	6⅜	160
B—Grip section, approximate	1	25	1	25	1¾	45
C—Diameter of end section, approximate	¾	20	1⅛	30	1⅞	48
E—Length of shoulder, min	¼	6	¼	6	5/16	8
F—Diameter of shoulder	⅝ ± 1/64	16.0 ± 0.40	15/16 ± 1/64	24.0 ± 0.40	1 7/16 ± 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

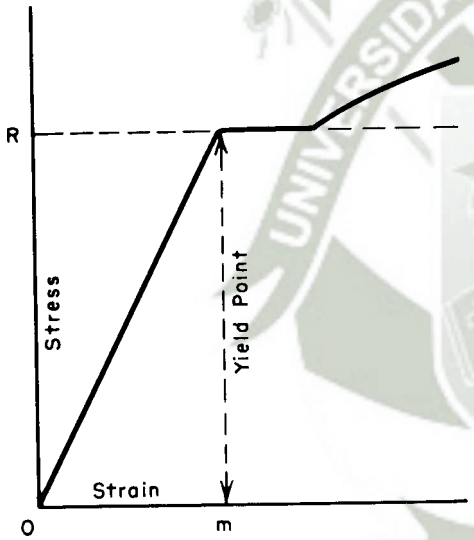


FIG. 7 Stress-Strain Diagram Showing Yield Point Corresponding with Top of Knee

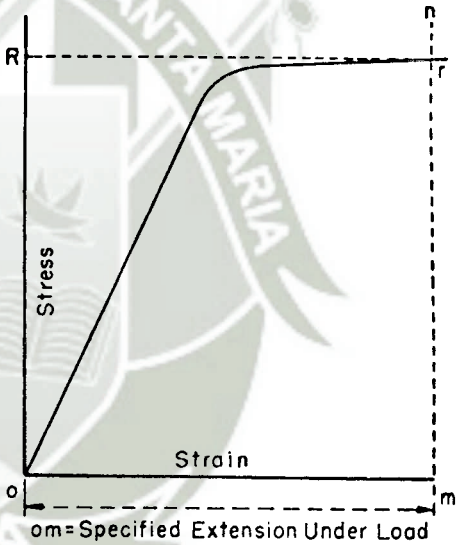


FIG. 8 Stress-Strain Diagram Showing Yield Point or Yield Strength by Extension Under Load Method

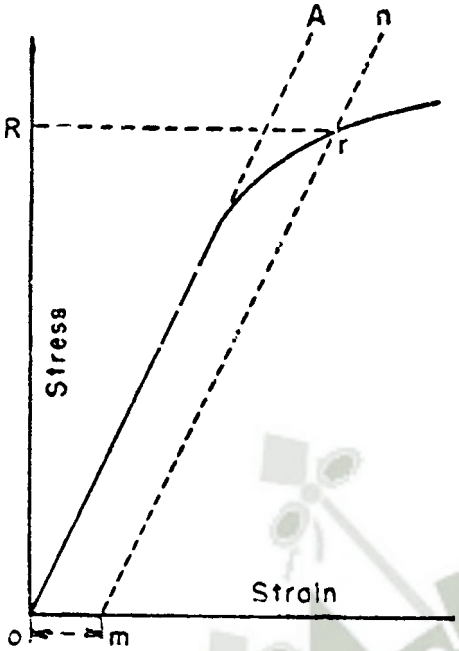
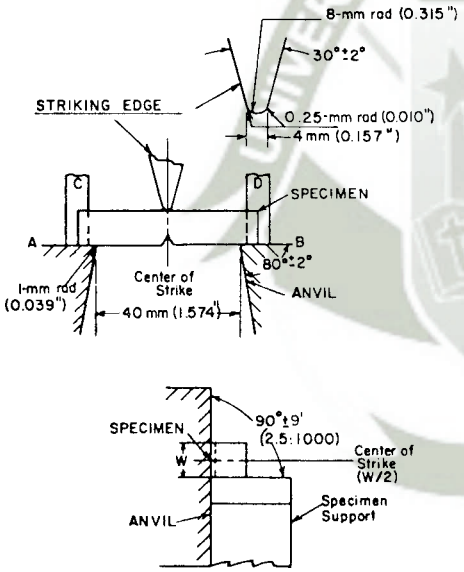


FIG. 9 Stress-Strain Diagram for Determination of Yield Strength by the Offset Method



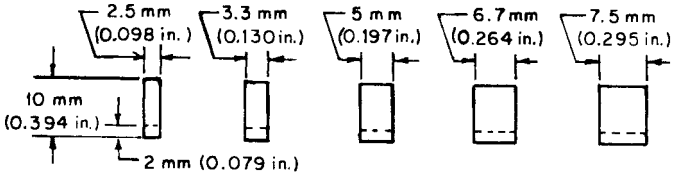
All dimensional tolerances shall be ±0.05 mm (0.002 in.) unless otherwise specified.

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.).

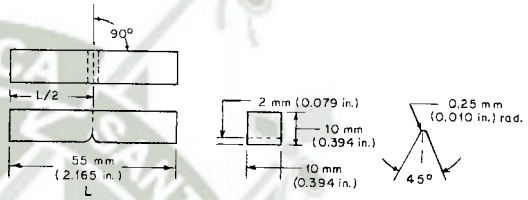
FIG. 10 Charpy (Simple-Beam) Impact Test



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

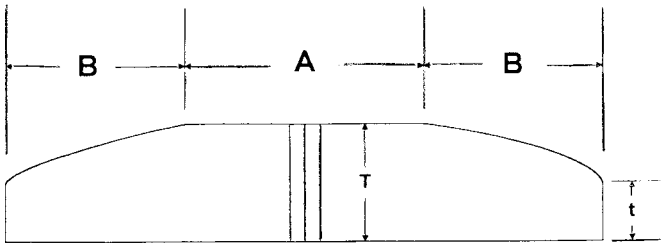
(*a*) Standard Full Size Specimen



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 %.

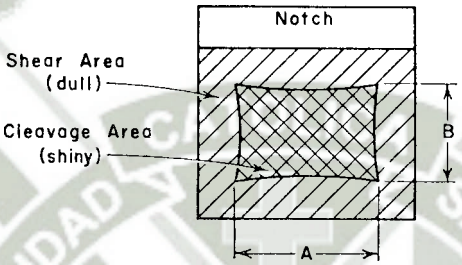
(*b*) Standard Subsize Specimens

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	½ T Minimum

FIG. 12 Tubular Impact Specimen Containing Original OD Surface



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

FIG. 14 Fracture Appearance Charts and Percent Shear Fracture Comparator

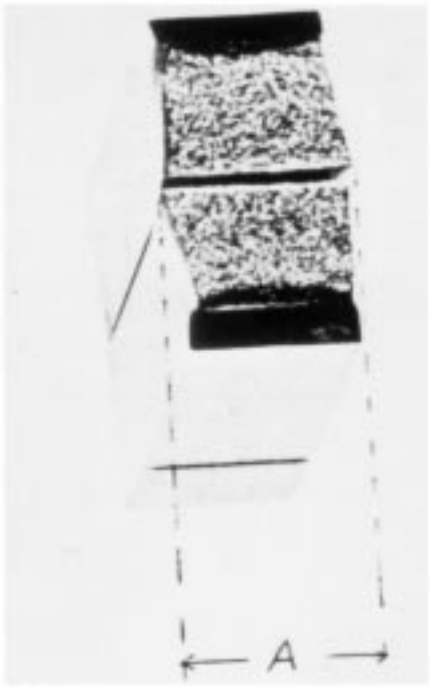


FIG. 15 Halves of Broken Charpy V-Notch Impact Specimen Joined for the Measurement of Lateral Expansion, Dimension *A*

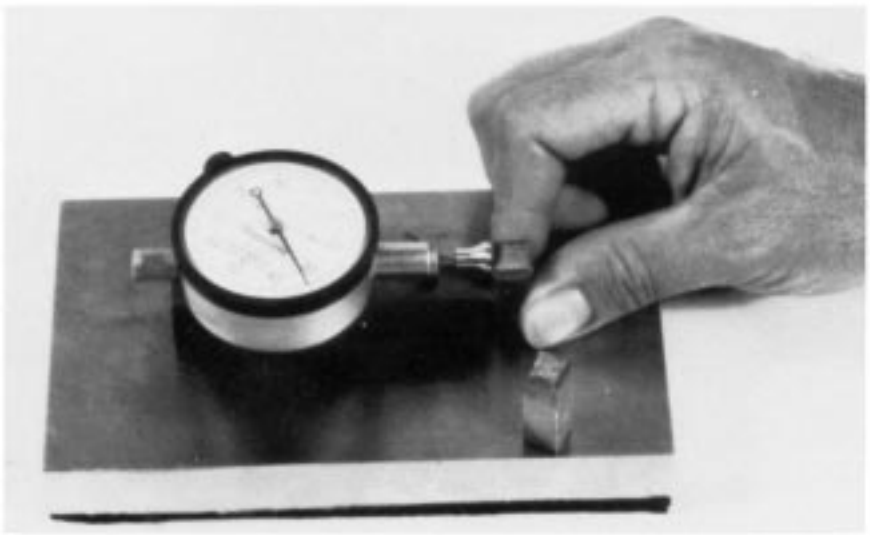


FIG. 16 Lateral Expansion Gage for Charpy Impact Specimens

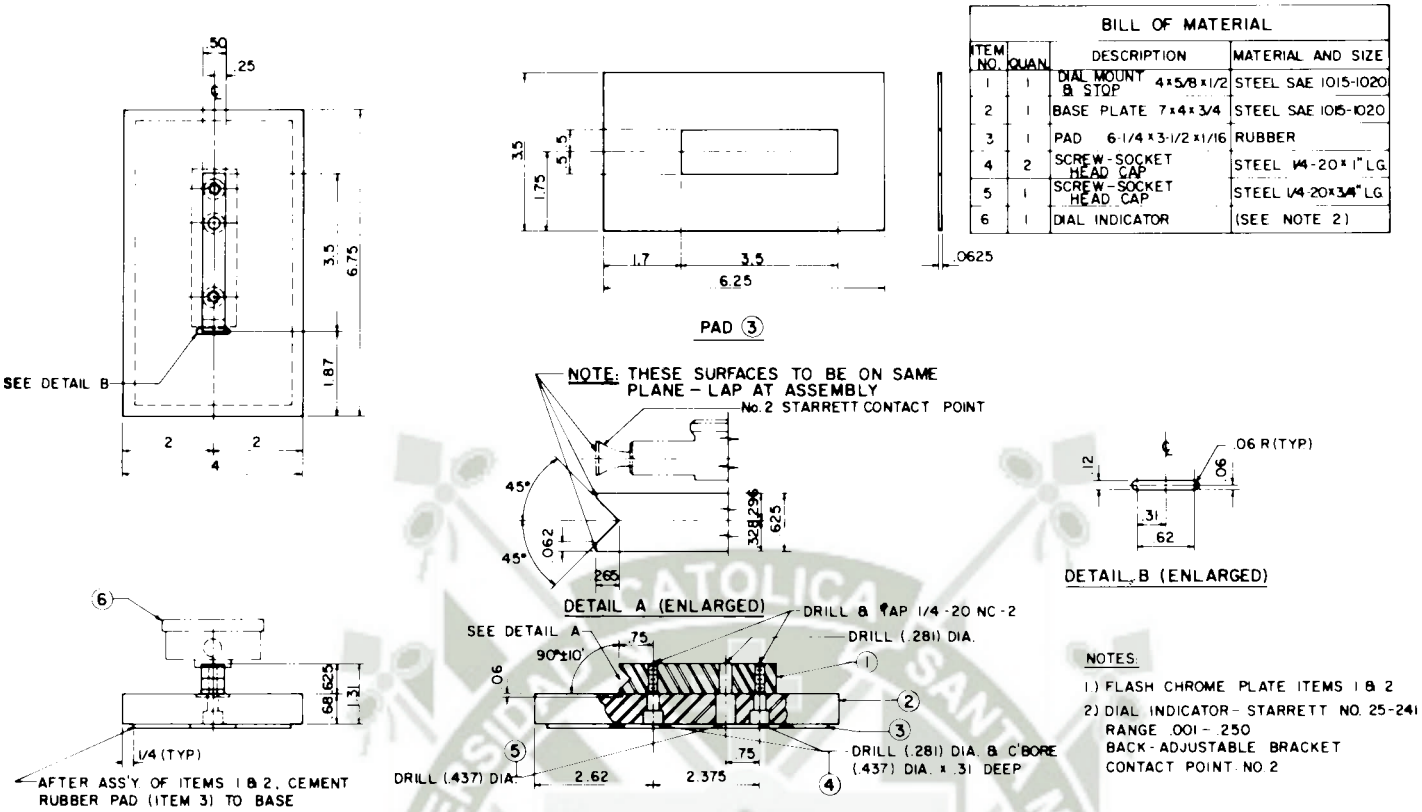


FIG. 17 Assembly and Details for Lateral Expansion Gage

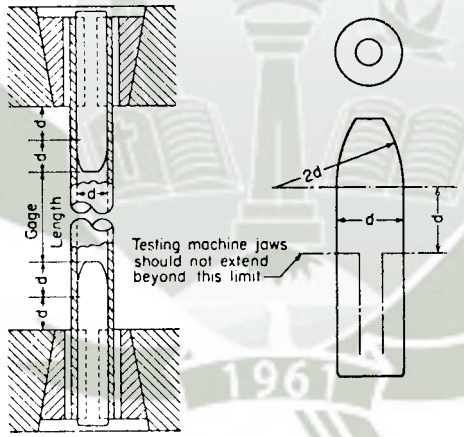
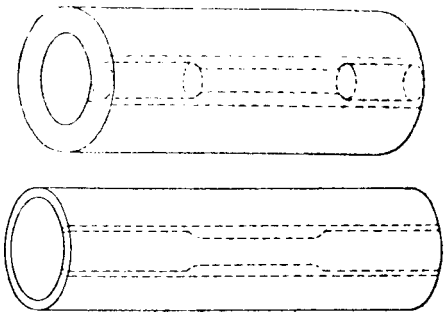
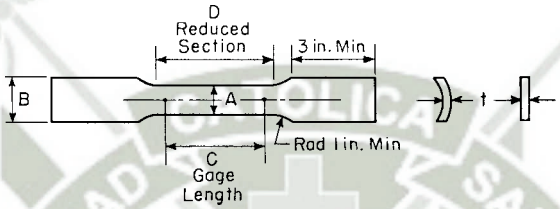


FIG. A2.1 Metal Plugs for Testing Tubular Specimens, Proper Location of Plugs in Specimen and of Specimen in Heads of Testing Machine



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 Tubing



DIMENSIONS

Specimen No.	Dimensions, in.			
	A	*B*	*C*	*D*
1	½ ± 0.015	11/16 approximately	2 ± 0.005	2¼ min
2	¾ ± 0.031	1 approximately	2 ± 0.005	2¼ min
			4 ± 0.005	4½min
3	1± 0.062	1½ approximately	2 ± 0.005	2¼ min
			4 ± 0.005	4½ min
4	1½ ± ⅛	2 approximately	2 ± 0.010	2¼ min
			4 ± 0.015	4½min
			8 ± 0.020	9 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 for 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 2*A* 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.

FIG. A2.3 Dimensions and Tolerances for Longitudinal Strip Tension Test Specimens for Tubing

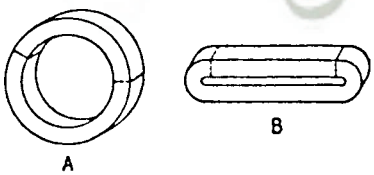
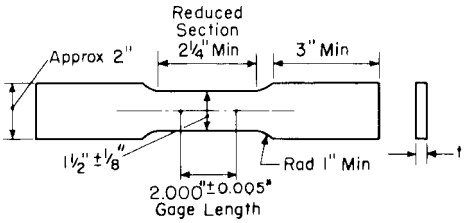


FIG. A2.4 Location of Transverse Tension Test Specimens in Ring Cut from Tubular Products.



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. = 25.4 mm.

FIG. A2.5 Transverse Tension Test Specimen Machined from Ring Cut from Tubular Products

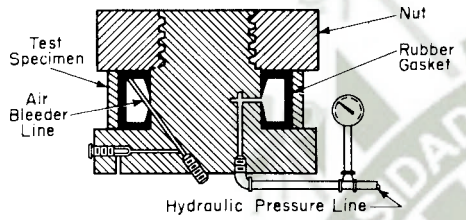


FIG. A2.6 Testing Machine for Determination of Transverse Yield Strength from Annular Ring Specimens

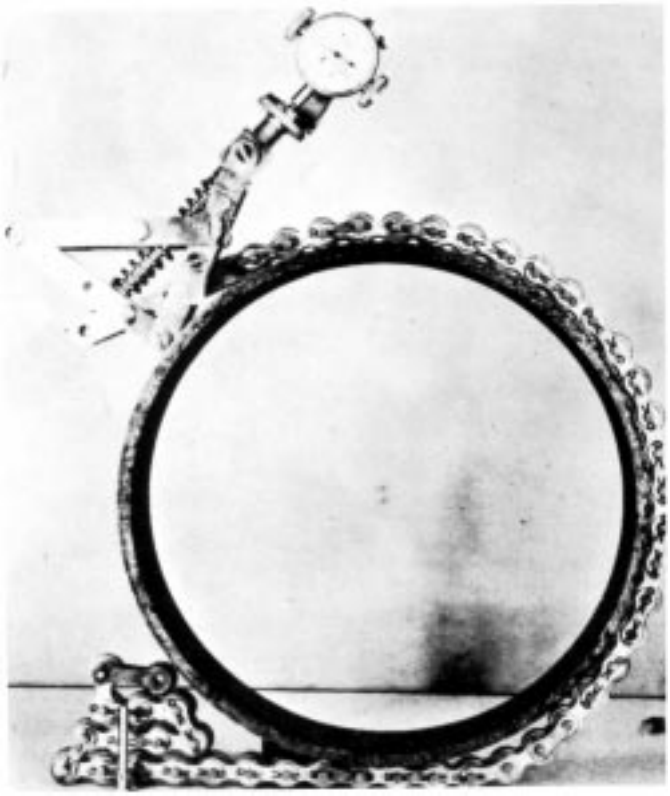


FIG. A2.7 Roller Chain Type Extensometer, Unclamped

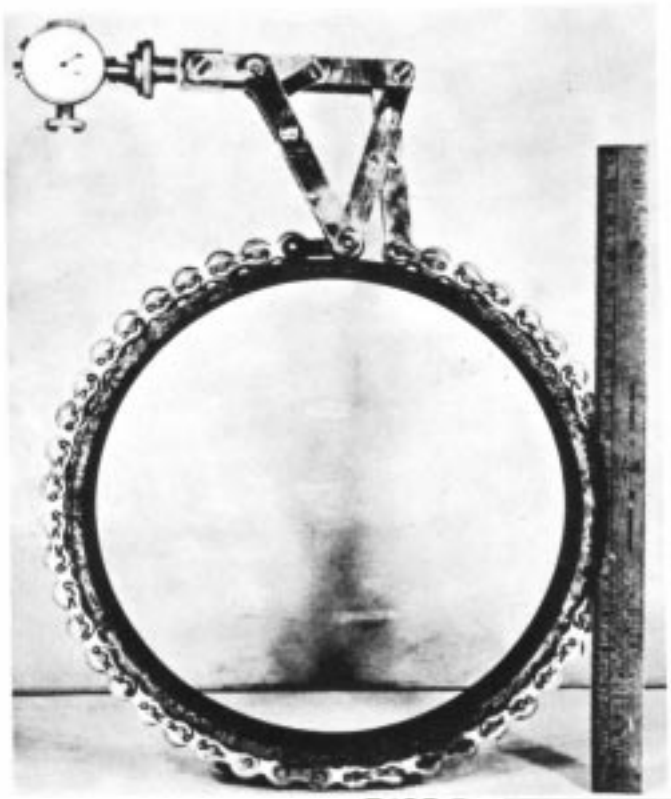
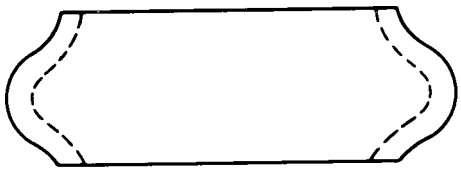


FIG. A2.8 Roller Chain Type Extensometer, Clamped



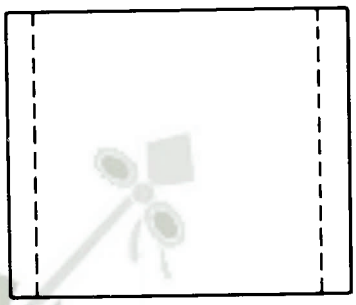
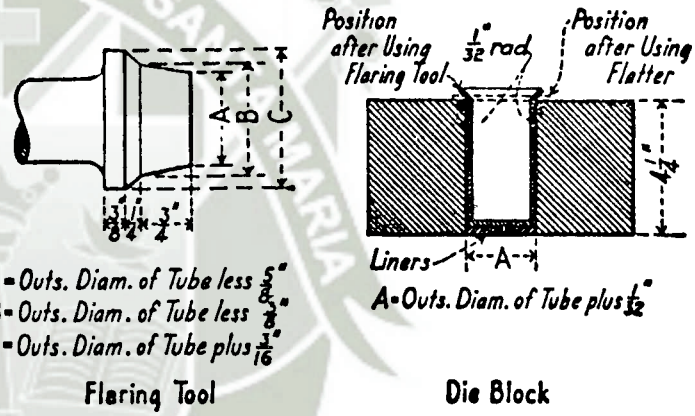
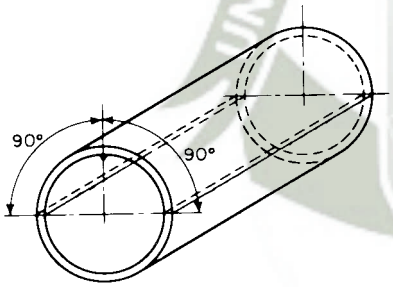


FIG. A2.10 Crush Test Specimen



NOTE 1—Metric equivalent: 1 in. = 25.4 mm.

FIG. A2.11 Flaring Tool and Die Block for Flange Test



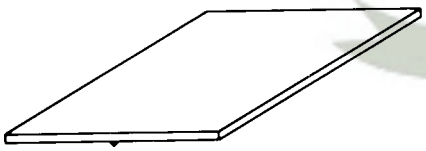


FIG. A2.9 Reverse Flattening Test

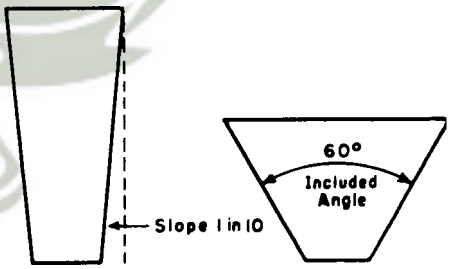
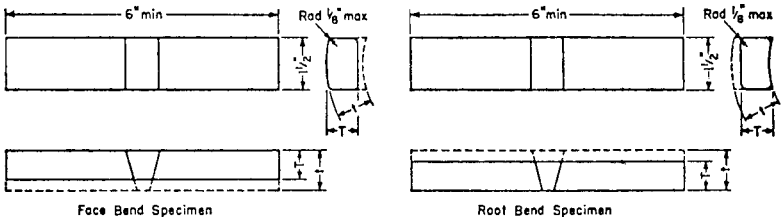


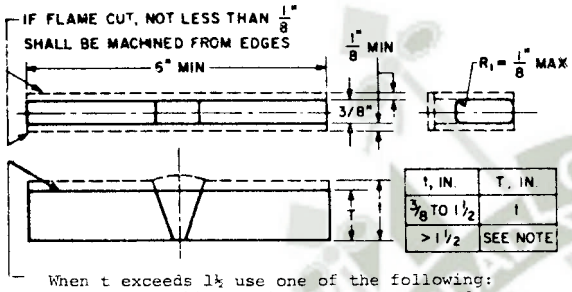
FIG. A2.12 Tapered Mandrels for Flaring Test



NOTE 1—Metric equivalent: 1 in. = 25.4 mm.

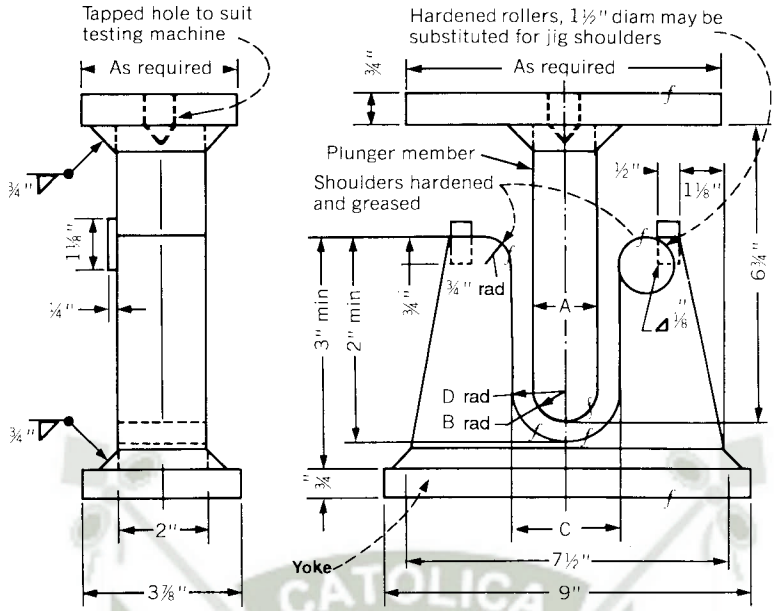
Pipe Wall Thickness (*t*), in.	Test Specimen Thickness, in.
Up to 3/8, incl	*t*
Over 3/8	3/8

FIG. A2.13 Transverse Face- and Root-Bend Test Specimens



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	
⅜	1½	¾	2⅜	1³⁄₁₆	
t	4*t*	2*t*	6*t* + ⅛	3*t* + 1⁄₁₆	
					Material
⅜	2½	1¼	3⅜	1¹¹⁄₁₆	Materials with a specified minimum tensile strength of 95 ksi or greater.
t	6⅔*t*	3⅓*t*	8⅔*t* + ⅛	4½*t* + 1⁄₁₆	

FIG. A2.15 Guided-Bend Test Jig

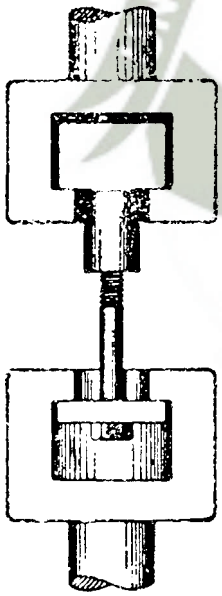
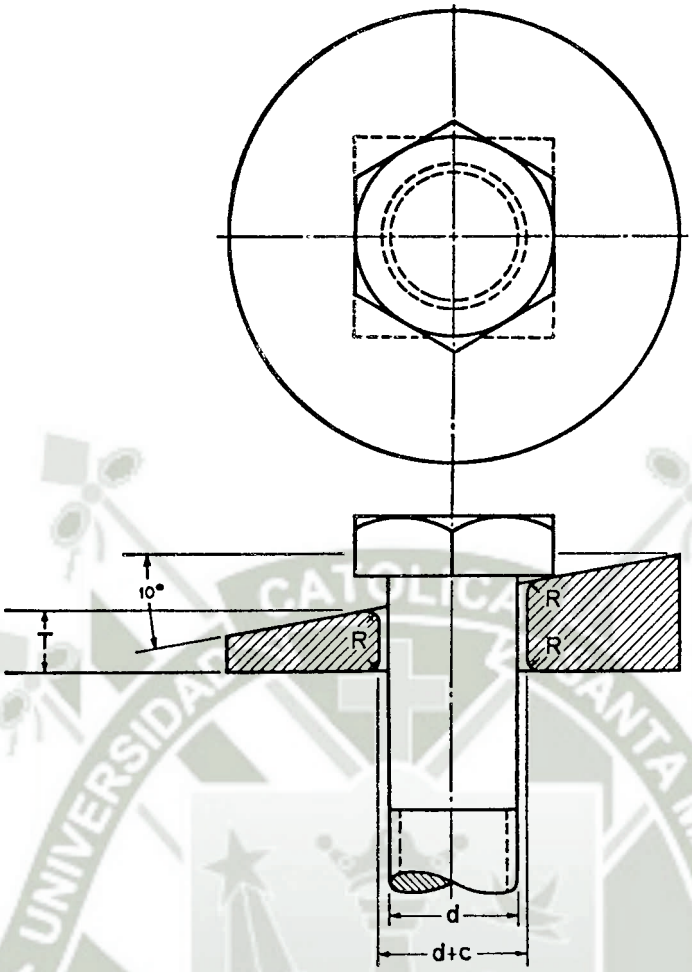
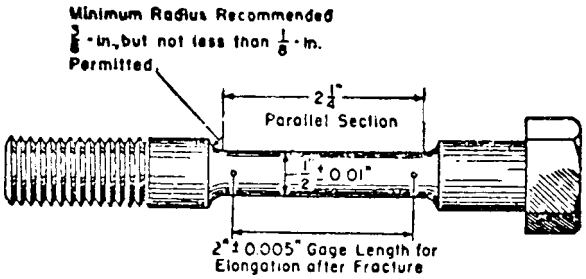


FIG. A3.1 Tension Testing Full-Size Bolt



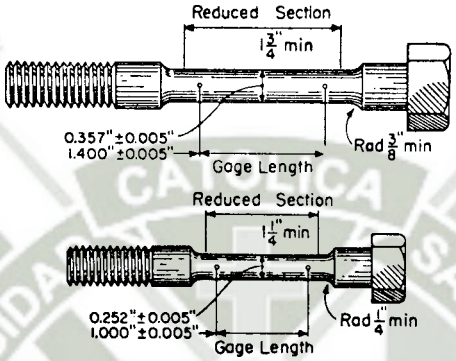
c = Clearance of wedge hole
d = Diameter of bolt
R = Radius
T = Thickness of wedge at short side of hole equal to one-half diameter of bolt

FIG. A3.2 Wedge Test Detail



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. Gage Length Specimen

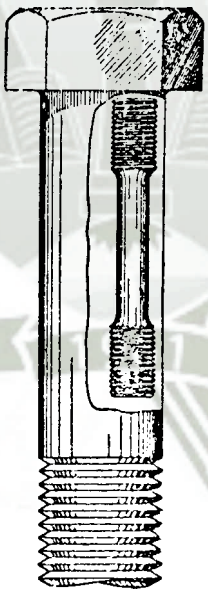
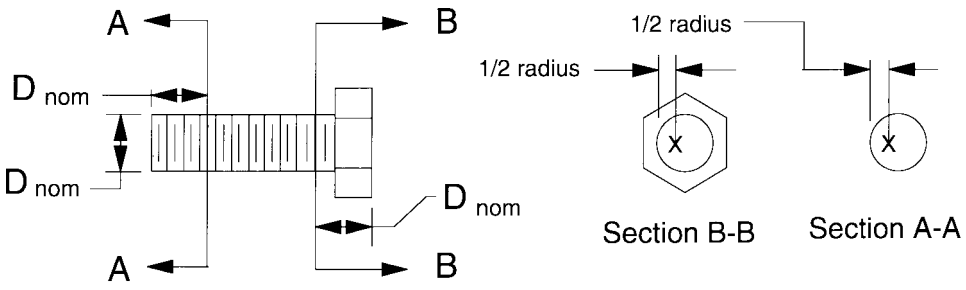


FIG. A3.5 Location of Standard Round 2-in. Gage Length Tension Test Specimen When Turned from Large Size Bolt



X=Location of Hardness Impressions

FIG. A3.6 Hardness Test Locations for Bolts in a Dispute

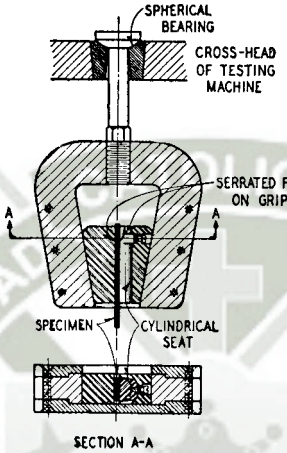


FIG. A4.1 Wedge-Type Gripping Device

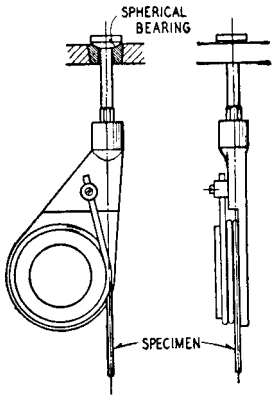


FIG. A4.2 Snubbing-Type Gripping Device

Designation: E 23 – 01

Standard Test Methods for Notched Bar Impact Testing of Metallic Materials[1]

This standard is issued under the fixed designation E 23; 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 (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 These test methods describe notched-bar impact testing of metallic materials by the Charpy (simple-beam) test and the Izod (cantilever-beam) test. They give the requirements for: test specimens, test procedures, test reports, test machines (see Annex A1) verifying Charpy impact machines (see Annex A2), optional test specimen configurations (see Annex A3), precracking Charpy V-notch specimens (see Annex A4), designation of test specimen orientation (see Annex A5), and determining the percent of shear fracture on the surface of broken impact specimens (see Annex A6). In addition, information is provided on the significance of notched-bar impact testing (see Appendix X1), methods of measuring the center of strike (see Appendix X2), and the availability of Charpy V-notch verification specimens (see Appendix X3).

1.2 These test methods do not address the problems associated with impact testing at temperatures below –196 °C (–320 °F, 77 °K).

1.3 The values stated in SI units are to be regarded as the standard. Inch-pound units are provided for information only.

1.4 *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.* Specific precautionary statements are given in Section 5.

2. Referenced Documents

2.1 *ASTM Standards:*

E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods[2]

E 399 Test Method for Plane-Strain Fracture Toughness of Metallic Materials[3]

E 604 Test Method for Dynamic Tear Energy of Metallic Materials[3]

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method[2]

E 1271 Practice for Qualifying Charpy Verification Specimens of Heat-treated Steel[3]

E 1313 Guide for Recommended Formats for Data Records Used in Computerization of Mechanical Test Data for Metals[4]

3. Summary of Test Method

3.1 The essential features of an impact test are: a suitable specimen (specimens of several different types are recognized), an anvil or support on which the test specimen is placed to receive the blow of the moving mass, a moving mass that has sufficient energy to break the specimen placed in its path, and a device for measuring the energy absorbed by the broken specimen.

4. Significance and Use

4.1 These test methods of impact testing relate specifically to the behavior of metal when subjected to a single application of a force resulting in multi-axial stresses associated with a notch, coupled with high rates of loading and in some cases with high or low temperatures. For some materials and temperatures the results of impact tests on notched specimens, when correlated with service experience, have been found to predict the likelihood of brittle fracture accurately. Further information on significance appears in Appendix X1.

5. Precautions in Operation of Machine

5.1 Safety precautions should be taken to protect personnel from the swinging pendulum, flying broken specimens, and hazards associated with specimen warming and cooling media.

6. Apparatus

6.1 *General Requirements*:

6.1.1 The testing machine shall be a pendulum type of rigid construction.

6.1.2 The testing machine shall be designed and built to conform with the requirements given in Annex A1.

6.2 *Inspection and Verification*

6.2.1 Inspection procedures to verify impact machines directly are provided in A2.2 and A2.3. The items listed in A2.2 must be inspected annually.

6.2.2 The procedures to verify Charpy V-notch machines

---

[1] These test methods are under the jurisdiction of ASTM Committee E28 on Mechanical Testing and are the direct responsibility of Subcommittee E2807 on Impact Testing.

Current edition approved April 10, 2001. Published June 2001. Originally published as E 23 – 33 T. Last previous edition E 23 – 00.

[2] *Annual Book of ASTM Standards*, Vol 14.02.

[3] *Annual Book of ASTM Standards*, Vol 03.01.

[4] *Annual Book of ASTM Standards*, Vol 14.01.

indirectly, using verification specimens, are given in A2.4. Charpy impact machines must be verified annually.

7. Test Specimens

7.1 *Configuration and Orientation*:

7.1.1 Specimens shall be taken from the material as specified by the applicable specification. Specimen orientation should be designated according to the terminology given in Annex A5.

7.1.2 The type of specimen chosen depends largely upon the characteristics of the material to be tested. A given specimen may not be equally satisfactory for soft nonferrous metals and hardened steels; therefore, many types of specimens are recognized. In general, sharper and deeper notches are required to distinguish differences in very ductile materials or when using low testing velocities.

7.1.3 The specimens shown in Figs. 1 and 2 are those most widely used and most generally satisfactory. They are particularly suitable for ferrous metals, excepting cast iron.[5]

7.1.4 The specimen commonly found suitable for die-cast alloys is shown in Fig. 3.

7.1.5 The specimens commonly found suitable for powdered metals (P/M) are shown in Figs. 4 and 5. The specimen surface may be in the as-produced condition or smoothly machined, but polishing has proven generally unnecessary. Unnotched specimens are used with P/M materials. In P/M materials, the impact test results are affected by specimen orientation. Therefore, unless otherwise specified, the position of the specimen in the machine shall be such that the pendulum will strike a surface that is parallel to the compacting direction.

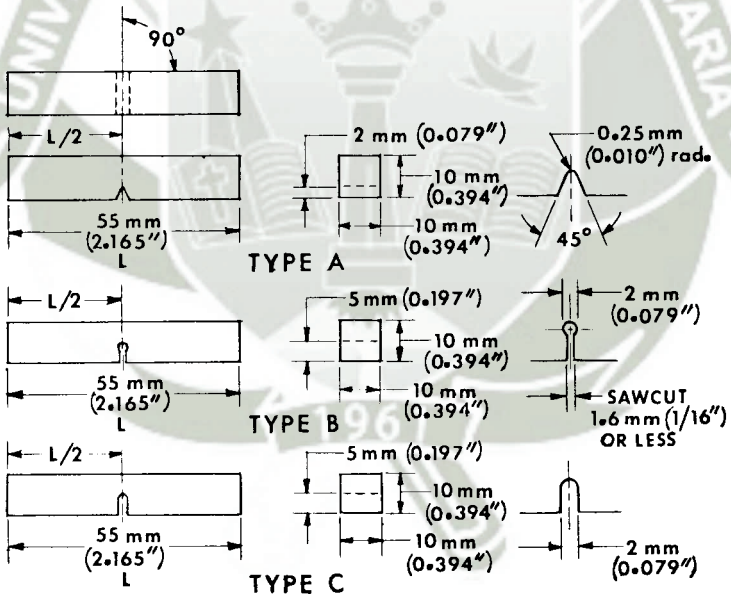
7.1.6 Sub-size and supplementary specimen recommendations are given in Annex A3.

7.2 *Specimen Machining*:

7.2.1 When heat-treated materials are being evaluated, the specimen shall be finish machined, including notching, after the final heat treatment, unless it can be demonstrated that the impact properties of specimens machined before heat treatment are identical to those machined after heat treatment.

7.2.2 Notches shall be smoothly machined but polishing has proven generally unnecessary. However, since variations in notch dimensions will seriously affect the results of the tests, adhering to the tolerances given in Fig. 1 is necessary (Appendix X1.2 illustrates the effects from varying notch dimensions on Type A specimens). In keyhole specimens, the round hole shall be carefully drilled with a slow feed rate. The slot may be cut by any feasible method, but care must be exercised in cutting the slot to ensure that the surface of the drilled hole opposite the slot is not damaged.

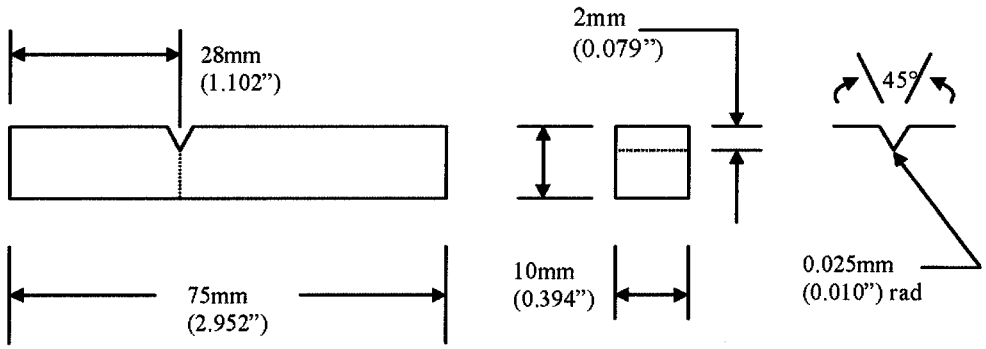
[5] Report of Subcommittee XV on Impact Testing of Committee A-3 on Cast Iron, Proceedings, ASTM, Vol 33 Part 1, 1933.



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:	
Type A specimen	±0.025 mm (±0.001 in.)
Types B and C specimen	±0.075 mm (±0.003 in.)
Finish requirements	2 µm (63 µin.) on notched surface and opposite face; 4 µm (125 µin.) on other two surfaces

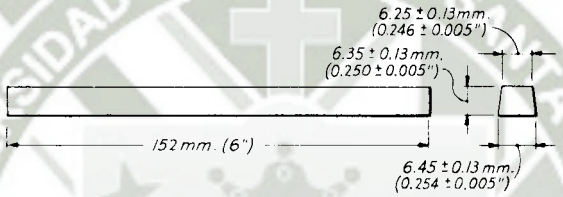
FIG. 1 Charpy (Simple-Beam) Impact Test Specimens, Types A, B, and C



NOTE 1—Permissible variations shall be as follows:

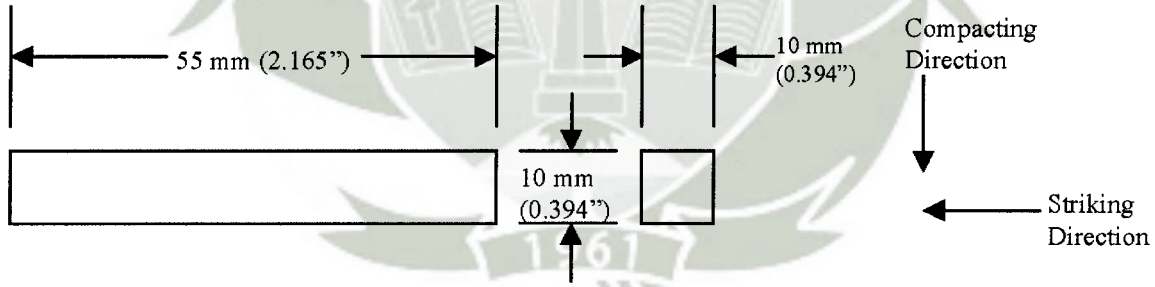
Notch length to edge	90 ±2°
Cross-section dimensions	±0.025 mm (±0.001 in.)
Length of specimen	+0, −2.5 mm (±0, −0.100 in.)
Angle of notch	±1°
Radius of notch	±0.025 mm (±0.001 in.)
Notch depth	±0.025 mm (±0.001 in.)
Adjacent sides shall be at	90° ± 10 min
Finish requirements	2 µm (63 µin.) on notched surface and opposite face; 4 µm (125 µin.) on other two surfaces

FIG. 2 Izod (Cantilever-Beam) Impact Test Specimen, Type D



NOTE 1—Two Izod specimens may be cut from this bar.
NOTE 2—Blow shall be struck on narrowest face.

FIG. 3 Izod Impact Test Bar for Die Castings Alloys



NOTE 1—Permissible variations shall be as follows:

Adjacent sides shall be at	90° ± 10 min
Cross section dimensions	±0.125 mm (0.005 in.)
Length of specimen	+0, −2.5 mm (+0, −0.100 in.)

FIG. 4 Charpy (Simple Beam) Impact Test Specimens for Metal Powder Structural Parts

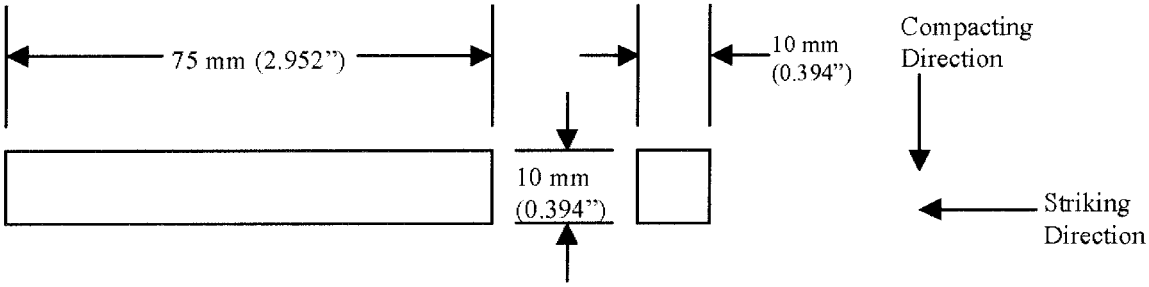
7.2.3 Identification marks shall only be placed in the following locations on specimens: either of the 10-mm square ends; the side of the specimen that faces up when the specimen is positioned in the anvils (see Note 1); or the side of the specimen opposite the notch. No markings, on any side of the specimen, shall be within 15 mm of the center line of the notch. An electrostatic pencil may be used for identification purposes, but caution must be taken to avoid excessive heat.

NOTE 1—Careful consideration should be given before placing identification marks on the side of the specimen to be placed up when positioned in the anvils. If the test operator is not careful, the specimen may be placed in the machine with the identification marking resting on the specimen supports. Under these circumstances, the absorbed energy value obtained may be unreliable.

8. Procedure

8.1 *Preparation of the Apparatus*:

8.1.1 Perform a routine procedure for checking impact machines at the beginning of each day, each shift, or just prior to testing on a machine used intermittently. It is recommended that the results of these routine checks be kept in a log book for



NOTE 1—Permissible variations shall be as follows:

Adjacent sides shall be at	90° ± 10 min.
Cross section dimensions	±0.125 mm (0.005 in.)
Length of specimens	+0, −2.5 mm (+0, −0.100 in.)

FIG. 5 Izod (Cantilever-Beam) Impact Test Specimen for Metal Powder Structural Parts

the machine. After the testing machine has been ascertained to comply with Annex A1 and Annex A2, carry out the routine check as follows:

8.1.1.1 Visually examine the striker and anvils for obvious damage and wear.

8.1.1.2 Check the zero position of the machine by using the following procedure: raise the pendulum to the latched position, move the pointer to near the maximum capacity of the range being used, release the pendulum, and read the indicated value. The pointer should indicate zero on machines reading directly in energy. On machines reading in degrees, the reading should correspond to zero on the conversion chart furnished by the machine manufacturer.

NOTE 2—On machines that do not compensate for windage and friction losses, the pointer will not indicate zero. In this case, the indicated values, when converted to energy, shall be corrected for frictional losses that are assumed to be proportional to the arc of swing.

8.1.1.3 To ensure that friction and windage losses are within allowable tolerances, the following procedure is recommended: raise the pendulum to the latched position, move the pointer to the negative side of zero, release the pendulum and allow it to cycle five times (a forward and a backward swing together count as one swing), prior to the sixth forward swing, set the pointer to between 5 and 10 % of the scale capacity of the dial, after the sixth forward swing (eleven half swings), record the value indicated by the pointer, convert the reading to energy (if necessary), divide it by 11 (half swings), then divide by the maximum scale value being used and multiply it by 100 to get the percent friction. The result, friction and windage loss, shall not exceed 0.4 % of scale range capacity being tested and should not change by more than 5 % of friction measurements previously made on the machine. If the friction and windage loss value does exceed 0.4 % or is significantly different from previous measurements, check the indicating mechanism, the latch height, and the bearings for wear and damage. However, if the machine has not been used recently, let the pendulum swing for 50 to 100 cycles, and repeat the friction test before undertaking repairs to the machine.

8.2 *Test Temperature Considerations*:

8.2.1 The temperature of testing affects the impact properties of most materials. For materials with a body centered cubic structure, a transition in fracture mode occurs over a temperature range that depends on the chemical composition and microstructure of the material. Test temperatures may be chosen to characterize material behavior at fixed values, or over a range of temperatures to characterize the transition region, lower shelf, or upper shelf behavior, or all of these. The choice of test temperature is the responsibility of the user of this test method and will depend on the specific application.

8.2.2 The temperature of a specimen can change significantly during the interval it is removed from the temperature conditioning environment, transferred to the impact machine, and the fracture event is completed (see Note 5). When using a heating or cooling medium near its boiling point, use data from the references in Note 5 or calibration data with thermocouples to confirm that the specimen is within the stated temperature tolerances when the striker contacts the specimen. If excessive adiabatic heating is expected, monitor the specimen temperature near the notch during fracture.

8.2.3 Verify temperature-measuring equipment at least every six months. If liquid-in-glass thermometers are used, an initial verification shall be sufficient, however, the device shall be inspected for problems, such as the separation of liquid, at least twice annually.

8.2.4 Hold the specimen at the desired temperature within ± 1 °C (± 2 °F) in the temperature conditioning environment (see 8.2.4.1 and 8.2.4.2). Any method of heating or cooling or transferring the specimen to the anvil(s) may be used provided the temperature of the specimen immediately prior to fracture is essentially the same as the holding temperature (see Note 5). The maximum change in the temperature of the specimen allowed for the interval between the temperature conditioning treatment and impact is not specified here, because it is dependent on the material being tested and the application. The user of nontraditional or lesser used temperature conditioning and transfer methods (or sample sizes) shall show that the temperature change for the specimen prior to impact is comparable to or less than the temperature change for a standard size specimen of the same material that has been thermally conditioned in a commonly used medium (oil, air, nitrogen, acetone, methanal), and transferred for impact within 5 seconds (see Note 5). Three temperature conditioning and transfer methods used in the past are: liquid bath thermal

conditioning and transfer to the specimen supports with centering tongs; furnace thermal conditioning and robotic transfer to the specimen supports; placement of the specimen on the supports followed by in situ heating and cooling.

8.2.4.1 For liquid bath cooling or heating use a suitable container, which has a grid or another type of specimen positioning fixture. Cover the specimens, when immersed, with at least 25 mm (1 in.) of the liquid, and position so that the notch area is not closer than 25 mm (1 in.) to the sides or bottom of the container, and no part of the specimen is in contact with the container. Place the device used to measure the temperature of the bath in the center of a group of the specimens. Agitate the bath and hold at the desired temperature within ± 1°C (± 2°F). Thermally condition the specimens for at least 5 min before testing, unless a shorter thermal conditioning time can be shown to be valid by measurements with thermocouples. Leave the mechanism (tongs, for example) used to handle the specimens in the bath for at least 5 min before testing, and return the mechanism to the bath between tests.

8.2.4.2 When using a gas medium, position the specimens so that the gas circulates around them and hold the gas at the desired temperature within ± 1°C (± 2°F) for at least 30 min. Leave the mechanism used to remove the specimen from the medium in the medium except when handling the specimens.

NOTE 3—Temperatures up to +260°C (+500°F) may be obtained with certain oils, but "flash-point" temperatures must be carefully observed.

NOTE 4—For testing at temperatures down to –196°C (–320 °F, 77 °K), standard testing procedures have been found to be adequate for most metals.

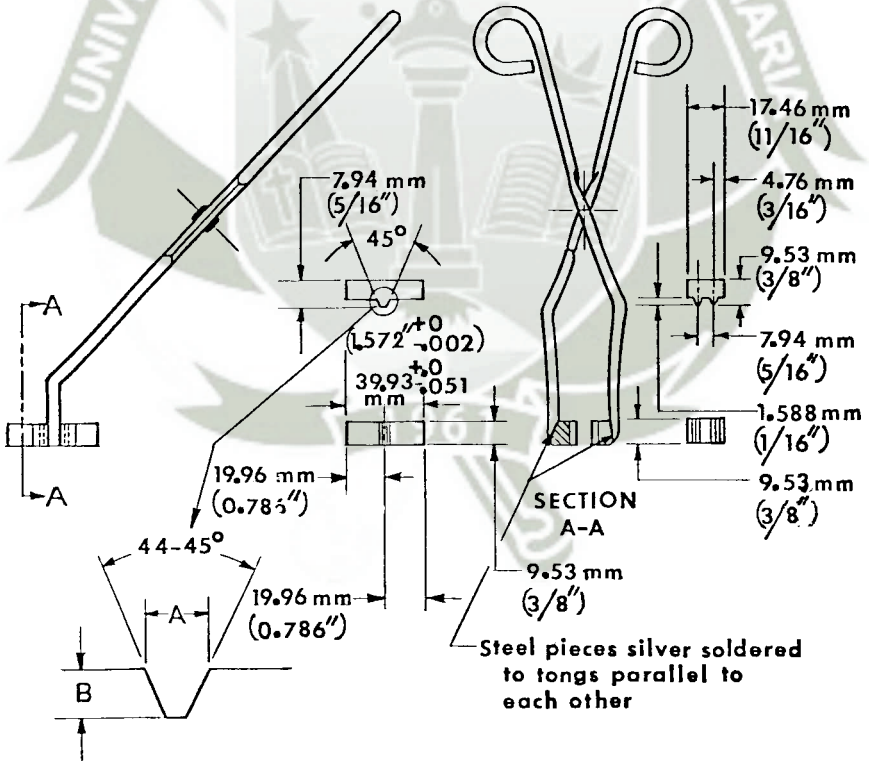
NOTE 5—A study has shown that a specimen heated to 100 C in water can cool 10 C in the 5 s allowed for transfer to the machine supports **(1)**[6]. Other studies, using cooling media that are above their boiling points at room temperature have also shown large changes in specimen temperature during the transfer of specimens to the machine anvils. In addition, some materials change temperature dramatically during impact testing at cryogenic temperatures due to adiabatic heating **(2)**.

8.3 *Charpy Test Procedure*:

8.3.1 The Charpy test procedure may be summarized as follows: the test specimen is thermally conditioned and positioned on the specimen supports against the anvils; the pendulum is released without vibration, and the specimen is impacted by the striker. Information is obtained from the machine and from the broken specimen.

8.3.2 To position a test specimen in the machine, it is recommended that self-centering tongs similar to those shown in Fig. 6 be used (see A1.10.1). The tongs illustrated in Fig. 6 are for centering V-notch specimens. If keyhole specimens are used, modification of the tong design may be necessary. If an end-centering device is used, caution must be taken to ensure

[6] The boldface numbers given in parentheses refer to a list of references at the end of the text.



NOTE 1—Unless otherwise shown, permmissible variation shall be ±1 mm (0.04 in.).

Specimen Depth, mm (in.)	Base Width (A), mm (in.)	Height (B), mm (in.)
10 (0.394)	1.60 to 1.70 (0.063 to 0.067)	1.52 to 1.65 (0.060 to 0.065)
5 (0.197)	0.74 to 0.80 (0.029 to 0.033)	0.69 to 0.81 (0.027 to 0.032)
3 (0.118)	0.45 to 0.51 (0.016 to 0.020)	0.36 to 0.48 (0.014 to 0.019)

FIG. 6 Centering Tongs for V-Notch Charpy Specimens

that low-energy high-strength specimens will not rebound off this device into the pendulum and cause erroneously high recorded values. Many such devices are permanent fixtures of machines, and if the clearance between the end of a specimen in test position and the centering device is not approximately 13 mm (0.5 in.), the broken specimens may rebound into the pendulum.

8.3.3 To conduct the test, prepare the machine by raising the pendulum to the latched position, set the energy indicator at the maximum scale reading, or initialize the digital display, or both, position the specimen on the anvils, and release the pendulum. If a liquid bath or gas medium is being used for thermal conditioning, perform the following sequence in less than 5 s (for standard 10 × 10 × 55 mm specimens, see 8.2.4). Remove the test specimen from its cooling (or heating) medium with centering tongs that have been temperature conditioned with the test specimen, place the specimen in the test position, and, release the pendulum smoothly. If a test specimen has been removed from the temperature conditioning bath and it is questionable that the test can be conducted within the 5 s time frame, return the specimen to the bath for the time required in 8.2 before testing.

8.3.3.1 If a fractured impact specimen does not separate into two pieces, report it as unbroken. Unbroken specimens with absorbed energies of less than 80 % of the machine capacity may be averaged with values from broken specimens. If the individual values are not listed, report the percent of unbroken specimens with the average. If the absorbed energy exceeds 80 % of the machine capacity and the specimen passes completely between the anvils, report the value as approximate (see 10.1) and not averaged with the others. If an unbroken specimen does not pass between the machine anvils, the result will be reported as exceeding the machine capacity. A specimen shall never be struck more than once.

8.3.3.2 If a specimen jams in the machine, disregard the results and check the machine thoroughly for damage or maladjustment, which would affect its calibration.

8.3.3.3 To prevent recording an erroneous value, caused by jarring the indicator when locking the pendulum in its upright (“ready”) position, read the value for each test from the indicator prior to locking the pendulum for the next test.

8.4 *Izod Test Procedure*:

8.4.1 The Izod test procedure may be summarized as follows: the test specimen is positioned in the specimen-holding fixture and the pendulum is released without vibration. Information is obtained from the machine and from the broken specimen. The details are described as follows:

8.4.2 Testing at temperatures other than room temperature is difficult because the specimen-holding fixture for Izod specimens is often part of the base of the machine and cannot be readily cooled (or heated). Consequently, Izod testing is not recommended at other than room temperature.

8.4.3 Clamp the specimen firmly in the support vise so that the centerline of the notch is in the plane of the top of the vise within 0.125 mm (0.005 in.). Set the energy indicator at the maximum scale reading, and release the pendulum smoothly. Sections 8.3.3.1-8.3.3.3 inclusively, also apply when testing Izod specimens.

9. Information Obtainable from Impact Tests

9.1 *The absorbed energy* shall be taken as the difference between the energy in the striking member at the instant of impact with the specimen and the energy remaining after breaking the specimen. This value is determined by the machine’s scale reading which has been corrected for windage and friction losses.

NOTE 6—Alternative means for energy measurement are acceptable provided the accuracy of such methods can be demonstrated. Methods used in the past include optical encoders and strain gaged strikers.

9.2 *Lateral expansion measurement* methods must take into account the fact that the fracture path seldom bisects the point of maximum expansion on both sides of a specimen. One half of a broken specimen may include the maximum expansion for both sides, one side only, or neither. Therefore, the expansion on each side of each specimen half must be measured relative to the plane defined by the undeformed portion on the side of the specimen, as shown in Fig. 7. For example, if A_1 is greater than A_2, and A_3 is less than A_4, then the lateral expansion is the sum of $A_1 + A_4$.

9.2.1 Before making any expansion measurements, it is essential that the two specimen halves are visually examined for burrs that may have formed during impact testing; if the burrs will influence the lateral expansion measurements, they must be removed (by rubbing on emery cloth or any other suitable method), making sure that the protrusions to be measured are not rubbed during the removal of the burr. Then, examine each fracture surface to ascertain that the protrusions have not been damaged by contacting an anvil, a machine mounting surface, ect. Lateral expansion shall not be measured on a specimen with this type of damage.

9.2.2 Lateral expansion shall not be reported for specimens that did not separate into two halves during the impact test, with one exception. The lateral expansion of an unbroken specimen can be reported if the following two conditions are met: 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.

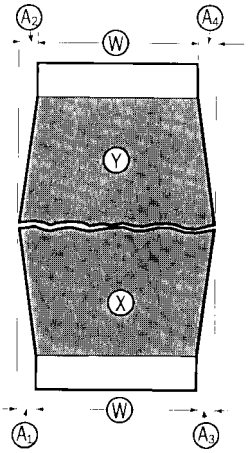


FIG. 7 Halves of Broken Charpy V-Notch Impact Specimen Illustrating the Measurement of Lateral Expansion, Dimensions A_1, A_2, A_3, A_4 and Original Width, Dimension W

9.2.3 Lateral expansion may be measured easily by using a gage like the one shown in Fig. 8 (assembly and details shown in Fig. 9). Using this type of gage the measurement is made with the following procedure: orient the specimen halves so that the compression sides are facing each another, take one half of the fractured specimen and press it against the anvil and dial gage plunger and record the reading, make a similar measurement on the other half (same side) of the fractured specimen and disregard the lower of the two values, do the same for the other side of the fractured specimen, report the sum of the maximum expansions for the 2 sides as the lateral expansion for the specimen.

9.3 *The percentage of shear fracture* on the fracture surfaces of impact specimens may be determined using a variety of methods. The acceptable methods are defined in Annex A6. For each method, the user must distinguish between regions formed by ductile stable crack growth mechanisms, and regions formed by brittle fast crack propagation (unstable crack growth mechanisms). The typical zones of fracture appearance are shown in Fig. 10, where the "flat fracture" region is the region in which unstable crack growth occurs on a microsecond time scale.

The percent shear area on the fracture surface of a Charpy impact specimen is typically calculated as the difference between the total fractured area and the area of flat fracture. The measurement methods described here provide estimates for the area of the macroscopically flat fracture region (directly or indirectly), but do not consider details of the fracture mode for this "flat" region of unstable fracture. The flat fracture region could be 100 percent cleavage, a mixture of cleavage and ductile-dimple fracture morphologies, or other combinations of ductile-brittle fracture morphologies. Estimates of ductility within the unstable crack growth region are beyond the scope of these methods.

10. Report

10.1 *Absorbed energy values above 80 %* of the scale range are inaccurate and shall be reported as approximate. Ideally an impact test would be conducted at a constant impact velocity. In a pendulum-type test, the velocity decreases as the fracture progresses. For specimens that have impact energies approaching 80 % of the capacity of the pendulum, the velocity of the pendulum decreases (to about 45 % of the initial velocity) during fracture to the point that accurate impact energies are no longer obtained.

10.2 *For commercial acceptance testing*, report the following information (for each specimen tested):

10.2.1 Specimen type (and size if not the full-size specimen),

10.2.2 Test temperature,

10.2.3 Absorbed energy, and

10.2.4 Any other contractual requirements.

10.3 *For other than commercial acceptance testing* the following information is often reported in addition to the information in 10.2:

10.3.1 Lateral expansion,

10.3.2 Unbroken specimens,

10.3.3 Fracture appearance (% shear, See Note A6.1),

10.3.4 Specimen orientation, and

10.3.5 Specimen location.

NOTE 7—A recommended format for computerization of notched bar impact test data is available in Practice E 1313.

11. Precision and Bias

11.1 *An Interlaboratory study* used CVN specimens of low energy and of high energy to find sources of variation in the CVN absorbed energy. Data from 29 laboratories were included with each laboratory testing one set of five specimens of

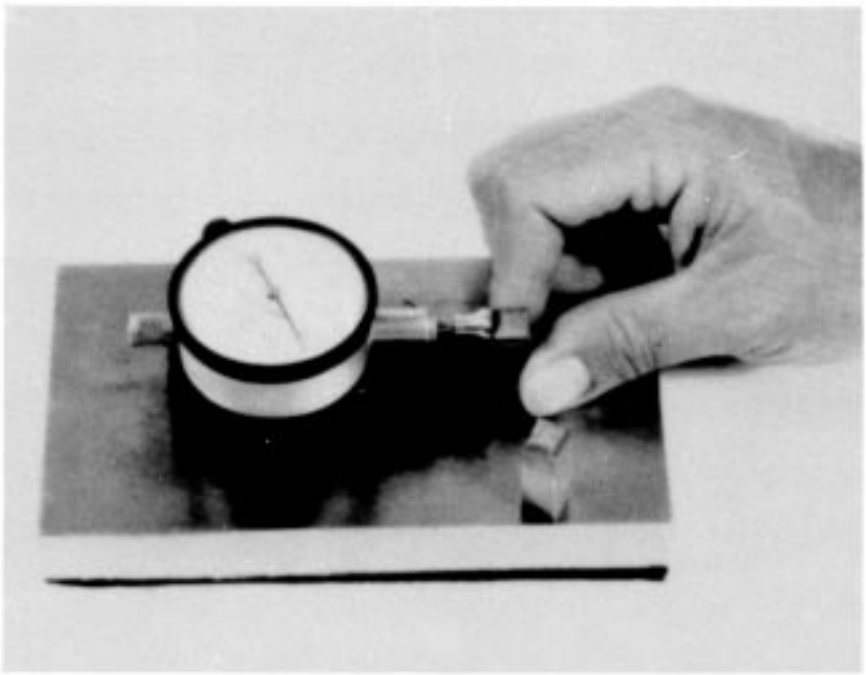


FIG. 8 Lateral Expansion Gage for Charpy Impact Specimens

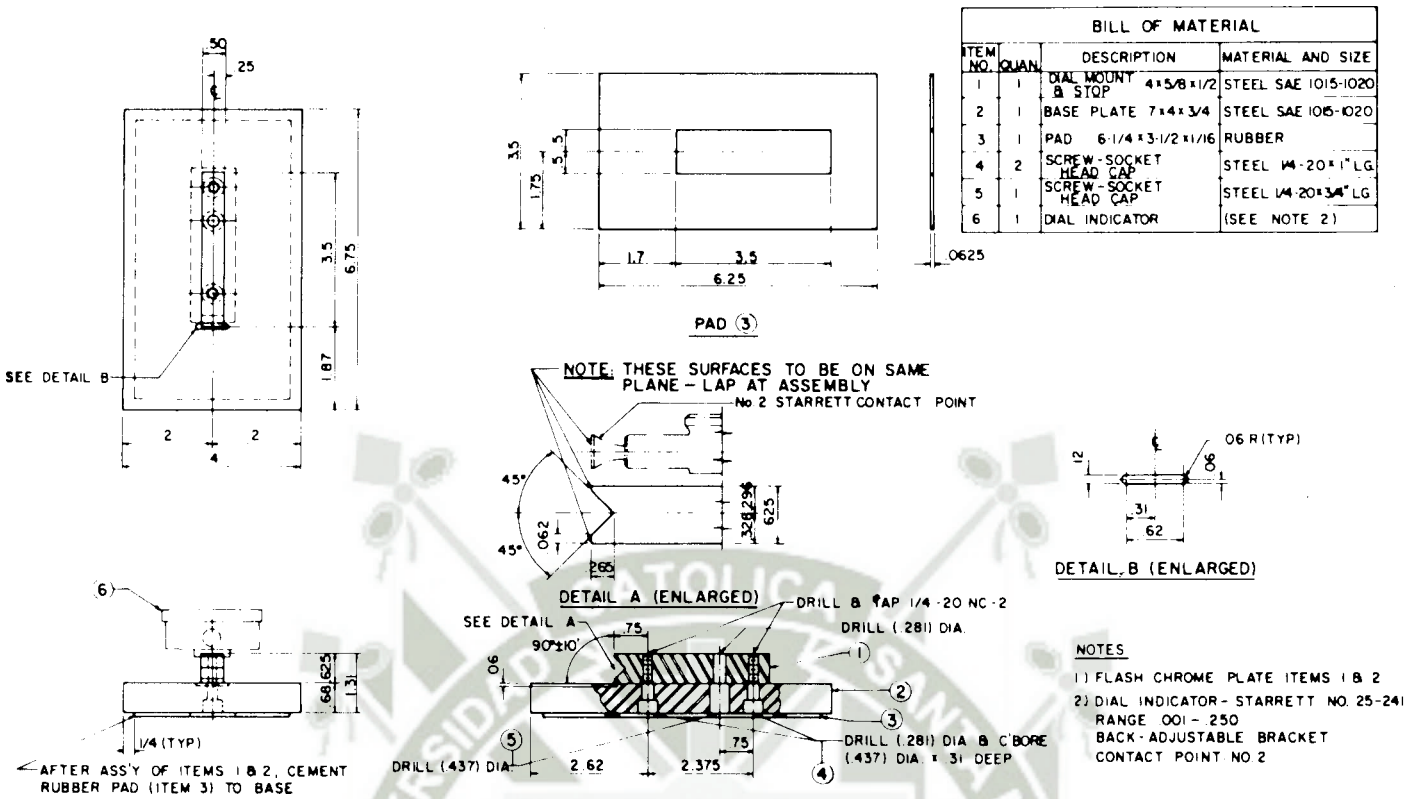
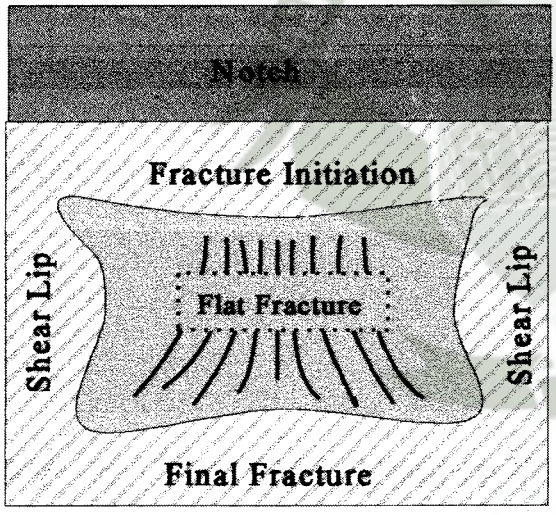


FIG. 9 Assembly and Details for Lateral Expansion Gage



NOTE 1—The shear of ductile fracture regions on the fracture surface include the fracture initiation region, the two shear lips, and the region of final fracture. The flat or radial fracture region is a region of less ductile unstable crack growth.

FIG. 10 Determination of Percent Shear Fracture

each energy level. Except being limited to only two energy levels (by availability of reference specimens), Practice E 691 was followed for the design and analysis of the data, the details are given in ASTM Research Report NO. RR:E28-1014.[7]

11.2 *Precision—The Precision* information given below (in units of J and ft·lbf) is for the average CVN absorbed energy of five test determinations at each laboratory for each material.

Material	Low Energy		High Energy	
	J	ft-lbf	J	ft-lbf
Absorbed Energy	15.9	11.7	96.2	71.0
95 % Repeatability Limit	2.4	1.7	8.3	6.1
95 % Reproducibility Limits	2.7	2.0	9.2	6.8

The terms repeatability and reproducibility limit are used as defined in Practice E 177. The respective standard deviations among test results may be obtained by dividing the above limits by 2.8.

11.3 *Bias— Bias cannot be defined* for CVN absorbed energy. The physical simplicity of the pendulum design is complicated by complex energy loss mechanisms within the machine and the specimen. Therefore, there is no absolute standard to which the measured values can be compared.

12. Keywords

12.1 charpy test; fracture appearance; Izod test; impact test; notched specimens; pendulum machine

[7] Supporting data have been filed at ASTM Headquarters and may be obtained by requesting Research Report E28–1014.

ANNEXES

(Mandatory Information)

A1. GENERAL REQUIREMENTS FOR IMPACT MACHINES

A1.1 *The machine frame* shall be equipped with a bubble level or a machined surface suitable for establishing levelness of the axis of pendulum bearings or, alternatively, the levelness of the axis of rotation of the pendulum may be measured directly. The machine shall be level to within 3:1000 and securely bolted to a concrete floor not less than 150 mm (6 in.) thick or, when this is not practical, the machine shall be bolted to a foundation having a mass not less than 40 times that of the pendulum. The bolts shall be tightened as specified by the machine manufacturer.

A1.2 *A scale or digital display*, graduated in degrees or energy, on which readings can be estimated in increments of 0.25 % of the energy range or less shall be furnished for the machine.

A1.2.1 The scales and digital displays may be compensated for windage and pendulum friction. The error in the scale reading at any point shall not exceed 0.2 % of the range or 0.4 % of the reading, whichever is larger. (See A2.3.8.)

A1.3 *The total friction and windage losses* of the machine during the swing in the striking direction shall not exceed 0.75 % of the scale range capacity, and pendulum energy loss from friction in the indicating mechanism shall not exceed 0.25 % of scale range capacity. See A2.3.8 for friction and windage loss calculations.

A1.4 *The position of the pendulum*, when hanging freely, shall be such that the striker is within 2.5 mm (0.10 in.) from the test specimen. When the indicator has been positioned to read zero energy in a free swing, it shall read within 0.2 % of scale range when the striker of the pendulum is held against the test specimen. The plane of swing of the pendulum shall be perpendicular to the transverse axis of the Charpy specimen anvils or Izod vise within 3:1000.

A1.5 *Transverse play of the pendulum* at the striker shall not exceed 0.75 mm (0.030 in.) under a transverse force of 4 % of the effective weight of the pendulum applied at the center of strike. Radial play of the pendulum bearings shall not exceed 0.075 mm (0.003 in.).

A1.6 *The impact velocity* (tangential velocity) of the pendulum at the center of the strike shall not be less than 3 nor more than 6 m/s (not less than 10 nor more than 20 ft/s).

A1.7 *The height of the center of strike* in the latched position, above its free hanging position, shall be within 0.4 % of the range capacity divided by the supporting force, measured as described in A2.3.5.1 If windage and friction are compensated for by increasing the height of drop, the height of drop may be increased by not more than 1 %.

A1.8 *The mechanism for releasing the pendulum* from its initial position shall operate freely and permit release of the pendulum without initial impulse, retardation, or side vibration. If the same lever used to release the pendulum is also used to engage the brake, means shall be provided for preventing the brake from being accidentally engaged.

A1.9 *Specimen clearance* is needed to ensure satisfactory results when testing materials of different strengths and compositions. The test specimen shall exit the machine with a minimum of interference. Pendulums used on Charpy machines are of three basic designs, as shown in Fig. A1.1.

A1.9.1 When using a C-type pendulum or a compound pendulum, the broken specimen will not rebound into the pendulum and slow it down if the clearance at the end of the specimen is at least 13 mm (0.5 in.) or if the specimen is deflected out of the machine by some arrangement such as that shown in Fig. A1.1.

A1.9.2 When using the U-type pendulum, means shall be provided to prevent the broken specimen from rebounding against the pendulum (see Fig. A1.1). In most U-type pendulum machines, steel shrouds should be designed and installed to the following requirements: (*a*) have a thickness of approximately 1.5 mm (0.06 in.), (*b*) have a minimum hardness of 45 HRC, (*c*) have a radius of less than 1.5 mm (0.06 in.) at the underside corners, and (*d*) be so positioned that the clearance between them and the pendulum overhang (both top and sides) does not exceed 1.5 mm (0.06 in.).

NOTE A1.1—In machines where the opening within the pendulum permits clearance between the ends of a specimen (resting on the anvil supports) and the shrouds, and this clearance is at least 13 mm (0.5 in.), the requirements (*a*) and (*d*) need not apply.

A1.10 *Charpy Apparatus*:

A1.10.1 Means shall be provided (see Fig. A1.2) to locate and support the test specimen against two anvil blocks in such a position that the center of the notch can be located within 0.25 mm (0.010 in.) of the midpoint between the anvils (see 8.3.2).

A1.10.2 The supports and striker shall be of the forms and dimensions shown in Fig. A1.2. Other dimensions of the pendulum and supports should be such as to minimize interference between the pendulum and broken specimens.

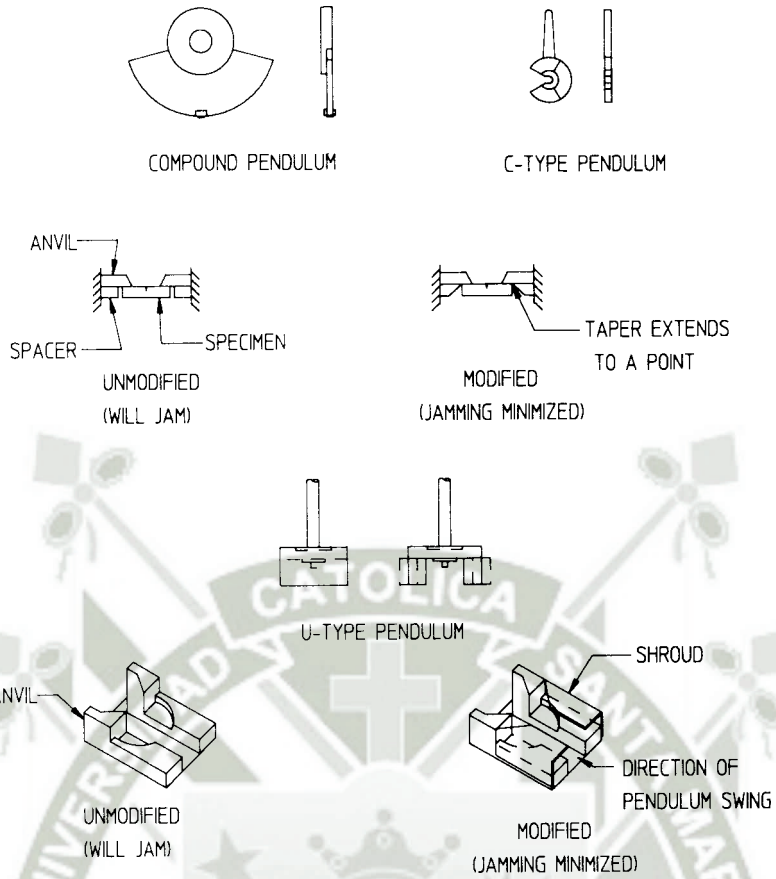


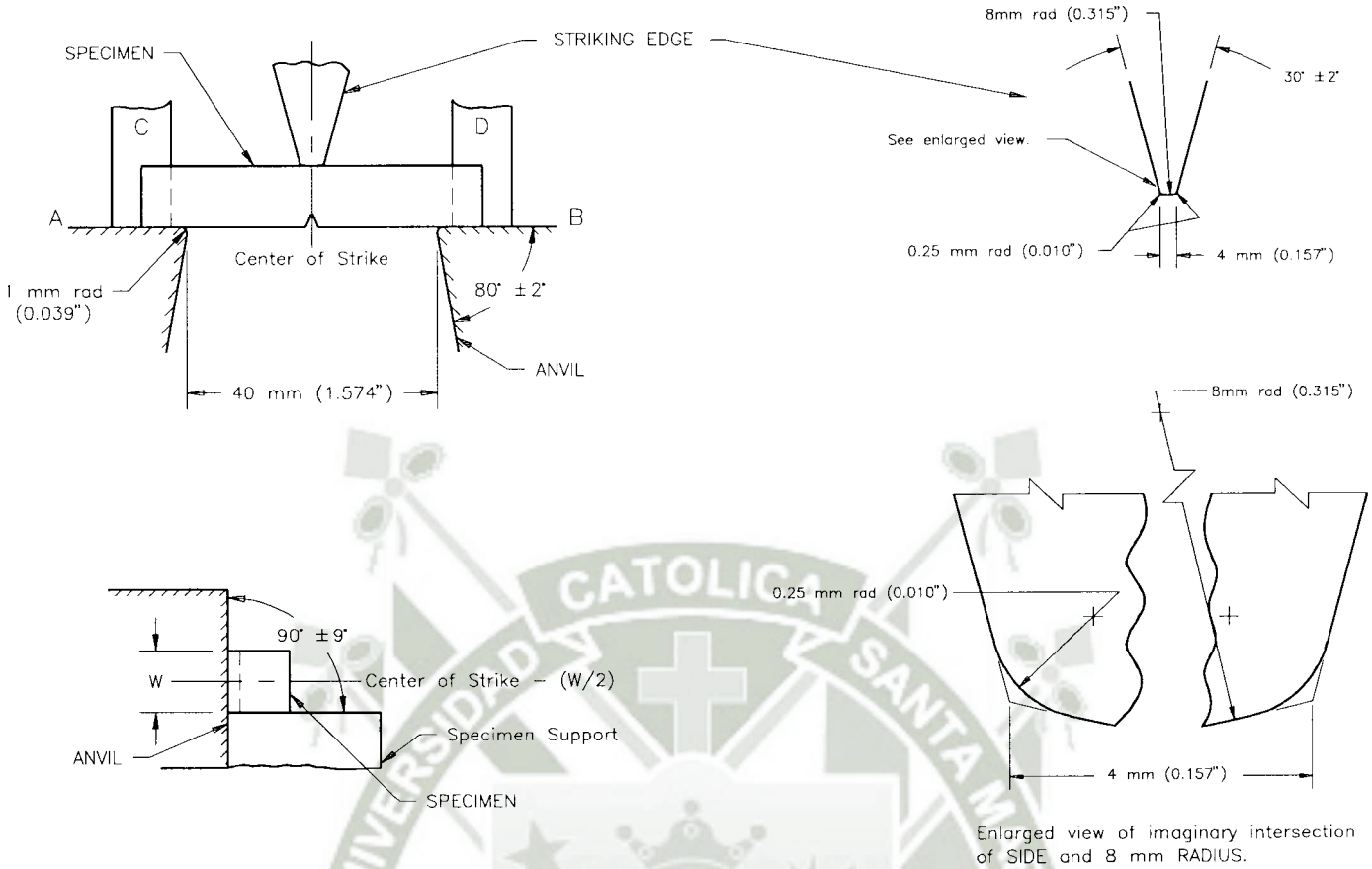
FIG. A1.1 Typical Pendulums and Anvils for Charpy Machines, Shown with Modifications to Minimize Jamming

A1.10.3 The center line of the striker shall advance in the plane that is within 0.40 mm (0.016 in.) of the midpoint between the supporting edges of the specimen anvils. The striker shall be perpendicular to the longitudinal axis of the specimen within 5:1000. The striker shall be parallel within 1:1000 to the face of a perfectly square test specimen held against the anvil.

A1.11 *Izod Apparatus*:

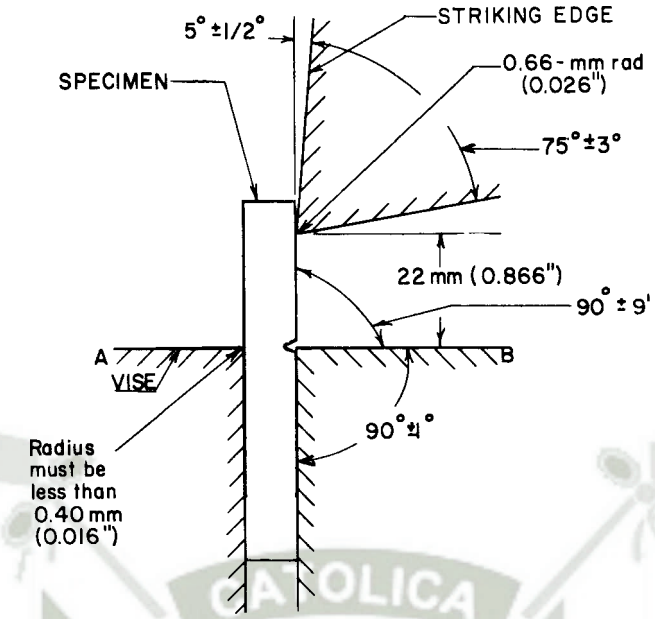
A1.11.1 Means shall be provided (see Fig. A1.3) for clamping the specimen in such a position that the face of the specimen is parallel to the striker within 1:1000. The edges of the clamping surfaces shall be sharp angles of 90 ± 1° with radii less than 0.40 mm (0.016 in.). The clamping surfaces shall be smooth with a 2-µm (63-µin.) finish or better, and shall clamp the specimen firmly at the notch with the clamping force applied in the direction of impact. For rectangular specimens, the clamping surfaces shall be flat and parallel within 0.025 mm (0.001 in.). For cylindrical specimens, the clamping surfaces shall be contoured to match the specimen and each surface shall contact a minimum of $\pi/2$ rad (90°) of the specimen circumference.

A1.11.2 The dimensions of the striker and its position relative to the specimen clamps shall be as shown in Fig. A1.3.



All dimensional tolerances shall be ±0.05 mm (0.002 in.) unless otherwise specified.

FIG. A1.2 Charpy Striking Tup



All dimensional tolerances shall be ±0.05 mm (0.002 in.) unless otherwise specified.

NOTE 1—The clamping surfaces of A and B shall be flat and parallel within 0.025 mm (0.001 in.).

NOTE 2—Finish on unmarked parts shall be 2 µm (63 µin.).

NOTE 3—Striker width must be greater than that of the specimen being tested.

FIG. A1.3 Izod (Cantilever-Beam) Impact Test

A2. VERIFICATION OF PENDULUM IMPACT MACHINES

A2.1 *The verification of impact machines has two parts:* direct verification, which consists of inspecting the machine to ensure that the requirements of this annex and Annex A1 are met, and indirect verification, which entails the testing of verification specimens.

A2.1.1 Izod machines are verified by direct verification only.

A2.1.2 Charpy machines shall be verified annually. Data is valid only when produced within 365 days following the date of the most recent successful verification test. Charpy machines shall also be verified immediately after replacing parts that may affect the measured energy, after making repairs or adjustments, after they have been moved, or whenever there is reason to doubt the accuracy of the results, without regard to the time interval. These restrictions include cases where parts, which may affect the measured energy, are removed from the machine and then reinstalled without modification (for example, when the striker or anvils are removed to permit use of a different striker or set of anvils and then are reinstalled). It is not intended that parts not subjected to wear (such as pendulum and scale linearity) are to be directly verified each year unless a problem is evident. Only the items cited in A2.2 are required to be inspected annually. Other parts of the machine shall be directly verified at least once, when the machine is new, or when parts are replaced.

A2.2 *Direct Verification of Parts Requiring Annual Inspection*:

A2.2.1 Inspect the specimen supports, anvils, and striker and replace any of these parts that show signs of wear. A straight edge or radius gage can be used to discern differences between the used and unused portions of these parts to help identify a worn condition (see Note A2.1).

NOTE A2.1—To measure the anvil or striker radii, the recommended procedure is to make a replica (casting) of the region of interest and measure cross sections of the replica. This can be done with the anvils and striker in place on the machine or removed from the machine. Make a dam with cardboard and tape surrounding the region of interest, then pour a low-shrinkage casting compound into the dam (silicon rubber casting compounds work well). Allow the casting to cure, remove the dam, and slice cross sections through the region of interest with a razor. Use these cross sections to make radii measurements on optical comparators or other instruments.

A2.2.2 Ensure the bolts that attach the anvils and striker to the machine are tightened to the manufacture's specifications.

A2.2.3 Verify that the shrouds, if applicable, are properly installed (see A1.9.2).

A2.2.4 The pendulum release mechanism, which releases the pendulum from its initial position, shall comply with A1.8.

A2.2.5 Check the level of the machine in both directions (see A1.1).

A2.2.6 Check that the foundation bolts are tightened to the manufacturer's specifications.

NOTE A2.2—Expansion bolts or fasteners with driven in inserts shall not be used for foundations. These fasteners will work loose and/or tighten up against the bottom of the machine indicating a false high torque value when the bolts are tightened.

A2.2.7 Check the indicator zero and the friction loss of the machine as described in 8.1.

A2.3 *Direct Verification of Parts to be Verified at Least Once*:

A2.3.1 Specimen anvils and supports or Izod vises shall conform to the dimensions shown in Fig. A1.2 or Fig. A1.3.

NOTE A2.3—The impact machine will be inaccurate to the extent that some energy is used in deformation or movement of its component parts or of the machine as a whole; this energy will be registered as used in fracturing the specimen.

A2.3.2 The striker shall conform to the dimensions shown in Fig. A1.2 or Fig. A1.3. The mounting surfaces must be clean and free of defects that would prevent a good fit. Check that the striker complies with A1.10.3 (for Charpy tests) or A1.11.1 (for Izod tests).

A2.3.3 The pendulum alignment shall comply with A1.4 and A1.5. If the side play in the pendulum or the radial play in the bearings exceeds the specified limits, adjust or replace the bearings.

A2.3.4 *Determine the Center of Strike*—For Charpy machines the center of strike of the pendulum is determined using a half-width specimen (10 by 5 mm) in the test position. With the striker in contact with the specimen, a line marked along the top edge of the specimen on the striker will indicate the center of strike. For Izod machines, the center of strike may be considered to be the contact line when the pendulum is brought into contact with a specimen in the normal testing position.

A2.3.5 *Determine the Potential Energy*—The following procedure shall be used when the center of strike of the pendulum is coincident with the radial line from the centerline of the pendulum bearings (herein called the axis of rotation) to the center of gravity (see Appendix X2). If the center of strike is more than 1.0 mm (0.04 in.) from this line, suitable corrections in elevation of the center of strike must be made in A2.3.8.1 and A2.3.9, so that elevations set or measured correspond to what they would be if the center of strike were on this line. The potential energy of the system is equal to the height from which the pendulum falls, as determined in A2.3.5.2, times the supporting force, as determined in A2.3.5.1

A2.3.5.1 To measure the supporting force, support the pendulum horizontally to within 15:1000 with two supports, one at the bearings (or center of rotation) and the other at the center of strike on the striker (see Fig. A2.1). Then arrange the support at the striker to react upon some suitable weighing device such as a platform scale or balance, and determine the weight to within 0.4 %. Take care to minimize friction at either point of support. Make contact with the striker through a round rod crossing the edge at a 90° angle. The supporting force is the scale reading minus the weights of the supporting rod and any shims that may be used to maintain the pendulum in a horizontal position.

A2.3.5.2 Determine the height of pendulum drop for compliance with the requirement of A1.7. On Charpy machines determine the height from the top edge of a half-width (or

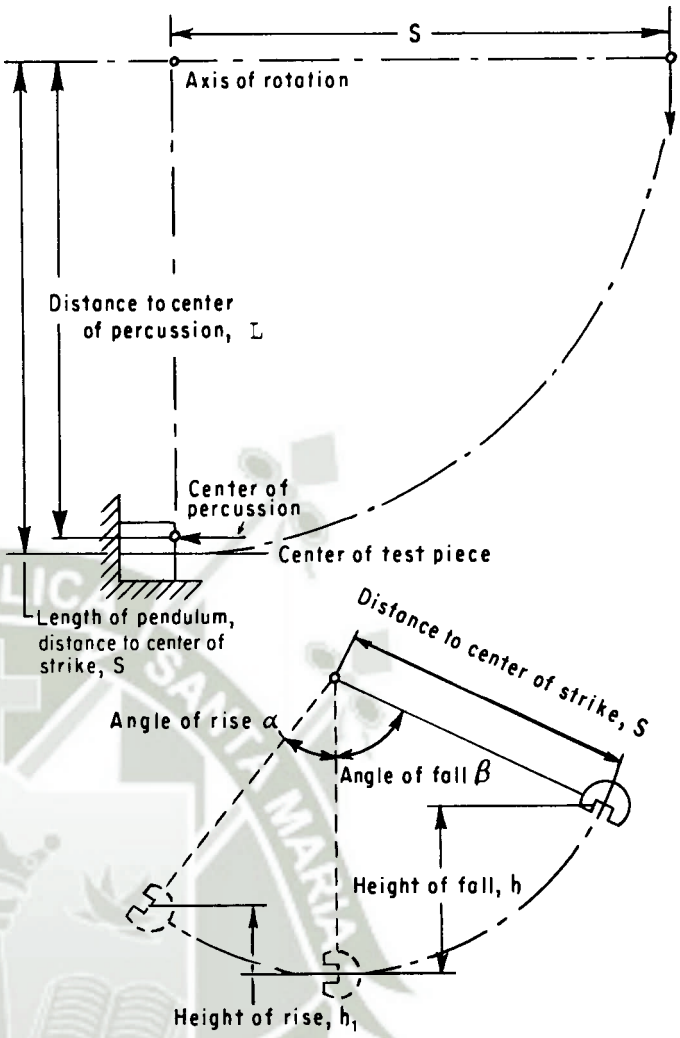


FIG. A2.1 Dimensions for Calculations

center of a full-width) specimen to the elevated position of the center of strike to 0.1 %. On Izod machines determine the height from a distance 22.66 mm (0.892 in.) above the vise to the release position of the center of strike to 0.1 %. The height may be determined by direct measurement of the elevation of the center of strike or by calculation from the change in angle of the pendulum using the following formulas (see Fig. A2.1):

$$h = S\,(1 - \cos\,(\beta)) \qquad \text{(A2.1)}$$

$$h_1 = S\,(1 - \cos\,(\alpha)) \qquad \text{(A2.2)}$$

where

h = initial elevation of the striker, m (ft),
S = length of the pendulum distance to the center of strike, m (ft),
β = angle of fall,
h_1 = height of rise, m (ft), and
α = angle of rise.

A2.3.6 Determine the impact velocity, [v], of the machine, neglecting friction, by means of the following equation:

$$v = \sqrt{2\,gh} \qquad \text{(A2.3)}$$

where:
v = velocity, m/s (ft/s),
g = acceleration of gravity, 9.81 m/s^2 (32.2 ft/s^2), and
h = initial elevation of the striker, m (ft).

A2.3.7 The center of percussion shall be at a point within 1 % of the distance from the axis of rotation to the center of strike in the specimen, to ensure that minimum force is transmitted to the point of rotation. Determine the location of the center of percussion as follows:

A2.3.7.1 Using a stop watch or some other suitable time-measuring device, capable of measuring time to within 0.2 s, swing the pendulum through a total angle not greater than 15° and record the time for 100 complete cycles (to and fro). The period of the pendulum then, is the time for 100 cycles divided by 100.

A2.3.7.2 Determine the center of percussion by means of the following equation:

$$L = \frac{qp^2}{4\pi^2} \quad \text{(A2.4)}$$

where:
L = distance from the axis to the center of percussion, m (ft),
g = local gravitational acceleration (accuracy of one part in one thousand), m/s^2 (ft/s^2),
π = 3.1416, and
p = period of a complete swing (to and fro), s.

A2.3.8 *Determination of the Friction Losses*—The energy loss from friction and windage of the pendulum and friction in the recording mechanism, if not corrected, will be included in the energy loss attributed to breaking the specimen and can result in erroneously high measurements of absorbed energy. For machines recording in degrees, frictional losses are usually not compensated for by the machine manufacturer, whereas in machines recording directly in energy, they are usually compensated for by increasing the starting height of the pendulum. Determine energy losses from friction as follows:

A2.3.8.1 Without a specimen in the machine, and with the indicator at the maximum energy reading, release the pendulum from its starting position and record the energy value indicated. This value should indicate zero energy if frictional losses have been corrected by the manufacturer. Now raise the pendulum slowly until it just contacts the indicator at the value obtained in the free swing. Secure the pendulum at this height and determine the vertical distance from the center of strike to the top of a half-width specimen positioned on the specimen rest supports within 0.1 % (see A2.3.5). Determine the supporting force as in A2.3.5.1 and multiply by this vertical distance. The difference in this value and the initial potential energy is the total energy loss in the pendulum and indicator combined. Without resetting the pointer, repeatedly release the pendulum from its initial position until the pointer shows no further movement. The energy loss determined by the final position of the pointer is that due to the pendulum alone. The frictional loss in the indicator alone is then the difference between the combined indicator and pendulum losses and those due to the pendulum alone.

A2.3.9 The indicating mechanism accuracy shall be checked to ensure that it is recording accurately over the entire range (see A1.2.1). Check it at graduation marks corresponding to approximately 0, 10, 20, 30, 50, and 70 % of each range. With the striker marked to indicate the center of strike, lift the pendulum and set it in a position where the indicator reads, for example, 13 J (10 ft·lbf). Secure the pendulum at this height and determine the vertical distance from the center of strike to the top of a half-width specimen positioned on the specimen supports within 0.1 % (see A2.3.5). Determine the residual energy by multiplying the height of the center of strike by the supporting force, as described in A2.3.5.1. Increase this value by the total frictional and windage losses for a free swing (see A2.3.8.1) multiplied by the ratio of the angle of swing of the pendulum from the latch to the energy value being evaluated to the angle of swing of the pendulum from the latch to the zero energy reading. Subtract the sum of the residual energy and proportional frictional and windage loss from the potential energy at the latched position (see A2.3.5). The indicator shall agree with the energy calculated within the limits of A1.2.1. Make similar calculations at other points of the scale. The indicating mechanism shall not overshoot or drop back with the pendulum. Make test swings from various heights to check visually the operation of the pointer over several portions of the scale.

NOTE A2.4—Indicators that indicate in degrees shall be checked using the above procedure. Degree readings from the scale shall be converted to energy readings using the conversion formula or table normally used in testing. In this way the formula or table can also be checked for windage and friction corrections.

A2.4 *Indirect Verification*:

A2.4.1 Indirect verification requires the testing of specimens with certified values to verify the accuracy of Charpy impact machines.

A2.4.1.1 Verification specimens with certified values are produced at low (12 to 20 J), high (88 to 115 J), and super-high (210 to 230 J) energy levels. To meet the verification requirements, the average value determined for a set of verification specimens at each energy level tested shall correspond to the certified values of the verification specimens within 1.4 J (1.0 ft·lbf)) or 5.0 %, whichever is greater.

A2.4.1.2 Verification specimens are available from the National Institute of Standards and Technology (NIST) through the Standard Reference Materials Program (see Annex A3). Other sources of verification specimens may be used provided they conform to Practice E 1271 and their reference value has been established on the three reference machines owned, maintained, and operated by NIST in Boulder, CO.

NOTE A2.5—Verification specimens are available for Charpy machines only. Detailed information pertaining to the availability of verification specimens is given in Appendix X3.

A2.4.2 The verified range of a Charpy impact machine is described with reference to the lowest and highest energy specimens tested on the machine. These values are determined from tests on sets of verification specimens at two or more levels of absorbed energy, except in the case where a Charpy machine has a maximum capacity that is too low for two energy levels to be tested. In this case, one level of absorbed energy can be used for indirect verification.

A2.4.3 Determine the usable range of the impact testing machine prior to testing verification specimens. The usable range of an impact machine is dependent upon the resolution of the scale or readout device at the low end and the capacity of the machine at the high end.

A2.4.3.1 The resolution of the scale or readout device establishes the lower limit of the usable range for the machine. The lower limit is equal to 25 times the resolution of the scale or readout device at 15J (11 ft-lbf).

NOTE A2.6—On analog scales, the resolution is the smallest change in energy that can be discerned on the scale. This is usually ¼ to ⅕ of the difference between 2 adjacent marks on the scale at the 15J (11 ft-lbf) energy level.

NOTE A2.7—Digital scales usually incorporate devices, such as digital encoders, with a fixed discrete angular resolution. The resolution of these types of readout devices is the smallest change in energy that can be consistently measured at 15J. The resolution of these types of devices is usually not a change in the last digit shown on the display because resolution is a function of the angular position of the pendulum and changes throughout the swing. For devices which incorporate a verification mode in which a live readout of absorbed energy is available, the pendulum may be moved slowly in the area of 15 J to observe the smallest change in the readout device (the resolution).

A2.4.3.2 The upper limit of the usable range of the machine is equal to 80 % of the capacity of the machine.

A2.4.4 Only verification specimens that are within the usable range of the impact machine shall be tested. To verify the machine over its full usable range, test the lowest and highest energy levels of verification specimens commercially available that are within the machines' usable range. If the ratio of the highest and lowest certified values tested is greater than four, testing of a third set of intermediate energy specimens is required (if the specimens are commercially available).

NOTE A2.8—Use the upper bound of the energy range given for the low, high, and super-high verification specimens (20, 115, and 230 J respectively to determine the highest energy level verification specimens that can be tested. Alternately, use the lower bound of the energy range given for the verification specimens to determine the minimum energy level for testing.

A2.4.4.1 If the low energy verification specimens were not tested (tested only high and super-high), the lower limit of the verified range shall be one half the energy of the lowest energy verification set tested.

NOTE A2.9—For example, if the certified value of the high energy specimens tested was 100J, the lower limit would be 50J.

A2.4.4.2 If the highest energy verification specimens available for a given Charpy machine capacity have not been tested, the upper value of the verified range shall be 1.5 times the certified value of the highest energy specimens tested.

NOTE A2.10—For example, if the machine being tested has a maximum capacity of 325 J (240 ft-lbf) and only low and high energy verification specimens were tested, the upper bound of the verified range would be 150 J (100 J * 1.5 = 150 J), assuming that the high energy samples tested had a certified value of 100J. To verify this machine over its full range, low, high, and super-high verification specimens would have to be tested, because super-high verification specimens can be tested on a machine with a 325J capacity (80 % of 325J is 260J, and the certified value of super-high specimens never exceed 230J). See Table A2.1.

TABLE A2.1 Verified Ranges for Various Machine Capacities and Verification Specimens Tested[A]

Machine Capacity J	Resolution J	Usable Range J	Verification Specimens Tested			Verified Range J
			Low	High	Super-high	
80	0.10	2.5 to 64	X	. . .	. . .	2.5 to 64
160	0.20	5.0 to 128	X	X	. . .	5.0 to 128
325	0.25	6.25 to 260	X	X	X	6.25 to 260
400	0.30	7.5 to 320	. . .	X	X	50 to 320
400	0.15	3.75 to 320	X	X	. . .	3.75 to 150
400	0.15	3.75 to 320	X	X	X	3.75 to 320

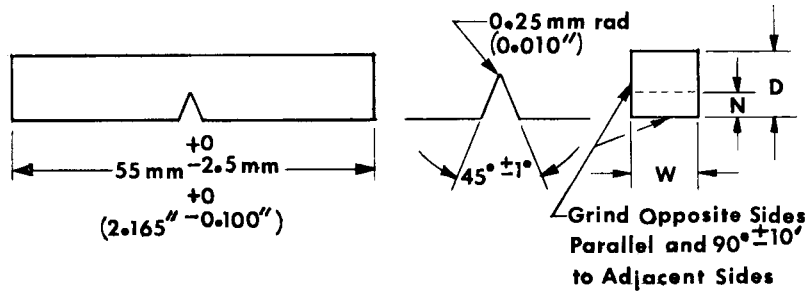
[A]In these examples, the high energy verification specimens are assumed to have a certified value of 100J.

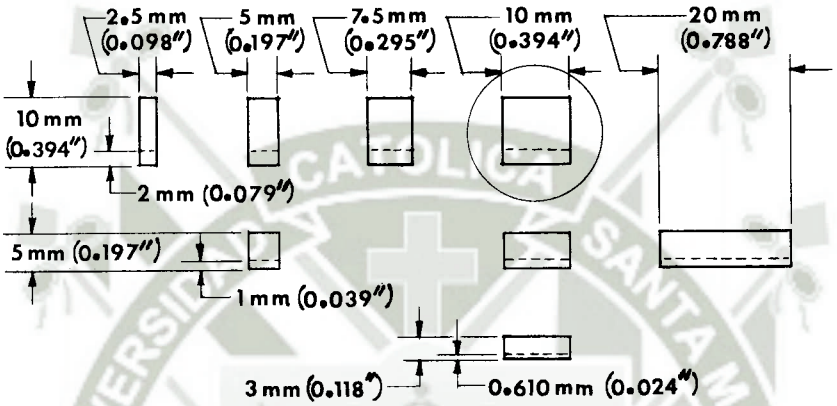
A3. ADDITIONAL IMPACT TEST SPECIMEN CONFIGURATIONS

A3.1 *Sub-Size Specimen*—When the amount of material available does not permit making the standard impact test specimens shown in Figs. 1 and 2, smaller specimens may be used, but the results obtained on different sizes of specimens cannot be compared directly (X1.3). When Charpy specimens other than the standard are necessary or specified, it is recommended that they be selected from Fig. A3.1.

A3.2 *Supplementary Specimens*—For economy in preparation of test specimens, special specimens of round or rectangular cross section are sometimes used for cantilever beam test. These are shown as Specimens X, Y, and Z in Figs. A3.2 and A3.3. Specimen Z is sometimes called the Philpot specimen, after the name of the original designer. For hard materials, the machining of the flat surface struck by the pendulum is sometimes omitted. Types Y and Z require a different vise from that shown in Fig. A1.3, each half of the vise having a semi-cylindrical recess that closely fits the clamped portion of the specimen. As previously stated, the results cannot be reliably compared with those obtained using specimens of other sizes or shapes.

On subsize specimens the length, notch angle, and notch radius are constant (see Fig. 1); depth (*D*), notch depth (*N*), and width (*W*) vary as indicated below.

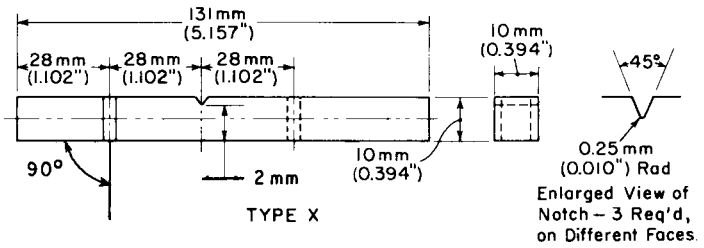




NOTE 1—Circled specimen is the standard specimen (see Fig. 1).
NOTE 2—Permissible variations shall be as follows:

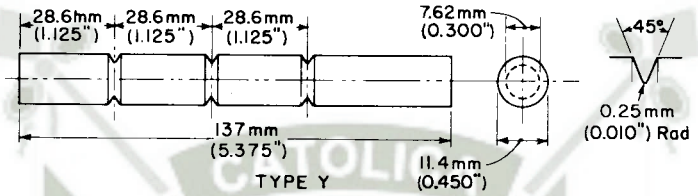
Cross-section dimensions	±1 % or ±0.075 mm (0.003 in.), whichever is smaller
Radius of notch	±0.025 mm (0.001 in.)
Depth of notch	±0.025 mm (0.001 in.)
Finish requirements	2 µm (63 µin.) on notched surface and opposite face; 4 µm (125 µin.) on other two surfaces

FIG. A3.1 Charpy (Simple-Beam) Subsize (Type A) Impact Test Specimens



NOTE 1—Permissible variations for type X specimens shall be as follows:

Notch length to edge	90± 2°
Adjacent sides shall be at	90°± 10 min
Notch depth of Type X specimen	±0.025 mm (±0.001 in.)

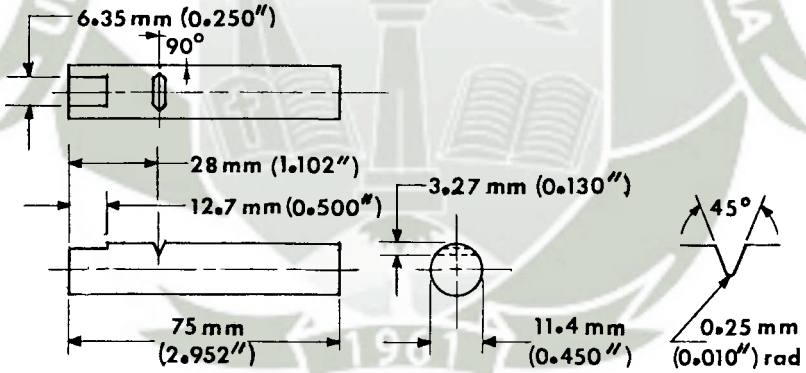


NOTE 2—Permissible variations for both specimens shall be as follows:

Cross-section dimensions	±0.025 mm (±0.001 in.)
Lengthwise dimensions	+0, −2.5 mm (+0, −0.100 in.)
Angle of notch	±1°
Radius of notch	±0.025 mm (±0.001 in.)
Notch diameter of Type Y specimen	±0.025 mm (±0.001 in.)

FIG. A3.2 Izod (Cantilever-Beam) Impact Test Specimens, Types X and Y

The flat shall be parallel to the longitudinal centerline of the specimen and shall be parallel to the bottom of the notch within 2:1000.



TYPE Z

NOTE 1—Permissible variations shall be as follows:

Notch length to longitudinal centerline	90± 2°
Cross-section dimensions	±0.025 mm (±0.001 in.)
Length of specimen	+0, −2.5 mm (+0 −0.100 in.)
Angle of notch	±1°
Radius of notch	±0.025 mm (±0.001 in.)
Notch depth	±0.025 mm (.130± 0.001 in.)

FIG. A3.3 Izod (Cantilever-Beam) Impact Test Specimen (Philpot), Type Z

A4. PRECRACKING CHARPY V-NOTCH IMPACT SPECIMENS

A4.1 Scope

A4.1.1 This annex describes the procedure for the fatigue precracking of standard Charpy V-notch (CVN) impact specimens. The annex provides information on applications of precracked Charpy impact testing and fatigue-precracking procedures.

A4.2 Significance and Use

A4.2.1 Section 4 also applies to precracked Charpy V-notch impact specimens.

A4.2.2 It has been found that fatigue-precracked CVN specimens generally result in better correlations with other impact toughness tests such as Test Method E 604 and with fracture toughness tests such as Test Method E 399 than the standard V-notch specimens **(3,4,5,6,7,8)**. Also, the sharper notch yields more conservative estimations of the notched impact toughness and the transition temperature of the material **(9,10)**.

A4.3 Apparatus

A4.3.1 The equipment for fatigue cracking shall be such that the stress distribution is symmetrical through the specimen thickness; otherwise, the crack will not grow uniformly. The stress distribution shall also be symmetrical about the plane of the prospective crack; otherwise the crack will deviate unduly from that plane and the test result will be significantly affected.

A4.3.2 The recommended fixture to be used is shown in Fig. A4.1. The nominal span between support rollers shall be 4 $D \pm 0.2\ D$, where D is the depth of the specimen. The diameter of the rollers shall be between $D/2$ and D. The radius of the ram shall be between $D/8$ and D. This fixture is designed to minimize frictional effects by allowing the support rollers to rotate and move apart slightly as the specimen is loaded, thus permitting rolling contact. The rollers are initially positioned against stops that set the span length and are held in place by low-tension springs (such as rubber bands). Fixtures, rolls, and ram should be made of high hardness (greater than 40 HRC) steels.

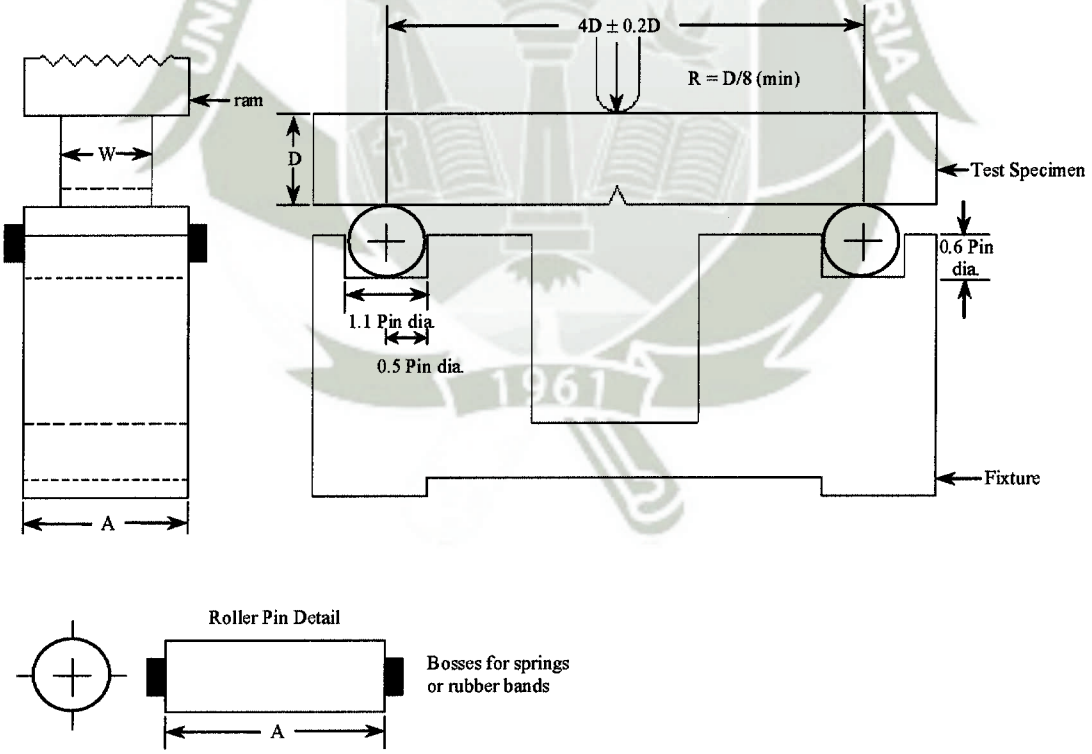
A4.4 Test Specimens

A4.4.1 The dimensions of the precracked Charpy specimen are essentially those of type-A shown in Fig. A4.2. The notch depth plus the fatigue crack extension length shall be designated as N. When the amount of material available does not permit making the standard impact test specimen, smaller specimens may be made by reducing the width; but the results obtained on different sizes of specimens cannot be compared directly (see X1.3).

A4.4.2 The fatigue precracking is to be done with the material in the same heat-treated condition as that in which it will be impact tested. No intermediate treatments between fatigue precracking and testing are allowed.

A4.4.3 Because of the relatively blunt machined V-notch in the Charpy impact specimen, fatigue crack initiation can be difficult. Early crack initiation can be promoted by pressing or milling a sharper radius into the V-notch. Care must be taken to ensure that excessive deformation at the crack tip is avoided.

A4.4.4 It is advisable to mark two pencil lines on each side of the specimen normal to the anticipated paths of the surface traces of the fatigue crack. The first line should indicate the point at which approximately two-thirds of the crack extension



L = length = 55 mm +0, −2.5 mm,
D = depth = 10 mm ± 0.075 mm,
W = variable width (see A3.1),
N = notch depth = 2 mm ± 0.025 mm, included angle of notch = 45°± 1°, and radius of notch = 0.25 mm ± 0.025 m.

FIG. A4.1 Fatigue Precracking-Fixture Design

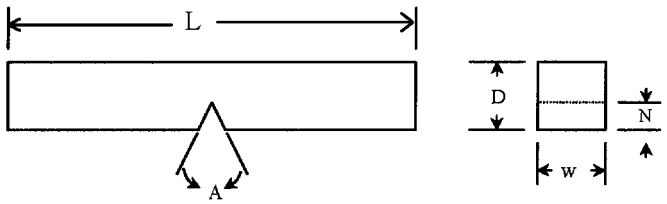


FIG. A4.2 Charpy (Simple-Beam, type A) Impact Test Specimen

has been accomplished. At this point, the stress intensity applied to the specimen should be reduced. The second line should indicate the point of maximum crack extension. At this point, fatigue precracking should be terminated.

A4.5 Fatigue Precracking Procedure

A4.5.1 Set up the test fixture so that the line of action of the applied load shall pass midway between the support roll center within 1 mm. Measure the span to within 1 % of the nominal length. Locate the specimen with the crack tip midway between the rolls within 1 mm of the span, and square to the roll axes within 2°.

A4.5.2 Select the initial loads used during precracking so that the remaining ligament remains undamaged by excessive plasticity. If the load cycle is maintained constant, the maximum K (stress intensity) and the K range will increase with crack length; care must be taken to ensure that the maximum K value is not exceeded to prevent excessive plastic deformation at the crack tip. This is done by continually shedding the load as the fatigue crack extends. The maximum load to be used at any instant can be calculated from Eq A4.1 and A4.2 while the minimum load should be kept at 10 % of the maximum. Eq A4.1 relates the maximum load to a stress intensity (K) value for the material that will ensure an acceptable plastic-zone size at the crack tip. It is also advisable to check this maximum load to ensure that it is below the limit load for the material using Eq A4.2. When the most advanced crack trace has almost reached the first scribed line corresponding to approximately two-thirds of the final crack length, reduce the maximum load so that 0.6 K_{max} is not exceeded.

A4.5.3 Fatigue cycling is begun, usually with a sinusoidal waveform and near to the highest practical frequency. There is no known marked frequency effect on fatigue precrack formation up to at least 100 Hz in the absence of adverse environments; however, frequencies of 15 to 30 Hz are typically used. Carefully monitor the crack growth optically. A low-power magnifying glass is useful in this regard. If crack growth is not observed on one side when appreciable growth is observed on the first, stop fatigue cycling to determine the cause and remedy for the behavior. Simply turning the specimen around in relation to the fixture will often solve the problem. When the most advanced crack trace has reached the halfway mark, turn the specimen around in relation to the fixture and complete the fatigue cycling. Continue fatigue cycling until the surface traces on both sides of the specimen indicate that the desired overall length of notch plus crack is reached. The fatigue crack should extend at least 1 mm beyond the tip of the V-notch but no more than 3 mm. A fatigue crack extension of approximately 2 mm is recommended.

A4.5.4 When fatigue cracking is conducted at a temperature T_1 and testing will be conducted at a different temperature T_2, and $T_1 > T_2$, the maximum stress intensity must not exceed 60 % of the K_{max} of the material at temperature T_1 multiplied by the ratio of the yield stresses of the material at the temperatures T_1 and T_2, respectively. Control of the plastic-zone size during fatigue cracking is important when the fatigue cracking is done at room temperature and the test is conducted at lower temperatures. In this case, the maximum stress intensity at room temperature must be kept to low values so that the plastic-zone size corresponding to the maximum stress intensity at low temperatures is smaller.

A4.6 Calculation

A4.6.1 Specimens shall be precracked in fatigue at load values that will not exceed a maximum stress intensity, K_{max}. or three-point bend specimens use:

$$P_{max} = [K_{max} * W * D^{3/2}] / [S * f(N/D)] \quad \text{(A4.1)}$$

where:

P_{max} = maximum load to be applied during precracking,
K_{max} = maximum stress intensity = $\sigma_{ys} * (2 * \pi * r_y)^{1/2}$, where r_y = is the radius of the induced plastic zone size which should be less than or equal to 0.5 mm,
D = specimen depth,
W = specimen width,
S = span, and
$f(N/D)$ = geometrical factor (see Table A4.1).

A4.6.2 See the appropriate section of Test Method E 399 for the $f(N/D)$ calculation. Table A4.1 contains calculated values for $f(N/D)$ for CVN precracking. Eq A4.2 should be used to ensure that the loads used in fatigue cracking are well below the calculated limit load for the material.

TABLE A4.1 Calculations of f(N/D)

N (mm)	D (mm)	N/D	f(N/D)
2.00	10.00	0.20	1.17
2.10	10.00	0.21	1.21
2.20	10.00	0.22	1.24
2.30	10.00	0.23	1.27
2.40	10.00	0.24	1.31
2.50	10.00	0.25	1.34
2.60	10.00	0.26	1.37
2.70	10.00	0.27	1.41
2.80	10.00	0.28	1.45
2.90	10.00	0.29	1.48
3.00	10.00	0.30	1.52
3.10	10.00	0.31	1.56
3.20	10.00	0.32	1.60
3.30	10.00	0.33	1.64
3.40	10.00	0.34	1.69
3.50	10.00	0.35	1.73
3.60	10.00	0.36	1.78
3.70	10.00	0.37	1.83
3.80	10.00	0.38	1.88
3.90	10.00	0.39	1.93
4.00	10.00	0.40	1.98
4.10	10.00	0.41	2.04
4.20	10.00	0.42	2.10
4.30	10.00	0.43	2.16
4.40	10.00	0.44	2.22
4.50	10.00	0.45	2.29
4.60	10.00	0.46	2.35
4.70	10.00	0.47	2.43
4.80	10.00	0.48	2.50
4.90	10.00	0.49	2.58
5.00	10.00	0.50	2.66

$$P_L = (4/3) * [D* (D - N)^2 * \sigma_{ys}]/S \quad (A4.2)$$

where:
P_L = limit load for the material.

A4.7 Crack Length Measurement

A4.7.1 After fracture, measure the initial notch plus fatigue crack length, *N*, to the nearest 1 % at the following three positions: at the center of the crack front and midway between the center and the intersection of the crack front with the specimen surfaces. Use the average of these three measurements as the crack length.

A4.7.2 If the difference between any two of the crack length measurements exceeds 10 % of the average, or if part of the crack front is closer to the machine notch root than 5 % of the average, the specimen should be discarded. Also, if the length of either surface trace of the crack is less than 80 % of the average crack length, the specimen should be discarded.

A4.8 Report

A4.8.1 Report the following information for each specimen tested: type of specimen used (and size if not the standard size), test temperatures, and energy absorption. Report the average precrack length in addition to these Test Method E 23 requirements.

A4.8.2 The following information may be provided as supplementary information: lateral expansion, fracture appearance, and also, it would probably be useful to report energy absorption normalized in some manner.

A5. SPECIMEN ORIENTATION

A5.1 *Designation of Specimen Axis*:

A5.1.1 The L-axis is coincident with the main direction of grain flow due to processing. This axis is usually referred to as the longitudinal direction (see Fig. A5.1, Fig. A5.2, and Fig. A5.3).

A5.1.2 The S-axis is coincident with the direction of the main working force. This axis is usually referred to as the short-transverse-direction.

A5.1.3 The T-axis is normal to the L- and S-axies. This axis is usually referred to as the transverse direction.

A5.1.4 Specimens parallel to the surface of wrought products, processed wit the same degree of homogenous deformation along the L- and T axies may be called T specimens.

A5.1.5 Specimens normal to the uniform grain flow of wrought products (or grain growth in cast products), whose grain flow is exclusively in one direction, so that T- and S specimens are equivalent, may be called S specimens.

A5.2 *Designation of Notch Orientation*:

A5.2.1 The notch orientation is designated by the direction in which fracture propagates. This letter is separated from the specimen-axis designation by a hyphen. In unique cases (Fig. A5.3), when fracture propagates across two planes, two letters are required to designate notch orientation.

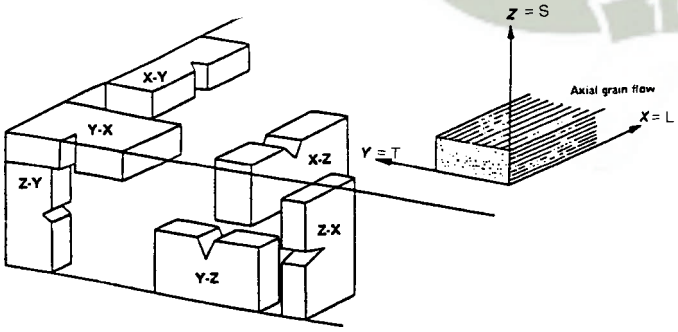


FIG. A5.1 Fracture Planes Along Principal Axes

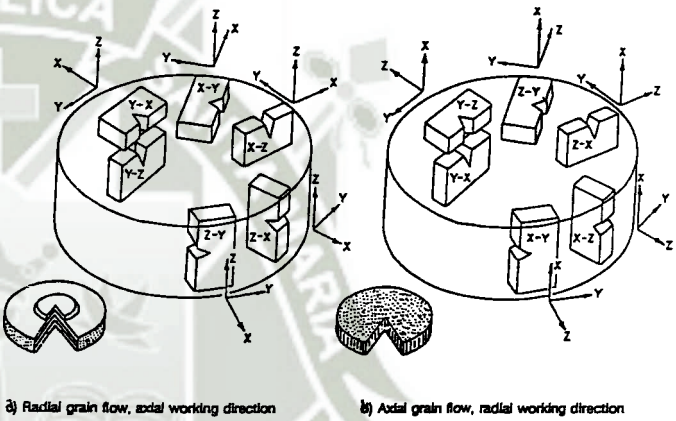


FIG. A5.2 Fracture Planes—Cylindrical Sections

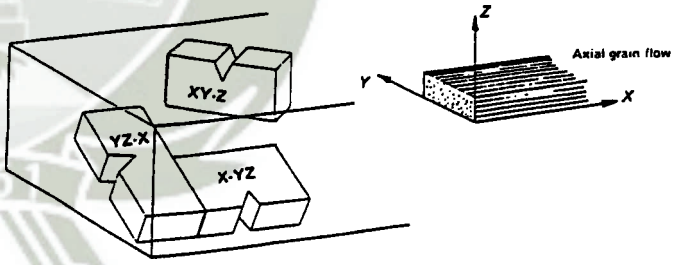


FIG. A5.3 Fracture Planes not Along Principal Axes

A6. DETERMINATION OF THE PROPORTION OF SHEAR FRACTURE SURFACE

A6.1 These fracture-appearance methods are bases on the concept that 100% shear (ductile) fracture occurs above the transition-temperature range and cleavage (brittle) fracture occurs below the range . This concept appears to be appropriate, at least for body-centered-cubic iron-based alloys that undergo a distinct ductile to brittle transition, but interpretation is complicated in materials which exhibit mixed mode fracture during unstable crack growth. In the transition-temperature range, fracture is initiated at the root of the notch by fibrous tearing. A short distance from the notch, unstable crack growth occurs as the fracture mechanism changes to cleavage or mixed mode mechanism, which often results in distinct radial markings in the central portion of the specimen (indicative of fast, unstable fracture). After several microseconds the unstable crack growth arrests. Finial fracture occurs at the remaining ligament and at the sides of the specimen in a ductile manner. As shear-lips are formed at the sides of the specimen, the plastic hinge at the remaining ligament ruptures. In the ideal case, a “picture frame” of fibrous (ductile) fracture surrounds a relatively flat area of cleavage (brittle) fracture.

The five methods used below may be used to determine the percentage of ductile fracture on the surface of impact specimens. It is recommended that the user qualitatively characterize the fracture mode of the flat fracture zone, and provide a description of how the shear measurements were made. The accuracy of the methods are grouped in order of increasing precision.

NOTE A6.1—Round robin data (five U.S. companies, 1990) estimates of the percent shear for five quenched and tempered 8219 steels and four microalloyed 1040 steels indicated the following: (1) results using method A6.1.1 systematically underestimated the percent shear (compared with method A6.1.4), (2) the error using method A6.1.2 was random and, (3) The typical variation in independent measurements using method A6.1.4 was on the order of 5 to 10 % for microalloyed 1040 steels.

A6.1.1 Measure the length and width of the flat fracture region of the fracture surface, as shown in Fig. 10, and determine the percent shear from either Table A6.1 or Table A6.2 depending on the units of measurement.

A6.1.2 Compare the appearance of the fracture of the specimen with a fracture appearance chart such as that shown in Fig. A6.1.

A6.1.3 Magnify the fracture surface and compare it to a precalibrated overlay chart or measure the percent shear fracture by means of a planimeter.

A6.1.4 Photograph the fracture surface at a suitable magnification and measure the percent shear fracture by means of a planimeter.

A6.1.5 Capture a digital image of the fracture surface and measure the percent shear fracture using image analysis software.

TABLE A6.1 Percent Shear for Measurements Made in Millimetres

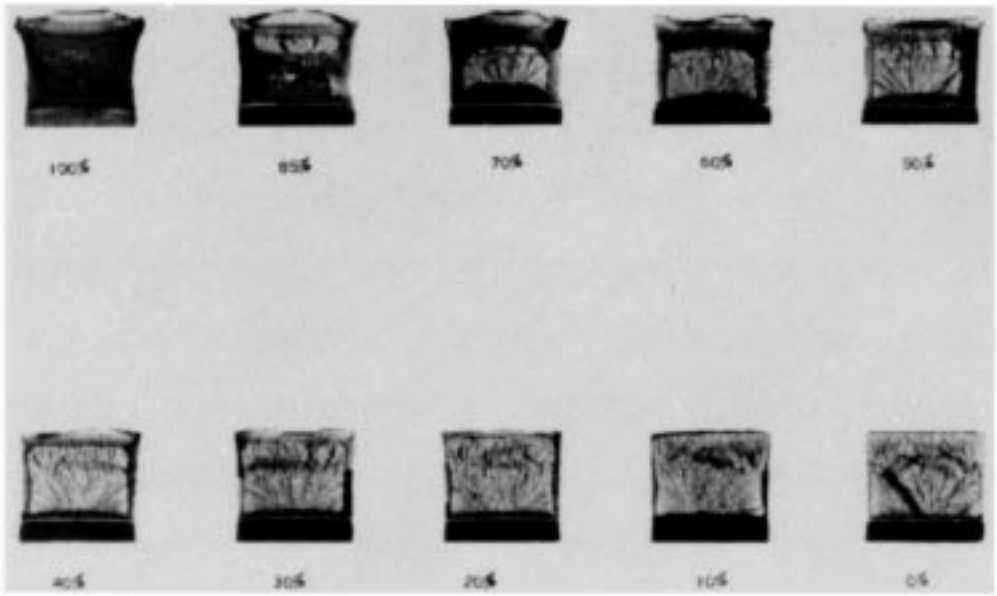
NOTE 1—100 % shear is to be reported when either *A* or *B* is zero.

Dimension *B*, mm	Dimension *A*, 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

TABLE A6.2 Percent Shear for Measurements Made in Inches

NOTE 1—100 % shear is to be reported when either *A* or *B* is zero.

Dimension *B*, in.	Dimension *A*, 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



(*a*) Fracture Appearance Charts and Percent Shear Fracture Comparator

(*b*) Guide for Estimating Fracture Appearance

FIG. A6.1 Fracture Appearance

APPENDIXES

(Nonmandatory Information)

X1. NOTES ON SIGNIFICANCE OF NOTCHED-BAR IMPACT TESTING

X1.1 *Notch Behavior*:

X1.1.1 The Charpy V-notch (CVN) impact test has been used extensively in mechanical testing of steel products, in research, and in procurement specifications for over three

decades. Where correlations with fracture mechanics parameters are available, it is possible to specify CVN toughness values that would ensure elastic-plastic or plastic behavior for fracture of fatigue cracked specimens subjected to minimum operating temperatures and maximum in service rates of loading.

X1.1.2 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 constraints to deformation in directions perpendicular to the major stress, or multi axial 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.

X1.2 *Notch Effect*:

X1.2.1 The notch results in a combination of multi axial 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 very low temperatures, 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.

X1.2.2 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.

X1.2.3 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.

X1.2.4 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 X1.1). 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.

X1.2.5 Variations in notch dimensions will seriously affect the results of the tests. Tests on E 4340 steel specimens[6] have shown the effect of dimensional variations on Charpy results (see Table X1.1).

X1.3 *Size Effect*:

X1.3.1 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 constraint 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.

TABLE X1.1 Effect of Varying Notch Dimensions on Standard Specimens

	High-Energy Specimens, J (ft·lbf)	Medium-Energy Specimens, J (ft·lbf)	Low-Energy Specimens, J (ft·lbf)
Specimen with standard dimensions	103.0 ± 5.2 (76.0 ± 3.8)	60.3 ± 3.0 (44.5 ± 2.2)	16.9 ± 1.4 (12.5 ± 1.0)
Depth of notch, 2.13 mm (0.084 in.)[A]	97.9 (72.2)	56.0 (41.3)	15.5 (11.4)
Depth of notch, 2.04 mm (0.0805 in.)[A]	101.8 (75.1)	57.2 (42.2)	16.8 (12.4)
Depth of notch, 1.97 mm (0.0775 in.)[A]	104.1 (76.8)	61.4 (45.3)	17.2 (12.7)
Depth of notch, 1.88 mm (0.074 in.)[A]	107.9 (79.6)	62.4 (46.0)	17.4 (12.8)
Radius at base of notch 0.13 mm (0.005 in.)[B]	98.0 (72.3)	56.5 (41.7)	14.6 (10.8)
Radius at base of notch 0.38 mm (0.015 in.)[B]	108.5 (80.0)	64.3 (47.4)	21.4 (15.8)

[A]Standard 2.0 ± 0.025 mm (0.079 ± 0.001 in.).
[B]Standard 0.25 ± 0.025 mm (0.010 ± 0.001 in.).

X1.3.2 In studies of such effects where the size of the material precludes the use of the standard specimen, for example when the material is 6.35-mm (0.25-in.) plate, subsize specimens are used. Such specimens (Fig. A3.1) are based on the Type A specimen of Fig. 1.

X1.3.3 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.

X1.4 *Temperature Effect*:

X1.4.1 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 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 absorbed energy 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.

X1.5 *Testing Machine*:

X1.5.1 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 striker, or the machine foundation bolts are not securely fastened, tests on ductile materials in the range from 108 J (80 ft·lbf) may actually indicate values in excess of 122 to 136 J (90 to 100 ft·lbf)

X1.5.2 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 15.2 m/s (50 ft/s) although they were struck by a pendulum traveling at speeds approximately 5.2 m/s (17 ft/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 14 to 34-J (10 to 25 ft-lb) range. Figure A1.1 illustrates a modification found to be satisfactory in minimizing jamming.

X1.6 *Velocity of Straining*:

X1.6.1 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.

X1.7 *Correlation with Service*:

X1.7.1 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 or 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.

X2. SUGGESTED METHODS OF MEASUREMENT

X2.1 *Position of the Center of Strike Relative to the Center of Gravity:*

X2.1.1 Since the center of strike can only be marked on an assembled machine, only the methods applicable to an assembled machine are described as follows:

X2.1.1.1 The fundamental fact on which all the methods are based is that when the friction forces are negligible, the center of gravity is vertically below the axis of rotation of a pendulum supported by the bearings only, (herein referred to as a free hanging pendulum). Paragraph A1.3 limits the friction forces in impact machines to a negligible value. The required measurements may be made using specialized instruments such as transits, clinometers, or cathometers. However, simple instruments have been used as described in the following to make measurements of sufficient accuracy.

X2.1.1.2 Suspend a plumb bob from the frame. The plumb line should appear visually to be in the plane of swing of the striking edge.

X2.1.1.3 Place a massive object on the base close to the latch side of the tup. Adjust the position of this object so that when back lighted, a minimal gap is visable between it and the tup when the pendulum is free hanging.

X2.1.1.4 With a scale or depth gage pressed lightly against the striking edge at the center of strike, measure the horizontal distance between the plumb line and striking edge. (The dimension *B* in Fig. X2.1.)

X2.1.1.5 Similarly, measure the distance in a horizontal plane through the axis of rotation from the plumb line to the clamp block or enlarged end of the pendulum stem. (Dimension *A* in Fig. X2.1.)

X2.1.1.6 Use a depth gage to measure the radial distance from the surface contacted in measuring *A* to a machined surface of the shaft which connects the pendulum to the bearings in the machine frame. (Dimension *C* in Fig. X2.1.)

X2.1.1.7 Use an outside caliper or micrometer to measure the diameter of the shaft at the same location contacted in measuring *C*. (Dimension *D* in Fig. X2.1.)

X2.1.1.8 Substitute the measured dimensions in the equation

$$X = A + C + D/2 - B \quad \text{(X2.1)}$$

where:

X = deviation of the center of strike from a line from the center of rotation through the center of gravity.

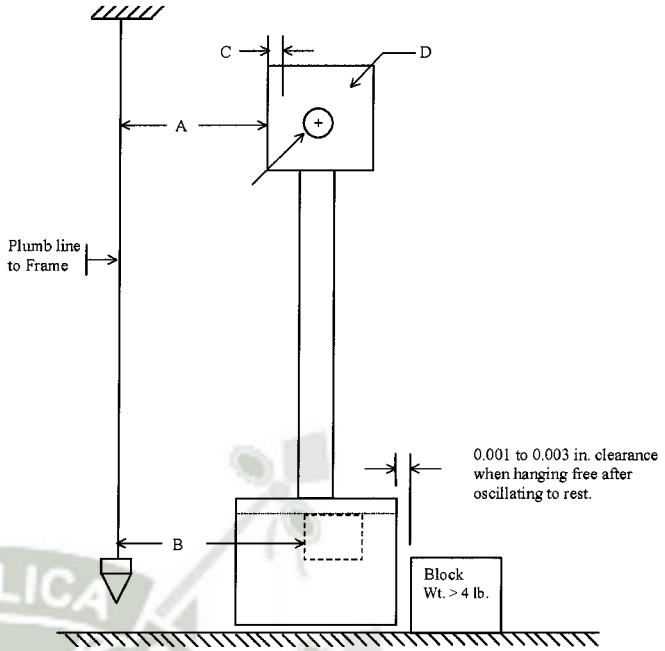


FIG. X2.1 Measurement of Deviation of Center of Strike from Vertical Plane through Axis of Rotation when Pendulum is Hanging Free

X3. CHARPY V-NOTCH VERIFICATION PROGRAM

X3.1 The National Institute of Standards and Technology (NIST) Standard Reference Materials Program (SRMP) conducts a Charpy machine qualification program originally developed by the U.S. Army. Under this program, verification specimens are used to certify Charpy impact machines to the requirements of these test methods.

X3.1.1 *Purchasing Verification Specimens*:

X3.1.1.1 Verification specimens may be obtained by contacting the SRMP sales office at the National Institute of Standards and Technology.[8]

X3.2 *Verification Test Evaluation*:

X3.2.1 To receive a written report on verification tests, mail the broken test specimens and questionnaire to: Charpy Program Coordinator at NIST.[9] NIST will evaluate the specimens and test results, and return a report. If a machine meets the direct and indirect verification requirements of ASTM Standard E 23, a letter of certification will be issued for the machine. If a machine is producing values outside the tolerances given in the ASTM E 23 standard, the report may suggest repair or replacement of certain machine parts, a change in testing techniques, or other adjustments.

X3.2.2 Questions on verification testing and results should be addressed to the Charpy Program Coordinator. Test results may be requested by phone or FAX, prior to the evaluation of broken specimens. To obtain informal results, the user must supply the lot code (for example, LL-xx, HH-xx, or SH-xx) and individual specimen identification numbers (stamped on the specimens), along with the absorbed energy values obtained during their test.

[8] National Institute of Standards and Technology, Standard Reference Material Program, Building 202, Room 204, Gaithersburg, MD 20899. E-mail: srminfo@nist.gov.

[9] Charpy Program Coordinator, NIST, Mail Code 853, 325 Broadway, Boulder, CO 80303-3328.

REFERENCES

(**1**) Nanstad, R. K., Swain, R. L. and Berggren, R. G., "Influence of Thermal Conditioning Media on Charpy Specimen Test Temperature," *Charpy Impact Test: Factors and Variables, ASTM STP 1072*, ASTM, 1990.

(**2**) Tobler R. L. Et al.," Charpy Impact Tests Near Absolute Zero," *Journal of Testing and Evaluation*, Vol 19, 1 1992.

(**3**) Wullaert, R. A., Ireland, D. R., and Tetelman, A. S., "Radiation Effects on the Metallurgical Fracture Parameters and Fracture Toughness of Pressure Vessel Steels," *Irradiation Effects on Structural Alloys for Nuclear Reactor Applications, ASTM STP 484*, ASTM, 1970, pp. 20–41.

(**4**) Sovak, J. F., "Correlation of Data from Standard and Precracked Charpy Specimens with Fracture Toughness Data for HY-130, A517-F, and HY-80 Steel," *Journal of Testing and Evaluation*, JTEVA, Vol 10, No. 3, May 1982, pp. 102–114.

(**5**) Succop, G. and Brown, W. F., Jr., "Estimation of K_{Ic} from Slow Bend Precracked Charpy Specimen Strength Ratios," *Developments in Fracture Mechanics Test Methods Standardization, ASTM STP 632*, W. F. Brown, Jr., and J. G. Kaufman, Eds., ASTM, 1977, pp. 179–192.

(**6**) Tauscher, S., "The Correlation of Fracture Toughness with Charpy V-notch Impact Test Data," Army Armament Research and Development Command, Technical Report ARLCB-TR-81012, 1981.

(**7**) Wullaert, R. A., Ireland, D. R., and A. S. Tetelman, "Use of the Precracked Charpy Specimen in Fracture Toughness Testing," *Fracture Prevention and Control*, pp. 255–282.

(**8**) Barsom, J. M. and Rolfe, S. T., "Correlations Between K_{Ic} and Charpy V-notch Test Results in the Transition-Temperature Range," *Impact Testing of Metals, ASTM STP 466*, ASTM, 1970, pp. 281–302.

(**9**) Mikalac, S., Vassilaros, M. G., and H. C. Rogers, "Precracking and Strain Rate Effects on HSLA-100 Steel Charpy Specimens," *Charpy Impact Test: Factors and Variables, ASTM STP 1072*, J. M. Holt, Ed., ASTM, 1990.

(**10**) Sharkey, R. L. and Stone, D. H., "A Comparison of Charpy V-notch, Dynamic Tear, and Precracked Charpy Impact Transition-Temperature Curves for AAR Grades of Cast Steel."