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# PRODUCTION OF A LARGE, ROLLED RING FORGING OF "200" GRADE MARAGING STEEL

BY

T. J. LILLIE

PREPARED FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CONTRACT NAS 3-7966



LADISH CO.

CUDAHY, WISCONSIN

LADISH 03-119

FINAL TECHNICAL REPORT

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CONTRACT NAS 3-7966

Technical Management
NASA Lewis Research Center
Cleveland, Ohio
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LADISH CO.
Cudahy, Wisconsin

# PRODUCTION OF A LARGE, ROLLED RING FORGING
# OF "200" GRADE MARAGING STEEL

by
T. J. Lillie

## ABSTRACT

A seamless, thin-walled, high-face-height cylinder of maraging steel was produced by the roll-forming process. The manufacturing process included hot-forging (by seamless ring-rolling) a 28,510-pound, vacuum-melted ingot into a 260-inch-diameter ring blank and then doubling the length of the ring blank by roll-forming at ambient temperature.

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# I. SUMMARY

Beginning with the procurement of a 28,510-pound vacuum-induction-melted plus consumable electrode vacuum-arc-remelted ingot, Ladish Co. hot-forged a seamless rolled ring 260 inches in diameter by 42-inch face height and then converted the 42-inch-high ring into a 79-inch face height cylinder by roll-forming at ambient temperature. The resultant cylinder was parted into five rings, three of which were sectioned for testing, while the other two were held for a future welding program.

The seamless ring-rolled blank of a modified "200" grade 18 per cent nickel maraging steel was hot-forged, sized, annealed, and machined without unusual incidents in a manner closely paralleling that successfully used in previously producing 260-inch-diameter SL Motor Case hardware. Roll-forming was accomplished at room temperature with no intermediate annealing cycles in four passes with a total wall reduction of 51 per cent. The final face height of the cylinder was 79 inches with a wall thickness of 0.614 inch.

During the first roll-forming pass a mis-match of the roll-forming rollers occurred and several related actions were observed:

1. An unusual and uneven diametral growth occurred which precluded cold-sizing the cylinder in its entirety.
2. Known and unknown discontinuous ultrasonic indications were intensified to the point of causing internal ruptures.
3. Unequal residual stresses were introduced into the final product.

The scope of the program to produce a cylinder of 72-inch-minimum face height by the roll-forming technique was achieved. The ability to cold-size a roll-formed product was demonstrated by cold-sizing one of the welding rings to match the dimensions of the other ring within the permissible tolerance.

Ultrasonic indications were investigated and related to a material defect which was aggravated by the roller mis-match. Mechanical properties produced by various combinations of thermal/mechanical processing were determined and are reported herein for reference purposes.

## II. BACKGROUND AND INTRODUCTION

In 1957, the metalworking industry was challenged to produce thin-walled, ultrahigh-strength pressure vessels for rocket motor case application. The state-of-the-art at that time was conventional pressure vessel manufacture; that is, rolled and welded plate for the cylindrical sections and press-formed plate for closures with relatively heavy walls and low strength levels being the norm. Ladish Co., which had many years of experience in the manufacture and production of this type of pressure vessel, pipe, and fittings for relatively high-temperature, high-pressure piping applications, had a thorough knowledge of the behavior of metals under these conditions. However, the thin-walled, high-strength vessel was altogether different in its characteristics.

Ladish Co. felt that a sound engineering approach coupled with a research and development program was a prerequisite to determine the parameters of the problem and to develop the manufacturing technology that would assure a highly reliable rocket motor case. Through the research effort it was found that conventional rolled and welded pressure vessels were extremely unpredictable and unreliable. The longitudinal welds and the closure outlet welds were vulnerable to welding and processing variables which could lead to premature and other disastrous failures.

As a result, a technology by which it was possible to produce improved, more reliable pressure vessels was introduced. This simple, but extremely effective, concept consisted of using seamless rolled rings for the cylindrical sections and die forgings having integral outlets for the closures. This technology has now produced hundreds of reliable solid-fueled rocket motor cases.

In a continuing effort to improve material utilization and to reduce the number of welds in rocket motor cases, the Ladish Co. roll-forming machine was designed and constructed. This process elongates the previously-available seamless cylinders, by cold-working between rolls, thereby reducing the number of girth welds required for a given length of motor case.

The principle of roll-forming had been successfully applied in sizes ranging from 40 to 156 inches in diameter to a variety of materials including 18 per cent nickel maraging steel, Ladish D6ac, INCO-718, 2014 aluminum alloy, commercially-pure beryllium, and 6Al-4V titanium alloy. Simultaneous with this period of development, the growth of the thin-walled, high-strength rocket motor case cylinders progressed to 260 inches in diameter. Successful demonstration cases were made using the combination of seamless rolled Y-ring forgings and rolled-and-welded plate for body cylinder material. The advancement of the state-of-the-art for production of seamless roll-formed 260-inch-diameter cylinders in order to eliminate longitudinal welds and upgrade reliability became the departure point for this Contract.

The manufacturing sequence for the Contract was determined and the weight requirement of the forging stock necessary to yield the final product was established at 26,000 pounds. This would be the minimum weight of cropped-and-conditioned ingot. However, to yield the greatest possible face height of roll-formed product, the heaviest available ingot would be procured.

The blank for roll-forming would be produced by the seamless ring-rolling process, which would involve:

1. Upset-forging the as-received ingot from its initial height to the approximate final height of the roll-forming blank.
2. Punching a 21-inch-diameter hole in the center of the as-upset-forged ingot (referred to as a "pancake" prior to being punched and as a "donut" after being punched).
3. Saddle-rolling the donut to approximately 100 inches inner diameter and flattening.
4. Seamless ring-rolling to final diameter in two passes.
5. Hot-sizing and annealing.

This was the same basic hot-working sequence successfully used on the 260-inch-diameter SL Motor Case Y-rings and routinely used at Ladish Co. in the daily production of seamless rings weighing up to 170,000 pounds. All the necessary facilities to accomplish the planned work were in existence:

1. A 23,000-ton hydraulic press with flat-die capacity of 132-inch diameter.
2. A ring-rolling machine with capacity for rolling rings of 170,000 pounds and 280 inches in diameter.
3. A sizing press capable of hot-sizing at 260-inch diameter.
4. Forging and heat treating furnaces with hearths measuring 25 feet square.
5. Machining capacity including a 28-foot vertical boring unit.

One tooling modification would be necessary to complete the hot-working sequence. The existing 260-inch-diameter hot-sizing segments measured 28 inches in face height, and would have to be adapted to achieve a height of 42 inches in order to size the roll-form blank ring forging. This modification would be accomplished by machining eight 25-inch-high ring segments from a seamless rolled ring to be produced in the same basic hot-working sequence as the roll-forming blank. These segments would be positioned underneath the existing 28-inch-high segments and would result in a height capacity for hot-sizing of approximately 53 inches.

The forged-and-heat-treated blank would be machined prior to roll-forming on an existing 28-foot vertical boring mill in a routine production manner and no special tooling or process requirements were needed. Based upon data generated by Ladish Co. from tests of previously-produced maraging steel roll-formed cylinders, a wall reduction of approximately 50 per cent would result in the desired optimum combination of toughness and strength, and, as such, was programmed for the 260-inch-diameter roll-formed cylinder. Since finished wall thickness after roll-forming was to be 0.610 inch, a wall thickness of 1.260 inches would be required in the machined blank. Extrapolation of previous roll-forming data indicated that a diametral growth of 0.800 inch could be expected during roll-forming. The diameter of the machined blank was, therefore, made 1.500 inches smaller (0.800 inch as projected and 0.700 inch as a safety factor in case diametral expansion was not as projected) than the final required diameter. The length of the roll-forming blank was to be machined to the maximum possible in order to obtain a maximum-height cylinder after roll-forming.

All dimensional aspects of the 260-inch-diameter roll-forming blank and cylinder would be established utilizing experience gained on the 260-inch-diameter SL cases. As before, Ladish Co. has not yet been able to obtain certified measuring devices for cylinders of this size. In order to confidently establish large diameters during the previous 260-inch-diameter SL Motor Case Program, the following technique had been devised and would again be put to use in this Contract:

1. The as-forged-and-heat-treated ring was set on the 28-foot vertical boring mill table.
2. A certifiable center plug, measuring 24 inches in diameter, was positioned at the center of the mill table. Verification of center was made by setting a dial indicator off the outer diameter of the plug and rotating the table.
3. A certifiable bar, measuring 118 inches long, was placed with one end at the circumference of the center plug to establish a 130-inch radius.
4. The as-forged ring was machined to dimensions required by referencing to the established 130-inch radius. After machining, and while restrained on the mill table in the as-machined position, the full dimensional inspection could then be performed.
5. The machined ring, in the restrained position, was then used as a standard to obtain two or more Pi-tape readings that would be in agreement so that the Pi tapes could be "certified" for use in subsequent inspections where the center-plug-and-bar method could not be used.

In these inspections, sufficient Pi tape readings would be taken in order to establish a confidence level as to the variation in measurements that could be reasonably expected.

After machining and completing the ultrasonic, liquid-penetrant, and dimensional inspections, the machined blank would be ready for roll-forming. The roll-forming process is a forming process developed by Ladish Co. and certain design and process details are considered proprietary. The basic process, however, involves deformation of a seamless cylinder by extruding and flowing metal between rolls located at both the outer and inner surfaces. This arrangement is beneficial in several ways. Since the material is being worked uniformly from both sides, the work penetration is imparted uniformly and the resultant stress is neutral. Additionally, integral internal and external stiffeners can be positioned circumferentially at any point along the face of the cylinder. This is possible because there is no internal mandrel (as in conventional shear-forming), or an external ring die (as in roll-extrusion), to interfere.

Upon completion of roll-forming, liquid-penetrant, ultrasonic, and dimensional inspections would again be performed. The scope of work also provided that, should any ultrasonic indications be found, they would be radiographed. The methods and techniques of ultrasonic inspection were selected to attain maximum flexibility in the event that techniques other than the previously-used methods would have to be used. Ladish Co. Procedure 9-Q-17, utilized for ultrasonic inspection of the 260-inch-diameter SL forgings, would be used as a guide.

The roll-formed, dimensionally-inspected, and non-destructively-tested cylinder would then be cold-sized to final required dimensions. As previously pointed out, slight diametral growth is expected in roll-forming and cold-sizing has been incorporated as part of the process to positively compensate for any diametral variances encountered in the cylinder. The amount of planned cold-sizing was approximately one inch on diameter, which, at 260 inches, is 0.4 per cent.

In order to machine the roll-formed and cold-sized cylinder (for purposes of demonstrating the ability to machine to a dimension and to maintain a tolerance at that dimension), an existing machining fixture would be adapted to accommodate the required diameter. An internal expanding spider fixture would be modified for use. This fixture would allow positioning of the high-face-height, thin-walled cylinder into a true round condition from the inside of the cylinder. Through a slight collapsing of the fixture, the cylinder could be simply raised or lowered and repositioned to obtain maximum rigidity for machining weld bevels or parting in any particular spot along the cylindrical length. Machining operations after cold-sizing were to include machining of the ends, parting of the cylinder into five rings, and machining weld bevels on the two rings to be welded.

The entire schedule as planned is shown in Figure 1. The right-hand column lists the sequences as they would occur according to the pre-planning. The left-hand portion shows the four major supporting activities that had to be carried out concurrently in order to meet the schedule commitment. Figure 2 illustrates how the conversion of ingot to roll-formed cylinder was to be accomplished and is proportioned accordingly. In the sections that follow, the actual events that occurred, and the data generated, are presented and discussed.

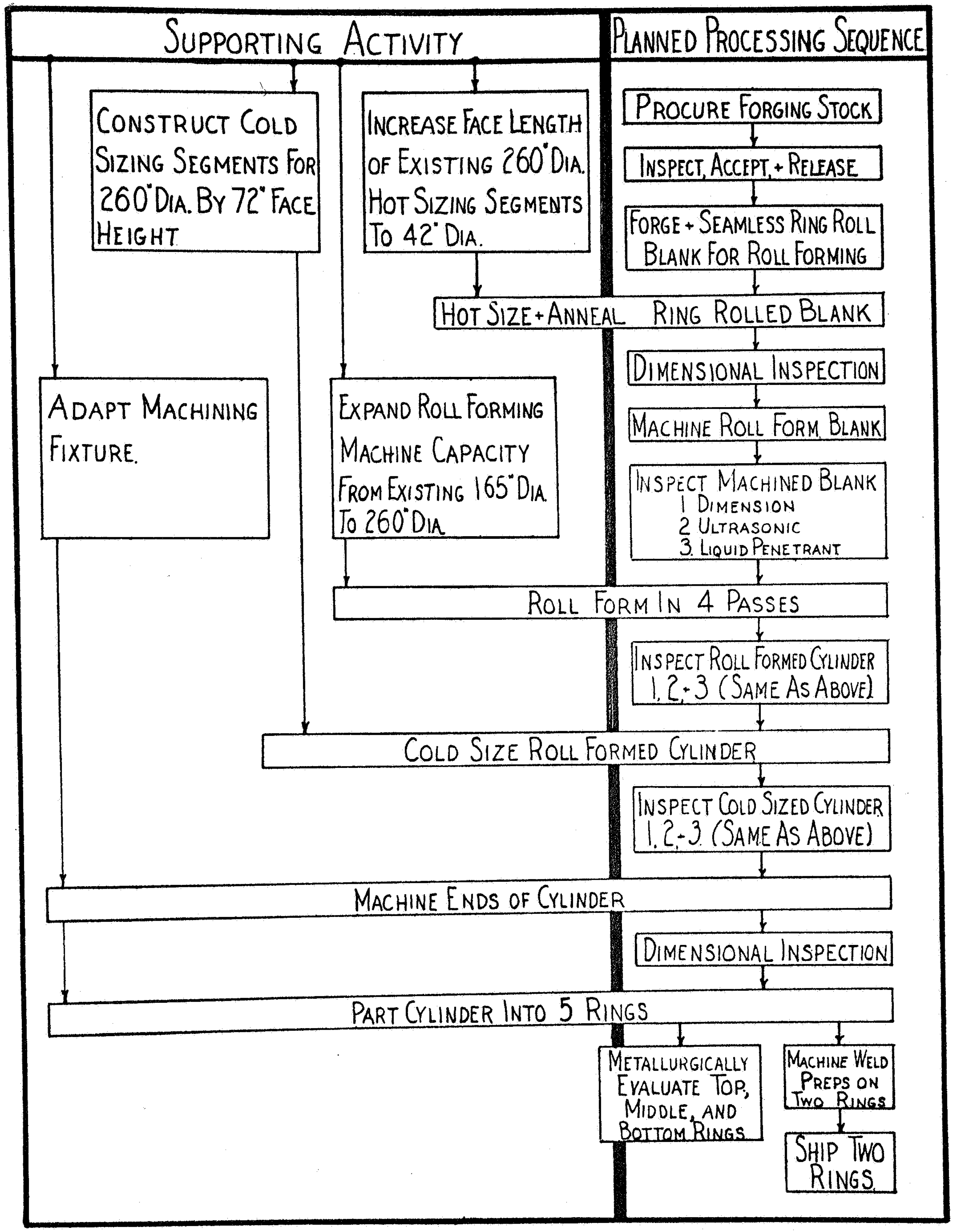


FIGURE 1

MANUFACTURING PLAN FOR 260-INCH-DIAMETER ROLL-FORMED CYLINDER

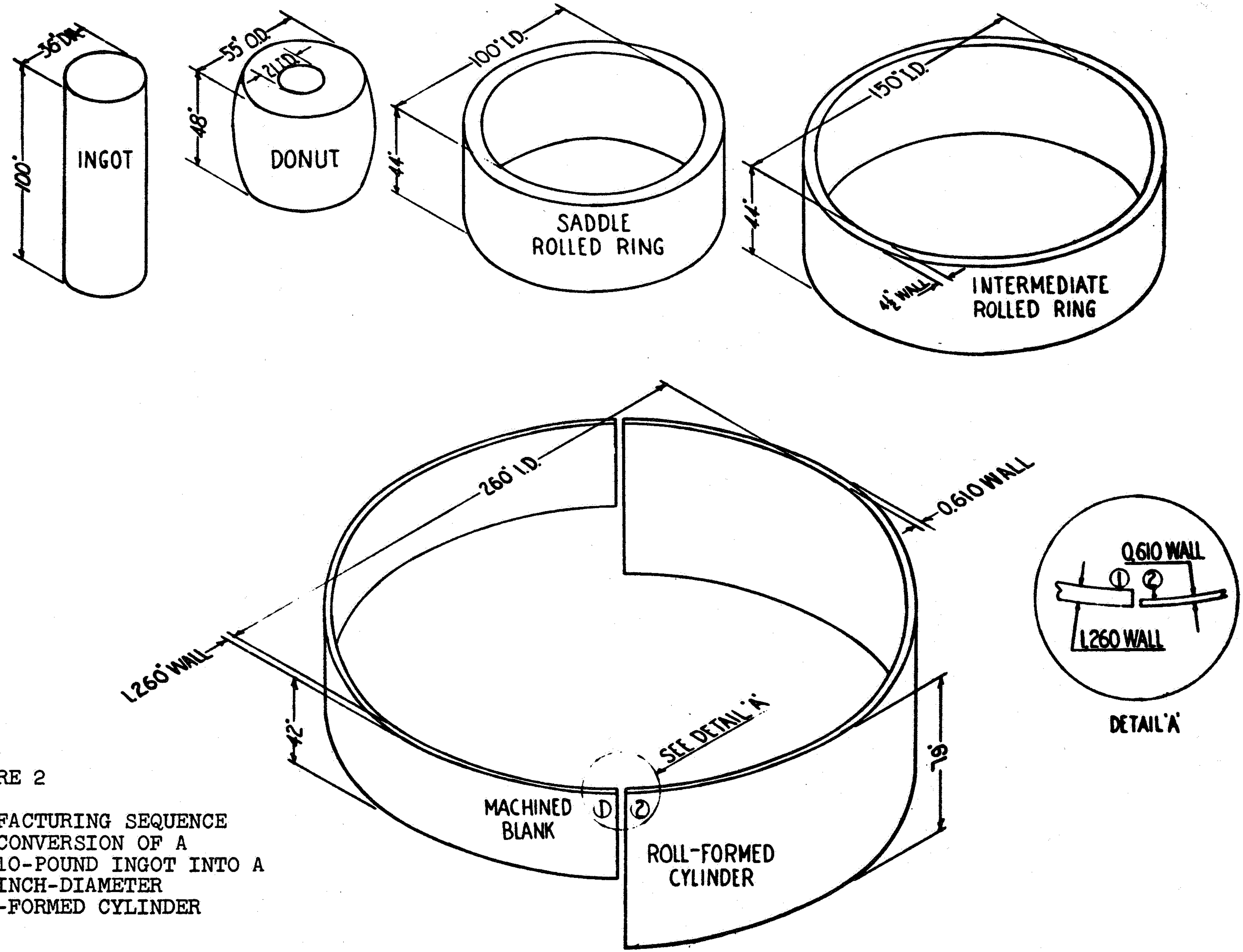


FIGURE 2

MANUFACTURING SEQUENCE
FOR CONVERSION OF A
28,510-POUND INGOT INTO A
260-INCH-DIAMETER
ROLL-FORMED CYLINDER

## III. MANUFACTURING DETAILS

### A. MATERIAL PROCUREMENT AND ACCEPTANCE

The use of vacuum-arc-remelted 18 per cent nickel maraging steel, "200" grade, was proven in the 260-inch-diameter SL Motor Case effort and this basic material was selected by the National Aeronautics and Space Administration for roll-forming. Test material from a 156-inch-diameter experimental roll-formed cylinder previously produced by Ladish Co. had been given to NASA for study. The results of this study suggested that a lower strength level should produce a better balance desired by NASA between fracture toughness and strength in the 260-inch-diameter roll-formed cylinder.

Rather than project the program into the unknown of a new material, the "200" grade 18 per cent nickel composition was modified by reducing the titanium and molybdenum contents in an attempt to achieve lower strength levels. Procurement Specification 2-F-4, Table I, was issued by Ladish Co. and producers were inquiried for a vacuum-arc-remelted, cropped-and-conditioned ingot of 26,000 pounds minimum weight on a basis other than product-of-best-effort.

Three suppliers responded and the source chosen was selected on the basis of the following factors:

1. Guaranteed delivered weight would be 28,000 pounds minimum. This factor was important, as the Statement of Work called for the highest possible cylinder.
2. The ingot would be vacuum-induction-melted, followed by consumable electrode vacuum-arc-remelting, thereby yielding a material of greatest microcleanliness.
3. The ingot diameter was the largest, which would enhance the initial upset-forging ratio.

The incoming ingot was subjected to visual, dye-penetrant, and ultrasonic inspections. Routine minor surface discontinuities were removed and no abnormalities were recorded. At the given diameter, ultrasonic inspection can only suggest the presence of gross piping and none was seen.

Several metallurgical tests were performed on a slice of test material removed from the bottom of the ingot. These tests and results are reported in detail in Section V, Part A. Mechanical properties from these tests indicated the material had a yield strength of about 183 to 190 Ksi, which was lower than the normal "200" grade, but perhaps not as low as initially desired. The chemistry check was satisfactory, and the ingot was released for manufacturing.

### B. HOT-WORKING AND ANNEALING

Hot-working of the 260-inch-diameter roll-forming blank was completed as planned and without major changes in the approach. A

| ISSUED: 1/16/67 REVISED: | METALLURGICAL DEPARTMENT QUALITY ASSURANCE PROCEDURE LADISH CO., CUDAHY, WIS. | 2 F 4 |
|---|---|---|

TITLE: MATERIAL PROCUREMENT SPECIFICATION FOR 18% NICKEL SPECIAL CHEMISTRY VACUUM ARC REMELTED MARAGING STEEL

**SCOPE:**

This specification covers procurement of 18% Nickel Special Chemistry vacuum arc remelted steel for Contract #NAS3-7966.

**MATERIAL:**

Maraging Steel, Consumable Electrode Vacuum Arc remelted to following chemistry:

| | | | |
|---|---|---|---|
| Nickel | 17.0-19.0 | Carbon | 0.03 max. |
| Molybdenum | 3.8-4.0 | Manganese | 0.10 max. |
| Cobalt | 7.0-8.0 | Phosphorous | 0.010 max. |
| Titanium | 0.08-0.10 | Sulphur | 0.01 max. |
| Aluminum | 0.05-0.15 | Silicon | 0.10 max. |
| | | Iron | Balance |

Additives: Boron 0.003; Zirconium 0.02; Calcium 0.06

Check limits of AMS 2248 applicable except that Molybdenum shall be 0.10 over maximum and 0.10 under minimum.

**THERMAL CONDITION:**

Ingot or billet stock may be supplied in the as-cast, as-forged or 1650°F ± 25°F solution annealed condition. If solution annealed at 1650°F, time at temperature should not exceed 6 hours. Mill analysis certification must indicate thermal condition of as-shipped stock.

**MECHANICAL PROPERTY CAPABILITY:**

After forging to a 3" x 3" cross section test bar, solution annealing at 1650°F ± 25°F, (air cooling), aging* at 900°F ± 25°F, (air cooling) material shall have following minimum mechanical properties using Federal Test Method 151 0.252" diameter R-3 test specimens cut from the 3" x 3" test bar.

| | Longitudinal | Transverse |
|---|---|---|
| Fty (0.2% offset) | 170.0-190.0 ksi | 170.0-190.0 ksi |
| Ftu | 180.0-200.0 ksi | 180.0-200.0 ksi |
| % Elong. | 12 | 10 |
| % Red. of Area | 60 | 40 |

*Aging of entire test bar or individual test specimens after cutting from test bar at suppliers option.

WRITTEN BY G. J. Lillie — G. J. LILLIE, Project Engineer
APPROVED C. A. Furgason — C. A. FURGASON, Vice-President Research & Metallurgy

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TABLE I

MATERIAL PROCUREMENT SPECIFICATION

TITLE:

MICROCLEANLINESS:

Metallographic specimen cut from mid-radius position of material representing top and bottom of ingot shall be examined in the 1650°F solution annealed condition on the longitudinal axis in accordance with Jernkontoret Chart in ASTM E-45-51. Ratings not to exceed:

| | A | B | C | D | E* |
|---|---|---|---|---|---|
| T | 1.5 | 1.5 | 1.0 | 1.5 | 2.5 |
| H | 1.0 | 1.0 | 1.0 | 1.0 | 1.5 |

*Titanium compounds to be listed as "E" series.

ULTRASONIC INSPECTION CAPABILITY:

Seamless rolled ring products produced from material ordered to this specification shall be capable of meeting the Class II Quality Assurance Level of Ladish Co. Quality Assurance Procedure 9Q17 dated 11/15/63. (5/64" and 8/64" FBH Reference Standards).

MECHANICAL CONDITION:

Stock supplied for forging must be conditioned all over with ends flat and parallel for upset forging. Stock will be dye penetrant inspected to insure that cropping and conditioning by steel supplier has removed all defects traceable to piping and porosity.



TABLE I (Continued)
MATERIAL PROCUREMENT SPECIFICATION

summary of the forging history is shown in Table II. It consisted of pancaking, plugging, and punching to convert the ingot into a donut, saddle-rolling to expand the diameter, ring-rolling to sizing dimensions, sizing, and annealing. Annealing was completed in accordance with Ladish Co. Heat Treatment Procedure 13-F-308, shown in Table III.

The results of dimensional inspections conducted on the as-annealed ring prior to any machining are recorded in Appendix I, Part B. Inspection at this point insured that the forged ring would, after machining, yield the required blank for roll-forming.

## C. MACHINING AND INSPECTING THE ROLL-FORMING BLANK

Machining of the blank was accomplished at Ladish Co. on a 28-foot vertical boring mill. Operations included turning the outer diameter, boring the inner diameter, machining both faces, and machining a holding groove.

The dimensional inspection after machining the blank is shown in Appendix I, Parts C-1 and C-2. This inspection was performed with the machined blank in both restrained and unrestrained states. The design dimensions were achieved.

All surface areas of the machined blank were subjected to a dye-penetrant inspection in accordance with Ladish Co. Quality Assurance Procedure No. 9-Q-108 and no defects were observed. The results of this inspection and the procedure are reported in Appendix II.

Ultrasonic inspection of the machined blank was completed using longitudinal-wave inspection procedure. Standards for this inspection were 3/64- and 5/64-inch flat-bottomed-holes in separately-forged reference blocks. The inspection located four areas of indications and all indications in each area were well within previously-established 5/64- and 8/64-inch flat-bottomed-hole standards for the 260-inch-diameter SL Motor Case Program. Section IV contains all pertinent discussions of this ultrasonic inspection. Since the indications were small and discontinuous in nature, no significance was attached to them at this time. The machined blank, shown in Figure 3, was released for roll-forming.

## D. ROLL-FORMING AND INSPECTIONS SUBSEQUENT TO ROLL-FORMING

A 51-per-cent total wall reduction from 1.260 inches to 0.610 inch was accomplished by roll-forming, with a simultaneous lengthening of the face height from 42 to 79 inches. The roll-forming process was conducted at room temperature without intermediate annealing cycles. Figures 4 and 5 show the 79-inch-high cylinder after roll-forming. (In the Ladish Co. process, one end of the blank is held to the roll-forming machine. This end is referred to as the "clamping end;" the opposite end is referred to as the "free end.")

TABLE II

SUMMARY OF FORGING HISTORY TO PRODUCE 260-INCH-DIAMETER ROLL-FORMING BLANK

| | |
|---|---|
| Convert 36-inch round ingot into 48-inch high donut | Maximum furnace temperature . . . . . . . . . 2250°F<br>Minimum metal temperature during forging . . 1710°F<br>Initial heating cycle plus four reheating cycles. |
| Punch 21-inch hole in center of donut | Completed after last converting operation without reheating cycle.<br>Minimum metal temperature . . . . . . . . . . 1610°F |
| Pin-roll donut to 21-inch inner diameter by 48 inches high | Maximum furnace temperature . . . . . . . . . 2250°F<br>Minimum metal temperature . . . . . . . . . . 1620°F<br>One heating cycle. |
| Saddle-roll and flatten donut to 100-inch diameter by 44 inches high | Maximum furnace temperature . . . . . . . . . 2250°F<br>Minimum metal temperature . . . . . . . . . . 1600°F<br>Two initial heating cycles plus four reheating cycles. |
| Ring-roll to final diameter | Maximum furnace temperature . . . . . . . . . 2250°F<br>Minimum metal temperature . . . . . . . . . . 1400°F<br>Initial heating cycle plus one reheating cycle. |
| Size and anneal | Maximum furnace temperature for sizing . . . 1825°F<br>Maximum furnace temperature for annealing . 1675°F<br>Held three hours at temperature and air cooled. |

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## HEAT TREATMENT

| ALTERNATE DESIGNATIONS: | SPECIFICATION |
|---|---|
| MARAGING STEEL, 18% NI MODIFIED "200" GRADE | Ladish Co. |
| NASA 260" DIAMETER ROLL FORM RING | 2F4 |

### NOMINAL CHEMISTRY

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| CARBON | 0.03 max | BORON | -- | COBALT | 7.0-8.0 | COPPER | -- |
| MANGANESE | .10 max | IRON | Balance | TUNGSTEN | -- | COLUMBIUM | -- |
| PHOSPHORUS | .010 max | NICKEL | 17.0-19.0 | TITANIUM | .08-.10 | TANTALUM | -- |
| SULPHUR | 0.01 max | CHROMIUM | -- | VANADIUM | -- | | |
| SILICON | 0.10 max | MOLYBDENUM | 3.8-4.0 | ALUMINUM | .05-.15 | | |

| OPERATION | TEMPERATURE | INSTRUCTIONS |
|---|---|---|
| Sizing: Heat for 3 hours at temperature, Remove from hearth and size. | 1825°F +0° -30° or less | Load & position on hearth. Ring is thin walled, high face and large diameter. Use 8 thermocouples; 4 on top, 4 on bottom per sketch, (Pg. 2). Bury couples in 3" blocks; connect one couple to round face recorder, balance to multipoint chart. |
| Solution Treat: After sizing, reload into furnace, hold 3 hours at temp., remove from hearth and air cool. | 1675°F ± 25°F | Load on hearth. Connect one thermocouple to round face recorder. |

SPECIAL INSTRUCTIONS:

Forward round face recorder charts to Metallurgy with Part No., Control No., Code & Serial No.

| ISSUED BY | HEAT TREAT DIVISION | CHIEF METALLURGIST APPROVAL |
|---|---|---|
| T. J. LILLIE | W. DAVIS | R. BLOM |

TABLE III

HEAT TREATMENT PROCEDURE

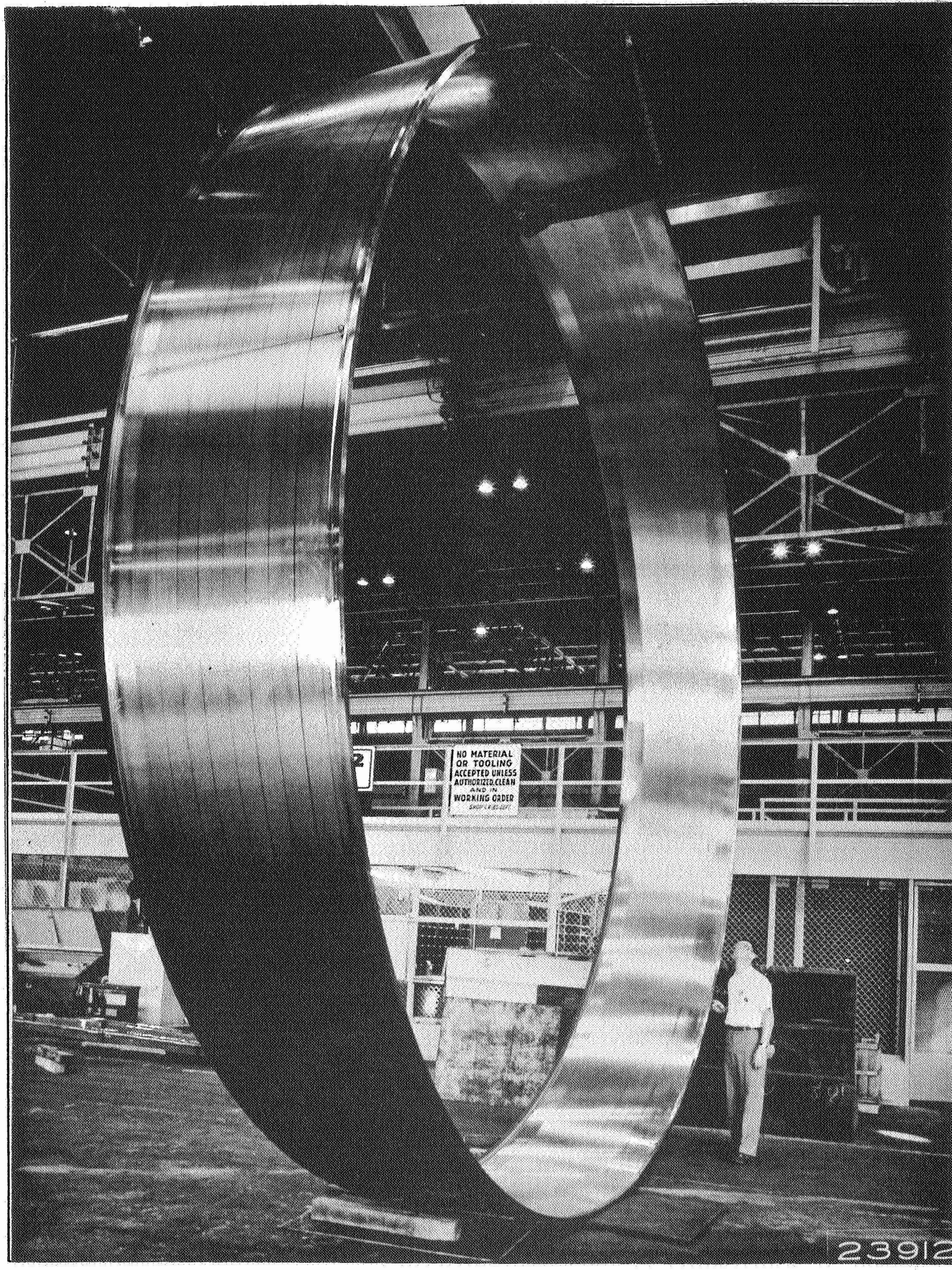



FIGURE 3

ROLL-FORM BLANK AFTER MACHINING

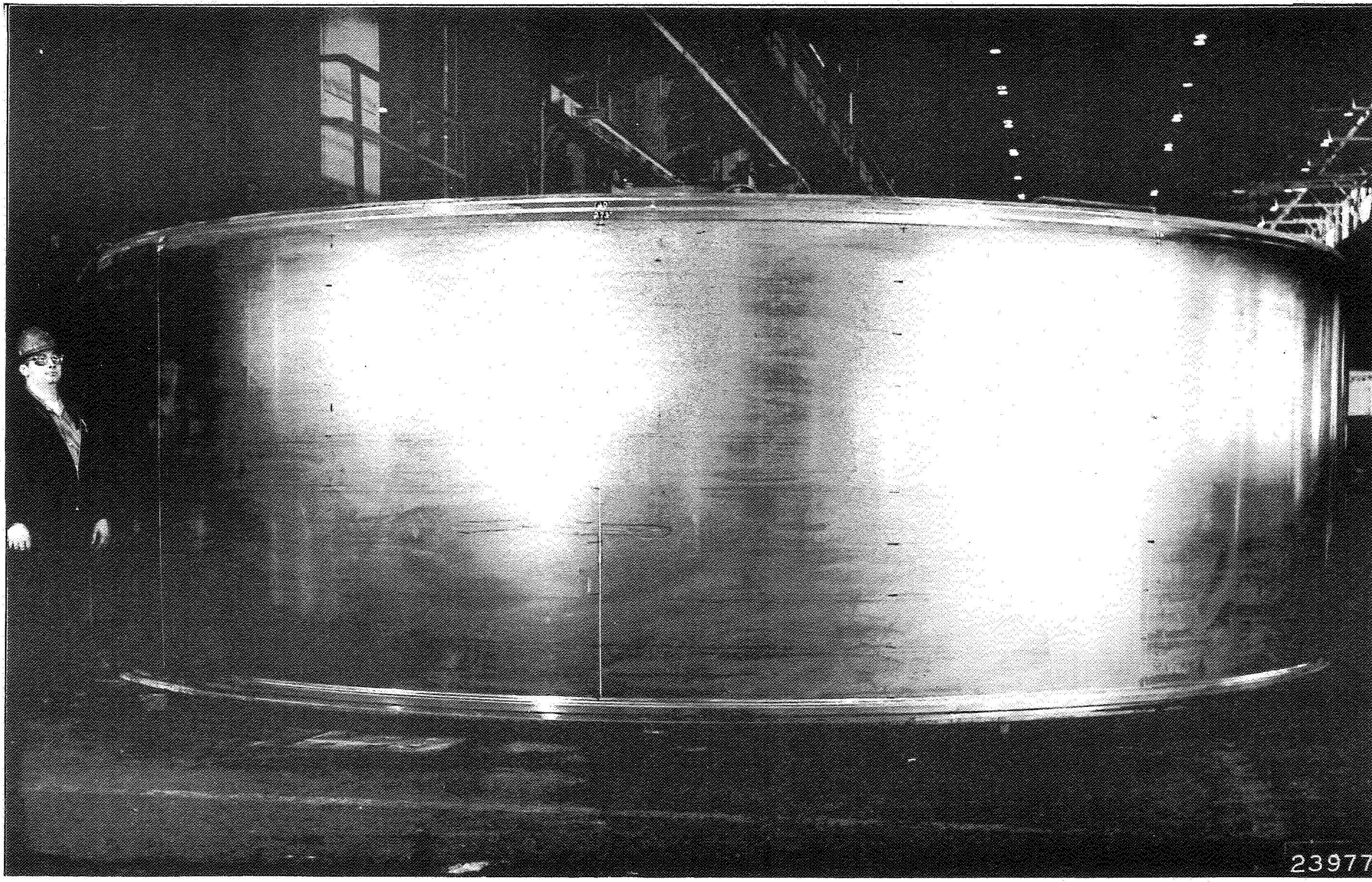



FIGURE 4

79-INCH FACE HEIGHT ROLL-FORMED CYLINDER

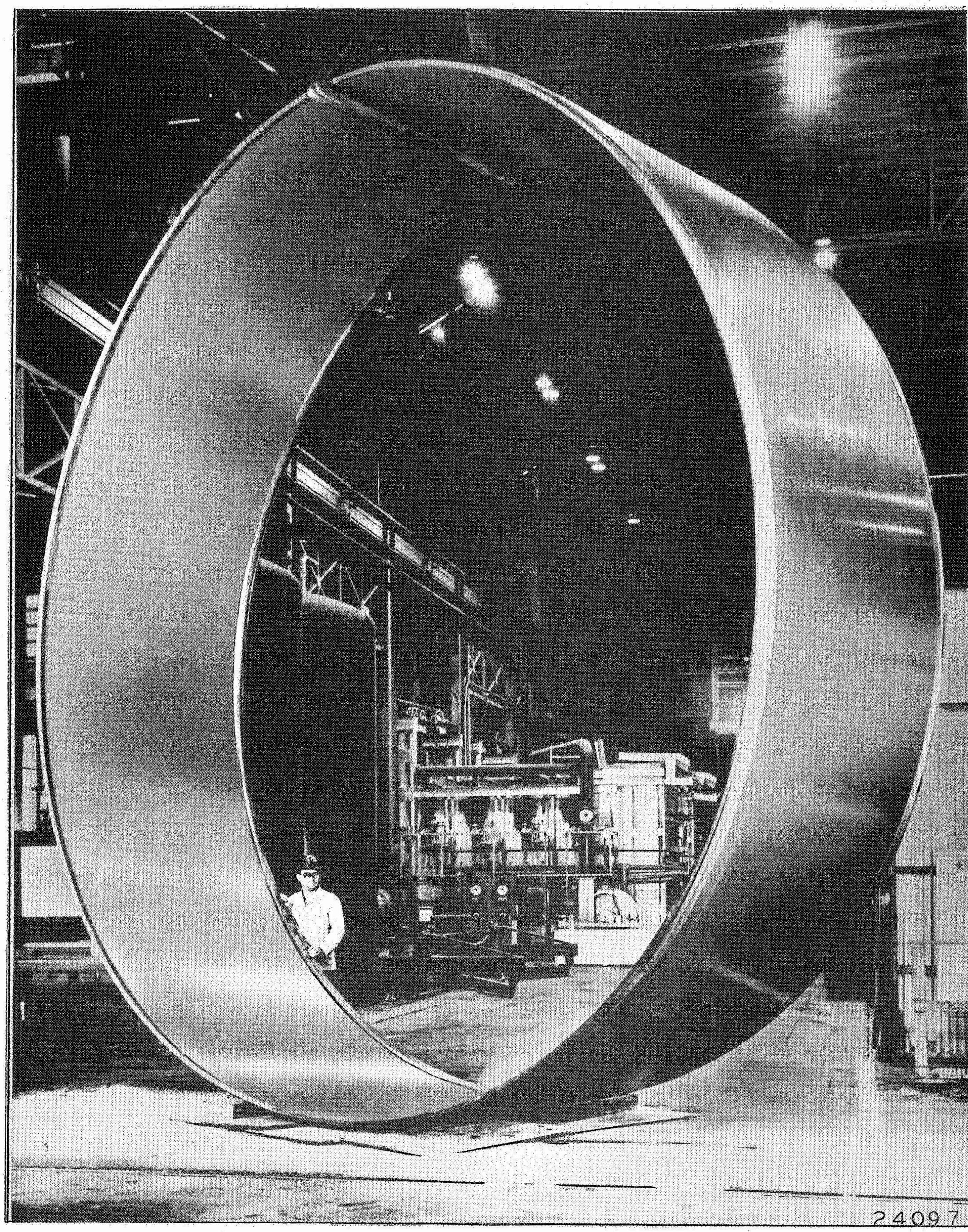


FIGURE 5

ROLL-FORMED 260-INCH-DIAMETER CYLINDER

The total wall reduction was accomplished in the planned four passes. At the end of the first roll-forming pass, a diametral growth of 0.857 inch was observed. Since this growth was well in excess of that anticipated, the roll-forming machined was immediately inspected for improper adjustments and/or malfunctions. The inspection revealed that a bearing retainer lock washer had sheared, initiating a chain reaction which ultimately resulted in a 3/8-inch misalignment of the rollers at the end of the first pass. A positive repair was made at this point and in subsequent passes the diametral growth was basically as anticipated.

The roll-forming pass in which the 3/8-inch misalignment occurred originated at the clamping end. There is no question that the misalignment induced a very high and varying degree of residual stress in the forging. Subsequent observations during cutting of the three test rings, coupled with metallurgical test data, lend support to the belief that the misalignment was progressive. Whenever previously-produced roll-formed cylinders have been sectioned longitudinally for testing, the observed circumferential movement was less than 1/2 inch, with no twisting. When Serial No. 1, from the free end of the 260-inch-diameter cylinder, was parted longitudinally, it catastrophically opened about 13 feet.

Serial No. 3, from the mid-height of the roll-formed cylinder, expanded about nine feet catastrophically when parted. However, Serial No. 5, from the clamping end, expanded less than 1/2 inch when parted, and this is the normally-expected action. These observations support the theory of progressive mis-match.

The second roll-forming pass was completed without incident. Visual inspection of the cylinder after the third roll-forming pass disclosed indentations at one location on both the inner and outer diameter surfaces of the cylinder. These indentations were circumferential in orientation, only 0.009 inch deep, approximately 25 inches long, and the width was less than the width of the imparting-work-surface of the rolls. During the third pass, an unexpected momentary variation in the machine's hydraulic pressure was observed and, at this point in time, the indentations were attributed to this unexplained pressure variation. Furthermore, since the indentations were only 0.009 inch deep, and since the next roll-forming pass would reduce each surface of the cylinder 0.050 inch, it was felt the indentations would be blended out as part of the next pass.

Inspection of the cylinder surfaces after the fourth and final roll-forming pass disclosed the indentations to be both present and unaltered. These indentation areas were dye-penetrant inspected and no surface defects were observed. When subsequent ultrasonic, radiographic, and sectioning investigations proved that a material rupture did exist beneath the surface, it was concluded that the observed hydraulic pressure variation was, in fact, an instantaneous indication of the material failure, rather than a cause of the indentations.

After roll-forming, the cylinder was subjected to dimensional, dye-penetrant, ultrasonic, and radiographic inspections. The dimensional inspection results are tabulated in Appendix I, Parts D-1 and D-2.

Ultrasonic inspection of the roll-formed cylinder, this time using shear-wave to a three-per-cent notch standard, disclosed four areas of highly significant ultrasonic indications. Three of the four areas could be related to areas found prior to roll-forming; the remaining area could not be so related. However, this area, designated as Area No. 3, was located beneath the 0.009-inch-deep indentations observed after the third roll-forming pass.

To confirm the indications, radiographic inspection was employed. Two of the four areas detected by ultrasonic inspection as having defects were confirmed by the X-ray inspection. However, the X-ray operation was performed on the cylinder in an open shop area with some adaptations in technique to accommodate the large size and lack of shielding. Section IV continues with the discussions on ultrasonic indications and investigative work completed by Ladish Co.

Dye-penetrant inspections were completed on all surfaces with emphasis upon those areas where ultrasonic indications were detected. No surface defects were detected, and the report is in Appendix II.

## E. COLD-SIZING

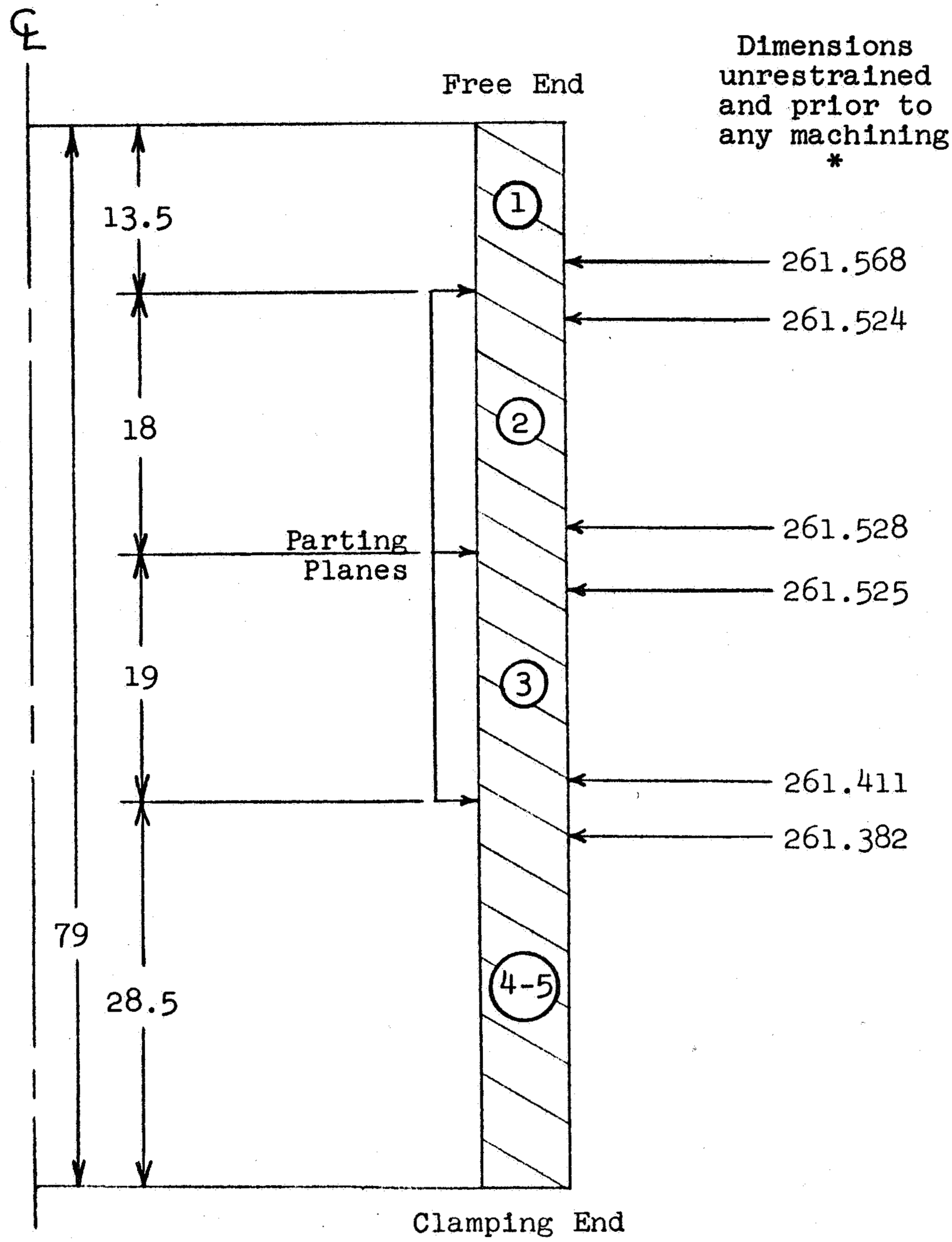
The Statement of Work required that the roll-formed cylinder be cold-sized, have the non-roll-formed ends machined to specified dimensions, and then be parted into five separate rings as follows:

1. The top, middle, and bottom (Serials 1, 3, and 5) for sectioning and testing purposes.
2. The middle two rings (Serials 2 and 4) for a future girth-welding work program under the direction of NASA.

Because of the detected ultrasonic indications, the necessity arose to deviate from the pre-planning. The following sequence was employed:

1. With the roll-formed cylinder in the unrestrained state, parting lines were marked and the top and bottom diameters of the rings were measured and recorded as shown in Figure 6. At this time, Serial No. 3, which would be the test ring representing the mid-height of the cylinder, was positioned within the roll-formed cylinder so as to contain all four areas of ultrasonic indications when parted.

2. The cylinder was positioned in the 28-foot vertical boring mill with the clamping end down and the top ring (Serial No. 1, representing the free end) was parted. The bottom




* All dimensions in inches (diameters Pi tape).

FIGURE 6

LOCATIONS OF PARTING LINES AND RECORDED OUTER DIAMETERS PRIOR TO ANY MACHINING diameter of Serial No. 1 was measured in the free state and recorded. The top diameter of Serial No. 2 was measured while it was positioned in the mill and integral with the balance of the cylinder.

3. Serial No. 2 was then parted and the top and bottom diameters were measured in the free state and the dimensions recorded. The top diameter of Serial No. 3 was obtained while it was positioned in the mill and integral with the balance of the cylinder.

4. Serial 3 was parted and the top and bottom diameters were measured and recorded. The top diameter of Serial No. 4 was obtained while it was positioned in the mill and integral with Serial No. 5. Composite Serial 4-5 was then removed from the boring mill and re-measured in the unrestrained state. All diameters obtained in Steps 2, 3, and 4 are presented in Figure 7 in the sequence obtained.

5. Serial 2 and Serial 4-5 (the composite) were ultrasonically inspected from the end faces using a 3/64-inch flat-bottomed-hole reference standard and no defects were observed.

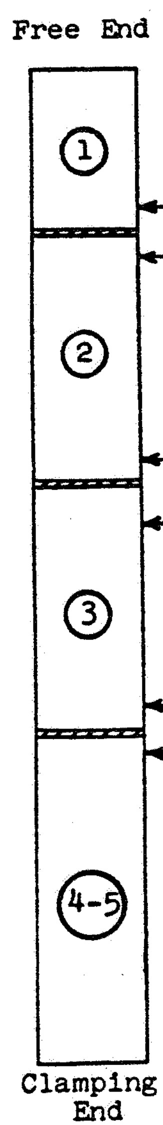
6. Since the "as-built" dimensions of Serial 2 were oversize (261.520 inches at the top and 261.606 inches at the bottom versus the 261.220-inch maximum as planned), Composite Serial 4-5 was cold-sized so that its top end would match with one of the as-built ends of Serial 2. Sizing was accomplished by placing the composite serial around the cold-sizing segments and expanding them hydraulically, allowing the ring to set, releasing the segments, re-measuring, and repeating the cycle until the desired match dimension was obtained. This match was within the maximum allowable tolerance of ±0.060 inch. The dimensions are recorded in Figure 8, wherein it is seen that the top of Serial 4-5, at 261.573 inches, is within 0.060 inch of either end of Serial 2.

7. After cold-sizing, the Composite Serial 4-5 was subjected to ultrasonic and dye-penetrant inspections. Ultrasonic inspection used the shear-wave technique to a three-percent notch standard. No defects were found by either inspection method.

## F. MACHINING OF THE NON-ROLL-FORMED CLAMPING MATERIAL

The requirement to machine the non-roll-formed clamping end of the cylinder to an inner diameter of 260.000 ± 0.030 inches was accomplished as follows:

1. Composite Serial 4-5 was positioned in the 28-foot mill with the clamping end up.



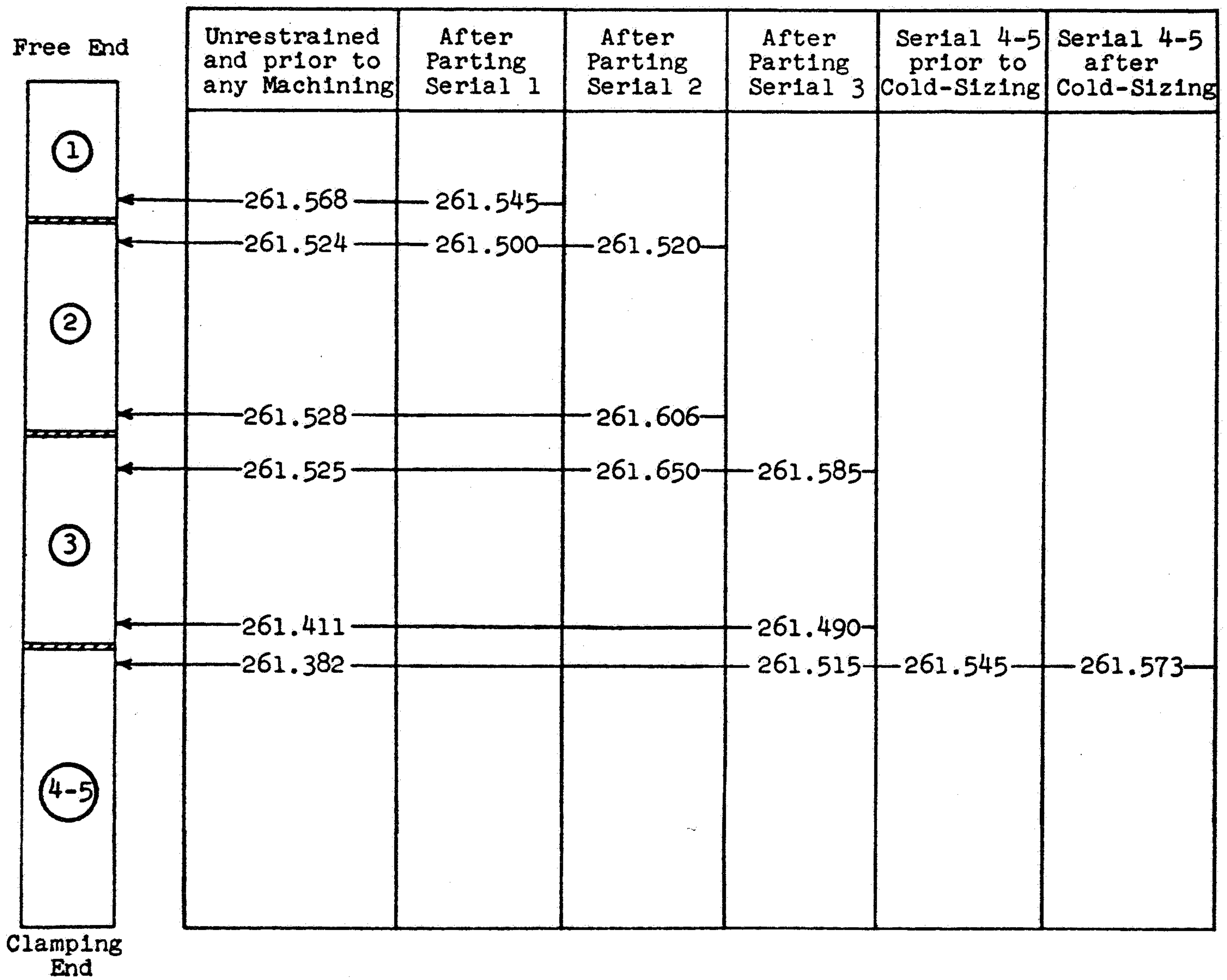

| Unrestrained and prior to any Machining | After Parting Serial 1 | After Parting Serial 2 | After Parting Serial 3 | Serial 4-5 prior to Cold-Sizing |
|---|---|---|---|---|
| 261.568 | 261.545 | | | |
| 261.524 | 261.500 | 261.520 | | |
| 261.528 | | 261.606 | | |
| 261.525 | | 261.650 | 261.585 | |
| 261.411 | | | 261.490 | |
| 261.382 | | | 261.515 | 261.545 |

Note:

All dimensions in inches (Pi tape).

FIGURE 7

OUTER DIAMETERS OF PARTED RINGS




Note:

All dimensions in inches (Pi tape).

FIGURE 8

OUTER DIAMETER OF SERIAL 4-5 AFTER COLD-SIZING

2. This end was machined in a free state to dimensions ranging from 259.973 to 259.979 inches inner diameter.
3. Serial 5 was then parted from the composite serial, leaving Serial 4 in a finished state. It was removed from the mill and dimensionally inspected. The results are shown in Figure 9.

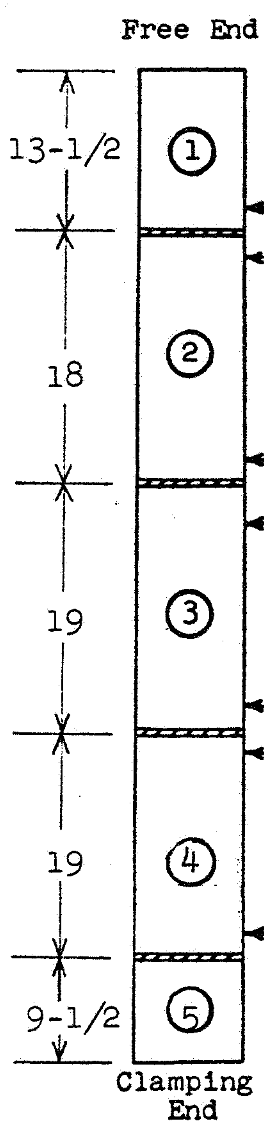
This completed the forging, roll-forming, and machining operations and complied with the intent of the program by providing two 18-inch-high roll-formed rings for the girth-welding program, and three rings (representing the top, middle, and bottom of the 79-inch-high roll-formed cylinder) for sectioning, testing, and metallurgical evaluation.

## G. EVENTS SUBSEQUENT TO FINAL MACHINING

The two rings for welding were placed in shipping frames to await future work while sectioning commenced on the three designated test rings. When the three test rings were cut apart, two of the three sprang open as previously reported. Metallurgical testing was completed on these rings, and is reported in detail in Section V.

Additional ultrasonic investigative work completed on the sectioned test rings suggested that the two rings in storage be ultrasonically inspected from the outer diameter surfaces using a longitudinal-wave technique. The rings were removed from storage, dimensionally re-checked, and subjected to the additional ultrasonic inspection.

The dimensions after storage are shown in Figure 10. The ultrasonic inspection revealed indications heretofore undiscovered in both Serials 2 and 4. These indications exceed the settings from 5/64- and 8/64-inch flat-bottomed-hole reference standards, and are discussed in Section IV.



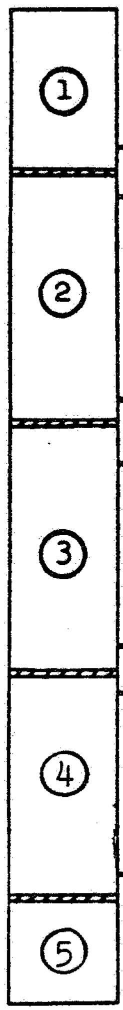

| Unrestrained and prior to any Machining | After Parting Serial 1 | After Parting Serial 2 | After Parting Serial 3 | Serial 4-5 prior to Cold-Sizing | Serial 4-5 after Cold-Sizing | After Parting Serial 4 |
|---|---|---|---|---|---|---|
| 261.568 | 261.545 | | | | | |
| 261.524 | 261.500 | 261.520 | | | | |
| 261.528 | | 261.606 | | | | |
| 261.525 | | 261.650 | 261.585 | | | |
| 261.411 | | | 261.490 | | | |
| 261.382 | | | 261.515 | 261.545 | 261.573 | 261.566 |
| | | | | | | 261.195 |

Note: All dimensions in inches (diameters Pi tape).

FIGURE 9

OUTER DIAMETERS OF SERIAL 4 AFTER PARTING

Free End




Clamping End

| Unrestrained and prior to any Machining | After Parting Serial 1 | After Parting Serial 2 | After Parting Serial 3 | Serial 4-5 prior to Cold-Sizing | Serial 4-5 after Cold-Sizing | After Parting Serial 4 | Serial 4 After Storage |
|---|---|---|---|---|---|---|---|
| 261.568 | 261.545 | | | | | | |
| 261.524 | 261.500 | 261.520 | | | | | |
| 261.528 | | 261.606 | | | | | |
| 261.525 | | 261.650 | 261.585 | | | | |
| 261.411 | | | 261.490 | | | | |
| 261.382 | | | 261.515 | 261.545 | 261.573 | 261.566 | 261.550 |
| | | | | | | 261.195 | 261.204 |

Note: All dimensions in inches (Pi tape).

FIGURE 10

OUTER DIAMETERS OF SERIAL 4 AFTER STORAGE

## SECTION IV. ULTRASONIC AND RADIOGRAPHIC INSPECTIONS AND INVESTIGATIONS

The ultrasonic inspection techniques and standards planned at program initiation were based upon prior experience gained through work done on the 260-inch-diameter SL Program using Aerojet-General Corporation Specification AGC-32115 as a guide. In order to provide the maximum flexibility required for developmental programs such as this, the methods of ultrasonic inspection were kept flexible to permit added techniques and/or tightening of calibration and evaluation standards. The basic methods to be used consisted of a longitudinal-wave inspection of the as-annealed-and-machined roll-forming blank and shear-wave inspection of the full-length roll-formed cylinder. The methods and the techniques that were used are summarized in Table IV, and are set out in the individual ultrasonic test reports for each inspection performed.

### A. INGOT

The first inspection was performed on the raw material in ingot form. Inspections performed on material of this nature and size (36-inch diameter weighing 28,510 pounds as-cast) do not lend themselves to the high resolution or good penetration that can be achieved when inspecting a fully-wrought structure. A raw material inspection of this kind will be crude by comparison, and, at best, will only detect ingot defects such as gross piping. The results of this inspection once again confirmed past inspection results. However, experience with double-vacuum-melted mill products has shown that complete absence of gross defects indicates that the mill product can safely be released for manufacturing.

### B. MACHINED BLANK

It was only after the cast ingot had been transformed to a wrought seamless ring by the refinement gained through the hot-working and annealing cycle that a metallurgical structure suitable for ultrasonic inspection was available. In order to complete the requirements for the inspection process, a surface that provides for good coupling and ultrasound transmission is necessary. For this particular configuration and critical application, completely machined (250 RMS) surfaces were necessary.

When the as-forged-and-heat-treated ring was machined to the required dimensions and surface finish, a longitudinal-wave inspection was performed. At a test frequency of 5.0 MHZ, good penetration and resolution were obtained from the outer-diameter surface. All indications observed were evaluated by calibrating the inspection equipment through use of 3/64- and 5/64-inch-diameter flat-bottomed-hole (or FBH) calibration standards. Only one indication was equal to the response from the 5/64-inch FBH standard, and, in total, all indications were well within previously-used acceptance standards. An attempt was made to perform a longitudinal-wave inspection from the end face in the axial direction. No confirmation of the known indications could be observed. The combination of a relatively thin wall, long axial length, plus indication orientation were considered factors which would prohibit detection of small indications.

TABLE IV

SUMMARY OF ULTRASONIC INSPECTIONS

| SUB-SECTION | BASIC INSPECTIONS | SUPPLEMENTARY INSPECTIONS |
|---|---|---|
| A Ingot | Longitudinal-wave of 36-inch diameter by 28,510-pound ingot. | |
| B Machined Blank | Longitudinal-wave from outer diameter of hot-worked, annealed and machined blank prior to roll-forming. | |
| C Roll-Formed Cylinder | Shear-wave from outer diameter in one axial and one circumferential direction after roll-forming. | Evaluation of defects by longitudinal-wave from outer diameter. |
| D Initial Inspection After Sectioning | | Longitudinal-wave from end face of Serial 2 and Multiple Serial 4-5 after parting. |
| | Shear-wave of Serials 2 and 4 from outer-diameter surface in axial and circumferential directions opposite to above. | |
| E Re-Inspection After Sectioning | | Longitudinal-wave from outer diameter of sectioned test panels from Ring No. 5. |
| | | Longitudinal-wave from outer diameter surface of Serials 2 and 4. |

For these reasons, the ring was released for further manufacture. The Ladish Co. ultrasonic testing report is shown in Appendix III, Part B.

## C. ROLL-FORMED CYLINDER

Upon completion of roll-forming, shear-wave inspection was performed as had been planned. This inspection was made on a grid pattern from the outer diameter of the cylinder in one axial and one circumferential direction. A notch, representing three per cent of the wall thickness, was used to establish test sensitivity. Using this technique, four indication areas were found. The observed indication areas were circumferentially oriented and varied in length from 8-1/2 to 46-1/2 inches. The indications in each area were then evaluated by comparison to both the three-per-cent notch for shear-wave and an 8/64-inch FBH reference standard for longitudinal-wave and were found to be in excess of the reference standards. Based upon previously-used standards and Aerojet-General Corporation Specification AGC-32115, the observed indications would be adequate cause for rejection of the cylinder. The ultrasonic inspection reports are shown in Appendix III, Parts C and D.

Three of the four indication areas were correlated to the location of the minor indications detected in the piece prior to roll-forming. The fourth indication area appeared in a location previously considered sound, but was definitely associated with the surface indentation observed during the third roll-forming pass. A plot of all encountered indications and their relationship prior to and after roll-forming is shown in Figure 11. An analysis of this figure reveals that the ultrasonic techniques used up to this point did not relocate indications numbered 3 and 4 observed in the machined blank.

For purposes of clarity in explanation, this discussion has drawn a distinction between the observed indications by referring to those detected prior to roll-forming as "indications," and those detected after roll-forming as "indication areas," or simply "areas." Table V is presented to summarize the ultrasonic test results through this point in time, and to tabulate (for reference) the investigations to be discussed. The three left-hand columns identify the indications prior to roll-forming and their identification as areas after roll-forming, while the right-hand side continues with the added investigations.

The program scope of work anticipated the occurrence of ultrasonic indications and required that observations be verified by radiography. Radiographic equipment was taken into the shop where the cylinder was located, as its size precluded taking the cylinder to the Radiographic Laboratory. All four areas were radiographed perpendicularly. This initial inspection confirmed the presence of voids in Areas 1 and 3, but not in Areas 2 and 4. A portion of the defect in Area 3 as revealed in the X-ray film is reproduced in Figure 12. Since Areas 1 and 3 were confirmed by perpendicular-beam inspection, they were not re-radiographed at an angle as were Areas 2 and 4. This second inspection also failed to confirm Areas 2 and 4. The radiographic procedures employed are shown in Appendix III, Part E.

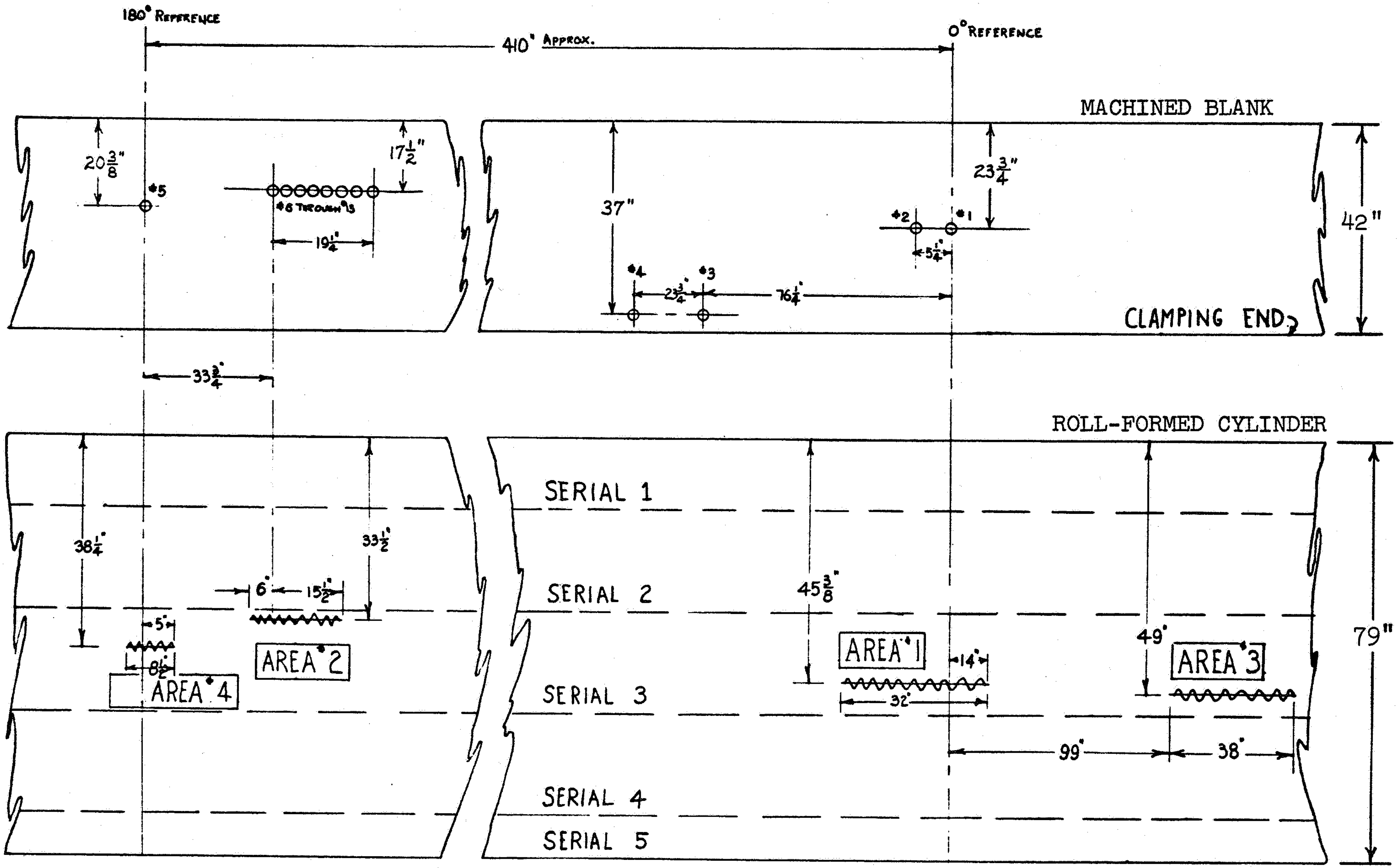



FIGURE 11

SKETCH SHOWING LOCATIONS OF ULTRASONIC INDICATIONS DETECTED PRIOR TO AND AFTER ROLL-FORMING

## TABLE V

## SUMMARY OF ULTRASONIC INSPECTION RESULTS

| CROSS REFERENCE OF ULTRASONIC INDICATIONS BY DETECTION | | | CONFIRMATION ATTEMPTS | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 10/24/67 REPORT OF INSPECTION OF THE AS-MACHINED BLANK PRIOR TO ROLL-FORMING | 10/30/67 REPORT OF INSPECTION AFTER ROLL-FORMING | LADISH CO. INSPECTION ON RE-CHECK BASIS | BY X-RAY INSPECTION ON 260-INCH ROLL-FORMED CYLINDRICAL SHAPE | | BY LABORATORY X-RAY INSPECTION OF SECTIONED TEST PANELS | | BY ULTRASONIC INSPECTION ON GIRTH-WELD RINGS FROM END FACES | BY ULTRASONIC INSPECTION IN LABORATORY ON SECTIONED TEST PANELS | BY SELECTIVE SECTIONING OF TEST PANELS FOR METALLOGRAPHIC REVIEW |
| LONG.-WAVE | SHEAR-WAVE | LONG.-WAVE | STRAIGHT BEAM | ANGLE BEAM | STRAIGHT BEAM | ANGLE BEAM | | | |
| Indications No. 1 and 2 | Area No. 1 | Confirmed | Yes | N.I.* | N.I. | N.I. | N.I. | N.I. | Inclusions and rupture |
| Indications No. 3 and 4 | Not Detected | N.I. | N.I. | N.I. | N.I. | N.I. | Not Detected | Detected | No apparent defects |
| Indication No. 5 | Area No. 4 | Confirmed | Not Detected | Not Detected | Yes | Yes | N.I. | N.I. | Inclusions and rupture |
| Indications No. 6 through 13 | Area No. 2 | Confirmed | Not Detected | Not Detected | Not Detected | Not Detected | N.I. | N.I. | Inclusions, but no rupture |
| Not Detected | Area No. 3 | Confirmed | Yes | N.I. | N.I. | N.I. | N.I. | N.I. | Inclusions and rupture |

* N.I. means not inspected.

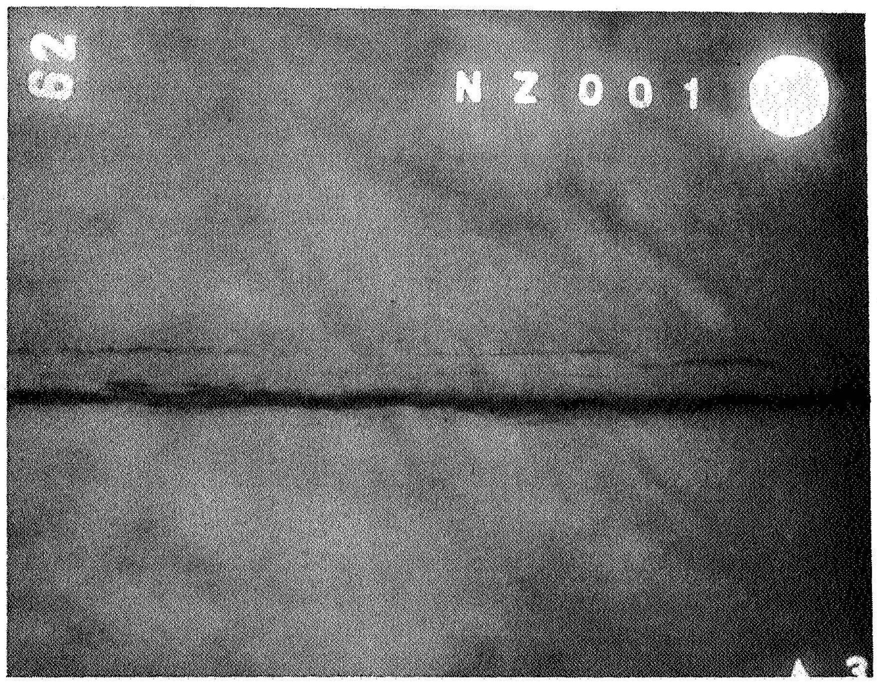



FIGURE 12

REPRODUCTION OF RADIOGRAPHIC FILM CONFIRMATION
ULTRASONIC INDICATION AREA NO. 3

In summary, to this point the roll-formed cylinder had been inspected by shear-wave technique in one axial and one circumferential direction. Areas of indications had been detected and their locations marked on the cylinder. Major work still to be done included parting of the cylinder into five rings (three for testing and two for welding), and cold-sizing of one or both of the welding rings. Parting of the cylinder into five rings was designed so that all the observed and identified indication areas would be contained within one of the rings scheduled for testing. In this manner, work in three areas continued concurrently:

1. Laboratory investigation of the observed indication areas.
2. Longitudinal-wave ultrasonic inspection from end faces after parting of the cylinder into five rings.
3. Final manufacturing operations including cold-sizing and shear-wave inspections in directions opposite to those already completed.

## D. INITIAL INSPECTION AFTER SECTIONING

After the cylinder had been parted into test rings and the test rings cut into sections, test panels containing the ultrasonic indication Areas 2 and 4 were re-radiographed under laboratory conditions. This inspection confirmed the presence of the ultrasonic indication in Area 4 by both perpendicular and angle techniques, but still failed to confirm the indication in Area 2. The parameters of this inspection are contained in Appendix III, Part F.

Test panels containing ultrasonic indication areas were then sectioned for metallographic investigation. This examination was coordinated with the NASA Project Manager and resulted in a shift of emphasis from a relatively routine metallographic review to a comprehensive evaluation to determine the cause of failure. As a result, the four areas of indications were sectioned in a manner that would reveal initiation and propagation of the indications. The results of these investigations have shown that the areas detected were caused by nonmetallic inclusions composed principally of silicates. The photomicrograph in Figure 13 is typical of silicates observed in ultrasonic indication Area 3. Three of the four ultrasonic indication areas exhibited quantities of inclusions along which cracks initiated, propagated, and ultimately terminated.

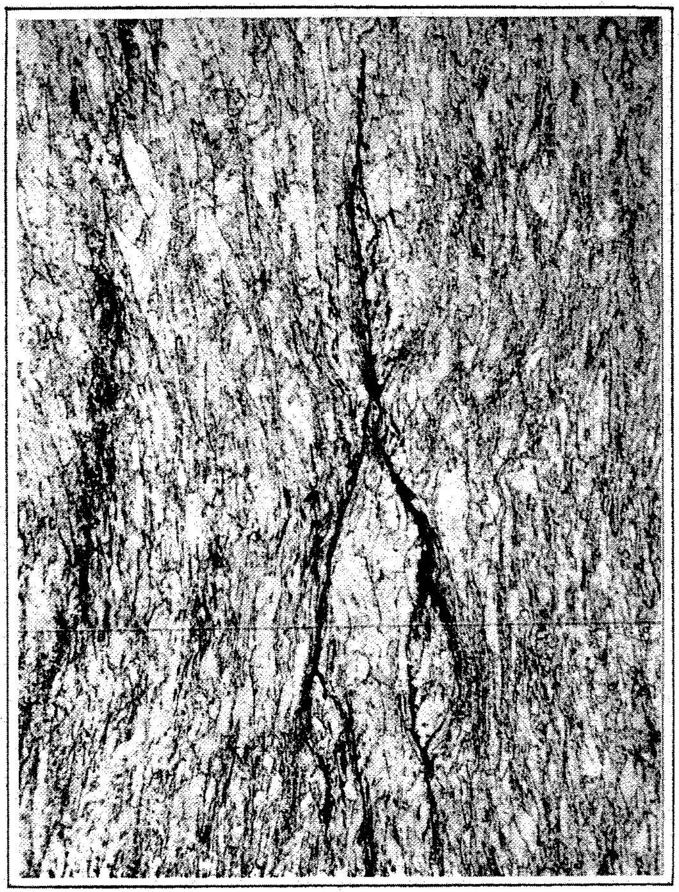
Each of the indication areas had varying degrees of inclusions and ruptures as shown in Figures 14 and 15. The left photomicrograph in Figure 14 shows the progression of the resulting rupture in Area 1, while the photomicrograph on the right shows only a slight hint of inclusions in Area 2. In Figure 15, a photomicrograph of an as-polished surface from Area 3, different than that of Figure 13, is shown. This photomicrograph is near one end of the rupture and shows the distribution and size of inclusions and voids found.

Although the metallurgical structure in the ultrasonic indication areas is generally that of the cold-worked and deformed grains,

Microspecimen No. H-382
Magnification 100X
As-Polished

Microspecimen No. H-382
Magnification 500X
As-Polished, Polarized Light

FIGURE 13: ULTRASONIC INDICATION AREA 3 VIEWED AS-POLISHED AND UNDER POLARIZED LIGHT. THE INCLUSIONS ARE CONSIDERED TO BE SILICATES BECAUSE OF THE COLOR AND INTENSITY OF THE REFLECTED LIGHT.



Microspecimen No. G-9482D
ULTRASONIC INDICATION AREA NO. 1

Microspecimen No. G-9995
ULTRASONIC INDICATION AREA NO. 2

Magnification 63X; etchant 50 ml. HCl, 25 ml. $HNO_3$, 1 gm. $CuCl_2$, and 150 ml. $H_2O$.

FIGURE 14: CROSS SECTIONS OF AREAS DETECTED BY ULTRASONIC INSPECTION AS HAVING INDICATIONS. AREA NO. 1 WAS CONFIRMED BY RADIOGRAPHIC INSPECTION AND HAS A RUPTURE; AREA NO. 2 WAS NOT CONFIRMED BY RADIOGRAPHY AND SHOWS ONLY A FEW INCLUSIONS. (18 PER CENT NICKEL MARAGING STEEL FOR THE 260-INCH DIAMETER ROLL-FORMED CYLINDER.)

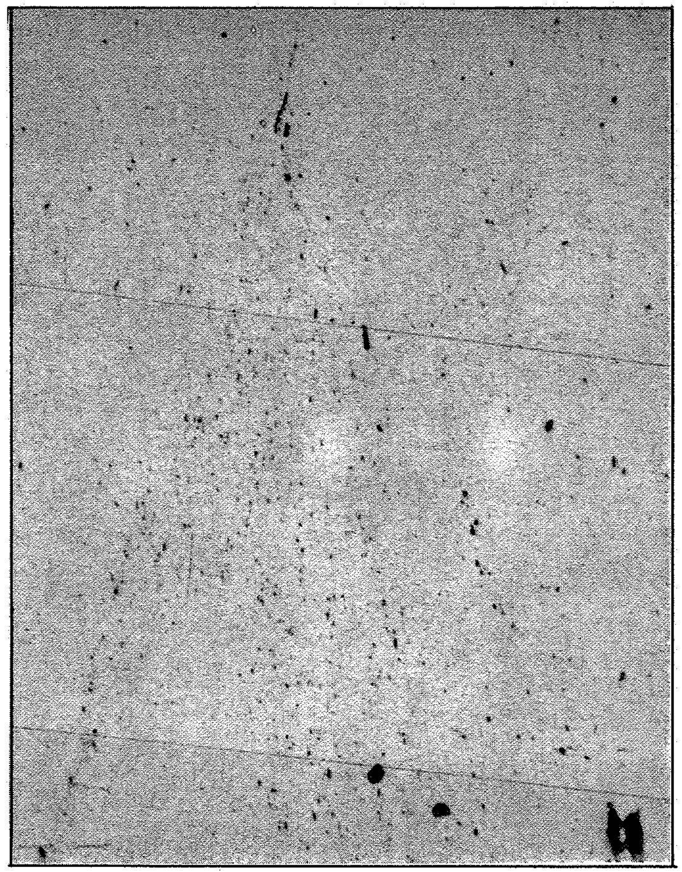


FIGURE 15: CROSS SECTION OF ULTRASONIC INDICATION AREA 3 IN THE AS-POLISHED CONDITION SHOWING VARIOUS-SIZED VOIDS AND INCLUSIONS IN BOTH ORIENTATION AND RANDOM DISTRIBUTION PATTERNS. (MICROSPECIMEN NO. G-9909 AT A MAGNIFICATION OF 25X.)

significance must be placed upon the finding of equiaxed grains in some areas, as shown in Figure 16. In this photomicrograph from Area 4, equiaxed grains of hot-working can be seen next to the rupture and confirms the ultrasonic inspection finding that some of these indications existed prior to roll-forming.

The following conclusions were drawn as a result of investigating the ultrasonic indications:

1. The raw material, although melted by a double-vacuum process, contained impurities not typical of the material or representative of the melting process. Thirteen ultrasonic indications containing these impurities were detected in the machined blank prior to roll-forming. All were within specification requirements, however, and the ring would have been acceptable as a hot-worked forging product.

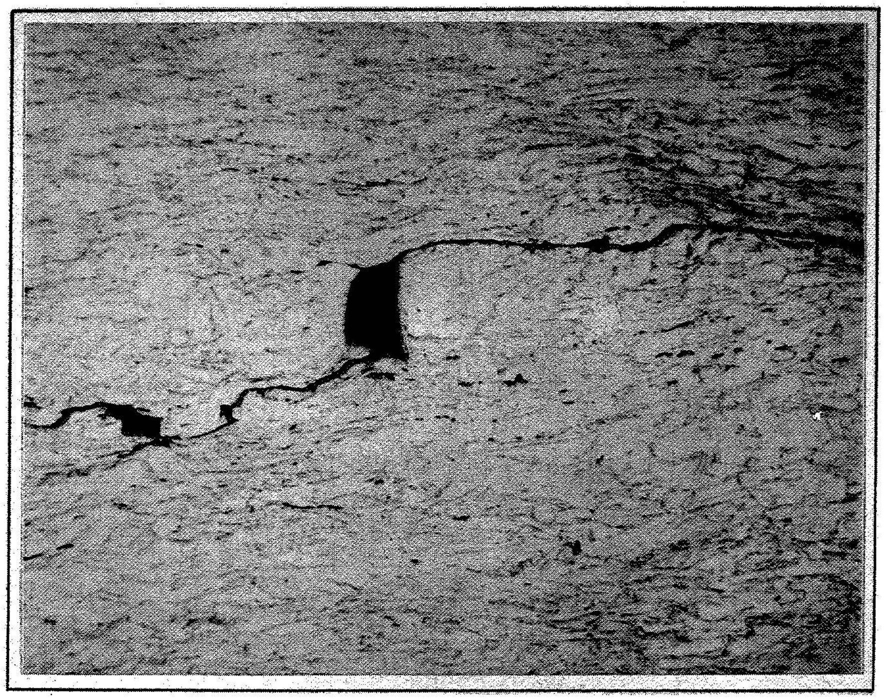
2. The impurities were present in varying concentrations and distributions. Although some were detectable by ultrasonic inspection, others were not. After roll-forming, indications were located and confirmed in Area 3, which, in the machined blank state, was either free of indications or had indications undetectable by the inspection technique employed.

3. Roll-forming did increase the magnitude and scope of the known indications, and, in the case of Area 3, served as an inspection device to locate a previously-undetected area.

4. Since the first roll-forming pass was accomplished with the rolls mis-matched, stresses not normal to the process were introduced into the material. The tolerance level for deformation of these inclusion areas by roll-forming is still to be determined.

While the above-described investigation was in progress, work on Ring Serials 2 and 4-5 continued. As soon as they were parted from the cylinder, these two rings were given a longitudinal-wave inspection from the end faces. No defects were observed and the processing continued. The ultrasonic test report is shown in Appendix III, Part G.

After roll-forming, shear-wave inspection in one axial and one circumferential direction had not detected any indications and Ring Serial 4-5 was released for a cold-sizing operation. This composite was cold-sized to provide a matching end for welding to Serial 2. Then Serial 4 was parted and subjected to the planned shear-wave inspection in directions opposite to those already completed. No indications were observed. The inspection report is shown in Appendix III, Part H. The second shear-wave inspection of Serial 2 was not undertaken at this time, and both Serials 2 and 4 were placed in storage pending future work.



Magnification 63X; etchant 50 ml. HCl, 25 ml. $HNO_3$, 1 gm. $CuCl_2$, and 150 ml. $H_2O$.

FIGURE 16: CROSS SECTION OF ULTRASONIC INDICATION AREA 4 SHOWING MIXED STRUCTURE OF BOTH ELONGATED AND EQUIAXED GRAINS. (MICROSPECIMEN NO. G-9979.)

While the parting and cold-sizing efforts were being accomplished, the previously-unanswered question of why indications numbered 3 and 4 in the machined blank were not relocated in the roll-formed cylinder was given consideration. Test panels from the area where these indications should have appeared in the cylinder were brought into the Ultrasonic Testing Laboratory and re-inspected.

Another shear-wave inspection also did not reveal any indications. However, by using a twin 5 MHZ crystal and conducting a longitudinal-wave inspection from the outer-diameter surface, three stringer-type indications 1-1/2 to two inches in length were located and are reported in Appendix III, Part I. The locations of these three stringer indications were marked on the test panels and then the panels were cut open for metallographic examination. No ruptures could be seen in any of the exposed sections. Each surface was then repeatedly polished and examined metallographically. At best, only a very slight trace of small inclusions could be found.

## E. RE-INSPECTION AFTER SECTIONING

Although the intended ultrasonic inspections were now completed except for a final shear-wave inspection of Serial 2, and the two welding rings apparently were free of ultrasonic indications, the experience gained with indications numbered 3 and 4 could not be overlooked. If these two indications, detected in the machined blank prior to roll-forming, could not be detected by conventional shear-wave inspection, but could be found by longitudinal-wave inspection with a twin crystal operating at 5 MHZ, it would seem to be a logical requirement to re-inspect the already acceptable (by shear-wave inspection) Serials 2 and 4 using the longitudinal-wave technique.

Both rings were removed from storage and the final shear-wave inspection of Serial 2 was completed. No defects were seen. The report is in Appendix III, Part J. The longitudinal-wave inspections were conducted on both Serials 2 and 4 and additional indications were found. The initial search was conducted with a 3/64-inch FBH reference standard and evaluation of located defects was made versus 5/64- and 8/64-inch FBH standards. All the located indications exceed the setting from these standards and, therefore, would be considered adequate cause for rejection. This evaluation confirmed the earlier conclusion that all of the raw material impurities were not detectable in the machined blank. The reports of this final longitudinal-wave inspection are in Appendix III, Part K.

As delineated in the Introduction to this report, the intention of the program was to demonstrate the ability to manufacture a 72-inch-minimum face height cylinder of 260.000 inches inner diameter. The ultrasonic difficulties encountered on this initial cylinder have provided both information to advance the state-of-the-art as well as identification of additional areas for technical exploration. Specifically, the state-of-the-art was advanced by demonstrating that longitudinal-wave ultrasonic inspection from the outer-diameter surface of a cylinder should be conducted during or after the cold-working operation, and that additional technical effort is necessary to determine whether or not indications so detected are detrimental.

# V. METALLURGICAL TEST DATA

The metallurgical testing requirements for this Contract were divided into sections as outlined below.

A. Acceptance Testing of Forging Stock

This would be accomplished by Ladish Co. as an option and be contingent upon availability of material.

B. Testing of the As-Roll-Formed Cylinder for Uniformity

Test rings representing the top, middle, and bottom of the roll-formed cylinder would be sectioned for circumferential and axial tensile testing at each of three locations. This testing would be done on specimens in the as-roll-formed condition (solution treated at 1675°F prior to roll-forming, plus 51 per cent reduction cold-working). Grain structure analysis, microcleanliness, chemical composition, and hardness would also be checked at this stage.

C. Heat Treatment Response

The response to varying maraging cycles would be determined from a test panel at the mid-height location. Tensile specimens would be aged at 850, 900, 915, and 950°F for four, eight, and 16 hours. In addition, other specimens would be re-annealed at temperatures ranging from 1500 to 1750°F and then aged as above. (It is not likely that a process for producing thin-walled cylinders by cold-working would require subjection of the final product to a high-temperature annealing cycle. However, background data was sought in the event this possibility ever becomes a reality.)

D. Final Aging

After the heat treatment response had been evaluated, one treatment would be selected and material from all three test rings would be heat treated by this method and then tested.

## A. ACCEPTANCE TESTING OF FORGING STOCK

Ordering data for the 28,000-pound (minimum), 36-inch-diameter, consumable electrode vacuum-arc-remelted ingot included a requested two-inch-thick slice off the ingot bottom for testing and acceptance. This slice, if obtained, would be used for two primary purposes:

1. Chemistry check, and
2. Macroetch review;

and one subsidiary check:

3. Tensile properties from a forged test bar.

When the yield of a melting process is pushed to the maximum, the two-inch slice from the ingot bottom can include remnants of the consumable electrode starting material, and may or may not be truly representative of the electrode itself. Samplings for chemistry are normally taken immediately adjacent to the surface exposed by cutting the slice and re-forging test coupons are cut from the slice and macroetched for homogeneity. Either the slice, or the actual ingot bottom, may be macroetched. The problems in handling a 28,510-pound ingot, however, direct that the slice be etched.

The chemistry check analysis by Ladish Co. was acceptable and is shown in Table VI, along with the specification chemistry and mill certification of chemisty. A photograph of the macroetch is shown in Figure 17. No unusual characteristics were observed.

Four test bars to determine mechanical property capabilities were forged with the following final forging temperatures:

1. Above 2100°F
2. 1950 to 2100°F
3. 1850 to 1950°F
4. Below 1850°F

Each test bar was reduced from 2-1/2 inches to one inch in thickness in the specified temperature range. All bars were given a 1650°F, one-hour annealing cycle and then were sectioned for aging at times of three or six hours. Longitudinal and transverse tensile and pre-cracked Charpy V-notch impact tests were conducted at room temperature for information purposes. The results of these tests showed the range of properties to be:

TABLE VII

SUMMARY OF ROOM-TEMPERATURE MECHANICAL PROPERTIES FROM FORGED ACCEPTANCE TEST BARS

| TEST DIRECTION | 0.2% $F_{ty}$ (KSI) | $F_{tu}$ (KSI) | ELONG. (%) | R.A. (%) | P.C.I. (W/A) (IN-LBS./IN.$^2$) |
|---|---|---|---|---|---|
| Longitudinal | 184 - 190 | 196.5 - 201.0 | 13 - 14 | 60 - 62 | 2100 - 2740 |
| Transverse | 183 - 190 | 194.5 - 201.0 | 12 - 14 | 43 - 52 | 1160 - 1790 |

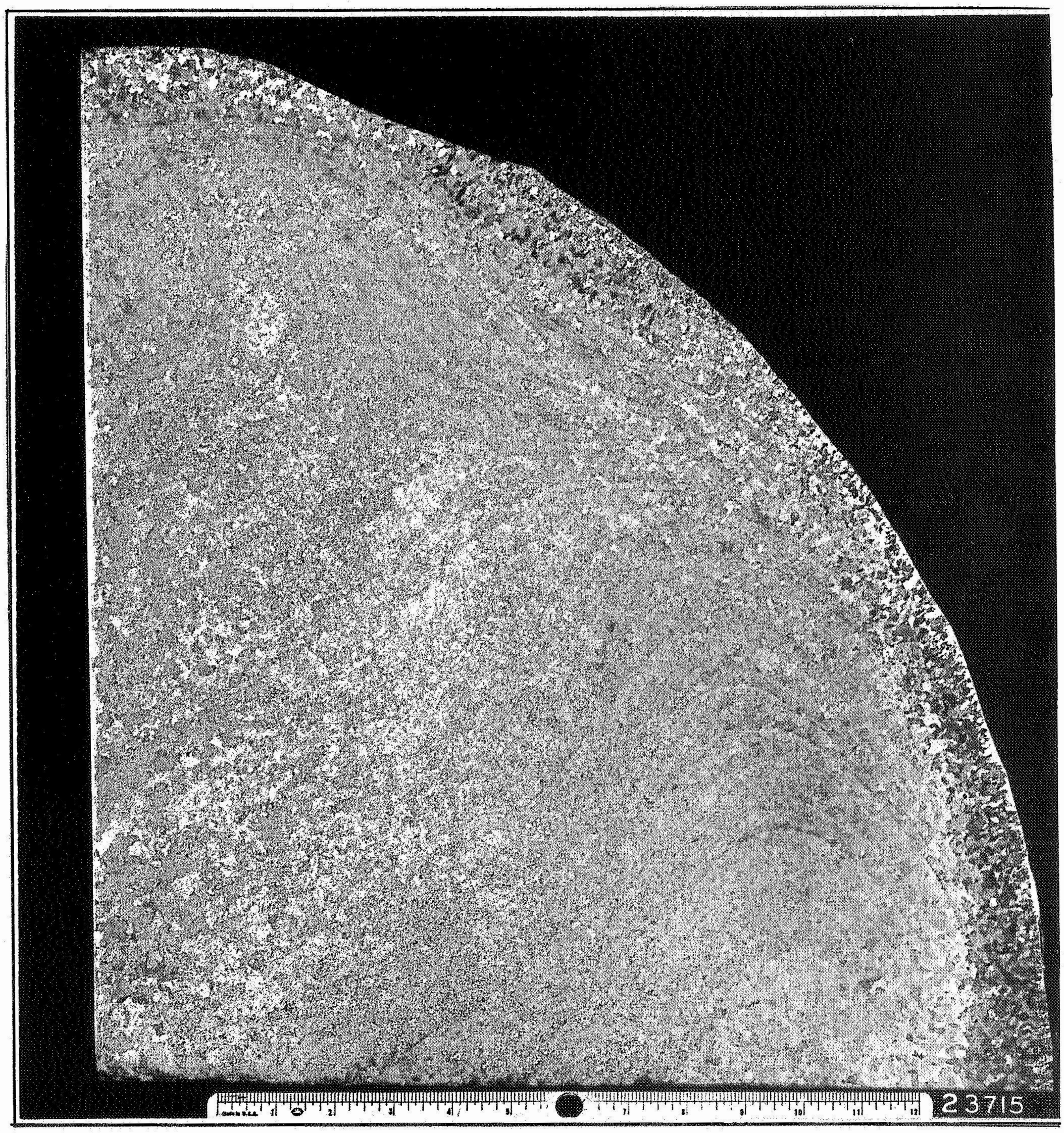
Since the chemistry of this material had been altered to reduce the strength levels, the results, as expected, were below the normal "200" grade 18 per cent nickel maraging steel mechanical property levels. The material was released for forging.

TABLE VI

TABULATION OF CHEMICAL COMPOSITION FROM MILL AND CHECK ANALYSES

| SOURCES OF ANALYSES | ELEMENT (WEIGHT PERCENTAGES) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | Mn | P | S | Si | Ni | Co | Mo | Ti | Al | Fe |
| Ordering Document Specification 2-F-4 | 0.03 Max. | 0.10 Max. | 0.010 Max. | 0.010 Max. | 0.10 Max. | 17.0/ 19.0 | 7.0/ 8.0 | 3.8/ 4.0 | 0.08/ 0.10 | 0.05/ 0.15 | Balance |
| Mill Certification | 0.006 | 0.01 | 0.004 | 0.004 | 0.01 | 17.51 | 7.55 | 3.87 | 0.08 | 0.07 | Balance |
| Ladish Co. Check Analysis On Ingot | 0.023 | 0.03 | 0.007 | 0.007 | 0.01 | 18.30 | 7.89 | 3.95 | 0.09 | * | Balance |

* Not determined.




Magnification 1X (reduced for printing); etchant $HCl-HNO_3$.

FIGURE 17

MACROETCH PHOTOGRAPH OF 28,510-POUND MARAGING STEEL VACUUM-MELTED INGOT

## B. TESTING OF THE AS-ROLL-FORMED CYLINDER FOR UNIFORMITY

After roll-forming, the full-length cylinder was sectioned to yield three test rings and two rings for welding as described in previous sections of this report. Table VIII shows the schedule of testing for uniformity. The entire sectioning diagram for all tests, as related to the completed cylinder, is shown in Figure 18.

TABLE VIII

SCHEDULE OF TESTING THE AS-ROLL-FORMED CYLINDER FOR UNIFORMITY

| | |
|---|---|
| CHEMICAL COMPOSITION | One analysis was made on each test ring. |
| HARDNESS (Brinell and Rockwell "C")<br>GRAIN SIZE<br>MICROCLEANLINESS<br>TENSILE TESTS (Circumferential and Axial) | Each ring was tested at three locations at 120-degree intervals. Locations in the mid-height ring were rotated 40 degrees from locations in the top ring; locations in the bottom ring were rotated 80 degrees from locations in the top ring. |

The results of chemical analysis checks are shown in Table IX, which is an extension of previously-presented Table VI. It is noted that the results for carbon content varied within the specification requirements, but no other variations in chemical composition were observed.

Tabulations of microcleanliness, grain size, and hardness values from the as-roll-formed cylinder are shown in Table X. In view of the ultrasonic difficulties, the microcleanliness specimens were carefully reviewed for additional evidence of inclusion concentrations, but no unusual quantities or distribution patterns were seen in the selected specimens. The grain structure was cold-worked and the actual grain size was difficult to determine. Representative photomicrographs of each test ring are shown in Figure 19.

Tensile tests were conducted in both the circumferential and axial directions at three different locations in each as-roll-formed test ring (refer to Figure 18). These test results are shown in Table XI and reflect two very important points:

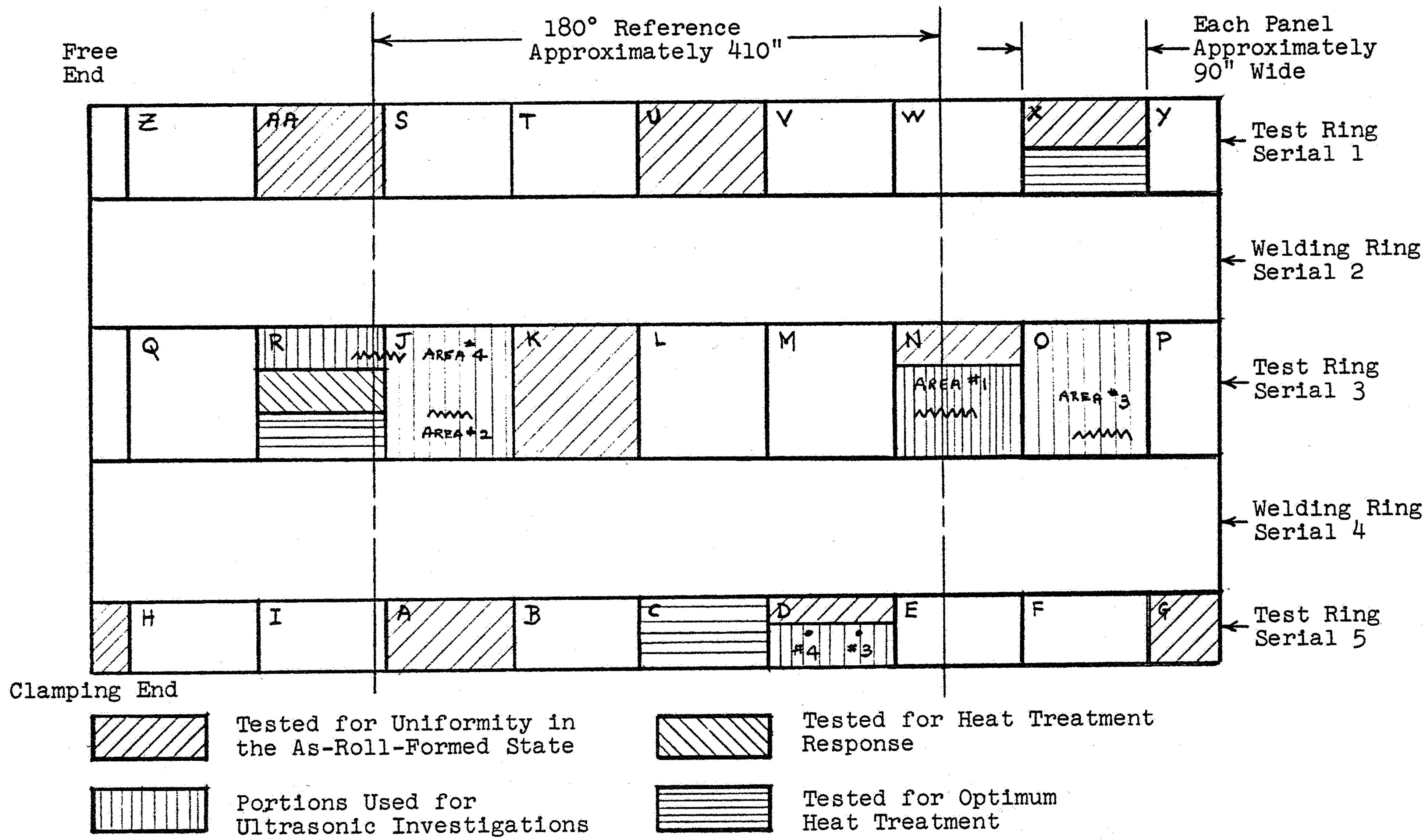



FIGURE 18

SECTIONING DIAGRAM FOR THE 260-INCH-DIAMETER ROLL-FORMED CYLINDER

TABLE IX

TABULATION OF CHEMICAL COMPOSITION FROM MILL AND CHECK ANALYSES PLUS ANALYSES OF TEST PANELS FROM THE AS-ROLL-FORMED CYLINDER

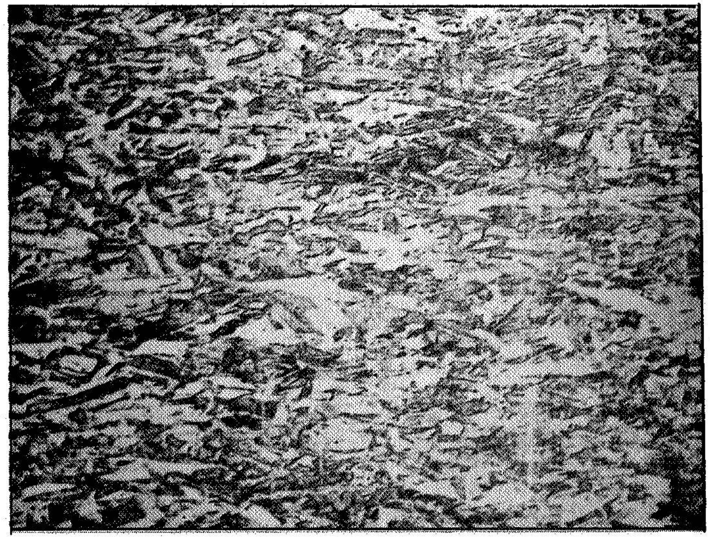
| SOURCES OF ANALYSES | ELEMENT (WEIGHT PERCENTAGES) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | Mn | P | S | Si | Ni | Co | Mo | Ti | Al | Fe |
| Ordering Document Specification 2-F-4 | 0.03 Max. | 0.10 Max. | 0.010 Max. | 0.010 Max. | 0.10 Max. | 17.0/ 19.0 | 7.0/ 8.0 | 3.8/ 4.0 | 0.08/ 0.10 | 0.05/ 0.15 | Balance |
| Mill Certification | 0.006 | 0.01 | 0.004 | 0.004 | 0.01 | 17.51 | 7.55 | 3.87 | 0.08 | 0.07 | Balance |
| Ladish Co. Check Analysis On Ingot | 0.023 | 0.03 | 0.007 | 0.007 | 0.01 | 18.30 | 7.89 | 3.95 | 0.09 | * | Balance |
| Test Panel C | 0.0075 | <0.001 | 0.005 | 0.007 | 0.02 | 18.17 | 7.78 | 3.88 | 0.04 | 0.055 | Balance |
| Test Panel R | 0.0154 | <0.001 | 0.005 | 0.005 | 0.02 | 18.26 | 7.82 | 3.90 | 0.04 | 0.07 | Balance |
| Test Panel AA | 0.0086 | <0.001 | <0.005 | 0.008 | Nil | 18.16 | 7.77 | 3.90 | 0.09 | 0.07 | Balance |

* Not determined.

TABLE X

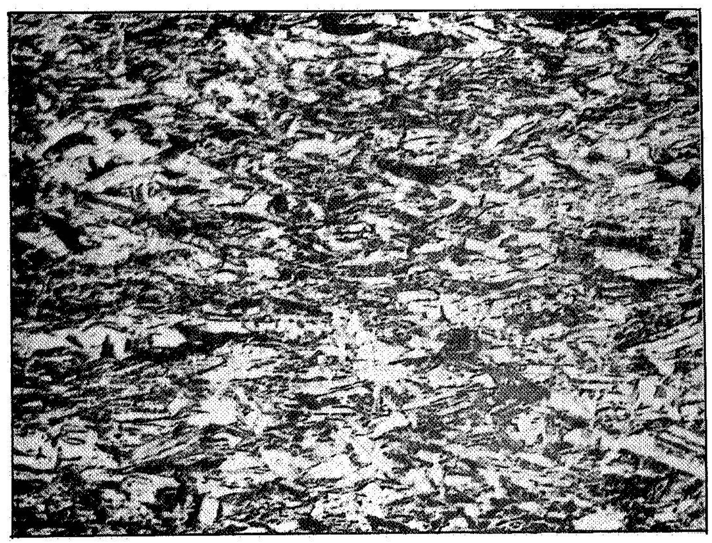
MICROCLEANLINESS ANALYSES, HARDNESS, AND GRAIN STRUCTURE EVALUATIONS OF TEST PANELS IN THE AS-ROLL-FORMED CONDITION

| TEST PANEL NO. | MICROCLEANLINESS | | | | | | | | GRAIN SIZE | HARDNESS | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | TYPE A | | TYPE B | | TYPE C | | TYPE D | | (APPROXIMATION DUE TO COLD-WORKED NATURE.) | $R_c$ | BHN |
| | T | H | T | H | T | H | T | H | | | |
| A | 1.0 | 0 | 0 | 0 | 0 | 0 | 1.0 | 1.0 | 7 | 30 | 285 |
| D | 0 | 0 | 0 | 0 | 1.0 | 0 | 1.0 | 1.0 | 7 | 30 | 285 |
| G | 0 | 0 | 0 | 0 | 0 | 0 | 1.0 | 1.0 | 7 | 30 | 285 |
| K | 0 | 0 | 0 | 0 | 0 | 0 | 0.5 | 0 | 6 | 30 | 285 |
| N | 0 | 0 | 0 | 0 | 0 | 0 | 1.0 | 0 | 7 | 31.5 | 302 |
| Q | 0 | 0 | 0 | 0 | 0 | 0 | 0.5 | 0 | 7 | 30 | 285 |
| U | 0 | 0 | 0 | 0 | 0 | 0 | 0.5 | 0 | 6 | 31.5 | 302 |
| Y | 0 | 0 | 0 | 0 | 0 | 0 | 1.0 | 0 | 6 | 31 | 293 |
| AA | 0 | 0 | 0 | 0 | 0 | 0 | 0.5 | 0 | 6 | 31 | 293 |
| Spec. 2F4 | 1.5 Max. | 1.0 Max. | 1.5 Max. | 1.0 Max. | 1.0 Max. | 1.0 Max. | 1.5 Max. | 1.0 Max. | N/A | N/A | |



SERIAL 5

SERIAL 3



SERIAL 1

⟵ Circumferential Direction ⟶

Magnification 100X; etchant 50 ml. HCl, 25 ml. $HNO_3$, 1 gm. $CuCl_2$, and 150 ml. $H_2O$.

FIGURE 19

PHOTOMICROGRAPHS SHOWING REPRESENTATIVE MICROSTRUCTURES FROM THE AS-ROLL-FORMED CYLINDER

TABLE XI

ROOM-TEMPERATURE TENSILE TEST RESULTS FROM THE AS-ROLL-FORMED CYLINDER

| TEST PANEL | CIRCUMFERENTIAL DIRECTION | | | | AXIAL DIRECTION | | | |
|---|---|---|---|---|---|---|---|---|
| | ULTIMATE STRENGTH (KSI) | 0.2% OFFSET YIELD STRENGTH (KSI) | ELONGATION (PER CENT) | REDUCTION IN AREA (PER CENT) | ULTIMATE STRENGTH (KSI) | 0.2% OFFSET YIELD STRENGTH (KSI) | ELONGATION (PER CENT) | REDUCTION IN AREA (PER CENT) |
| A | 158.7 | 150.0 | 11 | 51 | 147.3 | 139.5 | 12 | 56 |
| | 156.9 | 150.0 | 11 | 58 | 147.9 | 139.5 | 12 | 54 |
| D | 157.2 | 149.4 | 11 | 53 | 149.7 | 141.9 | 12 | 55 |
| | 157.8 | 150.0 | 11 | 52 | 149.1 | 141.9 | 12 | 54 |
| G | 158.1 | 149.4 | 12 | 56 | 146.4 | 140.1 | 13 | 59 |
| | 157.8 | 149.1 | 12 | 57 | 147.6 | 139.2 | 12 | 57 |
| K | 159.6 | 151.4 | 11 | 54 | 148.2 | 144.2 | 12 | 62 |
| | 159.7 | 149.6 | 11 | 56 | 148.2 | 143.8 | 12 | 58 |
| N | 160.7 | 153.5 | 11 | 54 | 148.8 | 144.9 | 11 | 58 |
| | 159.5 | 152.3 | 11 | 56 | 148.0 | 142.6 | 10 | 54 |
| Q | 161.0 | 150.8 | 10 | 51 | 149.5 | 144.9 | 12 | 56 |
| | 161.9 | 151.9 | 11 | 53 | 150.1 | 145.3 | 12 | 59 |
| U | 157.3 | 150.6 | 10 | 54 | 148.4 | 145.0 | 12 | 61 |
| | 159.1 | 152.4 | 11 | 55 | 147.8 | 144.6 | 12 | 60 |
| X | 159.0 | 152.4 | 11 | 54 | 149.4 | 145.8 | 12 | 60 |
| | 159.0 | 152.6 | 10 | 56 | 150.4 | 147.2 | 12 | 63 |
| AA | 159.0 | 152.8 | 10 | 51 | 148.8 | 144.6 | 12 | 60 |
| | 160.2 | 152.4 | 11 | 53 | 148.7 | 145.7 | 12 | 60 |

1. The roll-forming process does impart uniform work penetration.

2. The previous observation of non-uniform residual stress due to roller mis-match was confirmed.

That the roll-forming process imparts uniform work to the piece is confirmed by looking at the figures of Table XI for any one particular ring. Examining the test results in either direction for the three locations in the mid-height ring, Serial 3, there was less than four Ksi maximum variation in either the yield or ultimate strength from location to location.

Confirmation of the non-uniform residual stress is shown more dramatically in Table XII, which summarizes the data of Table XI by presenting the average of the six tests per test ring per test direction. In progressing from the clamping end to the free end of the cylinder, the yield strength, for either test direction, increases. Since this increase in yield strength is <u>not</u> accompanied by a corresponding increase in ultimate tensile strength, the spread between yield and ultimate strength, therefore, decreases.

## C. HEAT TREATMENT RESPONSE

Test specimens from one panel were utilized to conduct a heat treatment response evaluation. The total scope of the testing is shown in Table XIII and the numerous results are listed in Appendix IV. The anticipated processing of a cold-worked product such as this roll-formed cylinder would normally include development of properties through cold-working or by subsequent relatively low-temperature thermal treatment. Mechanical properties response to direct aging of the cold-worked material was, therefore, determined by aging for three different periods of time (four, eight, and 16 hours) at four different temperatures (850, 900, 915, and 950°F).

Material was also re-solution annealed at temperatures of 1500 to 1750°F and then subjected to the aging treatment described above. This was done in order to provide reference data should the processing approach warrant serious consideration at some time in the future.

The volume of generated tensile test data can be evaluated endlessly for any specific criterion or potential parameter of application. In total, however, it is best examined by considering, for example, one particular aging temperature and studying its effect upon the yield strength and reduction in area. This was done in Figure 20 wherein the data resulting from the 900°F aging treatment is shown graphically.

The test results show that when the roll-formed product was aged directly at 900°F a yield strength level of approximately 210 Ksi would be obtained, along with a 45 per cent reduction in area.

TABLE XII

SUMMARY OF ROOM-TEMPERATURE TENSILE TEST RESULTS FROM AS-ROLL-FORMED CYLINDER

(AVERAGES OF SIX TEST RESULTS IN EACH DIRECTION)

| IDENTITY | CIRCUMFERENTIAL VALUES (KSI) | | | AXIAL VALUES (KSI) | | |
|---|---|---|---|---|---|---|
| | $F_{tu}$ | $F_{ty}$ | $\langle \overline{x}F_{tu} \rangle - \langle \overline{x}F_{ty} \rangle$ | $F_{tu}$ | $F_{ty}$ | $\langle \overline{x}F_{tu} \rangle - \langle \overline{x}F_{ty} \rangle$ |
| Ring No. 5<br>Test Panels A, D, G<br>(Clamping End) | 157.8 | 149.7 | 8.1 | 148.0 | 140.4 | 8.4 |
| Ring No. 3<br>Test Panels K, N, Q<br>(Mid-Height) | 160.4 | 151.6 | 8.8 | 148.8 | 144.3 | 4.5 |
| Ring No. 1<br>Test Panels U, X, AA<br>(Free End) | 158.9 | 152.2 | 6.7 | 148.9 | 145.5 | 3.4 |

TABLE XIII

PLAN FOR EVALUATION OF HEAT TREATMENT RESPONSE

| | CYCLE AND TEMPERATURES (°F) | | AGING TEMPERATURES (°F) AND TIMES AT TEMPERATURE |
|---|---|---|---|
| As-roll-formed material | Direct age after final roll-forming | | 850, 900, 915, and 950 for four, eight, or 16 hours |
| | Re-solution anneal one hour at temperature after final roll-forming | 1500<br>1550<br>1600<br>1650<br>1700<br>1750 | 850, 900, 915, and 950 for four, eight, or 16 hours<br><br>Circumferential test direction for all tests at four- and eight-hour aging times<br><br>Axial test direction for all tests at 16-hour aging time. |

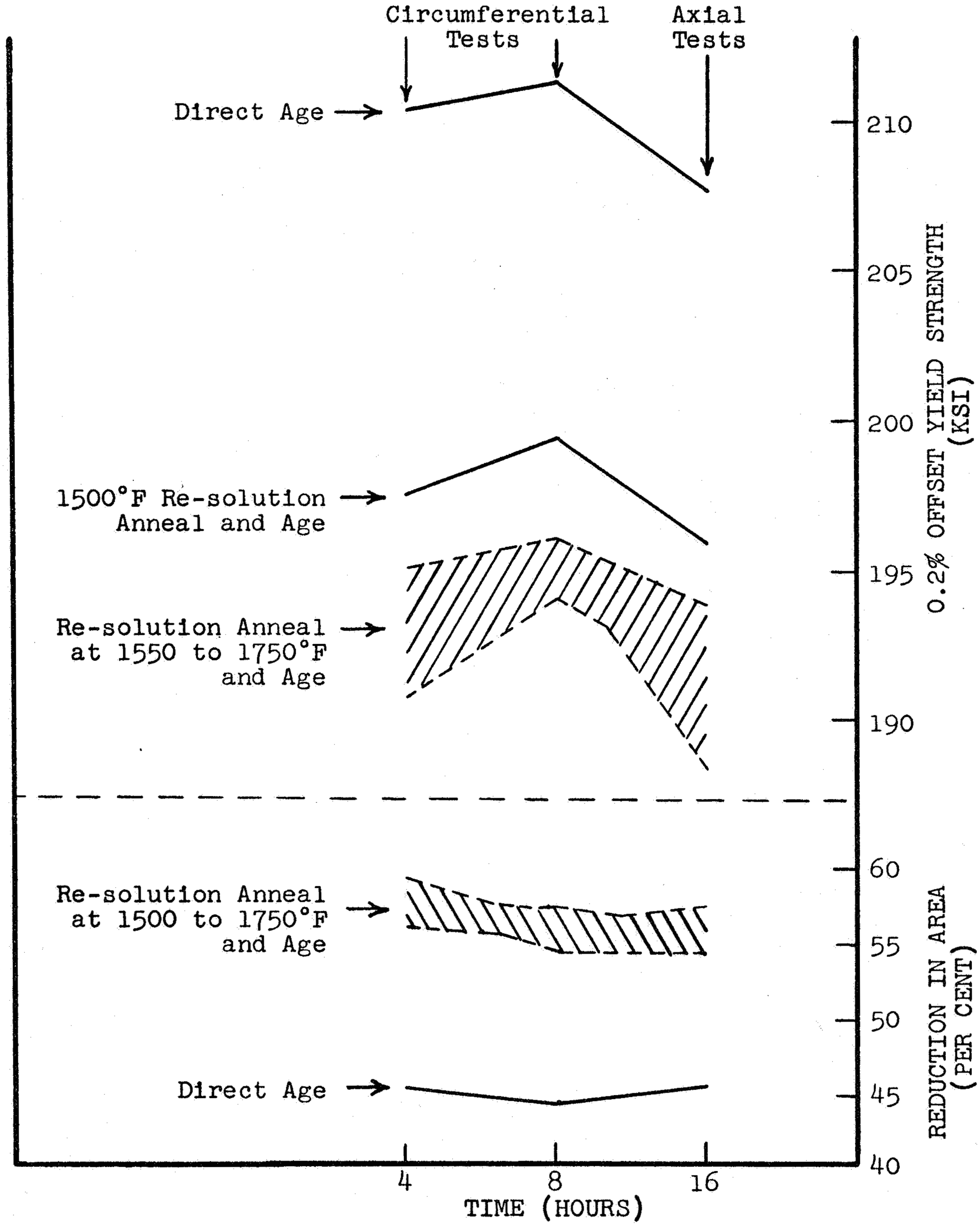



FIGURE 20

SUMMARY OF YIELD STRENGTH AND REDUCTION IN AREA FOR 900°F AGING TEMPERATURE AT VARIOUS TIMES WITH AND WITHOUT RE-SOLUTION ANNEALING CYCLES

When the product is re-solution annealed prior to subsequent aging at 900°F, the reduction in area increases to approximately 55 per cent and the yield strength will be at the 190 to 200 Ksi level. With reference to yield strength, it was observed that with a 1500°F re-solution annealing cycle, the resultant properties were definitely two or three Ksi above, and separate from, all the other values, which were generally mixed. The test results are presented graphically without further discussion for individual analyses as described in Figures 21 through 27.

## D. FINAL AGING

The final testing requirement specified that fracture toughness and tensile tests be conducted on material from each test ring after it was subjected to a selected heat treatment (900°F for eight hours). Direct aging of the test material at 900°F for eight hours was completed, and the test results, along with data from the previously-produced 156-inch-diameter roll-formed cylinder, are shown in Tables XIV through XVI.

The tensile test results in Table XIV reflect two noteworthy points:

1. For either test direction, a uniformity in mechanical property response exists after aging and non-uniformity reflected in Table XII has been eliminated.

2. The yield strength levels of both test directions are considerably lower than test results obtained by Ladish Co. for a 156-inch-diameter roll-formed cylinder of the "200" grade 18 per cent nickel maraging steel. This comparison confirms the successful reduction of mechanical property levels by alteration of the chemical composition.

The pre-cracked Charpy V-notch impact test results in Table XV are reported as reference data, as are the fracture toughness values in Table XVI.

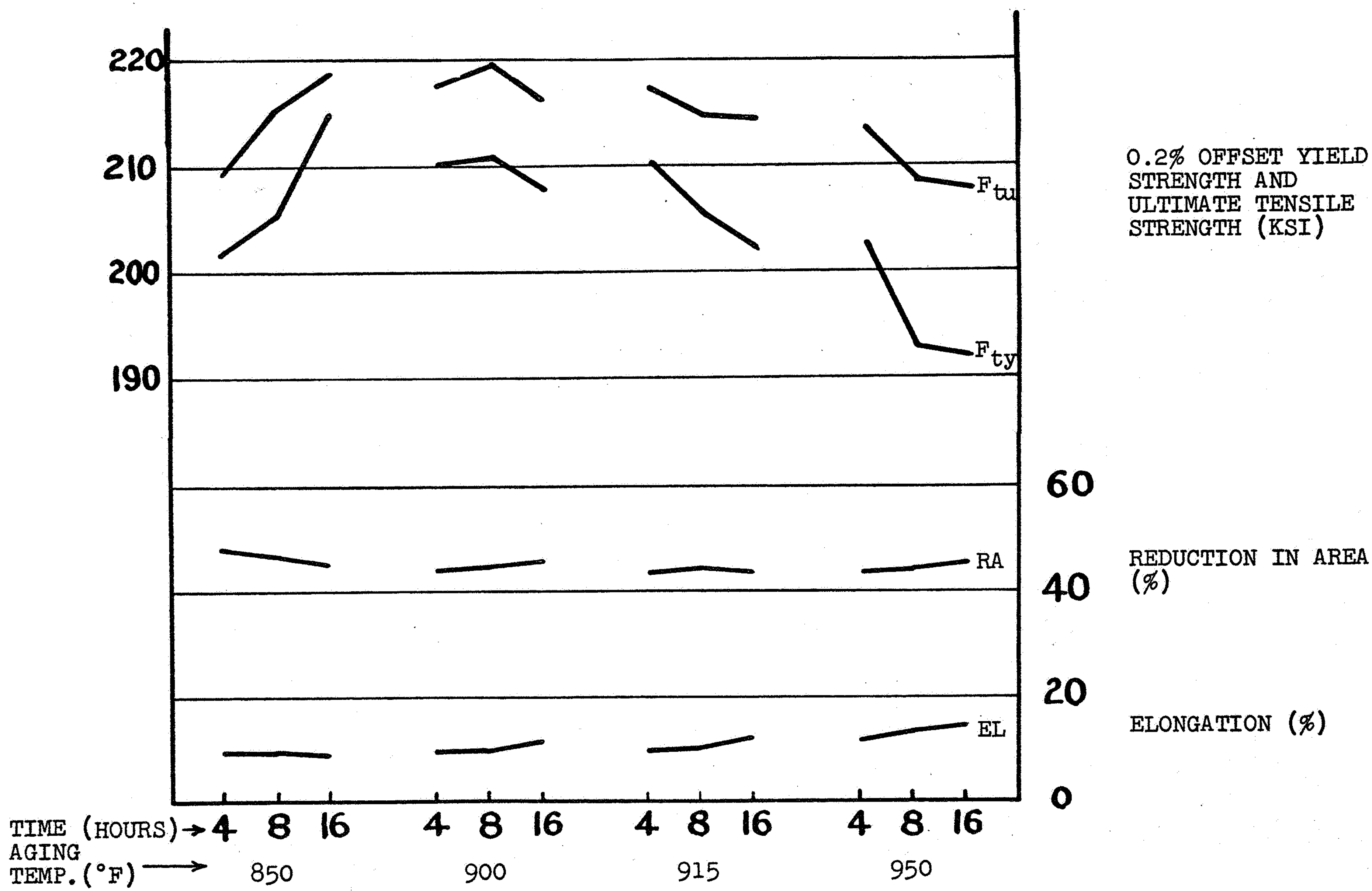



FIGURE 21

ROOM-TEMPERATURE MECHANICAL PROPERTIES AFTER DIRECT AGING

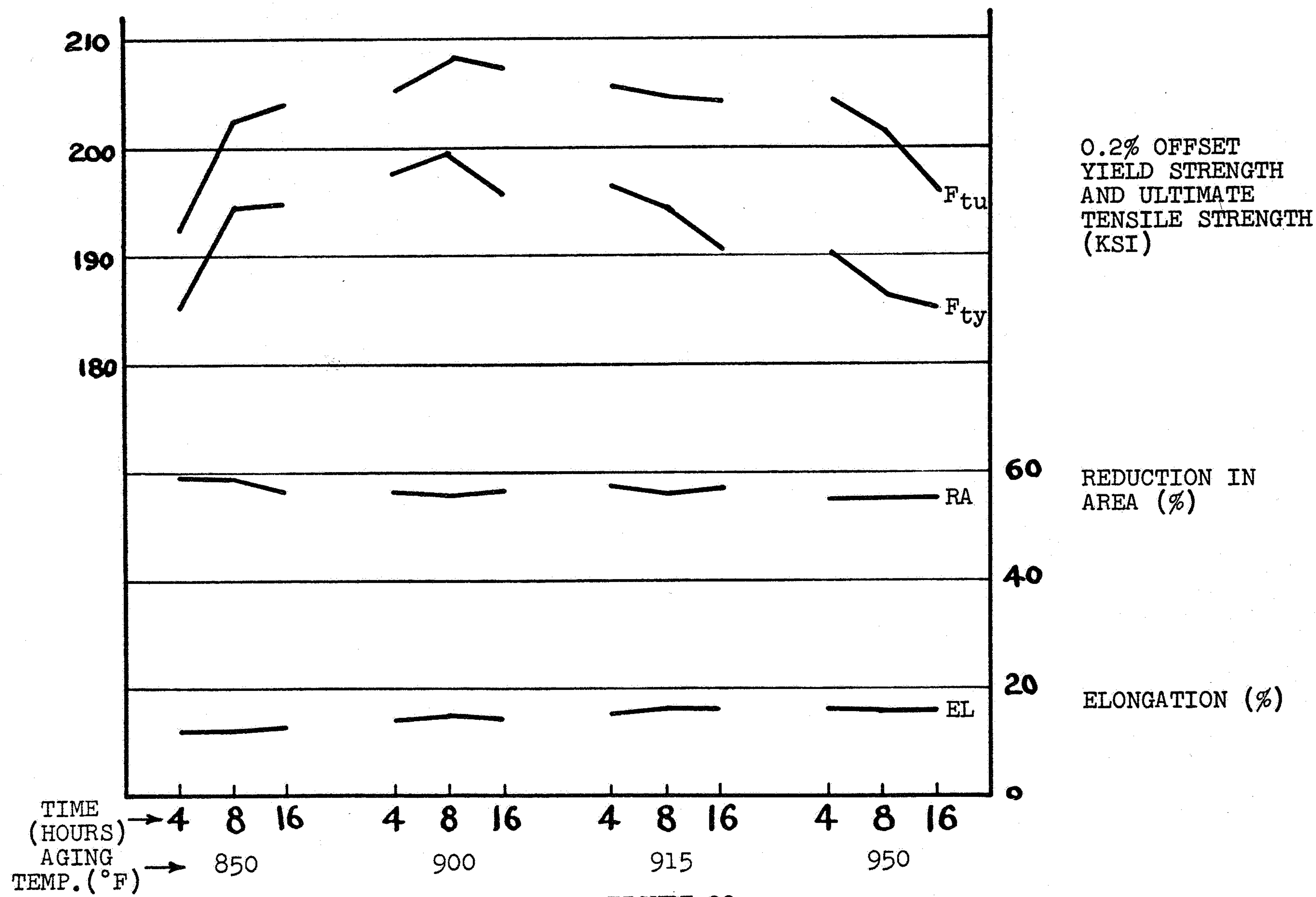



FIGURE 22

ROOM-TEMPERATURE MECHANICAL PROPERTIES AFTER 1500°F RE-SOLUTION ANNEAL AND AGE

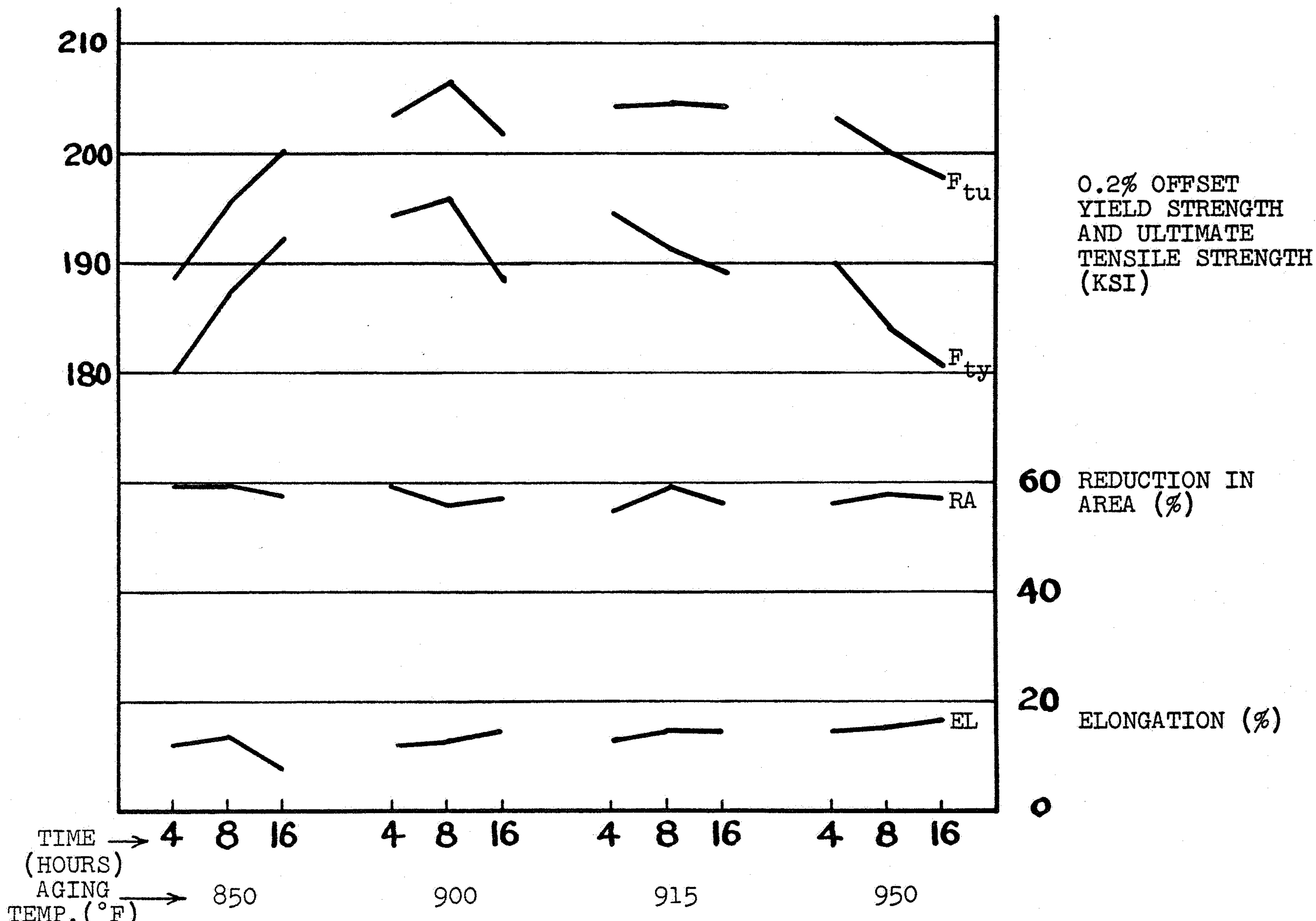



FIGURE 23

ROOM-TEMPERATURE MECHANICAL PROPERTIES AFTER 1550°F RE-SOLUTION ANNEAL AND AGE

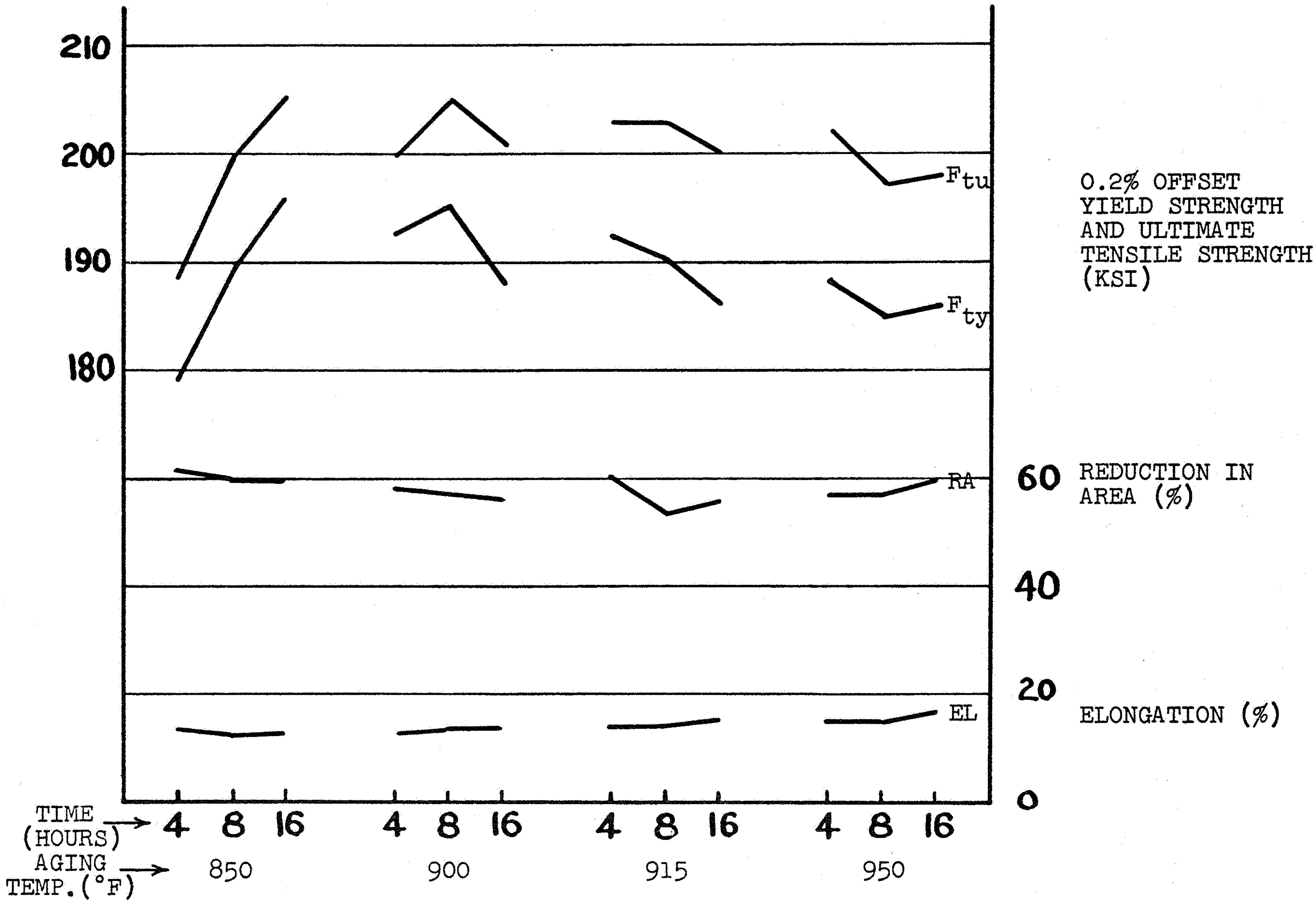



FIGURE 24

ROOM-TEMPERATURE MECHANICAL PROPERTIES AFTER 1600°F RE-SOLUTION ANNEAL AND AGE

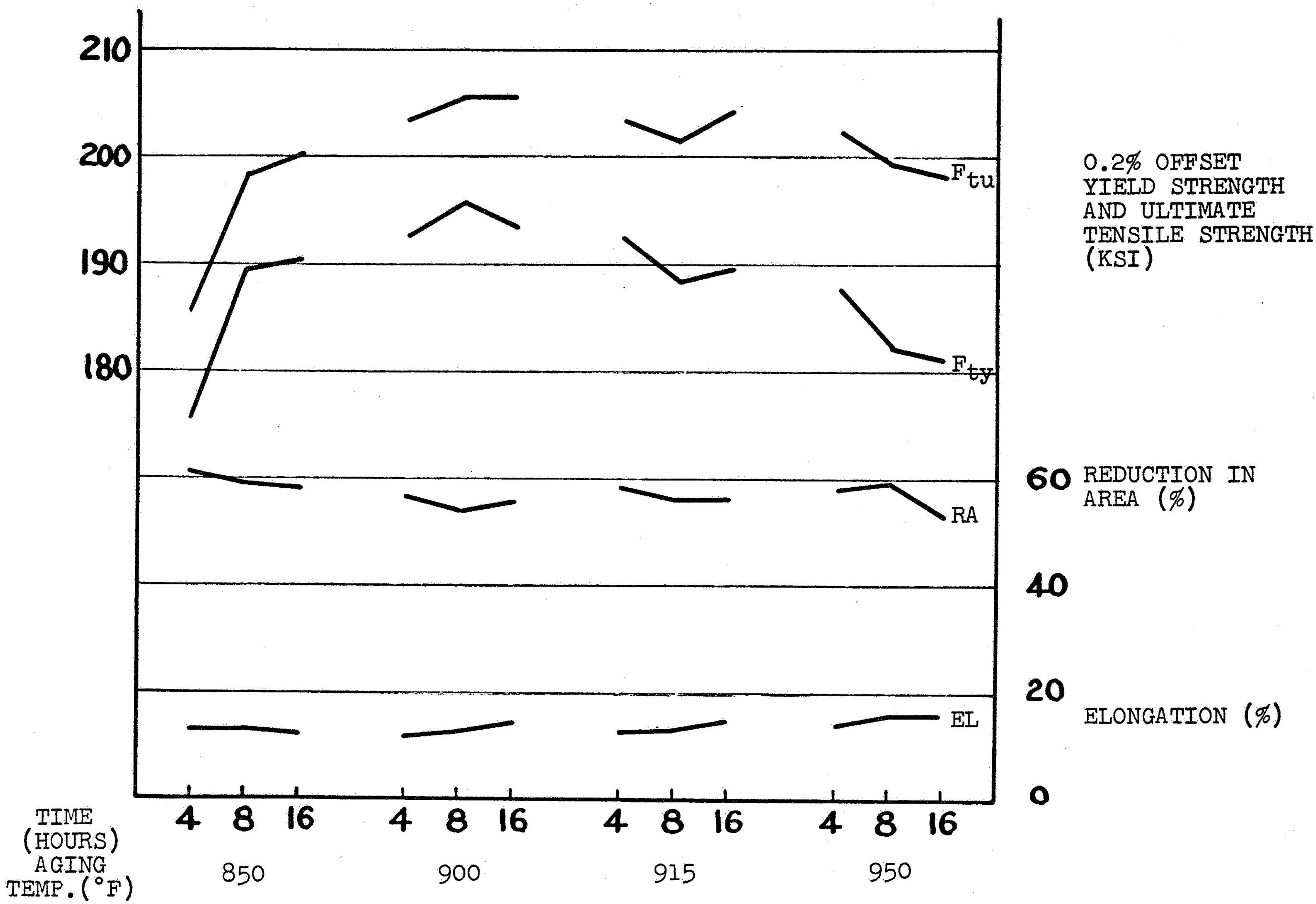



FIGURE 25

ROOM-TEMPERATURE MECHANICAL PROPERTIES AFTER 1650°F RE-SOLUTION ANNEAL AND AGE

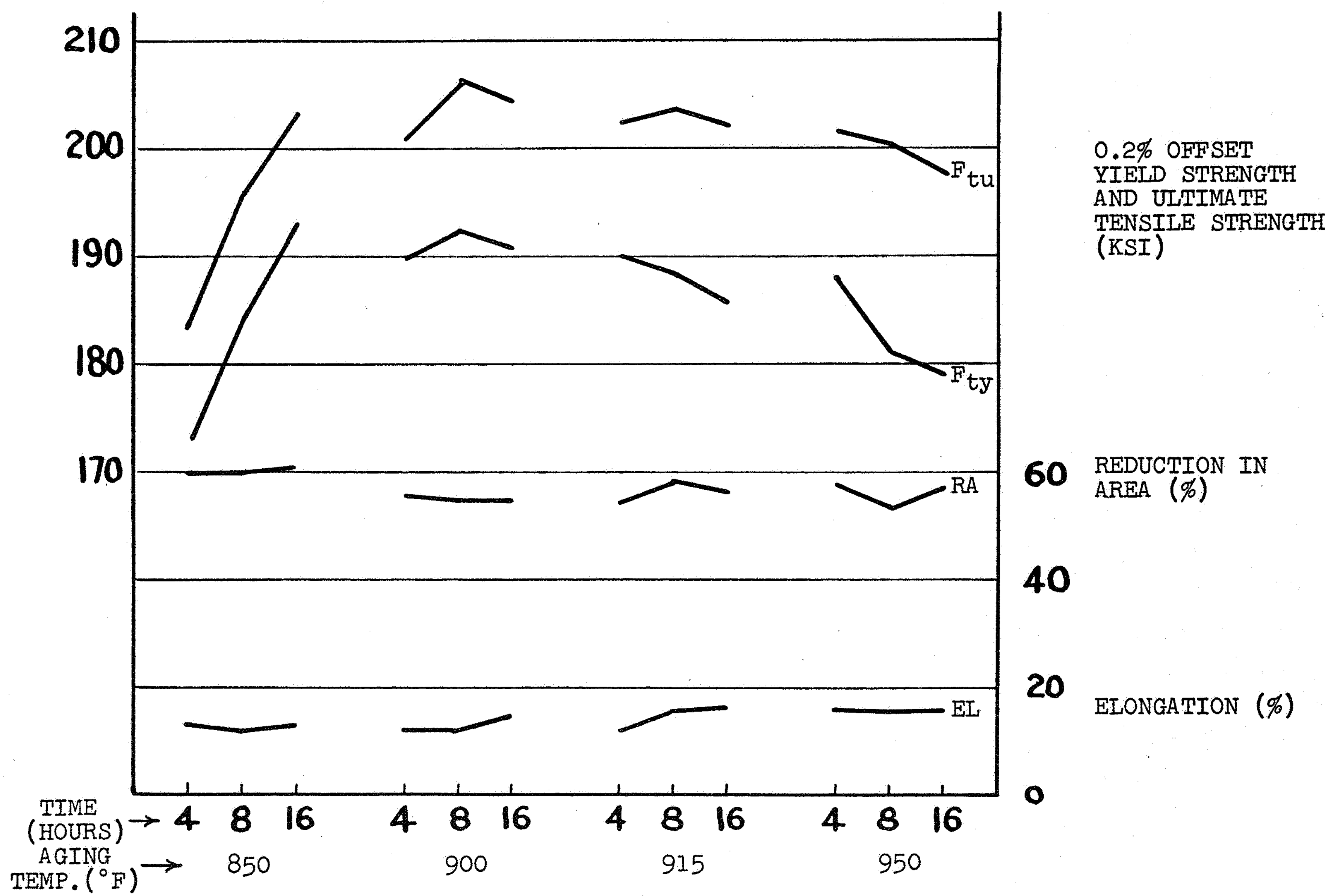



FIGURE 26

ROOM-TEMPERATURE MECHANICAL PROPERTIES AFTER 1700°F RE-SOLUTION ANNEAL AND AGE

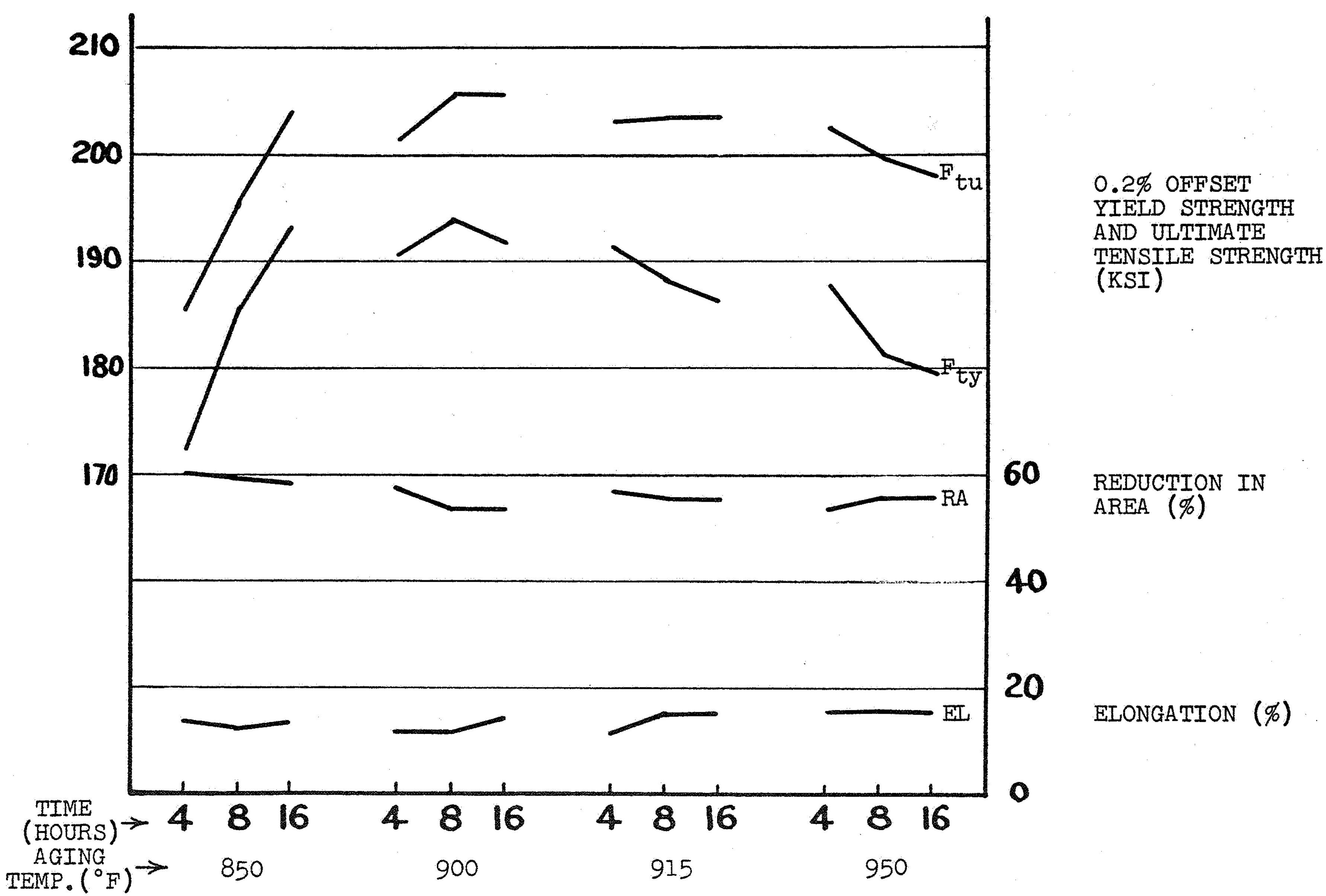



FIGURE 27

ROOM-TEMPERATURE MECHANICAL PROPERTIES AFTER 1750°F RE-SOLUTION ANNEAL AND AGE

TABLE XIV

COMPARISON OF ROOM-TEMPERATURE TENSILE TEST RESULTS FROM 156-INCH AND 260-INCH DIAMETER ROLL-FORMED CYLINDERS

| IDENTITY | CIRCUMFERENTIAL DIRECTION | | | | AXIAL DIRECTION | | | |
|---|---|---|---|---|---|---|---|---|
| | ULTIMATE STRENGTH (KSI) | 0.2% OFFSET YIELD STRENGTH (KSI) | ELONGATION (PER CENT) | REDUCTION IN AREA (PER CENT) | ULTIMATE STRENGTH (KSI) | 0.2% OFFSET YIELD STRENGTH (KSI) | ELONGATION (PER CENT) | REDUCTION IN AREA (PER CENT) |
| 260-INCH PANEL X | 211.4 | 206.3 | 11 | 52 | 219.7 | 210.7 | 9 | 40 |
| | 210.7 | 204.7 | 11 | 48 | 220.6 | 211.5 | 10 | 43 |
| 260-INCH PANEL R | 211.7 | 205.7 | 10 | 46 | 220.7 | 210.7 | 10 | 43 |
| | 212.2 | 206.6 | 11 | 45 | 220.7 | 211.7 | 10 | 44 |
| 260-INCH PANEL C | 212.5 | 208.1 | 9 | 44 | 219.7 | 214.5 | 9 | 45 |
| | 212.7 | 206.2 | 10 | 46 | 220.6 | 211.5 | 10 | 44 |
| 156-INCH CYLINDER | 246 | 241 | 6 | 33 | 235 | 226 | 11 | 46 |

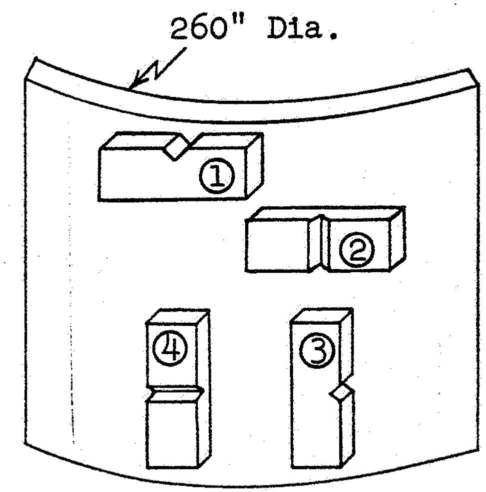
Note: The 260-inch data is from modified "200" grade 18 per cent nickel maraging steel reduced 51 per cent by roll-forming and aged at 900°F for eight hours. The 156-inch data was extrapolated at 50 per cent level from "200" grade 18 per cent nickel maraging steel roll-formed from 59 to 92 per cent and aged at 900°F for three hours.

TABLE XV

ROOM-TEMPERATURE PRE-CRACKED CHARPY V-NOTCH IMPACT TEST RESULTS OF ROLL-FORMED CYLINDER TEST PANELS AGED AT 900°F FOR EIGHT HOURS

| TEST PANEL IDENTITY * | P.C.I. W/A (INCH-POUNDS/INCH$^2$) 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| X | 1191 | 1149 | 1442 | 2669 |
| | 1218 | 2051 | 1398 | 2575 |
| R | 1218 | 2034 | 1290 | 1868 |
| | 1377 | 1935 | 1393 | 2433 |
| C | 1836 | 1984 | 1282 | 2170 |
| | 1253 | 2205 | 1360 | 2119 |

TEST SPECIMEN ORIENTATION




* See Figure 18.

TABLE XVI

SLOW-NOTCH BEND TEST RESULTS FROM AS-ROLL-FORMED AND AGED (900°F FOR EIGHT HOURS) 260-INCH-DIAMETER CYLINDER

SLOW - NOTCH - BEND TEST REPORT

NASA 18% Ni VAR 200 GRADE MARAGING STEEL ROLLED RING FORGINGS

| Specimen No. | Test Panel Identity * | B Bar Width (in.) | W Bar Depth (in.) | $a_o$ Crack Depth (1) (in.) | P Proportional Load (2) (lb.) | e Proportional Deflection (in.) | $K_{Ic}$ psi $\sqrt{in.}$ |
|---|---|---|---|---|---|---|---|
| 413 | C | .592 | .592 | .1396 | 9,960 | .0247 (3) | 150,445 (4) |
| 415 | C | " | " | .1563 | - | - (3) | - |
| 423 | R | " | " | .1162 | 8,160 | .0257 | 110,370 |
| 425 | R | " | " | .1244 | 8,100 | .0250 | 113,947 |
| 433 | X | " | " | .1437 | 7,560 | .0258 | 116,386 |
| 435 | X | " | " | .1638 | 7,080 | .0245 | 119,594 |

TEST CONDITIONS:

A. Material as received (roll-formed and aged eight hours at 900°F)
B. Temperature 70°F - Relative Humidity - 65%
C. Three Point Bending - 3" Span

NOTES:

1. Crack depth = Notch & Fatigue Crack; Average of five estimates each.
2. Proportional Load = Load at deviation from linearity
3. Mechanical difficulties with recording device
4. $K_{Ic}$ calculated of little value

* See Figure 18

SUN SHIPBUILDING & DRY DOCK COMPANY

Aero/Hydro Space Division

## VI. CONCLUSIONS

1. A 260-inch-diameter maraging steel cylinder was produced by forging and seamless ring-rolling a starting blank and then roll-forming the blank at ambient temperature to its final 0.610-inch wall thickness and 79-inch face height.

2. Mechanical property determinations showed the final product was capable of being aged in the cold-worked condition at 900°F for eight hours with resultant yield strength of 205 to 214 Ksi.

3. The final length (or height) of a 260-inch-diameter roll-formed cylinder is limited only by the available input weight of the raw material.

4. All dimensions measured were compared to a Ladish Co. standard devised by building up a series of traditionally certified smaller standards. Repetitive dimensional comparisons made throughout the manufacturing process to the devised standard are within ±0.001 inch.

5. The roll-forming process was demonstrated to be a successful manufacturing technique for increasing the length (or height) capability of large-diameter, hot-forged, seamless rolled ring forgings. Under this program, the length was doubled.

6. Small, but acceptable, ultrasonic indications were detected in the blank prior to roll-forming. During the first roll-forming pass, a mis-match of the rollers occurred, which introduced abnormal stresses into the cylinder. The areas of inclusions, in some cases, were transformed into internal ruptures as a result of the introduced stresses.

7. No conclusion about the possible tolerance level and response of inclusions to roll-forming under design conditions can be drawn because the roller mis-match and abnormal stresses resulted in the roll-forming operation acting as a super-critical metal inspection device.

8. The maraging steel material can readily be roll-formed at room temperature. This was demonstrated by the three successful roll-forming passes (subsequent to the mis-match pass) which were completed under design conditions without thermal or mechanical stress relief of the material, and without the material exhibiting any external failures.

9. Ultrasonic inspection proved to be more reliable than radiographic inspection. The ultrasonic test technique was modified to include longitudinal-wave inspection from the outer diameter surface with a 5 MHZ twin crystal. This inspection disclosed defects which escaped detection by the conventional shear-wave technique.

## VII. RECOMMENDATION

A second 260-inch-diameter roll-formed cylinder should be produced in order to fully demonstrate this manufacturing concept in advance of fabricating future 260-inch-diameter motor cases by alternate methods. Production of the second cylinder should shift emphasis from the manufacturing and processing to the development of the standards and procedures required for ultrasonic and/or radiographic inspection.

# APPENDIX I

## DIMENSIONAL INSPECTION DISCUSSION AND REPORTS

## APPENDIX I

### A. DISCUSSION OF DIMENSIONAL ACCURACY

This type of project presents a special problem in measuring technique. It is special because the tolerances required for parts of this size are almost one order of magnitude tighter than the extremes of finish close-machining work. Furthermore, tightening the tolerances by one order of magnitude, in turn, imposes restrictions of measuring variations that introduce some unknowns.

To illustrate the problem, a portion of the Ladish Co. publication, "Value Analysis Study of Tolerances" is reproduced in Figure IA. This chart shows that tolerances have a characteristic curve when the tolerances required are expressed as a percentage of the dimension to be measured. By starting at the left portion of the X-axis, where the given dimension is small, and referring to the Y-axis, where the tolerance is expressed as a percentage of a given dimension, it can readily be seen that, as the dimensions increase, the effect of the unit of measurement decreases to a point where its significance is nil compared to the tolerance which has become a fixed percentage. Also written into the curves are the usual units of measurement and the larger units that are required as the dimension to be measured increases. As can be seen, the surface finish must also improve if the refinement of tolerance is to increase.

The program required a weld preparation mis-match not exceeding 0.06 inch. This translates to 0.03 inch for each of two pieces being mated, which, in turn, is ±0.015 inch on a diameter of 260 inches. In this case, the ±0.015 inch tolerance, expressed as a percentage of the diameter, is ±0.0058 per cent, which cannot be plotted on the chart in Figure IA.

In addition, the traditional measuring variation that can be accepted without severe loss in tolerance for successful manufacture is 1/10 of the part tolerance. Since the part tolerance is ±0.015 inch, the measuring variation would then be 1/10 of 0.015, which, as a percentage of 260 inches, is $5.8 \times 10^{-4}$ per cent. The ability to calibrate and read instruments to these variations is not possible within the traditional framework of metrology.

The adaptations made to traditional metrology, however, are sound and practical, and, if understood, can produce the desired technical information. First, to arrive at the 260-inch diameter, parts that could be measured by conventional means were assembled and clamped to the table of a large boring mill. Using this derived calibration, there is assurance that the pieces being compared are within ±0.001 inch of each other. This method constituted the master calibration for all measurements taken by Ladish Co.

Using this approach to master calibration, the machined blank, while still on the boring mill, was then used to calibrate Pi tapes and to explore the accuracy of the tapes when used by inspection personnel. Past experience in measuring large-diameter (plus 200 inches), as-forged rings has shown that a team of two top-grade inspectors with a Pi tape will match readings and/or repeat 90 per cent of the readings to ±0.04 per cent or less. The mode of the dispersion curves for these readings is at ±0.02 per cent. Surface roughness affects the pull resistance of the tapes which introduces an appreciable amount of the variation.

For more refined measurements on machined rings, with special attention to surface cleanliness and lubricity, the inspection will improve to the point that 90 per cent of the readings will be ±0.006 per cent or less with the mode at ±0.003 per cent. Since the tolerance for this program is ±0.0058 per cent, it is concluded that measuring variables will represent about one-half of the allowable tolerance. This conclusion is tempered by the following two intangibles:

1. Previous parts inspected by this method were reported as "fitting-up" very well.
2. The natural and human interest in this program by all personnel on the project no doubt resulted in extra effort and care being exercised.

## RECOMMENDATION

Since no standards are available for diameters of this size, it is recommended that a master ring approximately 260 inches be forged and machined by Ladish Co. The ring would be calibrated by using the methods described in this report, and would then be parted into several rings of shorter face heights. The parted rings would become standards that could be distributed to locations where an agreement on fitting of parts would be required.

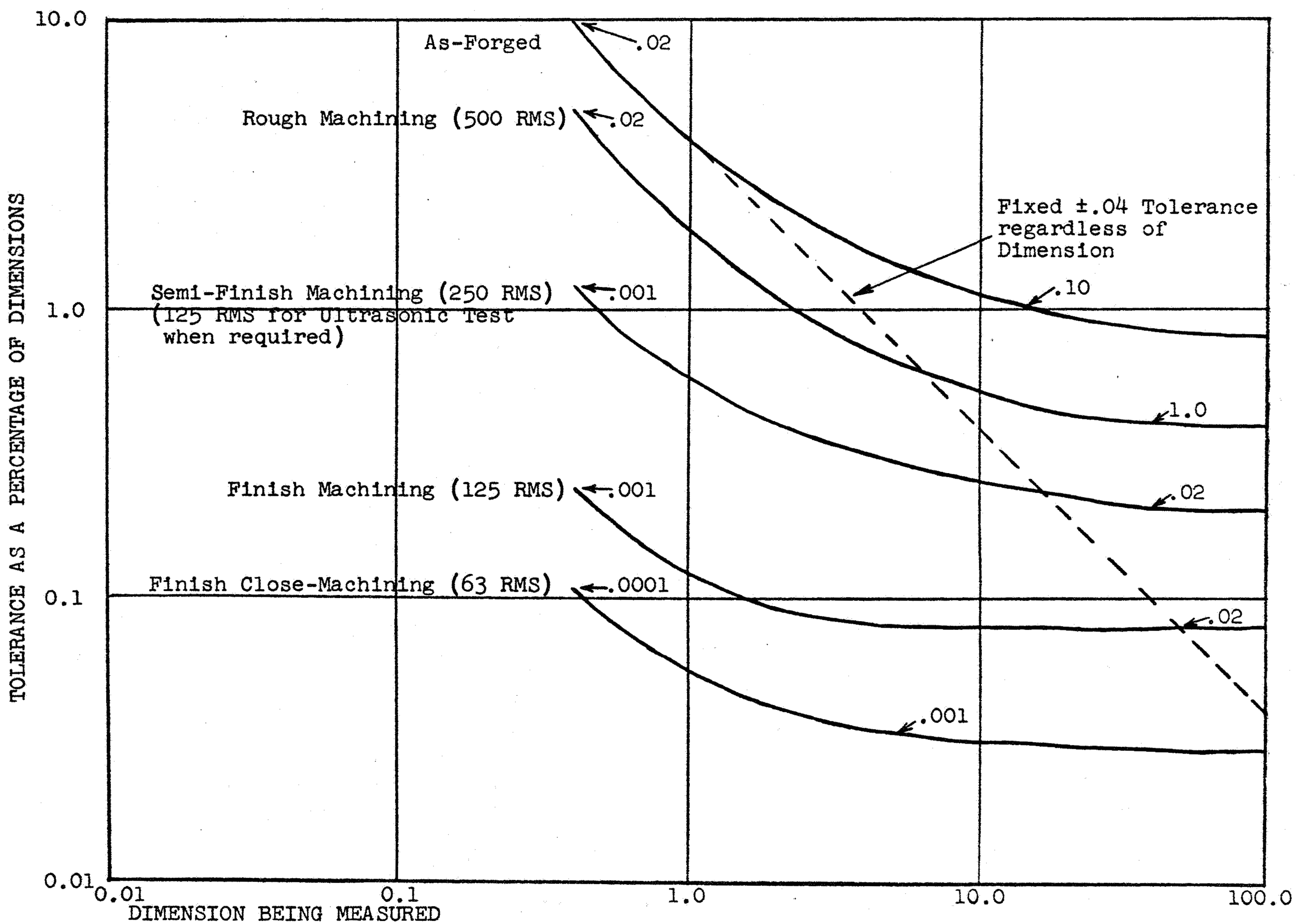
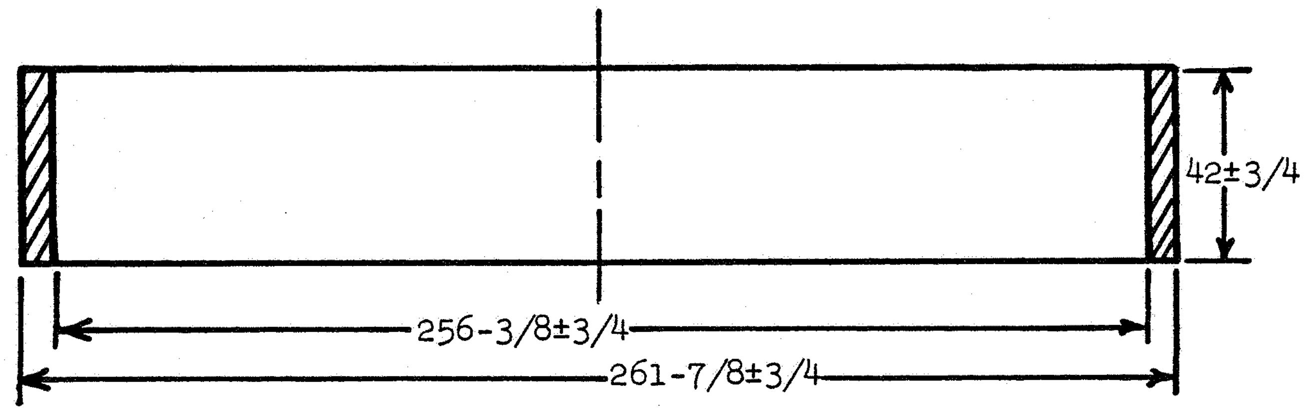



FIGURE IA
CHARACTERISTIC CURVES OF TOLERANCES (NOMINAL DIMENSIONS IN INCHES)
(FROM LADISH CO. PUBLICATION "VALUE ANALYSIS STUDY OF TOLERANCES")



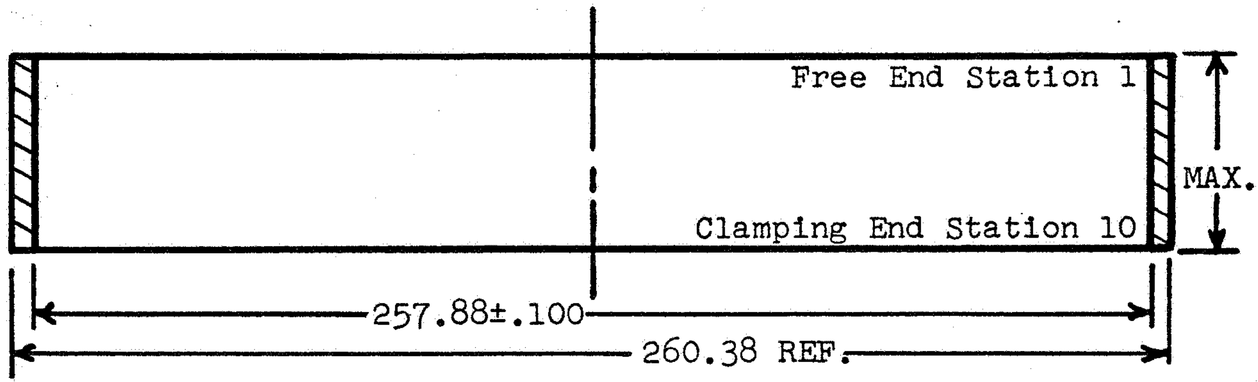

| LOCATION | OUTER DIAMETER | INNER DIAMETER | WALL THICKNESS | HEIGHT |
|---|---|---|---|---|
| MINIMUM | 261-9/16 | 256 | 2-5/8 | 43-1/2 |
| MAXIMUM | 263 | 257-5/8 | 2-3/4 | 43-3/4 |

| PI TAPE | |
|---|---|
| TOP | 262.175 |
| CENTER | 262.200 |
| BOTTOM | 262.260 |

TABLE IB

DIMENSIONS (ON AS-ANNEALED SURFACES) OF HOT-WORKED RING RECORDED AFTER HOT-SIZING AND ANNEALING

(ALL DIMENSIONS IN INCHES)




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0° | 257.891 | 257.892 | 257.893 | 257.895 | 257.896 | 257.893 | 257.891 | 257.895 | 257.892 | 257.908 | I.D. |
| 45° | 257.889 | 257.897 | 257.895 | 257.895 | 257.896 | 257.893 | 257.892 | 257.896 | 257.893 | 257.909 | |
| 90° | 257.891 | 257.893 | 257.895 | 257.896 | 257.895 | 257.894 | 257.892 | 257.895 | 257.893 | 257.908 | |
| 135° | 257.891 | 257.893 | 257.895 | 257.896 | 257.897 | 257.894 | 257.891 | 257.893 | 257.892 | 257.908 | |
| 0° | 1.260 | 1.263 | 1.263 | 1.262 | 1.261 | 1.262 | 1.261 | 1.260 | 1.259 | 1.252 | WALL |
| 45° | 1.262 | 1.261 | 1.261 | 1.262 | 1.262 | 1.262 | 1.260 | 1.260 | 1.259 | 1.251 | |
| 90° | 1.260 | 1.262 | 1.261 | 1.261 | 1.262 | 1.261 | 1.261 | 1.261 | 1.259 | 1.252 | |
| 135° | 1.260 | 1.263 | 1.261 | 1.261 | 1.261 | 1.261 | 1.261 | 1.261 | 1.259 | 1.252 | |
| 180° | 1.260 | 1.263 | 1.261 | 1.261 | 1.262 | 1.261 | 1.261 | 1.261 | 1.260 | 1.252 | |
| 225° | 1.260 | 1.260 | 1.261 | 1.261 | 1.261 | 1.261 | 1.261 | 1.260 | 1.259 | 1.252 | |
| 270° | 1.260 | 1.263 | 1.261 | 1.261 | 1.262 | 1.261 | 1.260 | 1.260 | 1.259 | 1.252 | |
| 315° | 1.260 | 1.262 | 1.261 | 1.261 | 1.261 | 1.261 | 1.261 | 1.262 | 1.260 | 1.252 | |

NOTE: TIR = .003.
HEIGHTS = 42-5/8 (MAXIMUM) AND 42-15/32 (MINIMUM)

TABLE IC-1

DIMENSIONS OF MACHINED ROLL-FORMING BLANK, RESTRAINED, USING CENTER PLUG AND BAR FOR DIAMETERS AND VIDIGAGE FOR WALL

(ALL DIMENSIONS IN INCHES)

TABLE IC-2

MEASURED DIMENSIONS OF MACHINED ROLL-FORMING BLANK, FREE STATE, USING PI TAPE FOR DIAMETERS

(Outer Diameter dimensions in inches.)

| STATION* | DIMENSION |
|---|---|
| 1 | 260.395 |
| 2 | 260.415 |
| 3 | 260.415 |
| 4 | 260.410 |
| 5 | 260.410 |
| 6 | 260.415 |
| 7 | 260.420 |
| 8 | 260.415 |
| 9 | 260.415 |
| 10 | 260.415 |

* Station 1 is at the free end of the cylinder; Station 10 is at the clamping end.

TABLE ID-1

MEASURED DIMENSIONS OF ROLL-FORMED CYLINDER RESTRAINED ON THE ROLL-FORMING MACHINE USING PI TAPE FOR DIAMETERS

(Outer Diameter dimensions in inches.)

| STATION* | DIMENSION |
|---|---|
| 1 | 261.527 |
| 2 | 261.557 |
| 3 | 261.440 |
| 4 | 261.495 |
| 5 | 261.509 |
| 6 | 261.475 |
| 7 | 261.382 |
| 8 | 261.263 |
| 9 | 261.018 |
| 10 | 260.700 |

* Station 1 is at the free end of the cylinder; Station 10 is at the clamping end.

TABLE ID-2

MEASURED DIMENSIONS OF ROLL-FORMED CYLINDER USING PI TAPE FOR DIAMETERS

(Outer Diameter dimensions in inches.)

| STATION* | DIMENSION |
|---|---|
| 1 | 261.530 |
| 2 | 261.540 |
| 3 | 261.430 |
| 4 | 261.482 |
| 5 | 261.495 |
| 6 | 261.450 |
| 7 | 261.350 |
| 8 | 261.225 |
| 9 | 260.975 |
| 10 | 260.660 |

* Station 1 is at the free end of the cylinder; Station 10 is at the clamping end.

## APPENDIX II

| ISSUED: 12-22-64<br>REVISED: | METALLURGICAL DEPARTMENT<br>**QUALITY ASSURANCE PROCEDURE**<br>LADISH CO., CUDAHY, WIS. | 9 Q 108 |
|---|---|---|

TITLE: LIQUID DYE PENETRANT INSPECTION PROCEDURE FOR NON-NUCLEAR, NON-FERROUS WROUGHT PRODUCTS.

1. SCOPE:

1.1 This procedure establishes the methods and techniques for liquid dye penetrant inspection of non-ferrous wrought products for the detection of surface discontinuities detrimental to the function of the part.

1.2 Quality assurance limits applicable shall be made part of and included in the instructions. Any modifications or changes thereof shall be in the form of amendments to the instructions.

1.3 This procedure covers only the use of the solvent removal process and materials.

2. APPLICABLE DOCUMENTS:

2.1 Military Standard - MIL-STD-410A.

2.2 Military Specification - MIL-I-6866B(ASG), Type II, Method C.

2.3 Customer specifications as shown in the instructions.

3. GENERAL REQUIREMENTS:

3.1 Inspection personnel shall be individually qualified in accordance with requirements of MIL-STD-410A.

3.2 Equipment shall be constructed and arranged to conform with safety regulations. Adequate lighting and ventilation shall be provided.

3.3 Materials used shall conform to the requirements of MIL-I-25135.

3.4 Liquid materials used shall be kept in separately identified closed containers.

3.4.1 Materials listed in Table I shall not be intermixed with those listed in Table II when performing the penetrant inspection process. Unless instructed otherwise, only Table I materials shall be used.

4. SUPPLIES:

4.1 Materials used shall be the non-water washable solvent removable type as listed in Tables I and II.

CONCURRED: H. P. Johnson

WRITTEN BY R. Schultz    APPROVED D. P. Bloom    

4.1 (Continued)

TABLE I

MAGNAFLUX CORP. TYPE "S" (FLAMMABLE)

| | | |
|---|---|---|
| Dye Penetrant | SKL-S | Lad. No. 3-855004 |
| Cleaner | SKC-S | Lad. No. 3-855005 |
| Developer (non-aqueous) | SKD-S | Lad. No. 3-855003 |

TABLE II

MAGNAFLUX CORP. TYPE "NF" (NON-FLAMMABLE)

| | | |
|---|---|---|
| Dye Penetrant | SKL-HF | Lad. No. 3-855022 |
| Cleaner | SKC-NF | Lad. No. 3-855023 |
| Developer (non-aqueous) | SKD-NF | Lad. No. 3-855024 |

4.2 Materials other than those listed in Tables I and II may be used provided they meet the requirements of MIL-I-25135, Group I.

5. SURFACE REQUIREMENTS:

5.1 Surfaces of parts to be inspected shall be free from scale, sharp burrs, paint, grease, oil, or other extraneous matter that would interfere with proper execution of the test.

6. PRE-CLEANING:

6.1 Prior to application of penetrants, surfaces of materials or specific areas shall be cleaned free of dirt, grease, lint, paint, machine coolants and coatings, vapor degreasing, commercial solvents, chemical etchants or abrasive-cleaning methods are permitted.

Use of chemical etchants shall be followed by thorough water rinse and drying. Abrasive blasting may be used only if the surface metal is not peened during the process or if surface defects are not sealed or contaminated with abrasive material.

7. PENETRANT APPLICATION:

7.1 Penetrant shall be applied by dipping, spraying, brushing or any other method which assures coverage of the area or material to be inspected.

7.2 The penetration time shall be 15-20 minutes min. and max., during which period the surface shall be kept thoroughly wetted.

7.3 Drying of the penetrant during the penetration time shall require recleaning and repeating the test.

7.4 Temperature of the penetrant or the part, prior to application of the penetrant, shall not be less than 50°F. or greater than 100°F.

8. PENETRANT REMOVAL:

8.1 Excess penetrant shall be removed by wiping the surface with dry cloths or paper towels.

8.2 The remaining penetrant shall be removed with lint-free cloths or paper towels moistened with the specified cleaner. Flushing the surface with cleaner is prohibited.

8.3 Drying after removal of excess penetrant shall be through normal evaporation, or by blotting with absorbant paper or lint-free cloths.

8.4 Time required for removal of excess penetrant shall be a maximum of 20 minutes or less.

9. DEVELOPER:

9.1 The developer shall be applied no later than 20 minutes after the surfaces have been cleaned of excess penetrant.

9.2 Prior to application the developer shall be thoroughly agitated.

9.3 The developer shall be uniformly applied by spraying the test surface with a thin coating. Care shall be taken to avoid heavy deposits of developer in corners, fillets, etc.

10. INSPECTION:

10.1 Inspection for indications per applicable standards shall be made after a 7 minute minimum or 30 minute maximum developing period. A preliminary inspection may be performed immediately after the developer has dried in order to observe the development of major defects which may become obscured by excessive bleed out.

10.2 Indications will appear as red lines or discolorations on the developer coating as the penetrant is drawn from a defect.

11. FINAL CLEANING:

11.1 On completion of inspection, or prior to release, the part shall be cleaned to remove all traces of residual penetrant or developer; approved cleaners are listed in Tables I and II.

12. ACCEPTANCE STANDARDS:

12.1 Material containing indications representing cracks, laps, porosity, seams, or welding defects, etc. shall be subject to rejection.

12.2 Material containing discontinuities as described in 12.1 may be salvageable by careful conditioning. Conditioned material shall be acceptable provided the conditioned area or defect does not extend into the final part profile.

12.2.1 Depressions, resulting from removal of defects, whose size infringe on print tolerances shall be submitted for possible weld repair, subject to quality review approvals.

12.3 Indications caused by surface irregularities such as nicks, scuffs, scratches, pits, grinding marks, machining marks, or similar imperfections visually identified as such, shall be considered acceptable.

12.3.1 When indications, not identifiable per 12.3 and believed to be irrelevant are present, 10% of each type indication may be explored, with suitable probing tools, by removing the condition believed to be causing the indications and re-inspecting the conditioned area. The absence of indications on re-inspection shall be considered proof that similar indications are not relevant to actual defects. Indications which re-appear on re-inspection shall be interpreted as legitimate defects.

13. MARKING:

13.1 Parts that have satisfactorily met the penetrant inspection requirements, as stated in the instructions, shall be marked with the symbol "P" by impression stamping, etching, electro-penciling or rubber stamping, as applicable per specifications on the part adjacent to the part number.

# LIQUID PENETRANT INSPECTION - VERIFICATION FORM

CUSTOMER NASA PART NO. NZ-001

PART DESCRIPTION Machined Blank PURCHASE ORDER NO. NAS 3-7966

MANUF. RELEASE NO. 03-119-04 SERIAL NO/S. INSPECTED AA - #1-5

SPECIFICATION (METHOD) NO. 9Q-108 ACCEPTANCE STANDARDS PER 9Q-108

***PROCESSES (Check)***

| PENETRANTS | PROCESS USED | DEVELOPERS: WET | DRY | SPRAY |
|---|---|---|---|---|
| FLUORESCENT (WATER WASHABLE) | | | | |
| FLUORESCENT (POST EMULSIFICATION) | | | | |
| COLOR-CONTRAST (WATER WASHABLE) | X | | | X |
| COLOR-CONTRAST (SOLVENT REMOVABLE | | | | |

OTHER - (EXPLAIN):

AREA INSPECTED 360° Outer and Inner Diameters except for two inches from bottom face and two inches from top face not liquid penetrant inspected.

REMARKS:

**VERIFICATION**

THE ABOVE PART/S HAS/HAVE BEEN LIQUID PENETRANT INSPECTED AND ACCEPTED IN ACCORDANCE WITH THE APPLICABLE SPECIFICATIONS.

INSPECTOR ID-10275 CERT. STAMP NO. P36 DATE 10/24/67

THE ABOVE INSPECTION PERSONNEL ARE CURRENTLY CERTIFIED IN ACCORDANCE WITH THE APPLICABLE SPECIFICATIONS. RECORDS OF THESE CERTIFICATIONS ARE ON FILE IN OUR QUALITY CONTROL DIVISION.

LADISH CO.

LCO 3092 R2 FC

# LIQUID PENETRANT INSPECTION - VERIFICATION FORM

CUSTOMER: NASA  PART NO.: NZ-001

PART DESCRIPTION: Roll-Formed Cylinder  PURCHASE ORDER NO.: NAS 3-7966

MANUF. RELEASE NO.: 03-119-04  SERIAL NO/S. INSPECTED: AA -#1-5

SPECIFICATION (METHOD) NO.: 9Q-108  ACCEPTANCE STANDARDS PER: 9Q-108

***PROCESSES (Check)***

| PENETRANTS | PROCESS USED | DEVELOPERS: WET | DEVELOPERS: DRY | DEVELOPERS: SPRAY |
|---|---|---|---|---|
| FLUORESCENT (WATER WASHABLE) | | | | |
| FLUORESCENT (POST EMULSIFICATION) | | | | |
| COLOR-CONTRAST (WATER WASHABLE) | | | | |
| COLOR-CONTRAST (SOLVENT REMOVABLE) | X | | | X |

OTHER - (EXPLAIN):

AREA INSPECTED: Outer and Inner Diameters of four marked areas (areas with ultrasonic indications).

REMARKS: No indications encountered.

**VERIFICATION**

THE ABOVE PART/S HAS/HAVE BEEN LIQUID PENETRANT INSPECTED AND ACCEPTED IN ACCORDANCE WITH THE APPLICABLE SPECIFICATIONS.

INSPECTOR: ID-1385  CERT. STAMP NO.: L13  DATE: 11/7/67

THE ABOVE INSPECTION PERSONNEL ARE CURRENTLY CERTIFIED IN ACCORDANCE WITH THE APPLICABLE SPECIFICATIONS. RECORDS OF THESE CERTIFICATIONS ARE ON FILE IN OUR QUALITY CONTROL DIVISION.

LADISH CO.

LCO 3092 R2 FC

# LIQUID PENETRANT INSPECTION - VERIFICATION FORM

CUSTOMER: NASA

PART NO.: NZ-001

PART DESCRIPTION: Roll-Formed Cylinder

PURCHASE ORDER NO.: NAS 3-7966

MANUF. RELEASE NO.: 03-119-04

SERIAL NO/S. INSPECTED: AA - #1-5

SPECIFICATION (METHOD) NO.: 9Q-108

ACCEPTANCE STANDARDS PER: 9Q-108

***PROCESSES (Check)***

| PENETRANTS | PROCESS USED | DEVELOPERS: WET | DEVELOPERS: DRY | DEVELOPERS: SPRAY |
|---|---|---|---|---|
| FLUORESCENT (WATER WASHABLE) | | | | |
| FLUORESCENT (POST EMULSIFICATION) | | | | |
| COLOR-CONTRAST (WATER WASHABLE) | X | | | X |
| COLOR-CONTRAST (SOLVENT REMOVABLE | | | | |

OTHER – (EXPLAIN):

AREA INSPECTED: Outer and Inner Diameters 100% except two inches from top face and two inches from bottom face.

REMARKS: No indications encountered.

**VERIFICATION**

THE ABOVE PART/S HAS/HAVE BEEN LIQUID PENETRANT INSPECTED AND ACCEPTED IN ACCORDANCE WITH THE APPLICABLE SPECIFICATIONS.

INSPECTOR: ID-10275 CERT. STAMP NO.: P36 DATE: 11/14/67

THE ABOVE INSPECTION PERSONNEL ARE CURRENTLY CERTIFIED IN ACCORDANCE WITH THE APPLICABLE SPECIFICATIONS. RECORDS OF THESE CERTIFICATIONS ARE ON FILE IN OUR QUALITY CONTROL DIVISION.

LADISH CO.

LCO 3092 R2 FC

# LIQUID PENETRANT INSPECTION - VERIFICATION FORM

CUSTOMER NASA PART NO. NZ-001

PART DESCRIPTION Roll-Formed Cylinder Multiple PURCHASE ORDER NO. NAS 3-7966

MANUF. RELEASE NO. 03-119-04 SERIAL NO/S. INSPECTED AA - Serial 4-5

SPECIFICATION (METHOD) NO. 9Q-108 ACCEPTANCE STANDARDS PER 9Q-108

***PROCESSES (Check)***

| PENETRANTS | PROCESS USED | DEVELOPERS: WET | DEVELOPERS: DRY | DEVELOPERS: SPRAY |
|---|---|---|---|---|
| FLUORESCENT (WATER WASHABLE) | | | | |
| FLUORESCENT (POST EMULSIFICATION) | | | | |
| COLOR-CONTRAST (WATER WASHABLE) | X | | | X |
| COLOR-CONTRAST (SOLVENT REMOVABLE | | | | |

OTHER - (EXPLAIN):

AREA INSPECTED 100%.

REMARKS: No indications encountered.

**VERIFICATION**

THE ABOVE PART/S HAS/HAVE BEEN LIQUID PENETRANT INSPECTED AND ACCEPTED IN ACCORDANCE WITH THE APPLICABLE SPECIFICATIONS.

INSPECTOR ID-10275 CERT. STAMP NO. P 36 DATE 11/27/67

THE ABOVE INSPECTION PERSONNEL ARE CURRENTLY CERTIFIED IN ACCORDANCE WITH THE APPLICABLE SPECIFICATIONS. RECORDS OF THESE CERTIFICATIONS ARE ON FILE IN OUR QUALITY CONTROL DIVISION.

LADISH CO.

LCO 3092 R2 FC

## APPENDIX III

ULTRASONIC AND RADIOGRAPHIC INSPECTION PROCEDURES AND REPORTS — PAGE

TITLE: ULTRASONIC INSPECTION PROCEDURE FOR MISSILE PARTS PRODUCED FROM MARAGING STEEL

1. SCOPE:

1.1 This procedure establishes the methods and techniques utilized in the inspection of rolled rings or forgings for missile applications produced from maraging steels.

2. REFERENCE DOCUMENTS:

2.1 AGC-32115 forms a part of this procedure to the extent referenced herein.

3. REQUIREMENTS:

3.1 Equipment - Immersion Inspection.

3.1.1 Curtiss-Wright Immerscope 424A, 424D, or equivalent.

3.1.2 Immersion Type Crystals - 5 mc, 10 mc and 15 mc frequencies, Lithium Sulfate, Barium Titanate or "Z" types permissible. Crystal size 3/8", 3/4" or 1" diameters.

3.1.3 Tank equipped with rotating device and positioner, containing water with a suitable wetting agent and rust inhibitor as an immersion medium.

3.1.4 Rotating device equipped with "water coupled" squirter type crystal positioner and holder. (Immersion type inspection.)

3.2 Equipment - Contact Inspection.

3.2.1 Sperry Reflectoscope, UR or UM.

3.2.2 Contact Type Crystals; 2.25 mc, 5 mc and 10 mc frequencies, Quartz, Barium Titanate or "Z" types permissible. Crystal size 3/4" or 1" diameters.

3.2.3 Medium weight oil as a contact couplant.

3.2.4 Surface finish shall be 250 RMS or finer.

3.3 Inspection Methods.

3.3.1 Forgings and rolled rings will be inspected by the immersion method when allowable by tank capacity. Large items, beyond tank capacity, will be inspected by the "water coupled" squirter method as soon as rotating device and equipment is available; in the interim the contact method will be used.

WRITTEN BY R. P. Mieczar APPROVED [signature]

3.4 Calibration.

3.4.1 Instrument calibration shall be accomplished by use of reference standards of similar material. Reference standards will be at least 2" in diameter with lengths of 1-1/4", 2", 3-1/4" 4-1/2" and 5-3/4" respectively and will contain 12/64", 8/64" 5/64" and 3/64" flat bottom holes drilled axially to a depth of 3/4" (.750"). This will provide face to hole distances of 1/2", 1-1/4", 2-1/2", 3-3/4" and 5" respectively. Instrument will be adjusted to portray a 50% indication (compared to full screen height being 100%) from the smallest test hole required in the applicable class of inspection and which most closely approximates 3/4 of the thickness of the area being inspected. When calibration on the larger test holes is required, the same level will be used. Calibration shall be confirmed every hour during inspection.

3.5 Inspection Technique.

3.5.1 Inspection will be performed at the 5 mc frequency on material 1" or over. On thicknesses less than 1", the 10 mc or 15 mc frequencies shall be used depending on the ability to detect the reference hole, ability to penetrate the material and test method used.

3.5.2 Scanning will be performed from the applicable surfaces as required. Indexing of the search probe shall be such that the scanning paths overlap by at least 10% of the crystal diameter.

3.5.3 Scanning speed shall not exceed 6" per second.

3.6 Inspection Sequence.

3.6.1 Rolled rings - longitudinal wave inspection will be performed in overlapping scans from the OD. The crystal will be positioned and indexed by a positioner, inspection will be perpendicular to the surface being scanned.

When the wall thickness is adequate and configuration permits rings will be inspected from the faces on an information basis using either the contact or immersion methods depending on the axial length.

3.6.2 Forgings - longitudinal wave inspection will be performed in overlapping scans from the outer surfaces, to the degree allowable by the configuration of the forging. The crystal will be positioned and indexed by a positioner, inspection will be perpendicular to the surface being scanned.

3.7 Evaluation of Flaws.

3.7.1 Flaw evaluation shall be by comparison of the amplitude of an indication of a discontinuity vs. the amplitude produced by the applicable test hole for the acceptance level and which most closely approximates the flaw depth.

3.7.2 Angular manipulation of the crystal shall be used to obtain the maximum response from individual discontinuities when using the immersion method.

4. QUALITY ASSURANCE:

4.1 The quality level criteria shall be in accordance with that specified in the contract or purchase order and be classified as follows:

4.1.2 Class I -

4.1.2.1 Pieces showing a single indication greater than the response from a 5/64" diameter flat bottom hole at the estimated discontinuity depth shall be reported.

4.1.2.2 Pieces showing indications greater than the response from a 3/64" diameter flat bottom hole at the estimated discontinuity depth, whose indicated centers are less than one inch apart, shall be reported.

4.1.2.3 Pieces showing indications greater than the response from a 3/64" diameter flat bottom hole which have a length greater than one inch shall be reported.

4.1.2.4 Concentrations of indications which cause a 50% or greater indication of the back reflection, provided loss is not caused by non-parallel or irregular surfaces, shall be reported.

4.1.3 Class II -

4.1.3.1 Pieces showing a single indication greater than the response from a 8/64" diameter flat bottom hole at the estimated discontinuity depth shall be reported.

4.1.3.2 Pieces showing indications greater than the response from a 5/64" diameter flat bottom hole at the estimated discontinuity depth, whose indicated centers are less than one inch apart, shall be reported.

4.1.3.3 Pieces showing indications greater than the response from a 5/64" diameter flat bottom hole which have a length greater than one inch shall be reported.

4.1.3.4 Concentrations of indications which cause a 50% or greater reduction of the back reflection, provided loss is not caused by non-parallel or irregular surfaces, shall be reported.

4.1.4 Class III -

4.1.4.1 Pieces showing a single indication greater than the response from a 12/64" diameter flat bottom hole at the estimated discontinuity depth shall be reported.

4.1.4.2 Pieces showing indications greater than the response from a 8/64" diameter flat bottom hole at the estimated discontinuity depth, whose indicated centers are less than one inch apart, shall be reported.

4.1.4.3 Pieces showing indications greater than the response from a 8/64" diameter flat bottom hole which have a length greater than one inch shall be reported.

4.1.4.4 Concentrations of indications which cause a 50% or greater indication of the back reflection, provided loss is not caused by non-parallel or irregular surfaces, shall be reported.

4.2 Review.

4.2.1 Pieces which contain indications in excess of that specified by the applicable class of inspection shall be considered on a review basis. Suitable reports and drawings shall be submitted for material review action, approval and/or disposition.

4.2.2 Pieces which contain indications in excess of the specified by the applicable class of inspection which are present in areas that will be removed in subsequent machining shall be reported but be considered acceptable.

5. REPORTS:

5.1 Certified test reports of the results of the ultrasonic inspection shall be provided to the customer upon completion of tests.

# LADISH CO.

**METALLURGICAL DEPT.**
**ULTRASONIC INSPECTION REPORT**

| | | |
|---|---|---|
| | | DATE 10/24/67 |
| CUSTOMER N.A.S.A. | PART NAME Machined Ring NZ-001 | P.O. NAS 3-7966 |
| MATERIAL SPEC. 2F4; 18% Ni 180 Grade Maraging | ULTRASONIC SPEC. Class II Stds. of Ladish 9Q17 | LSO / LJO 03-119-04 |

METHOD OF FORMING
[X] FORGED [ ] EXTRUDED [ ] FORMED [ ] ROLL & WELD

EQUIPMENT
[ ] REFLECTOSCOPE MODEL [X] IMMERSCOPE MODEL 424A [ ] OTHER

METHOD
[X] CONTACT [ ] IMMERSION [ ] ADAPTERS

WAVE FORM
[X] LONGITUDINAL [ ] SHEAR [ ] SURFACE

COUPLANT 011

WATER PATH DISTANCE

CRYSTAL TYPE & SIZE
Kelvin-Hughes Twin 5.0 MHZ

CRYSTAL FREQUENCY (MC)
[ ] 0.5 [ ] 1.0 [ ] 2.25 [X] 5.0 [ ] 10.0 [ ] 15.0 [ ] 25.0

SENSITIVITY
Set to produce an 80% indication vs. 3/64" and 5/64" FBHs in appropriate height reference standards.

SENSITIVITY SETTINGS

TEST PROCEDURE
Inspected in overlapping scans from O.D. surface.

INSPECTOR
Schittone, Lehman, Jamrog

## MATERIAL INSPECTED

| SERIAL | CODE | SIZE | DISPOSITION | EST RMS |
|---|---|---|---|---|
| 1-5 | AA | 260.38 OD x 257.88 ID x 42 H | Acceptable | 250 |

## COMMENTS

Good penetration noted throughout tests; several indications noted and evaluated. See attached drawings for information.

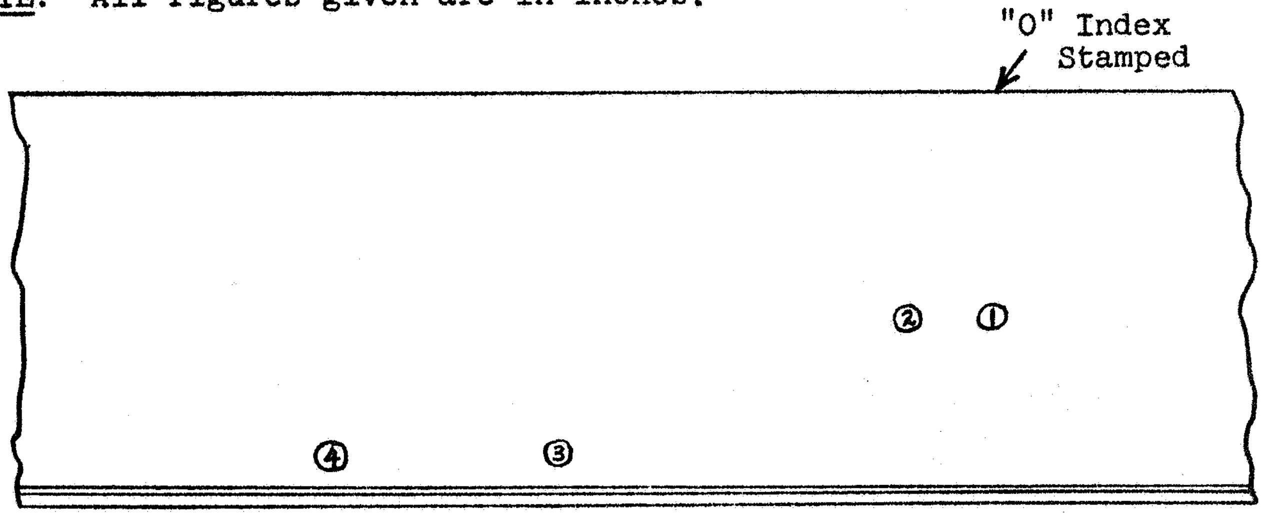
Piece is considered acceptable for further processing.

R. P. Mierzwa

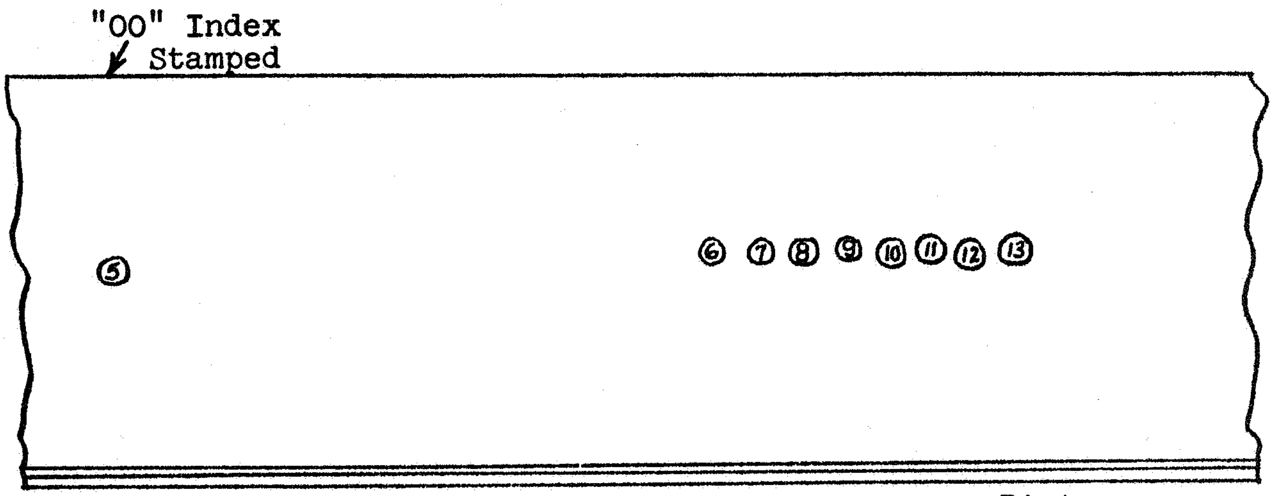
LCO 2096 R2

Machined Ring for N.A.S.A. (NZ-001) 10/24/67

NOTE: All figures given are in inches.




| Indication No. | Size | Depth from OD | Distance from Bottom | Distance Clockwise from "O" |
|---|---|---|---|---|
| 1 | +3/64; -5/64 | 1/2 | 18-1/4 | 0 |
| 2 | " " | 1/2 | 18-1/4 | 5-1/4 |
| 3 | " " | 3/4 | 5 | 76-1/4 |
| 4 | " " | 3/4 | 5 | 100 |




| Indication No. | Size | Depth from OD | Distance from Bottom | Distance Counter-Clockwise from "OO" |
|---|---|---|---|---|
| 5 | =5/64 | 1/2 | 21-5/8 | 0 |
| 6 | +3/64; -5/64 | 1 - 1-1/8 | 24-1/2 | 33-3/4 |
| 7 | " " | 1 - 1-1/8 | 24-3/8 | 36 |
| 8 | " " | 1 - 1-1/8 | 24-1/4 | 38-1/8 |
| 9 | " " | 1 - 1-1/8 | 24-1/2 | 42-3/4 |
| 10 | " " | 1 - 1-1/8 | 24-1/2 | 45 |
| 11 | " " | 1 - 1-1/8 | 25 | 46-3/4 |
| 12 | " " | 1 - 1-1/8 | 25 | 51-1/2 |
| 13 | " " | 1 - 1-1/8 | 24-5/8 | 53 |

All indications spot type; area from No. 6 to No. 13 showed some very small scattered indications in between recordable indications.

# LADISH CO.

**METALLURGICAL DEPT.**
**ULTRASONIC INSPECTION REPORT**

| | | |
|---|---|---|
| | | DATE 10/30/67 |
| CUSTOMER N.A.S.A. | PART NAME Roll-formed Cylinder NZ-001 | P.O. NAS 3-7966 |
| MATERIAL SPEC. 2F4; 18% Ni 180 Grade Maraging | ULTRASONIC SPEC. Shear Wave 3% Notch | LSO LJO 03-119-04 |

METHOD OF FORMING: ☒ FORGED and Roll-Formed ☐ EXTRUDED ☐ FORMED ☐ ROLL & WELD

EQUIPMENT: ☒ REFLECTOSCOPE MODEL 50E485 ☐ IMMERSCOPE MODEL ☐ OTHER

METHOD: ☒ CONTACT ☐ IMMERSION ☐ ADAPTERS

WAVE FORM: ☐ LONGITUDINAL ☒ SHEAR ☐ SURFACE

COUPLANT: 011

WATER PATH DISTANCE:

CRYSTAL TYPE & SIZE: 1/2" x 1" - 45° Angle Lithium-Sulfate

CRYSTAL FREQUENCY (MC): ☐ 0.5 ☐ 1.0 ☒ 2.25 ☐ 5.0 ☐ 10.0 ☐ 15.0 ☐ 25.0

SENSITIVITY
Set to produce a 3/4" sweep to peak indication from the 3% axially-oriented notch in the O.D. of piece being inspected.

SENSITIVITY SETTINGS

TEST PROCEDURE
Inspected on the basis of 12" grid lines; in the clockwise direction circumferentially and in the upward direction axially from the O.D. surface.

INSPECTOR Baldwin, Toth, Golner and Meador

**MATERIAL INSPECTED**

| SERIAL | CODE | SIZE | DISPOSITION | EST RMS |
|---|---|---|---|---|
| 1-5 | AA | 261.220 x 260.000 x 72" Min. | Rejectable | 250 |

**COMMENTS**

Calibration made on basis of 12" grid lines.

Inspection performed on same basis with use of oscillating motion of transducer to insure complete coverage of area being inspected.

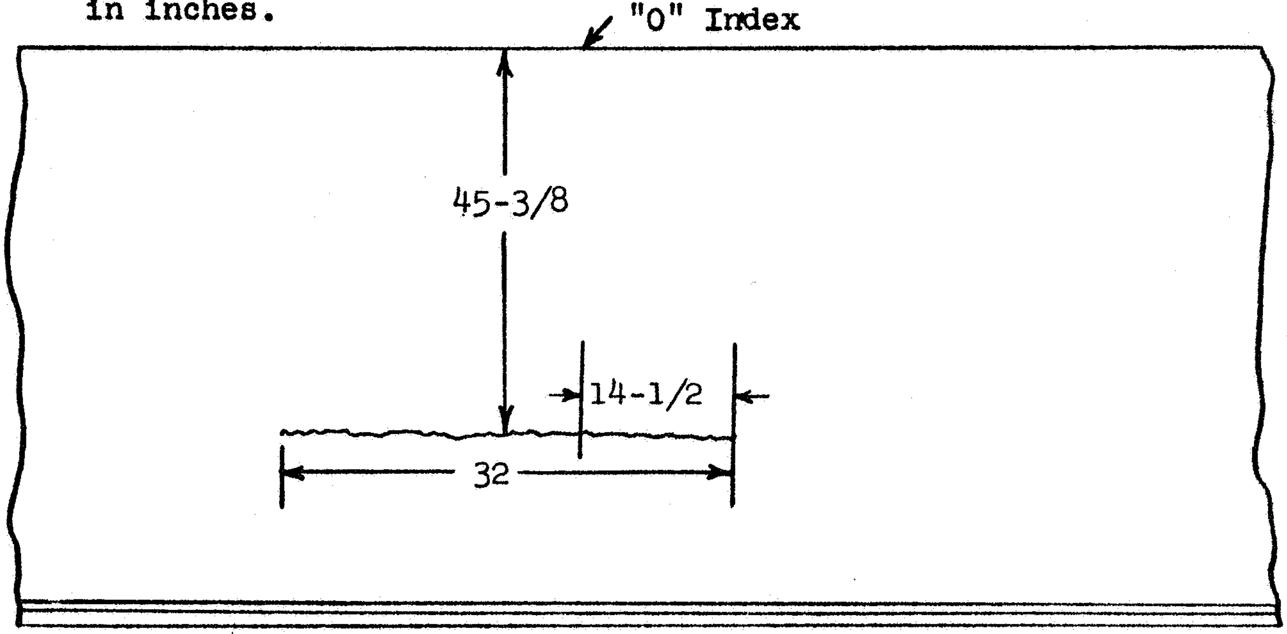
Four areas of indications noted while scanning in the axial direction; these plotted and evaluated. See attached drawings for information.

Areas of indications are cause for rejection and are to be evaluated using longitudinal wave.

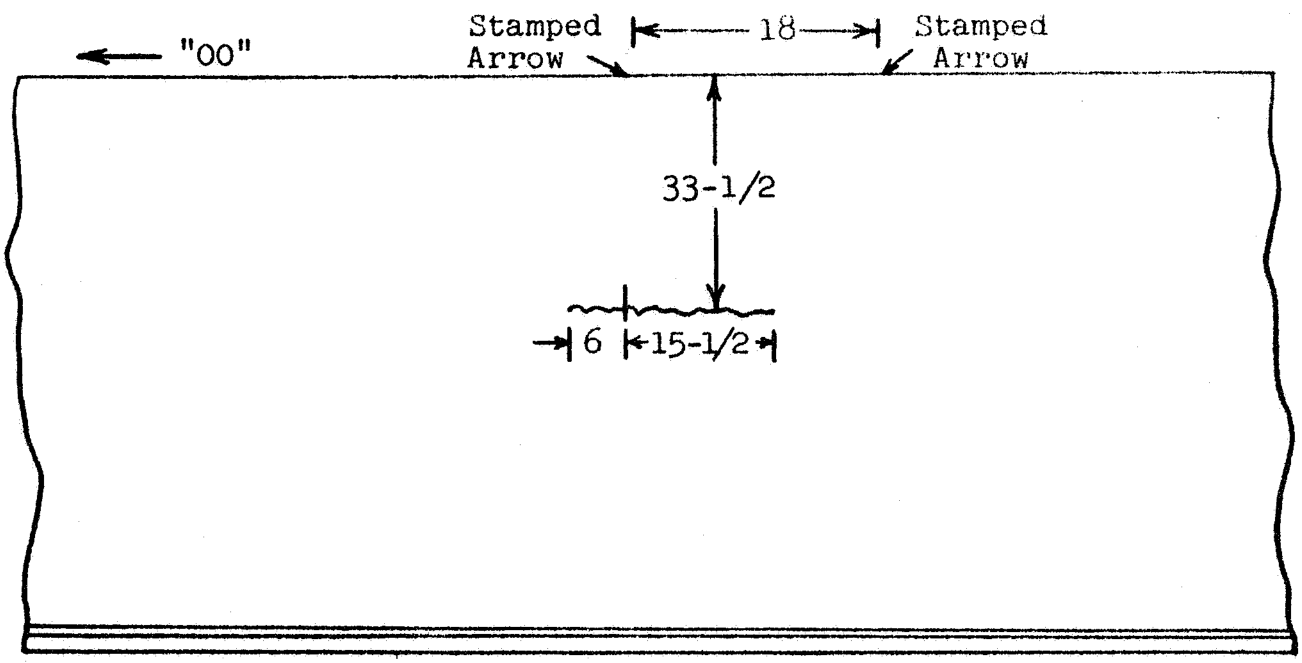
R. P. Mierzwa

LCO 2896 R2

**NOTE:** All figures are in inches.



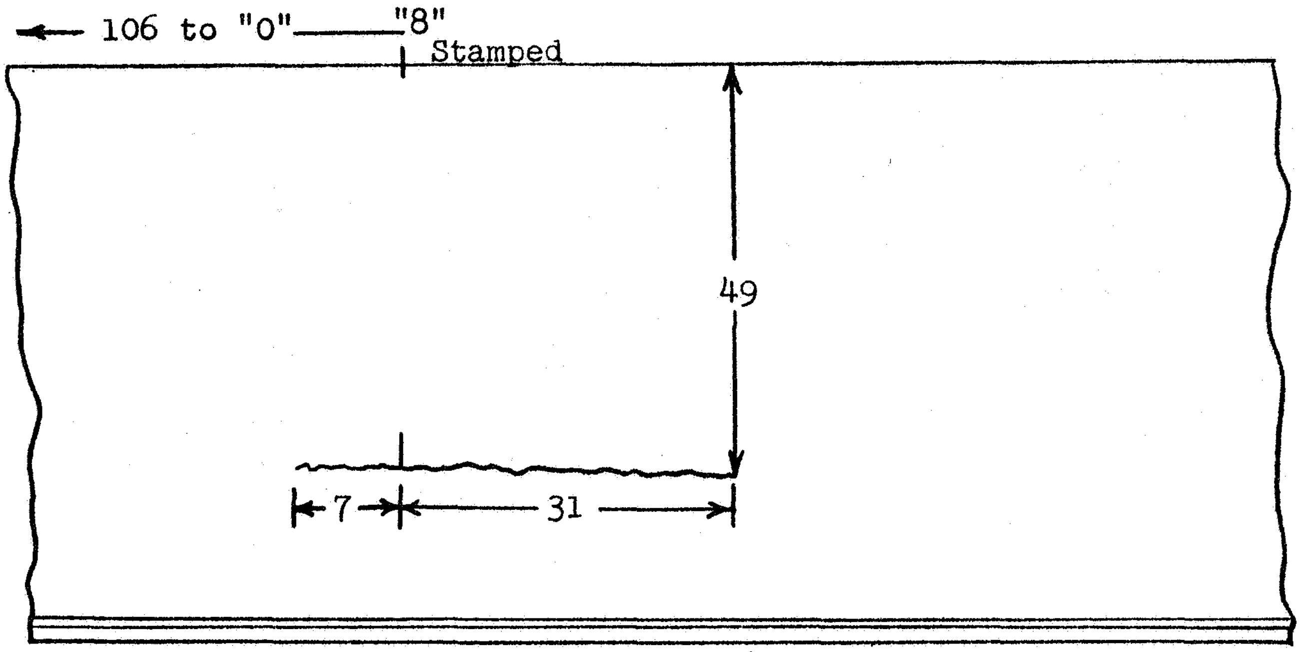

AREA #1



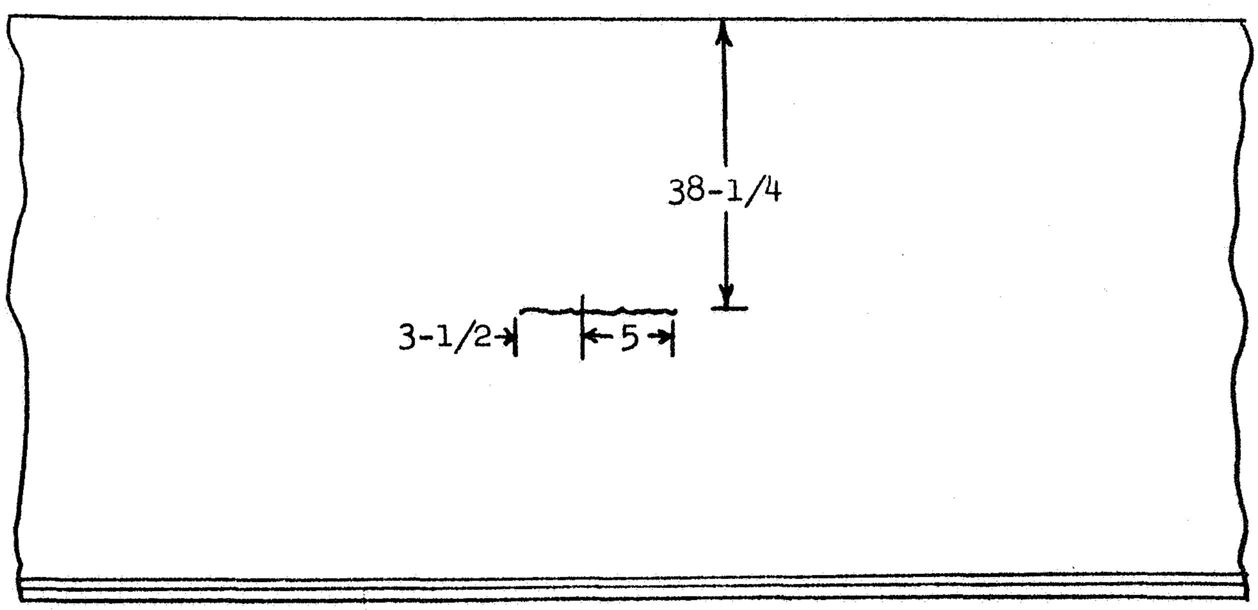

AREA #2

Roll-Formed Cylinder (NA-001) for N.A.S.A. 10/30/67

NOTE: All figures are in inches.




AREA #3




AREA #4

# LADISH CO.

**METALLURGICAL DEPT.**
**ULTRASONIC INSPECTION REPORT**

DATE: 11/1/67

CUSTOMER: N.A.S.A.

PART NAME: Roll-Formed Cylinder NZ-001

P.O.: NAS 3-7966

MATERIAL SPEC.: 2F4; 18% Ni 180 Grade Maraging

ULTRASONIC SPEC.: Class II Stds. of Ladish 9Q17

LSO / LJO: 03-119-04

METHOD OF FORMING: [X] FORGED and Roll-Formed [ ] EXTRUDED [ ] FORMED [ ] ROLL & WELD

EQUIPMENT: [ ] REFLECTOSCOPE MODEL [X] IMMERSCOPE MODEL 424A [ ] OTHER

METHOD: [X] CONTACT [ ] IMMERSION [ ] ADAPTERS

WAVE FORM: [X] LONGITUDINAL [ ] SHEAR [ ] SURFACE

COUPLANT: 011

WATER PATH DISTANCE:

CRYSTAL TYPE & SIZE: Kelvin-Hughes Twin 5.0 MHZ

CRYSTAL FREQUENCY (MC): [ ] 0.5 [ ] 1.0 [ ] 2.25 [X] 5.0 [ ] 10.0 [ ] 15.0 [ ] 25.0

SENSITIVITY: Set to produce a 50% S/P indication over 8/64" FBH in appropriate height reference standard.

SENSITIVITY SETTINGS:

TEST PROCEDURE: Inspected areas detected by shear wave inspection from outer diameter surface.

INSPECTOR: Baldwin

**MATERIAL INSPECTED**

| SERIAL | CODE | SIZE | DISPOSITION | EST RMS |
|---|---|---|---|---|
| 1-5 | AA | 261.220 x 260.000 x 72" Min. | Rejectable | 250 |

**COMMENTS**

All four areas of indications show amplitudes in excess of calibration settings. Piece remains rejectable. Disposition: Radiograph all four areas.

R. P. Mierzwa

LCO 2896 R2

TABLE III-E

RADIOGRAPHIC PROCEDURE AND DETAILS FOR 260-INCH-DIAMETER ROLL-FORMED CYLINDER

| ULTRASONIC INDICATION AREA NO. | STRAIGHT-BEAM EXPOSURE | | | 30°-ANGLE-BEAM EXPOSURE | | |
|---|---|---|---|---|---|---|
| | VOLTAGE (KV) | AMPERAGE (MA) | TIME (SECONDS) | VOLTAGE (KV) | AMPERAGE (MA) | TIME (SECONDS) |
| 1 | 200 | 4 | 255 | - | - | - |
| 2 | 200 | 4 | 255 | 200 | 4 | 300 |
| 3 | 200 | 4 | 255 | - | - | - |
| 4 | 200 | 4 | 255 | 200 | 4 | 300 |

SOURCE: Norelco Macrotank K; 1.5 mm. focal spot

FILM: Kodak Type "M" Lead Pack

FIXED FOCAL DISTANCE: 31 inches

## TABLE III-F

## RADIOGRAPHIC PROCEDURE AND DETAILS FOR RE-INSPECTION OF THE TEST PANELS

| ULTRASONIC INDICATION AREA NO. | STRAIGHT-BEAM EXPOSURE | | | 30°-ANGLE-BEAM EXPOSURE | | |
|---|---|---|---|---|---|---|
| | VOLTAGE (KV) | AMPERAGE (MA) | TIME (SECONDS) | VOLTAGE (KV) | AMPERAGE (MA) | TIME (SECONDS) |
| 2 | 185 | 15 | 420 | 225 | 12 | 330 |
| 4 | 185 | 15 | 420 | 225 | 12 | 330 |

| | |
|---|---|
| SOURCE: | Norelco MG 300; 5 mm. focal spot |
| FILM: | Kodak Type "M" Lead Pack |
| FIXED FOCAL DISTANCE: | 48 inches |

# LADISH CO.

**METALLURGICAL DEPT.**

**ULTRASONIC INSPECTION REPORT**

DATE: 11/22/67

CUSTOMER: N.A.S.A.

PART NAME: Roll-Formed Cylinder NZ-001

P.O.: NAS 3-7966

MATERIAL SPEC.: 2F4; 18% Ni 180 Grade Maraging

ULTRASONIC SPEC.: Class I Standards of Ladish

LSO / LJO: 03-119-04

METHOD OF FORMING: [X] FORGED and Roll-Formed [ ] EXTRUDED [ ] FORMED 9Q17 [ ] ROLL & WELD

EQUIPMENT: [X] REFLECTOSCOPE MODEL 50E485 [ ] IMMERSCOPE MODEL [ ] OTHER

METHOD: [X] CONTACT [ ] IMMERSION [ ] ADAPTERS

WAVE FORM: [X] LONGITUDINAL [ ] SHEAR [ ] SURFACE

COUPLANT: 011

WATER PATH DISTANCE:

CRYSTAL TYPE & SIZE: 1" Diameter Branson "ZR"

CRYSTAL FREQUENCY (MC): [ ] 0.5 [ ] 1.0 [X] 2.25 [ ] 5.0 [ ] 10.0 [ ] 15.0 [ ] 25.0

SENSITIVITY: Set to produce a 1/2" S/P indication from a 3/64" FBH in an 11" face-to-hole reference standard (UTB-138).

SENSITIVITY SETTINGS:

TEST PROCEDURE: Inspected in the downward axial direction from one end face.

INSPECTOR: Baldwin

**MATERIAL INSPECTED**

| SERIAL | CODE | SIZE | DISPOSITION | EST RMS |
|---|---|---|---|---|
| #2 | AA | 261.220 x 260.000 x 18" | Acceptable | 250 |
| #4-5 | AA | 261.220 x 260.000 x 27-1/2" | | |

**COMMENTS**

No indications detected.

R. P. Mierzwa

LCO 2096 R2

# LADISH CO.

**METALLURGICAL DEPT.**
**ULTRASONIC INSPECTION REPORT**

**DATE** 12/14/67

**CUSTOMER** N.A.S.A.

**PART NAME** Serial No. 4 Roll-Formed Ring Segment NZ-001

**P.O.** NAS 3-7966

**MATERIAL SPEC.** 2F4; 18% Ni 180 Grade Maraging and Roll-Formed

**ULTRASONIC SPEC.** Shear Wave 3% Notch

**LSO**
**LJO** 03-119-04

**METHOD OF FORMING** ☒ FORGED ☐ EXTRUDED ☐ FORMED ☐ ROLL & WELD

**EQUIPMENT** ☒ REFLECTOSCOPE MODEL 50E485 ☐ IMMERSCOPE MODEL ☐ OTHER

**METHOD** ☒ CONTACT ☐ IMMERSION ☐ ADAPTERS

**WAVE FORM** ☐ LONGITUDINAL ☒ SHEAR ☐ SURFACE

**COUPLANT** 011

**WATER PATH DISTANCE**

**CRYSTAL TYPE & SIZE** 1/2" x 1" - 45° Angle Lithium-Sulfate

**CRYSTAL FREQUENCY (MC)** ☐ 0.5 ☐ 1.0 ☒ 2.25 ☐ 5.0 ☐ 10.0 ☐ 15.0 ☐ 25.0

**SENSITIVITY**
Set to produce a 3/4" sweep to peak indication vs. a 3% axially-oriented notch.

**SENSITIVITY SETTINGS**

**TEST PROCEDURE**
Inspected on the basis of 12" grid lines in the counter-clockwise direction circumferentially and in the downward direction axially from the OD surface.

**INSPECTOR** Baldwin

**MATERIAL INSPECTED**

| SERIAL | CODE | SIZE | DISPOSITION | EST RMS |
|---|---|---|---|---|
| #4 | AA | 261.220 x 260.000 x 18" | Acceptable | 250 |

**COMMENTS**

No indications detected.

R. P. Mierzwa

LCO 2096 R2

# LADISH CO.

**METALLURGICAL DEPT.**
**ULTRASONIC INSPECTION REPORT**

| | | |
|---|---|---|
| | | DATE 12/20/67 |
| CUSTOMER N.A.S.A. | PART NAME Test Panels D and E NZ-001 | P.O. NAS 3-7966 |
| MATERIAL SPEC. 2F4; 18% Ni 180 Grade Maraging | ULTRASONIC SPEC. Class II Stds. of Ladish 9Q17 | LSO LJO 03-119-04 |

METHOD OF FORMING ☒ FORGED and Roll-Formed ☐ EXTRUDED ☐ FORMED ☐ ROLL & WELD

| | |
|---|---|
| EQUIPMENT ☐ REFLECTOSCOPE MODEL ☒ IMMERSCOPE MODEL 424A ☐ OTHER | METHOD ☒ CONTACT ☐ IMMERSION ☐ ADAPTERS |
| WAVE FORM ☒ LONGITUDINAL ☐ SHEAR ☐ SURFACE | COUPLANT 011 / WATER PATH DISTANCE |
| CRYSTAL TYPE & SIZE Kelvin-Hughes Twin 5.0 MHZ | CRYSTAL FREQUENCY (MC) ☐ 0.5 ☐ 1.0 ☐ 2.25 ☒ 5.0 ☐ 10.0 ☐ 15.0 ☐ 25.0 |

SENSITIVITY
Set to produce a 50% S/P indication over 5/64 and 8/64" FBHs in appropriate height reference standards.

SENSITIVITY SETTINGS

TEST PROCEDURE
Inspected sectioned Test Panels "D" and "E" from OD surface searching for previously-located indications #3 and #4.

INSPECTOR Hoover

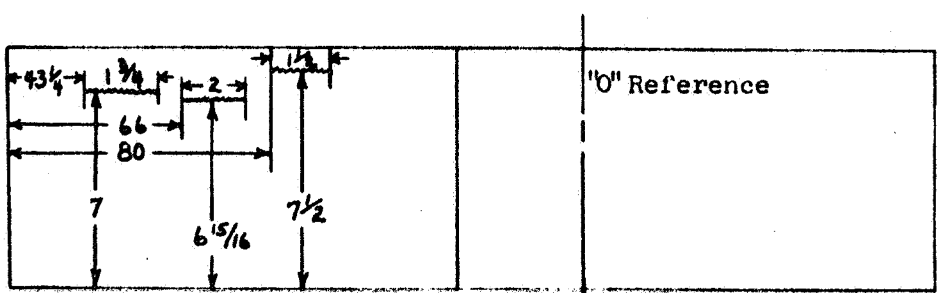
**MATERIAL INSPECTED**

| SERIAL | CODE | SIZE | DISPOSITION | EST RMS |
|---|---|---|---|---|
| #5 Panels D and E | AA | Test Panels sectioned from Roll-Formed Cylinder | For additional metallurgical investigation | 250 |

**COMMENTS**

Three stringer-type indications observed at approximately mid-wall in Test Panel "D".

All indications show amplitudes in excess of calibration setting.




Note: All figures are inches.

R. P. Mierzwa
LCO 2096 R2

# LADISH CO.

**METALLURGICAL DEPT.**

**ULTRASONIC INSPECTION REPORT**

| | |
|---|---|
| DATE | 2/24/68 |
| CUSTOMER | N.A.S.A |
| PART NAME | Serial #2 Roll-Formed Ring Segment NZ-001 |
| P.O. | NAS 3-7966 |
| MATERIAL SPEC. | 2F4; 18% Ni 180 Grade Maraging |
| ULTRASONIC SPEC. | Shear Wave 3% Notch |
| LSO / LJO | 03-119-04 |
| METHOD OF FORMING | [X] FORGED and Roll-Formed [ ] EXTRUDED [ ] FORMED [ ] ROLL & WELD |
| EQUIPMENT | [X] REFLECTOSCOPE MODEL 50E485 [ ] IMMERSCOPE MODEL [ ] OTHER |
| METHOD | [X] CONTACT [ ] IMMERSION [ ] ADAPTERS |
| WAVE FORM | [ ] LONGITUDINAL [X] SHEAR [ ] SURFACE |
| COUPLANT | Oil |
| WATER PATH DISTANCE | |
| CRYSTAL TYPE & SIZE | 1/2" x 1" - 45° Angle Lithium Sulfate |
| CRYSTAL FREQUENCY (MC) | [ ] 0.5 [ ] 1.0 [X] 2.25 [ ] 5.0 [ ] 10.0 [ ] 15.0 [ ] 25.0 |

**SENSITIVITY**

Set to produce a 3/4" sweep to peak indication vs. a 3% axially-oriented notch.

**SENSITIVITY SETTINGS**

**TEST PROCEDURE**

Inspected on the basis of 12" grid lines in the counter-clockwise direction circumferentially and in the downward direction axially from the OD surface.

**INSPECTOR** Jamrog, Hoover

**MATERIAL INSPECTED**

| SERIAL | CODE | SIZE | DISPOSITION | EST RMS |
|---|---|---|---|---|
| #2 | AA | 261.220 x 260.000 x 18" | Acceptable | 250 |

**COMMENTS**

No indications detected.

R. P. Mierzwa

LCO 2096 R2

# LADISH CO.

**METALLURGICAL DEPT.**

**ULTRASONIC INSPECTION REPORT**

**DATE** 2/24/68

**CUSTOMER** N.A.S.A.

**PART NAME** Serial No. 2 Roll-Formed Ring Segment NZ-001

**P.O.** NAS 3-7966

**MATERIAL SPEC.** 2F4; 18% Ni 180 Grade Maraging

**ULTRASONIC SPEC.** Class I Stds. of Ladish 9Q17

**LSO**

**LJO** 03-119-04

**METHOD OF FORMING** ☒ FORGED and Roll-Formed ☐ EXTRUDED ☐ FORMED ☐ ROLL & WELD

**EQUIPMENT** ☒ REFLECTOSCOPE MODEL UM ☐ IMMERSCOPE MODEL ☐ OTHER

**METHOD** ☒ CONTACT ☐ IMMERSION ☐ ADAPTERS

**WAVE FORM** ☒ LONGITUDINAL ☐ SHEAR ☐ SURFACE

**COUPLANT** Oil

**WATER PATH DISTANCE**

**CRYSTAL TYPE & SIZE** Kelvin-Hughes Twin 5.0 MHZ

**CRYSTAL FREQUENCY (MC)** ☐ 0.5 ☐ 1.0 ☐ 2.25 ☒ 5.0 ☐ 10.0 ☐ 15.0 ☐ 25.0

**SENSITIVITY**

Set to produce a 50% S/P indication over 3/64" FBH in appropriate height reference standards.

**SENSITIVITY SETTINGS**

Evaluation Setting: 50% S/P indication over 5/64" and 8/64" FBH in appropriate height reference standards.

**TEST PROCEDURE**

Inspected from OD surface.

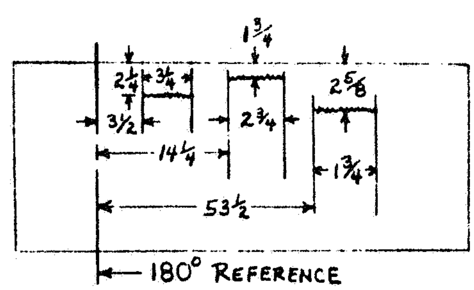
**INSPECTOR** Jamrog, Hoover

**MATERIAL INSPECTED**

| SERIAL | CODE | SIZE | DISPOSITION | EST RMS |
|---|---|---|---|---|
| #2 | AA | 261.220 x 260.000 x 18" | Rejectable | 250 |

**COMMENTS**

Three stringer-type indications observed at approximately mid-wall. All indications exceed limits considered to be acceptable.




R. P. Mierzwa

LCO 2096 R2

# LADISH CO.

**METALLURGICAL DEPT.**
**ULTRASONIC INSPECTION REPORT**

| | | |
|---|---|---|
| | | DATE 2/24/68 |
| CUSTOMER N.A.S.A. | PART NAME Serial No. 4 Roll-Formed Ring Segment NZ-001 | P.O. NAS 3-7966 |
| MATERIAL SPEC. 2F4: 18% Ni 180 Grade Maraging | ULTRASONIC SPEC. Class I Stds. of Ladish 9017 | LSO / LJO 03-119-04 |

METHOD OF FORMING: [X] FORGED and Roll-Formed [ ] EXTRUDED [ ] FORMED [ ] ROLL & WELD

EQUIPMENT: [X] REFLECTOSCOPE MODEL UM [ ] IMMERSCOPE MODEL [ ] OTHER

METHOD: [X] CONTACT [ ] IMMERSION [ ] ADAPTERS

WAVE FORM: [X] LONGITUDINAL [ ] SHEAR [ ] SURFACE

COUPLANT: 011 — WATER PATH DISTANCE:

CRYSTAL TYPE & SIZE: Kelvin-Hughes Twin 5.0 MHZ

CRYSTAL FREQUENCY (MC): [ ] 0.5 [ ] 1.0 [ ] 2.25 [X] 5.0 [ ] 10.0 [ ] 15.0 [ ] 25.0

SENSITIVITY
Set to produce a 50% S/P indication over 3/64" FBH in appropriate height reference standards

SENSITIVITY SETTINGS
Evaluation Setting: 50% S/P indication over 5/64" and 8/64" FBH in appropriate height reference standards.

TEST PROCEDURE
Inspected from OD surface.

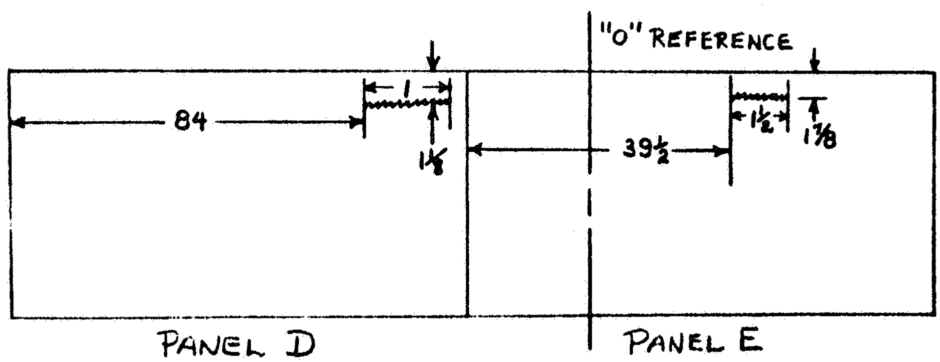
INSPECTOR: Hoover

**MATERIAL INSPECTED**

| SERIAL | CODE | SIZE | DISPOSITION | EST RMS |
|---|---|---|---|---|
| #4 | AA | 261.220 x 260.000 x 18" | Rejectable | 250 |

**COMMENTS**

Two stringer-type indications observed at approximately 2/3 wall. All indications exceed limits considered to be acceptable.




R. P. Mierzwa

LCO 2096 R2

# APPENDIX IV

| ROOM-TEMPERATURE MECHANICAL PROPERTIES DATA FROM THE HEAT TREATMENT RESPONSE STUDY | PAGE |
|---|---|

TABLE IV-A

ROOM-TEMPERATURE MECHANICAL PROPERTIES AFTER AGING AT 850°F

| | | TIME AT 850°F AGING TEMPERATURE | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | FOUR HOURS | | | | EIGHT HOURS | | | | 16 HOURS | | | |
| | | UTS* | YS | EL | RA | UTS | YS | EL | RA | UTS | YS | EL | RA |
| Direct age of roll-formed specimens | | 208.5 | 201.3 | 10 | 48 | 216.2 | 205.4 | 10 | 47 | 218.9 | 215.1 | 9 | 45 |
| Re-annealing temperature (°F) of roll-formed specimens | 1500 | 192.1 | 185.1 | 12 | 59 | 202.5 | 194.7 | 12 | 59 | 204.0 | 195.0 | 13 | 56 |
| | 1550 | 188.9 | 180.0 | 12 | 59 | 195.6 | 187.2 | 13 | 59 | 202.5 | 192.9 | 7 | 57 |
| | 1600 | 188.8 | 179.0 | 14 | 62 | 198.7 | 189.6 | 12 | 60 | 205.0 | 196.7 | 13 | 60 |
| | 1650 | 186.8 | 175.8 | 13 | 61 | 198.1 | 189.1 | 13 | 59 | 200.4 | 190.5 | 12 | 58 |
| | 1700 | 183.8 | 172.2 | 13 | 60 | 195.7 | 184.7 | 12 | 60 | 203.3 | 193.2 | 13 | 61 |
| | 1750 | 185.5 | 172.8 | 13 | 60 | 195.9 | 185.5 | 12 | 59 | 204.1 | 193.1 | 13 | 58 |

* LEGEND: UTS = Ultimate Tensile Strength (Ksi)
YS = 0.2% Offset Yield Strength (Ksi)
EL = Elongation (per cent)
RA = Reduction in Area (per cent)

TABLE IV-B

ROOM-TEMPERATURE MECHANICAL PROPERTIES AFTER AGING AT 900°F

| | | TIME AT 900°F AGING TEMPERATURE | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | FOUR HOURS | | | | EIGHT HOURS | | | | 16 HOURS | | | |
| | | UTS* | YS | EL | RA | UTS | YS | EL | RA | UTS | YS | EL | RA |
| Direct age of roll-formed specimens | | 217.9 | 210.1 | 10 | 44 | 219.6 | 211.2 | 10 | 45 | 216.9 | 207.5 | 12 | 46 |
| Re-annealing temperature (°F) of roll-formed specimens | 1500 | 205.3 | 197.3 | 12 | 56 | 208.1 | 199.3 | 14 | 57 | 207.7 | 195.7 | 15 | 56 |
| | 1550 | 203.5 | 194.9 | 12 | 59 | 206.7 | 195.9 | 13 | 56 | 201.9 | 188.7 | 15 | 57 |
| | 1600 | 200.9 | 192.6 | 13 | 58 | 205.9 | 195.3 | 14 | 57 | 201.6 | 188.1 | 14 | 56 |
| | 1650 | 203.3 | 192.8 | 12 | 57 | 205.9 | 195.7 | 13 | 54 | 205.7 | 193.3 | 15 | 56 |
| | 1700 | 201.1 | 190.5 | 12 | 56 | 206.1 | 193.9 | 12 | 55 | 204.5 | 191.1 | 15 | 55 |
| | 1750 | 201.9 | 190.8 | 13 | 58 | 205.7 | 193.9 | 12 | 54 | 205.3 | 191.7 | 14 | 54 |

* LEGEND: UTS = Ultimate Tensile Strength (Ksi)
YS = 0.2% Offset Yield Strength (Ksi)
EL = Elongation (per cent)
RA = Reduction in Area (per cent)

TABLE IV-C

ROOM-TEMPERATURE MECHANICAL PROPERTIES AFTER AGING AT 915°F

| | | TIME AT 915°F AGING TEMPERATURE | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | FOUR HOURS | | | | EIGHT HOURS | | | | 16 HOURS | | | |
| | | UTS* | YS | EL | RA | UTS | YS | EL | RA | UTS | YS | EL | RA |
| Direct age of roll-formed specimens | | 217.1 | 210.9 | 10 | 44 | 214.3 | 205.9 | 11 | 45 | 214.3 | 202.5 | 13 | 44 |
| Re-annealing temperature (°F) of roll-formed specimens | 1500 | 205.5 | 196.7 | 14 | 57 | 204.9 | 194.7 | 15 | 57 | 204.5 | 191.9 | 16 | 56 |
| | 1550 | 204.5 | 194.5 | 13 | 55 | 204.7 | 191.4 | 15 | 59 | 204.3 | 189.5 | 15 | 56 |
| | 1600 | 203.5 | 192.9 | 14 | 60 | 203.9 | 190.7 | 14 | 53 | 200.1 | 186.3 | 15 | 56 |
| | 1650 | 203.1 | 192.4 | 13 | 58 | 201.6 | 188.7 | 14 | 56 | 204.3 | 189.0 | 15 | 56 |
| | 1700 | 202.1 | 190.9 | 12 | 54 | 203.5 | 183.7 | 16 | 58 | 203.1 | 186.7 | 16 | 56 |
| | 1750 | 203.1 | 191.7 | 13 | 57 | 203.9 | 188.9 | 14 | 56 | 203.9 | 186.9 | 16 | 56 |

* LEGEND: UTS = Ultimate Tensile Strength (Ksi)
YS = 0.2% Offset Yield Strength (Ksi)
EL = Elongation (per cent)
RA = Reduction in Area (per cent)

TABLE IV-D

ROOM-TEMPERATURE MECHANICAL PROPERTIES AFTER AGING AT 950°F

| | | TIME AT 950°F AGING TEMPERATURE | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | FOUR HOURS | | | | EIGHT HOURS | | | | 16 HOURS | | | |
| | | UTS* | YS | EL | RA | UTS | YS | EL | RA | UTS | YS | EL | RA |
| Direct age of roll-formed specimens | | 213.5 | 202.9 | 12 | 44 | 208.1 | 193.3 | 14 | 45 | 208.5 | 192.7 | 15 | 46 |
| Re-annealing temperature (°F) of roll-formed specimens | 1500 | 204.5 | 191.5 | 16 | 57 | 201.5 | 186.5 | 16 | 55 | 195.9 | 180.3 | 16 | 55 |
| | 1550 | 203.3 | 190.1 | 15 | 56 | 200.0 | 184.0 | 16 | 58 | 198.9 | 181.8 | 17 | 57 |
| | 1600 | 202.9 | 188.7 | 15 | 57 | 197.1 | 180.6 | 15 | 57 | 198.1 | 181.4 | 17 | 60 |
| | 1650 | 202.5 | 188.7 | 14 | 58 | 199.4 | 182.4 | 16 | 59 | 198.1 | 181.2 | 16 | 53 |
| | 1700 | 202.9 | 188.1 | 16 | 58 | 200.7 | 181.9 | 16 | 54 | 197.7 | 179.8 | 16 | 57 |
| | 1750 | 202.9 | 187.1 | 14 | 54 | 199.5 | 181.4 | 16 | 56 | 198.1 | 179.8 | 16 | 56 |

* LEGEND: UTS = Ultimate Tensile Strength (Ksi)
YS = 0.2% Offset Yield Strength (Ksi)
EL = Elongation (per cent)
RA = Reduction in Area (per cent)

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