ORNL-4313-2
UC-80 – Reactor Technology

FABRICATION HISTORY OF THE THIRD AND FOURTH ASTM A-533 STEEL PLATES OF THE HEAVY STEEL TECHNOLOGY PROGRAM

C. E. Childress

OAK RIDGE NATIONAL LABORATORY
operated by
UNION CARBIDE CORPORATION
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U.S. ATOMIC ENERGY COMMISSION

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DIRECTOR'S DIVISION

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FEBRUARY 1970

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ABSTRACT

The fabrication history of the first two steel plates (HSST plates 01 and 02) for evaluation by the Heavy Section Steel Technology Program was presented in ORNL-4313.

Two additional 12-in.-thick A-533 grade B steel plates have been purchased from Lukens for evaluation. They were received for heat treatment in the as-rolled, stress relieved, and descaled condition. These would have been plates 03 and 04, but rerolling of plate 04 caused a change in the numbering system. It was originally planned to leave the plates at 12-in. gage and heat treat them in the same manner as plates 01 and 02 (normalize, austenitize, quench vertically, temper to class 1 mechanical properties, cut into plate sections, and stress relieve). However, it was decided to reroll portions of one plate to 8-in. and 4-in. gage and heat treat portions of the material to class 2 properties.

Since plates 01 and 02 were vertically quenched, it was decided to horizontally quench the second pair to test the effects of the quenching procedure. Accordingly, Lukens, who uses a horizontal quenching procedure, was chosen.

All material was ultrasonically inspected before and after heat treatment in accordance with PVRC specifications.

This report is to provide an objective account of the history of the latest HSST plates. In some instances Lukens' interpretation of the data is presented. Otherwise interpretation of the data is not included.

INTRODUCTION

The Heavy Section Steel Technology (HSST) Program is a long-range experimental program aimed at evaluating the structural reliability of light-water reactor pressure vessels containing metal imperfections under startup, operating, and accident conditions. Questions of vessel integrity have risen mainly from regulatory and licensing bodies and the Advisory Committee on Reactor Safeguards. Hopefully, these questions will be answered by reevaluating methods in use and extending these methods to develop the necessary technologies. Specifically, the program covers both material property investigations and fracture behavior based on transition temperature and fracture mechanics methods (including their extension to a quantitative delineation of toughness behavior).

The program is being carried out with the cooperation of, and in coordination with, many other research efforts sponsored by the federal government, private institutions, and industry. In particular, industry is sponsoring complementary efforts in nondestructive testing, material properties, and in-service inspection.

In the latter part of 1966, the first two heavy-section steel plates were purchased as a materials supply for researchers. Their history is presented in ORNL-4313.

Additional research material was provided with the purchase of two more heavy-section steel plates in the early part of 1967 from Lukens. These plates, originally identified as plates 03 and 04, were 12-in. thick ASTM A-533 grade B steel. Soon after the plates were rolled the HSST program decided that some study should be focused on materials of gages less than 12 in. and on the effects of rerolling. Accordingly, portions of one plate were rerolled to 8-in. and 4-in. gage and portions of the as-rolled and rerolled material were heat treated to class 2 mechanical properties.

Both plates were ultrasonically inspected in the as-rolled, stress-relieved condition; in one of the plates no "recordable" ultrasonic indications were found, but the other plate contained a number of recordable as well as nonrecordable indications. Consequently the plate containing the larger number was chosen to be rerolled to determine what effects rerolling might have on such ultrasonic indications.

Lukens was chosen as the fabricating contractor because they used the horizontal quench method. The first two plates had been vertically quenched, and it was desirable to investigate the effect of the quench method on the properties of the plates.

The purpose of this report is to provide for researchers and analysts a historical record of the latest HSST Program plates from the time they were melted, rolled, and fully processed by Lukens Steel Company. The intent is to provide the mill history and fabrication data as completely and objectively as possible.

The author wishes to thank the following for their assistance and for making essential test data available for this report: (1) the Metallurgical Department of Lukens Steel Company, particularly S. G. Johnson and E. K. Martini; (2) K. K. Klindt of the ORNL Inspection Engineering Department.

1. PLATE 03

A. ROLLING, PRELIMINARY INSPECTION, AND TESTING

Plate 03 was ordered from Lukens Steel Company on UCCND purchase order 73Y-49288V. Essentially, the order specified that the plate be 12 in. thick and meet the requirements of ASTM A-302B modified (and code case 1339 with 0.40 – 0.70% nickel in the ladle analysis), electric furnace melt, vacuum degassed, stress relieved, and descaled for heat treatment by the purchaser. A Combustion Engineering, Inc., specification was referenced for the heat treating operations. A copy of the purchase order is included in the Appendix. However, the Combustion Engineering specification is not included, since the heat treating procedures subsequently employed varied somewhat from those specified by Combustion Engineering.

The steel, melt C2702, was poured into ingot form in February 1967. In March the ingot was rolled into slab form, and the slab was rolled into plate on March 16, 1967.

Optical pyrometer readings indicated that prior to rolling but after the first descaling, the temperature of the slab was about 2150°F. Descaling during rolling was accomplished by alternate applications of moistened burlap and common salt to the slab at the entry side of the rolls. In both instances the materials were used to introduce moisture between the work rolls and the stock, where it vaporized instantaneously (with explosive effects in the case of the salt) and removed the surface scale. The moistened burlap is applied selectively during rolling where surface scale is observed.

Both transverse (side-to-side relative to top and bottom of ingot) and longitudinal (top-to-bottom relative to top and bottom of ingot) rolling were performed. The longitudinal-to-transverse rolling ratio was 1.7:1. During the process of rolling, the plate was visually inspected on both top and bottom surfaces for "snakes" and other surface imperfections, but none was noted. The temperature of the plate on completion of rolling was about 1700°F.

A 6-in.-thick plate was rolled immediately prior to the rolling of plate 03 and a 4-in.-thick plate immediately afterwards. The 6-in. plate was placed on the ground (inside the mill), and plate 03 was placed between it and the 4-in. plate for cooling. Lukens advised that it would require about six to seven days for plate 03 to return to ambient temperature, cooling in this manner.

Lukens reported the following information for plate 03:

Material Identification	**PVRC Code No.**
Heat C2702	Grade A533
Ingot 2	Class 1
Plate 2	Supplier L

Melting and Casting History
Furnace number – "C"
Furnace type – BEF (basic electric furnace)
Charge material – cold
Tap temperature – 2900°F
Deoxidation practice – 0.04% Al added
Degassing – yes
Degassing-type process – D&H (Dortmund and Horder) vacuum lifter type
Teeming practice – bottom
Teeming time – 8½ min
Ingot size – width 108 in., thickness 40 in., height 161 in., weight 136,000 lb
Ingot type – slab, bed (big end down)
Hot top type – disposable, cast, insulating only

Heating and Rolling History
Soaking time – 20 hr 40 min
Soaking temperature – 2350°F for 3 hr 40 min
Rolling practice:
Cross rolling ratio – 1.7:1
Finishing temperature – 1700°F

Heat Treatment History
Subcritical – 1150–1200°F, cool 100°F/hr to 600°F

The as-rolled plate was ultrasonically inspected at the perimeter of the proposed cutting boundary to determine the extent of sound metal. The plate pattern (120 × 240 × 12 in. thick) and the test plates were then cut (see Fig. 1.1).

On completion of rolling and preliminary processing but prior to shipment of a plate to a fabricator for heat treatment, specimens for physical testing are usually cut from the trim area for evaluation of physical properties according to the requirements of paragraph 9.2 of ASTM A-533-67, which states in part: "When the plates are to be heat treated by the fabricator as provided in 5.2, the test specimens shall be cut from coupons of full-plate thickness and of sufficient size so that the tensile specimens, and impact specimens if required, are at a minimum distance of 2 in. or 1.0 times the plate thickness, whichever is greater, from any as-quenched plate edge and midway between one surface and center of the plate (1/4 *T*) . . ." In this case, as well as with the other HSST plates, Lukens requested and was permitted to use their DATA TRAC[1] testing method (Programmed Testing Procedure) for plate qualification tests in lieu of the so-called "3T" test specified in A-533-67.

Specimens for plate qualification and development tests were removed from the locations shown in Fig. 1.1 and heat treated as follows:

1. austenitized at 1550 to 1650°F for a 4-hr hold,
2. program cooled according to the rate shown in Fig. 1.2 for 12-in.-thick plate,
3. tempered at 1200 to 1250°F for a 4-hr hold and air cooled to ambient temperature,
4. stress relieved at 1125 to 1175°F for a 20-hr hold and furnace cooled to 600°F.

See Part I of this report for full plate qualification test results.

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[1]John H. Scott, "New Test Method Promises Major Cost Savings in Construction of Big Pressure Vessels," ASME paper 67-MET-24.

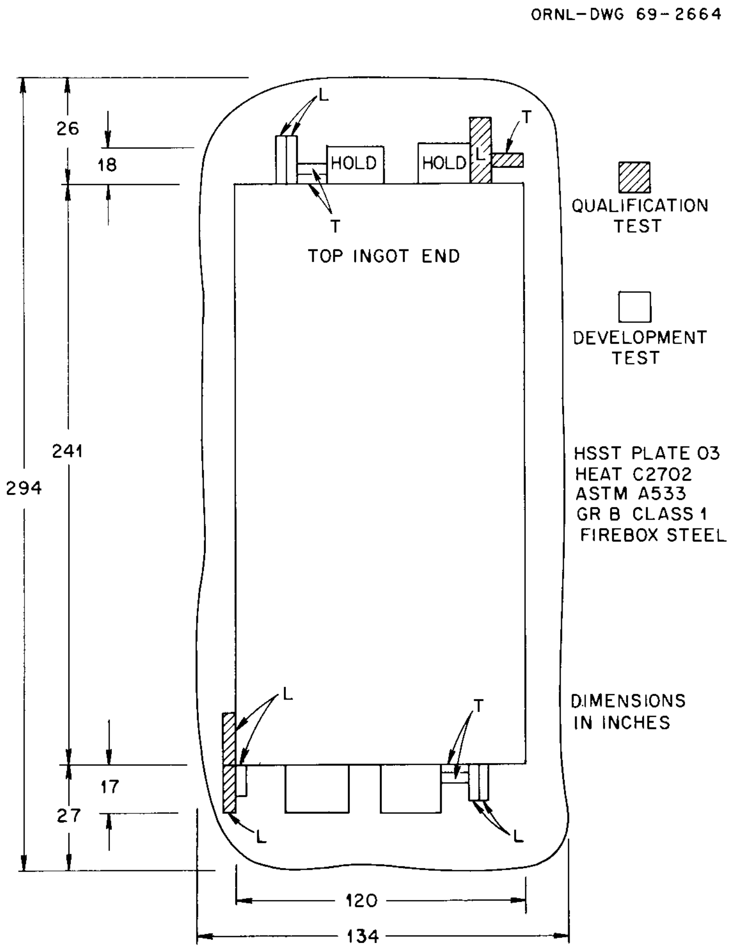

Fig. 1.1. Location of Test Specimens.

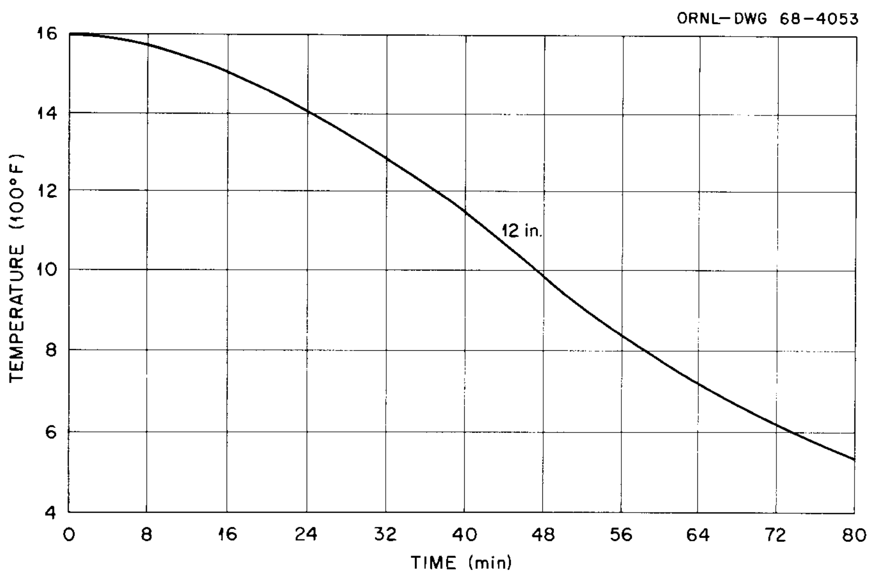

Fig. 1.2. Minimum Cooling Rate Specified for 12-in.-Thick Plate.

Specimens for the check chemical analyses were removed from the bottom ingot end of the plate at the 1/4 *T* position. The following is a tabulation of the ladle and check chemical analyses as reported by Lukens:

	C	Mn	P	S	Cu	Ni	Cr	Mo	Si	Al
Ladle	0.21	1.31	0.012	0.018	0.13	0.60	0.15	0.50	0.24	0.031
Check	0.20	1.26	0.011	0.018	0.12	0.56	0.10	0.45	0.25	0.034

B. FIRST ULTRASONIC INSPECTION

The first ultrasonic inspection of the plate was performed by Lukens for information purposes only. Inspection was performed from one surface with the plate in the as-rolled, stress-relieved, and descaled condition, using the longitudinal wave technique described in ASTM A-435. Coverage was 100% using a UM model 715 Reflectoscope, water-soap solution couplant, and a $1\frac{1}{8}$-in.-diam quartz crystal at a test frequency of 1 MHz. Only the areas which caused 100% loss of back-surface reflection were to be recorded. Only two indications of any significance were noted, but neither caused a complete loss of back-surface reflection. However, these were documented so that they could be compared with the more comprehensive pre- and post-heat-treatment ultrasonic test results which would be obtained later. The results of the first ultrasonic inspection are shown in Fig. 1.3.

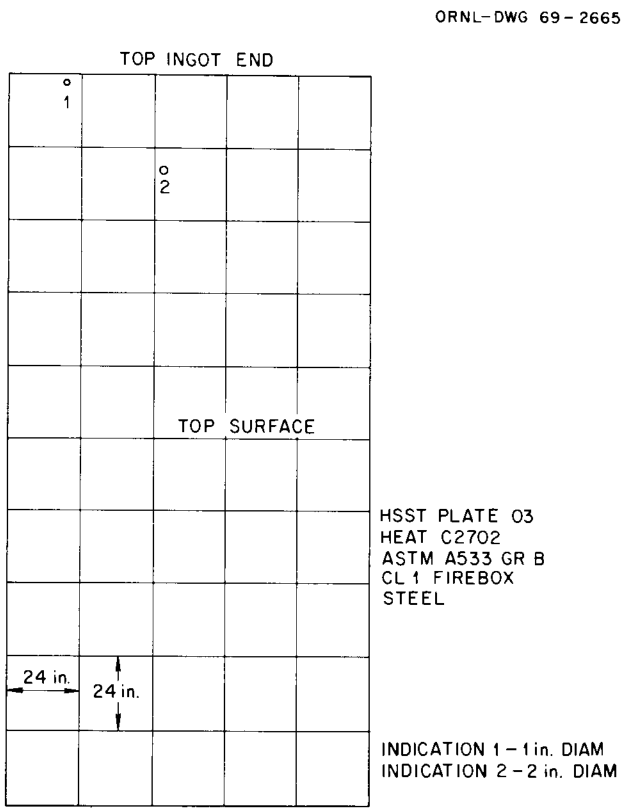

Fig. 1.3. Location of Ultrasonic Indications Found During First UT Inspection.

C. PROCESSING AND FABRICATION PROCEDURE

It was considered important to compare the physical properties of vertically quenched steels (such as HSST plates 01 and 02) with those of steels quenched horizontally. Accordingly, Lukens, who uses the horizontal quenching method, was requested to submit a proposal for heat treatment and inspection of the second pair of HSST plates.

Essentially, UCCND and Lukens agreed to the following procedure for inspection, heat treatment, and cutting of plate 03: [NOTE: Plate is in the as-rolled, stress-relieved, and descaled condition, and the ultrasonic (longitudinal wave) inspection for information purposes has been performed.] The plate shall be marked to maintain identity of top and bottom surfaces, heat number, and top and bottom as related to ingot orientation and to longitudinal direction of rolling throughout all operations.

A. Grit blast.

B. Ultrasonically inspect plate from the top surface only in accordance with Attachments 2A and 2B of the PVRC subcommittee report of April 10, 1967.[2]

C. Apply a punch mark near each corner of the plate for measuring dimensional changes after normalizing and tempering.

D. Normalize at 1675 ± 25°F for 12 hr and air cool.

E. Install 23 thermocouples.

F. Paint with descaling compound.

G. Austenitize at 1575 ± 25°F for 12 hr.

H. Quench in agitated water.

I. Temper at 1225 ± 25°F for 18 hr and furnace cool to 600°F.

J. Stress relieve for 40 hr at 1125 ± 25°F and furnace cool to 600°F.

K. Preheat plate to about 500°F and cut test specimens. Tests, for information purposes only, shall consist of transverse tensile, bend, homogeneity, Charpy V-notch transition curve (no guarantee), and nil ductility transition temperature determination per ASTM A-208.

L. Stress relieve plate for 12 hr at 1025 ± 25°F and furnace cool to 600°F.

M. Grit blast.

N. Reinspect in accordance with step B.[3]

O. Lay out cutting pattern on plate surface, stamp each plate section with HSST bench mark, and record coordinates of the bench marks.

P. Preheat to about 500°F and cut plate into plate sections.

Q. Stress relieve plate sections for 12 hr at 1025°F and furnace cool to 600°F.

R. Ship plate sections to the HSST storage facility.

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[2] Referred to in text as second ultrasonic inspection.

[3] Referred to in text as third ultrasonic inspection.

D. SECOND ULTRASONIC INSPECTION

In February 1968, Lukens prepared plate 03 for ultrasonic inspection by grit blasting and grinding the top surface (surface to the top during rolling). The surface finish thus obtained was approximately 250 rms or better. Inspection was performed in accordance with Attachments 2A and 2B of the Pressure Vessel Research Committee (PVRC) subcommittee report of April 10, 1967. Copies of the Attachments are included in the Appendix.

The ultrasonic inspection before heat treatment was performed to locate and record any discontinuities for comparison with the ultrasonic inspection results which would be obtained after heat treatment. A Reflectoscope model UR-600 and 10-W SAE oil couplant were used for both longitudinal and shear-wave inspections conducted at ambient temperatures near 0°F. Nonsoluble oil was used, contrary to the requirements of the applicable specification, Attachments 2A and 2B, because the use of glycerine or a soap-water solution as required by 2A and 2B was not feasible at such low ambient temperatures.

D.1 Longitudinal-Wave Inspection

A reference block made by the Midvale-Heppenstall Company was used for calibrating the ultrasonic equipment. The block was made from vacuum-arc remelted, double-quenched and tempered steel with a chemical composition quite similar to that of ASTM A-508 class 2 material. The finished block was checked against a comparable block of quenched and tempered A-533 steel by Midvale-Heppenstall, and they advised that the two had almost identical acoustic properties. The "Midvale" block is shown in Fig. 1.4.

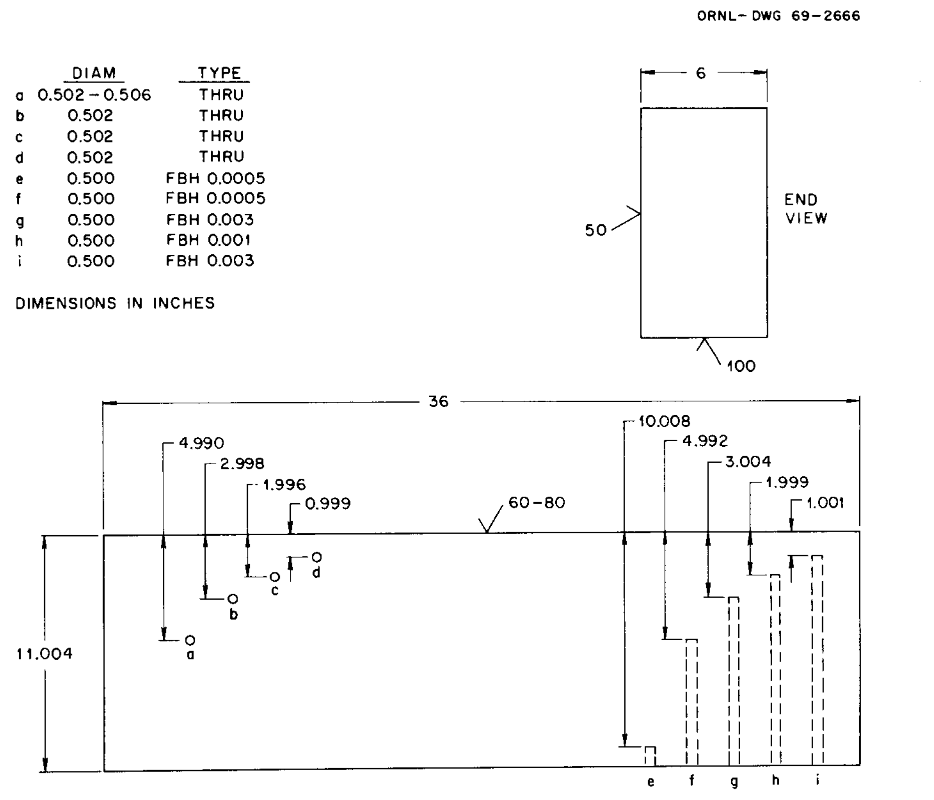

Fig. 1.4. Midvale-Heppenstall PVRC Reference Block Used for Calibration of the Ultrasonic Equipment.

The amplitude of reflection from each of the holes (bottom drilled for longitudinal-wave and side drilled for shear-wave tests) was recorded to relate signal amplitude to the depth below the scanned surface. Points of peak amplitude from each of the reference holes were plotted on the instrument screen, and these were connected to form a distance-amplitude correction (DAC) curve.

In general, calibration of the instrument for longitudinal-wave inspection was performed as follows:

1. Place the transducer directly over the flat-bottom hole that produced the highest amplitude signal on the instrument screen.

2. Adjust the sensitivity to produce a signal amplitude of approximately 75% of full scale. Without changing the instrument settings, place the transducer over each of the other flat-bottom holes, and plot the location and amplitude of the reflection from each hole on the instrument screen. This plotting results in a DAC curve.

3. Note and record the back-reflection amplitude with the transducer situated over a sound area on the reference block.

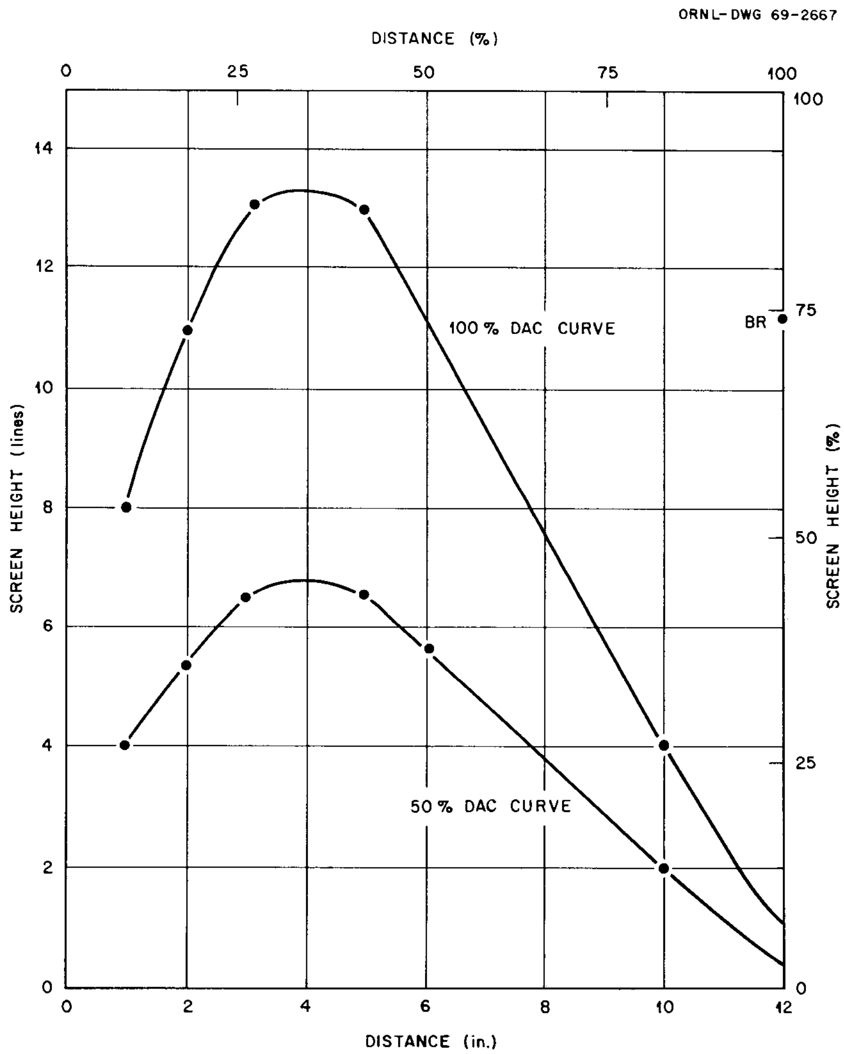

Fig. 1.5. Longitudinal-Wave DAC Curve.

4. Move to the plate, place the transducer over a sound area with a suitable surface preparation, and adjust the instrument sensitivity so that the amplitude of the first back reflection equals that received from the reference block.

All discontinuities which caused a complete loss of back-surface reflection and/or produced signals with an amplitude equal to or exceeding the DAC curve were to be considered "recordable."

A DAC curve for the longitudinal-wave inspection was plotted on the instrument screen from the following peak amplitude points:

Distance of Flat-Bottom Hole Below the Test Surface (in.)	Signal Amplitude (lines of height)
1	8
2	10¾
3	13
5	13
10	4
Back reflection	11

For this work the usable screen height is 3 in. A grid in front of the screen is scaled five lines per inch. Thus, 15 lines is full screen height, and 11 lines is approximately 75% of full screen height. The longitudinal-wave DAC curve plotted from the above points is shown in Fig. 1.5.

As noted previously, plate 03 was in the as-rolled, stress-relieved condition, but the reference block was in the quenched and tempered condition. As a result, the attenuation properties of the two were quite dissimilar. When transferring the crystal from the reference block to the plate under test, a loss of sensitivity was experienced. It became necessary to increase the sensitivity to produce 11 lines of height of back-surface reflection on the plate.

Inspection was performed using a Reflectoscope model UR-600 and a 1⅛-in.-diam, 2.25 MHz, internally grounded quartz crystal. The top surface (surface to the top during rolling) was hand ground to an approximate 250 rms finish, and 10-W SAE oil was used as a couplant.

Previous tests indicated that a signal approximately 50% of the height of the DAC curve would be produced if the crystal was moved $^5/_{16}$ in. off center from a ½-in.-diam flat-bottom hole. Accordingly, a scan path width of ⅝ in. was used.

The plate was laid out for scanning as shown in Fig. 1.6. A steel bar, marked off in ⅝-in. increments, was held securely along the longitudinal or transverse lines, and a T square was placed under the calibrated bar and used as a guide for scanning each grid section. In addition to recording the indications required by the specification, Lukens recorded the indications which produced signals 50% of the height of the DAC curve and those causing appreciable loss of back-surface reflection. Figure 1.6 shows the location of the "recordable" indications as well as the ones that were noted for information.

D.2 Shear-Wave Inspection

Shear-wave inspection of plate 03 was performed immediately following longitudinal-wave inspection. The same instrument (Reflectoscope UR-600) used for longitudinal wave inspection was retained for shear-wave testing, except that a 1 × 1 in. 45° quartz crystal was attached, and inspection was performed at a frequency of 1 MHz. Again, the couplant was 10-W SAE oil.

Probing from the top surface of the reference block, the reflected signals from the side-drilled holes were plotted at a sensitivity which would produce essentially full screen height utilization. The block was

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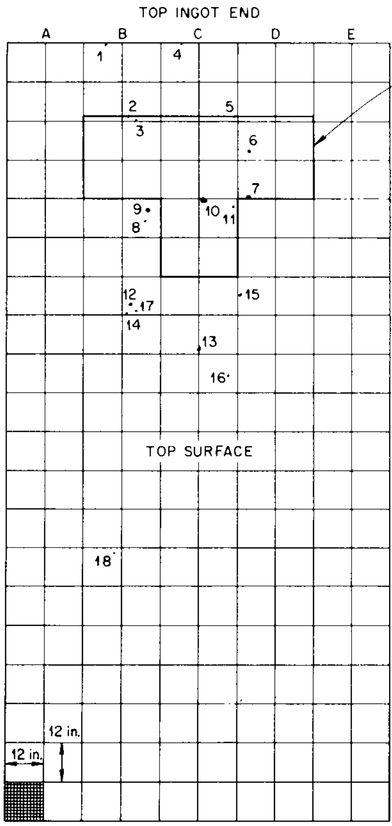

THIS AREA CONTAINED SEVERAL "NON-RECORDABLE" SHEAR WAVE INDICATIONS THAT EQUALED OR EXCEEDED 50 % OF HEIGHT OF DAC CURVE

RECORDABLE INDICATIONS FOUND DURING SECOND ULTRASONIC INSPECTION OF HSST PLATE 03

INDICATION	DEPTH (in.)	PERCENT OF DAC	PERCENT LOSS OF BACK SURFACE REFLECTION
6	6	> 100	90
7	6	100	18
9	6	100	27
10	6	100	0
12	6	11	100
13	6	100	0

HSST PLATE 03 HEAT C2702
ASTM A533 GR B CLASS 1
FIREBOX STEEL

Fig. 1.6. Ultrasonic Indications Found During Second UT Inspection.

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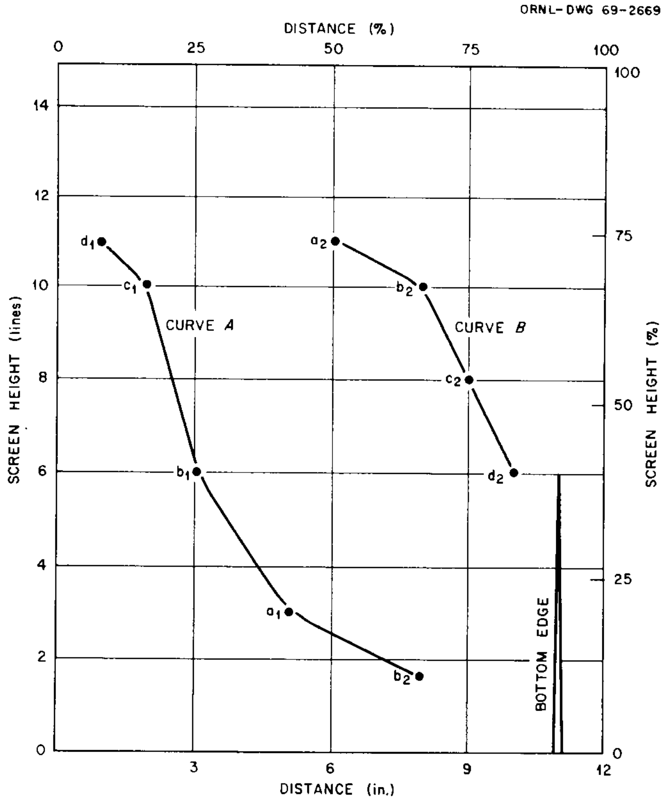


Fig. 1.7. Shear-Wave DAC Curves.

then inverted, and the reflected signal from hole *b* was plotted. Curve *A*, drawn from these points, is shown in Fig. 1.7.

The instrument sensitivity was then adjusted to increase the signal from the hole at b_2 to an amplitude of ten lines, and the points of peak amplitude from the other side-drilled holes, from the bottom surface, were plotted. Curve *B*, also shown in Fig. 1.7, is a plot of these data.

Plate coverage was 100% using the same scan path (⅝ in.) as was used for longitudinal-wave inspection. Each grid square was inspected from both longitudinal and transverse directions according to the procedure specified in PVRC Attachment 2B. No shear-wave indications of "recordable" magnitude were found in the plate. However, the T-shaped area, outlined in Fig. 1.6, contained numerous shear-wave signals which were noted for information purposes.

E. HEAT TREATMENT

Heat treatment of plate 03 consisted in normalizing, austenitizing, quenching, tempering, and stress relieving; it was carried out over a period of about two months. During this time, every effort was made to assure that only "normal production practices" were used in processing the plate. Probably the only departure from this practice was the installation of a rather large number (23) of thermocouples to record the heating and cooling cycles during the austenitizing and quenching operations, but this did not affect the quality of the end product.

Each heat treatment was performed in a natural-gas-fired car-bottomed furnace. Except for the normalizing heat treatment which was done in Lukens' furnace 6, all other heat treatments were accomplished in furnace 2.

Normalizing was required by the purchase order to simulate heating for hot forming, but no forming was done.

E.1 Normalizing

On March 28, 1968, at 2:30 AM the plate was loaded on a furnace car and charged into furnace 6 for the normalizing heat treatment. The plate was located in the furnace essentially as shown in Fig. 1.8. Lukens reported that four furnace thermocouples (Nos. 2, 3, 6, and 7) were used to record the heatup and hold periods.

After about 6½ hr the thermocouples were recording readings within the specified range of 1675 ± 25°F, and the 12-hr hold period was started. Throughout the hold period each of the thermocouples recorded temperatures within the permissible range. At 9:00 PM the 12-hr hold period was completed, and the plate was withdrawn from the furnace and cooled in air to ambient temperature. Figure 1.9 is a plot of the normalizing data. Since thermocouples were not attached to the plate, the cooling rate data were not recorded.

E.2 Austenitizing and Quenching

In the latter part of April, plate 03 was equipped with 23 stainless-steel-sheathed, type K, Chromel-Alumel thermocouples mounted in Honeywell type P measuring junctions. The type P junctions were installed by drilling ¼-in.-diam flat-bottom holes to the appropriate depth and counterboring each hole to ½ in. in diameter for one-fourth of the hole depth. A typical installation is shown in Fig. 2.17. (The holes were drilled from the bottom surface to avoid interference with the oxyacetylene cutting operation that would be used later to cut the plate into plate sections.)

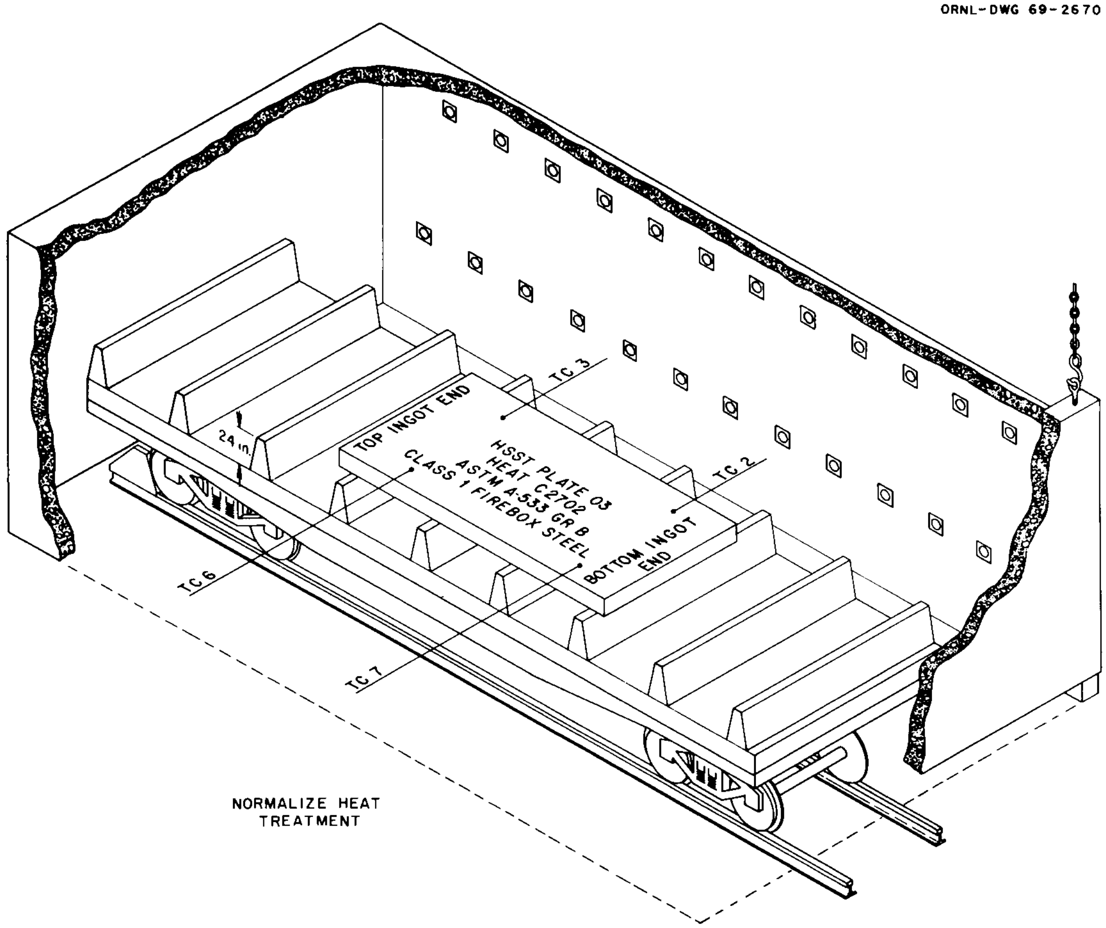


Fig. 1.8. Orientation of Plate 03 in the Furnace for the Normalizing Heat Treatment.

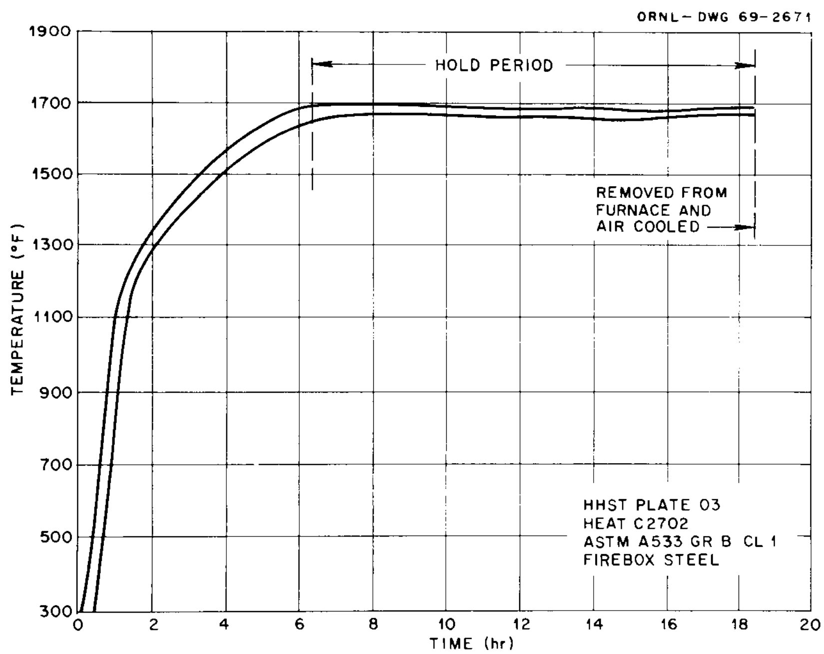
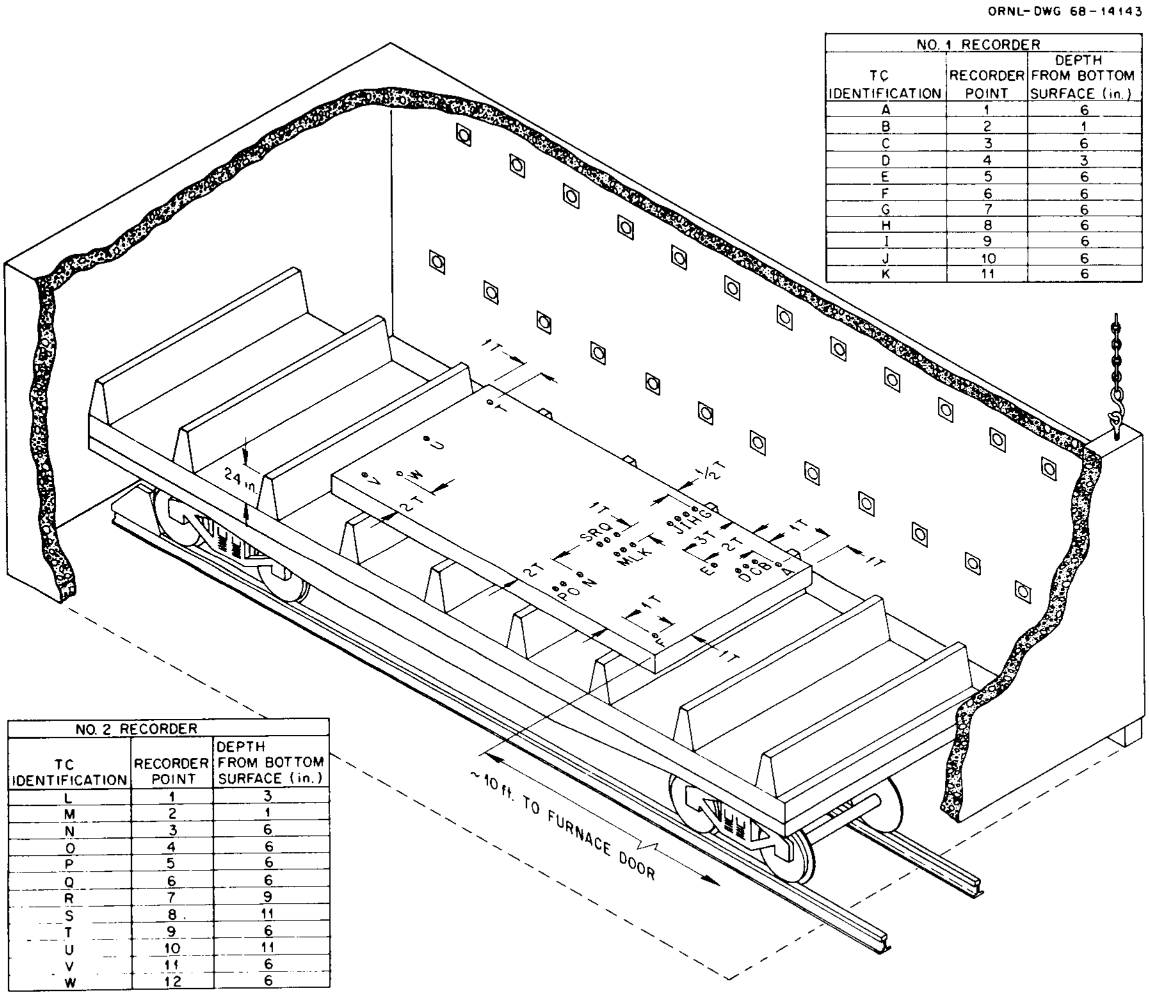


Fig. 1.9. Spread in Thermocouple Readings During the Normalizing Heat Treatment.

Thermocouple assemblies were inserted in the ¼-in.-diam holes until the hot junction was in intimate contact with the bottom of the hole. Asbestos material was then packed into the ½-in. counterbore to help hold the assembly in place and to shield the hot junction area from direct impingement of furnace gases. To preclude the possibility of the wires being torn from the hot junctions, each pair was secured to the plate near the respective holes with metal clips tack-welded to the plate. Two assemblies were installed at 1/4 *T*, sixteen at 1/2 *T*, one at 3/4 *T*, two at a depth of 1 in., and two at a depth of 11 in. The plate was then painted with a descaling compound (a Combustion Engineering proprietary brand) and allowed to dry. After the plate had dried, it was placed on a furnace car and charged into the furnace. Both plate and furnace were at ambient temperature at the time of charging. Figure 1.10 shows the location of the thermocouples and the orientation of the plate in the furnace. Figure 1.11 is a side view of the furnace showing the relative location of the furnace couples and the burners.

The thermocouple wires extended through a small opening in the bottom of the furnace door, and sand was used to seal the opening to prevent furnace drafts in this area. Stainless-steel-sheathed thermocouple lead wires were used from the hot junction points to about 5 ft outside the furnace; asbestos-sheathed thermocouple lead wires were used from this point to the recorders. Two recorders were used, one a



NO. 1 RECORDER		
TC IDENTIFICATION	RECORDER POINT	DEPTH FROM BOTTOM SURFACE (in.)
A	1	6
B	2	1
C	3	6
D	4	3
E	5	6
F	6	6
G	7	6
H	8	6
I	9	6
J	10	6
K	11	6

NO. 2 RECORDER		
TC IDENTIFICATION	RECORDER POINT	DEPTH FROM BOTTOM SURFACE (in.)
L	1	3
M	2	1
N	3	6
O	4	6
P	5	6
Q	6	6
R	7	9
S	8	11
T	9	6
U	10	11
V	11	6
W	12	6

Fig. 1.10. Location of Thermocouples for the Austenitizing Heat Treatment.

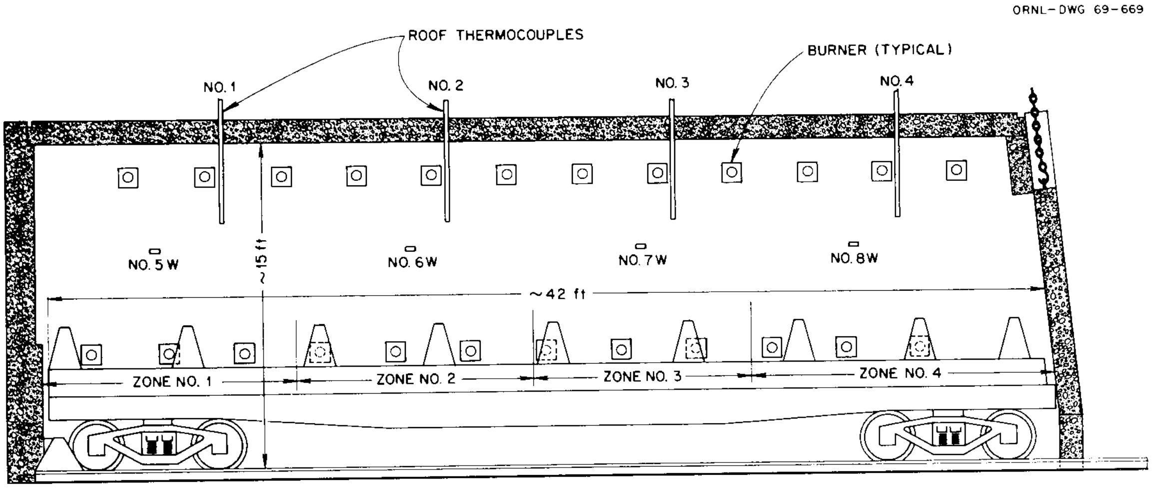


Fig. 1.11. Side View of Heat Treatment Furnace.

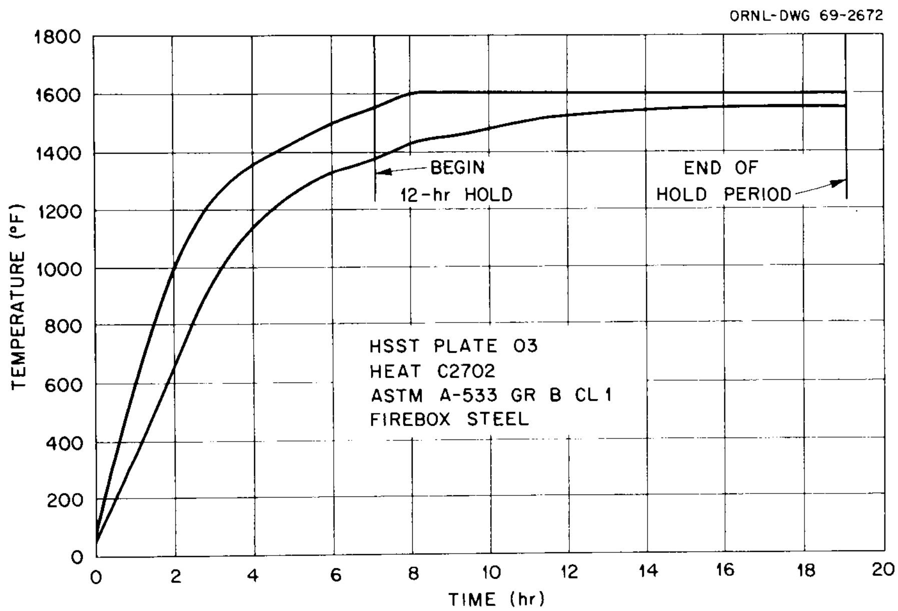


Fig. 1.12. Temperature Spread for Thermocouples *A* Through *K* During the Austenitizing Heat Treatment.

12-point Brown-Honeywell instrument, and the other a 12-point Leeds and Northrup instrument. Sufficient slack wiring was provided to permit the recorders to be moved and to provide ample distance between the plate and the furnace car during quenching.

The furnace was fired at 8:00 PM on the evening of May 1, 1968. At 3:15 AM the following morning (7 hr later) the thermocouple readings ranged between 1380°F at midthickness to 1590°F at the plate surface, and the 12-hr hold period was begun. During the ensuing 12 hr the temperature readings came closer together. Figures 1.12 and 1.13 show the temperature range of the thermocouples from the time of charging until the plate was withdrawn from the furnace for quenching.

Shortly before the plate was removed from the furnace for quenching, the thermocouple readings ranged between 1540 and 1600°F. The temperature of the water immediately prior to quench was 76°F.

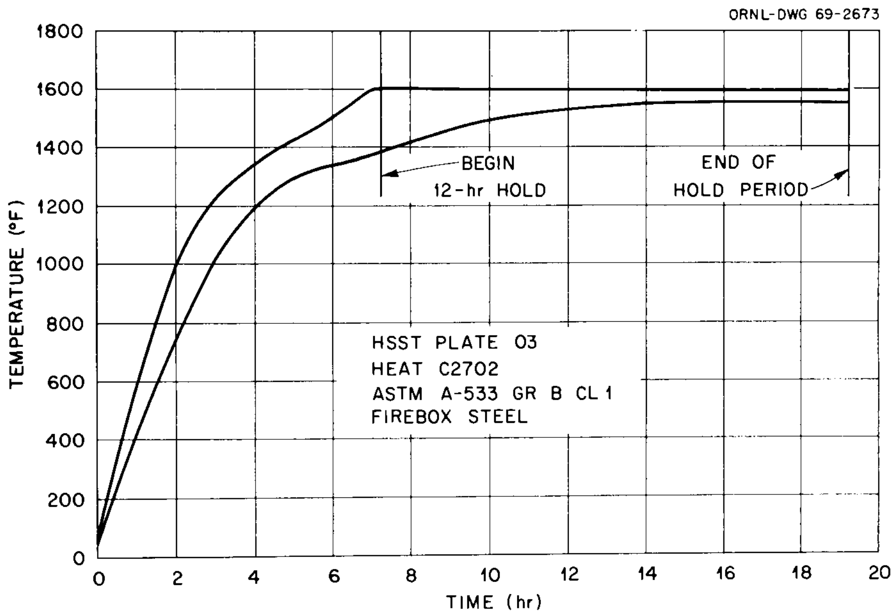


Fig. 1.13. Temperature Spread for Thermocouples *L* Through *W* During the Austenitizing Heat Treatment.

The time lapse between opening the furnace door and immersing the plate was slightly less than 2½ min. The plate was lifted from the furnace car with a lifting device called a "peel," which consisted of several "horseshoe-shaped" members suspended from an overhead crane. The steel blocks on which the plate was supported on the furnace car (see Fig. 1.10) were separated to allow the horseshoe-shaped members of the peel to fit between them.

Lukens' quench tank measured about 20 ft wide × 60 ft long × 8 ft deep. Agitation of the quench medium was provided by pump circulated water discharged through 8-in. water inlet piping.

The plate remained in the water 1 hr and 28 min, after which time the plate thermocouple readings ranged between 100 and 190°F. The temperature of the water increased 3° during the first 50 min that the plate was immersed; after that time, the water temperature gradually returned to 76°F.

Figures 1.14–1.16 show the cooling rates of various thermocouples which were attached to the plate. Generally, the thermocouples located at midthickness level and 1 *T* or more from an edge cooled at practically the same rate throughout the quench. The top surface couples (located 1 in. deep) and those located in the top 1/4 *T* cooled faster than the corresponding locations in the bottom half of the plate. This could be due in part to steam entrapment resulting in reduced circulation on the bottom side. Within the 1/4 *T* and 1/2 *T* planes, for couples located 12 in. or less from an edge, the cooling rate was faster than for those located at midwidth. This effect is also apparent in the surface locations; however, it appears that the bottom ingot end (end nearest the door while in the furnace) cools faster than the top ingot end. This trend does not hold true for couples in the 1/4 *T* and 1/2 *T* plane when comparing cooling rates of bottom ingot end couples with those located near midwidth.

E.3 Tempering

Shortly after the plate was withdrawn from the quench medium, the plate-attached couples were removed. Throughout the quenching operation the furnace door was left open and all firing units were shut off. This was done so that the furnace would be relatively cool when the plate was recharged for tempering.

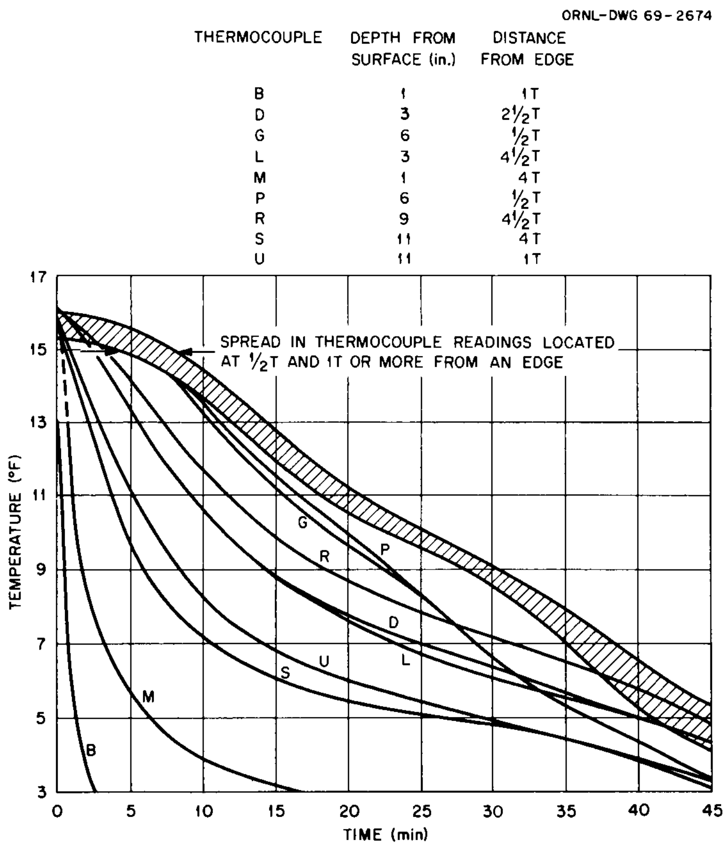


Fig. 1.14. Cooling Curves for Various Locations Within Plate.

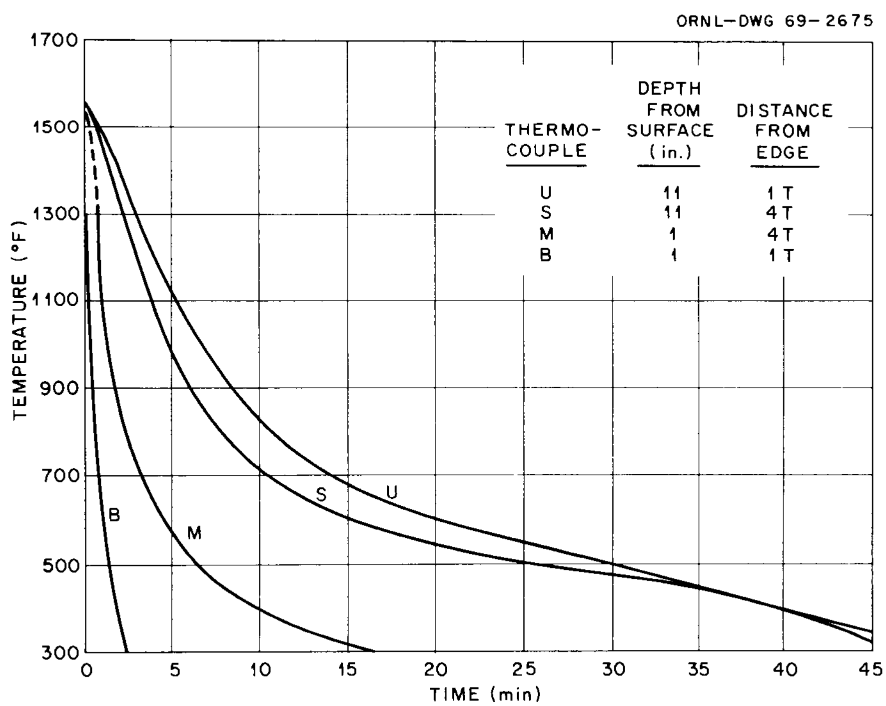


Fig. 1.15. Cooling Curves for Surface and Pseudosurface Thermocouples.

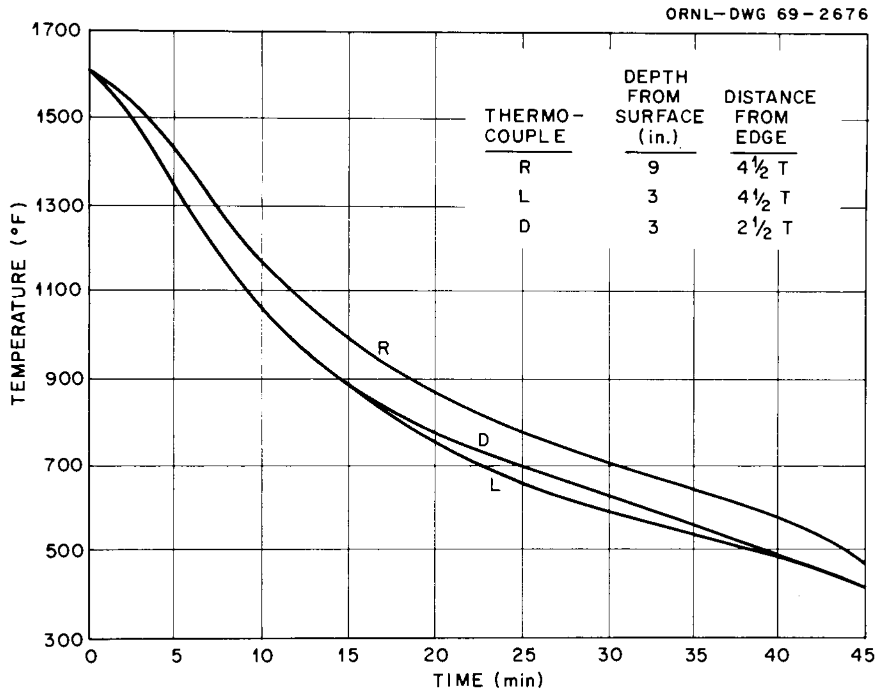


Fig. 1.16. Cooling Curves for Thermocouples Located at the ¼ *T* Position.

The plate was then reloaded on the furnace car and oriented as it was for the austenitizing heat treatment. Five furnace couples, 2, 3, 6, 7, and 8, were used to record the tempering cycle. The furnace was fired at 5:00 PM May 2, 1968; at 10:45 PM the highest thermocouple reading was near 1250°F, and the 18-hr hold period was begun. Lukens advised that they would attempt to hold the temperature variation within ±10°F of the nominal tempering temperature (1225°F).

Figure 1.17 shows the spread in thermocouple readings throughout the 38-hr heating and cooling cycle. It will be noted from this figure that the temperature varied somewhat more than ±10°F from the nominal 1225°F. Even so, the variation was probably no more than 20° on the high side.

At 4:45 PM the following day the prescribed 18-hr hold period was completed. The firing units were shut off, and the plate was allowed to furnace cool until the highest thermocouple reading was less than 600°F. The plate was then removed from the furnace and allowed to continue cooling in air.

E.4 First Stress Relief

The plate had cooled to slightly below 400°F when it was recharged into the furnace for stress relieving at 9:20 AM on May 4, 1968. The same furnace couples used for recording the temperatures for the tempering heat treatment were used to record those for the 40-hr stress relief. After slightly more than 6 hr in the furnace, the stress relief temperature of 1125 ± 25°F was attained, and the 40-hr hold period was begun. Throughout the hold period the thermocouple readings came closer together. During the last few hours, each was recording essentially the same temperature.

At 7:25 AM May 6, 1969, the 40-hr hold period was completed, the firing units were shut down, and the plate was left in the furnace to cool below 600°F. Some 6 hr later, the thermocouple readings were below 600°F, and the plate was withdrawn from the furnace for further cooling. A plot of the spread in thermocouple readings for the stress-relieving heat treatment is shown in Fig. 1.18.

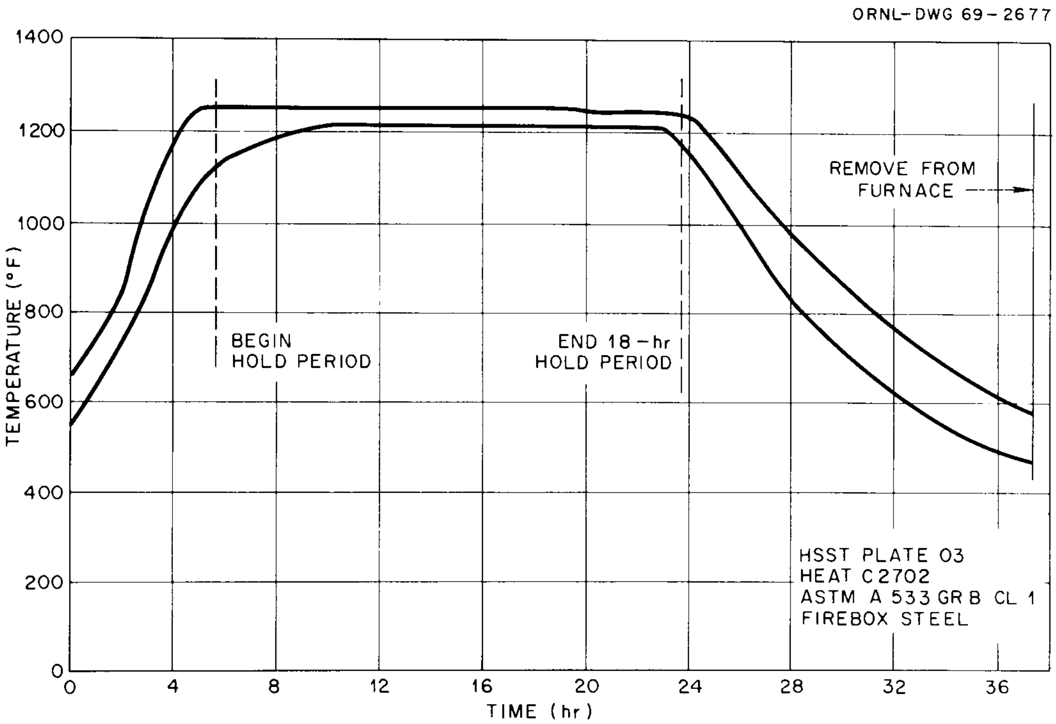


Fig. 1.17. Spread in Thermocouple Readings During Tempering Heat Treatment.

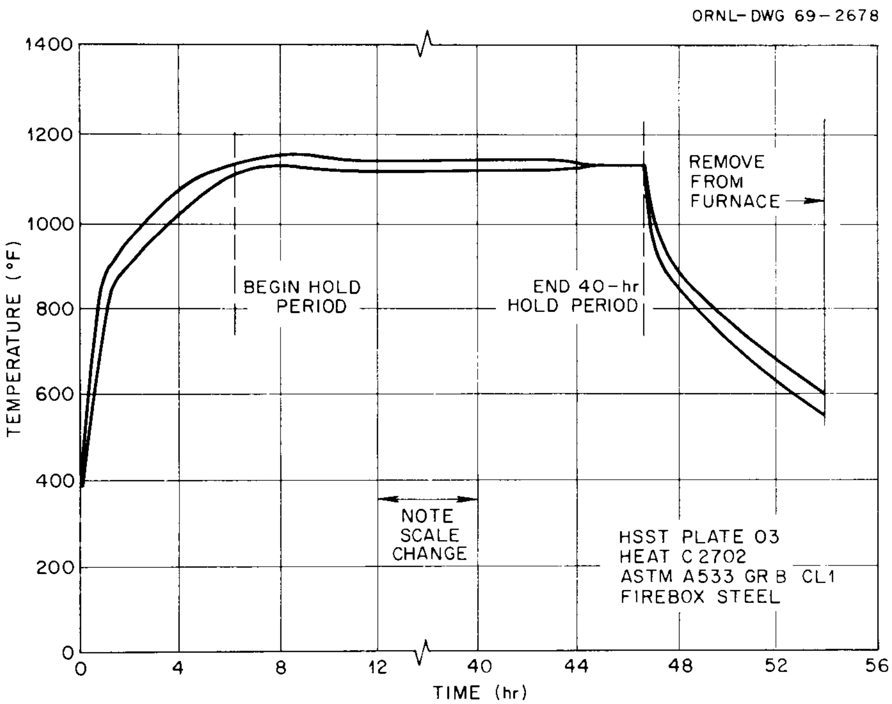


Fig. 1.18. Spread in Thermocouple Readings During the Stress-Relieving Heat Treatment Before Cutting.

E.5 Second Stress Relief

At this point in the processing sequence, the plate was preheated to about 500°F, and the plate test material was removed by oxyacetylene cutting from the locations shown in Fig. 1.21. Following removal of the test material, the plate was returned to the furnace for a 12-hr stress-relieving heat treatment. The plate was charged into the furnace at 10:00 AM on May 9, 1968. After 9 hr the temperature, as recorded by

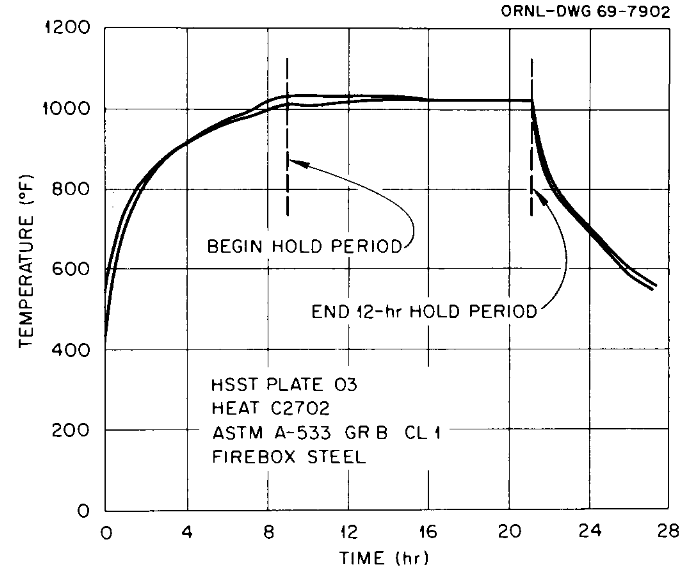


Fig. 1.19. Spread in Thermocouple Readings During Stress-Relief Heat Treatment After Cutting Test Plates.

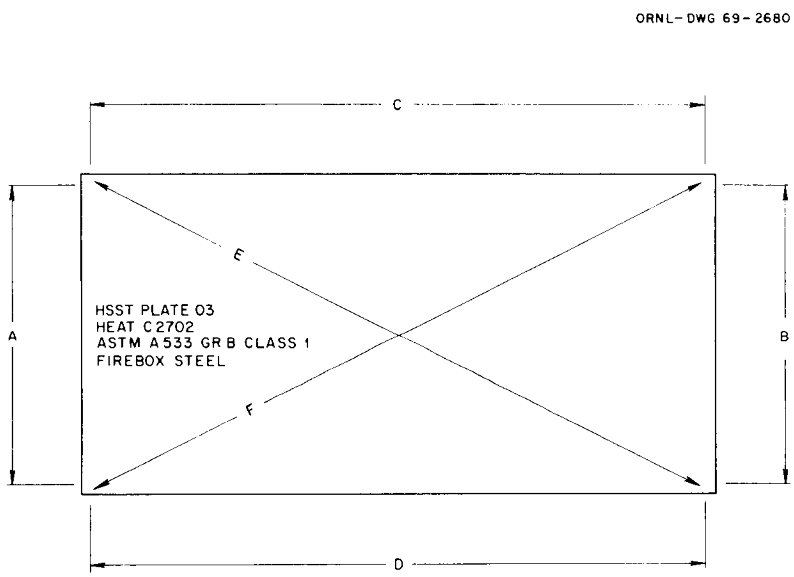


Fig. 1.20. Dimensional Data.

HSST PLATE 03 HEAT C2702

DIMENSION	DIMENSIONS AS ROLLED (in.)	AFTER NORMALIZING (in.)	DIMENSIONS AFTER QUENCH AND TEMPER (in.)	TOTAL CHANGE (in.)
A	108 3/8	108 3/8	108 3/4	3/8
B	108 3/8	108 3/8	108 13/16	7/16
C	228 7/16	228 1/2	229 9/32	27/32
D	228 5/8	228 5/8	229 11/32	23/32
E	252 15/16	253	253 13/16	7/8
F	252 7/16	252 15/16	253 3/4	1 5/16

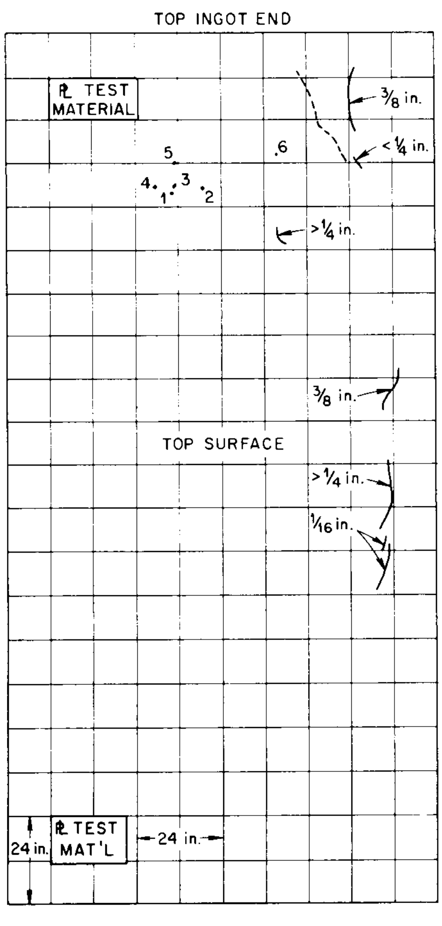
furnace couples 3, 4, 5, and 6, ranged from 1020–1035°F, and the hold period was begun. About 5 hr later each thermocouple was recording essentially the same reading, 1025°F. This temperature, as shown in Fig. 1.19, was maintained throughout the remainder of the hold period. On completion of the heat treatment, the firing units were shut off, and the plate was cooled in the furnace to below 600°F.

In order to determine the amount of dimensional change that occurred as a result of heat treatment, punch marks were applied in each of the four corners of the plate (as shown in Fig. 1.20) prior to normalizing. The dimensions between the punch marks were recorded when they were applied (as-rolled condition) and after the normalizing and tempering heat treatments. A tabulation of the dimensional changes is given in Fig. 1.20. The amount of dimensional change was essentially the same as that experienced during the heat treatment of plate 02 (see ORNL-4313).

F. THIRD ULTRASONIC INSPECTION

The plate was prepared for ultrasonic inspection after heat treatment by grit blasting and condition grinding. The surface finish of the plate after grinding was approximately 250 rms in most areas, better in others. Both longitudinal and shear-wave inspections were performed using a Reflectoscope model UM-721. Longitudinal-wave inspection was conducted with a $1\frac{1}{8}$-in.-diam, internally grounded, $2\frac{1}{4}$ MHz quartz

ORNL–DWG 69–2679



RECORDABLE INDICATIONS FOUND DURING THIRD ULTRASONIC INSPECTION OF HSST PLATE 03

INDICATION	DEPTH (in.)	PERCENT OF DAC	PERCENT LOSS OF BACK SURFACE REFLECTION
1	5–6	45	100
2	5–6	10	100
3	5–6	20	100
4	5–6	20	100
5	5–6	20	100
6	5–6	30	100

HSST PLATE 03
HEAT C 2702
ASTM A533 GR B CLASS 1
FIREBOX STEEL

Fig. 1.21. Location of UT Indications and Surface Imperfections Found During Third UT Inspection of Plate.

crystal; shear-wave with a 1 × 1 in., 45°, 1 MHz quartz crystal. A solution of liquid soap and water was used as the couplant for all testing.

During routine visual inspection of the plate after heat treatment, several areas, commonly referred to as "snakes," were observed. The length of the suspected areas was later determined by magnetic particle inspection. Five such areas were found on the top surface (surface uppermost during rolling) and one on the bottom surface. The location and maximum depth of each are shown in Fig. 1.21. The "snakes" on the top surface were removed by grinding to apparently solid metal; this was confirmed by magnetic particle inspection. The one on the bottom surface was ground to a depth slightly more than ¼ in., but defective metal was still visible. It was then decided to leave the remaining defective metal for possible investigative work. These snake-type defects were not detected during rolling nor during any of the subsequent heat treating operations.

F.1 Longitudinal-Wave Inspection

Longitudinal-wave inspection of plate 03 was performed on May 27–28, 1968. Calibration of the ultrasonic equipment was performed essentially in accordance with that described in D.1. The plate was again laid out for scanning as shown in Fig. 1.3, except that 2 ft^2 had been removed from each end for mechanical test specimens. For this inspection, only the areas which produced signals equal to the height of the 100% DAC curve and those causing a complete loss of back-surface reflection were recorded. There was one other deviation from the procedure described in D.1: Lukens decided to discontinue the practice of using the T square and calibrated bar to determine the crystal scan path and overlap. Instead, they chose to allow the inspector to scan each square without the benefit of a scanning guide, using only visual perception to determine the crystal scan path, and they chose to switch to a minimum 10% scan path overlap in lieu of the 50% overlap used during the second ultrasonic inspection.

A DAC curve for the longitudinal wave inspection was plotted on the instrument screen from the following peak amplitude points:

Distance of the Flat-Bottom Hole from the Test Surface (in.)	Signal Amplitude (lines of height)
1	8
2	9½
3	10¾
5	10¾
10	4
Back reflection	11

The longitudinal-wave DAC curve constructed from the above points is shown in Fig. 1.22.

The plate was now in the quenched and tempered condition, or essentially in the same condition as the reference block. Consequently, the two had similar acoustic properties.

Six "recordable" indications were found, each of which caused a 100% loss of back-surface reflection, but none of them produced a signal equal to the height of the DAC curve. Indication 1, Fig. 1.21, produced a signal more than three lines high, and it was the only indication larger than crystal size. Indication 6 was the only one that was detectable both before and after heat treatment. Before heat treatment, the amplitude of the signal from indication 6 ranged from 50 to 100% of the DAC curve; after heat treatment, to only 25%. The locations of the six ultrasonic indications found during this inspection are also shown in Fig. 1.21.

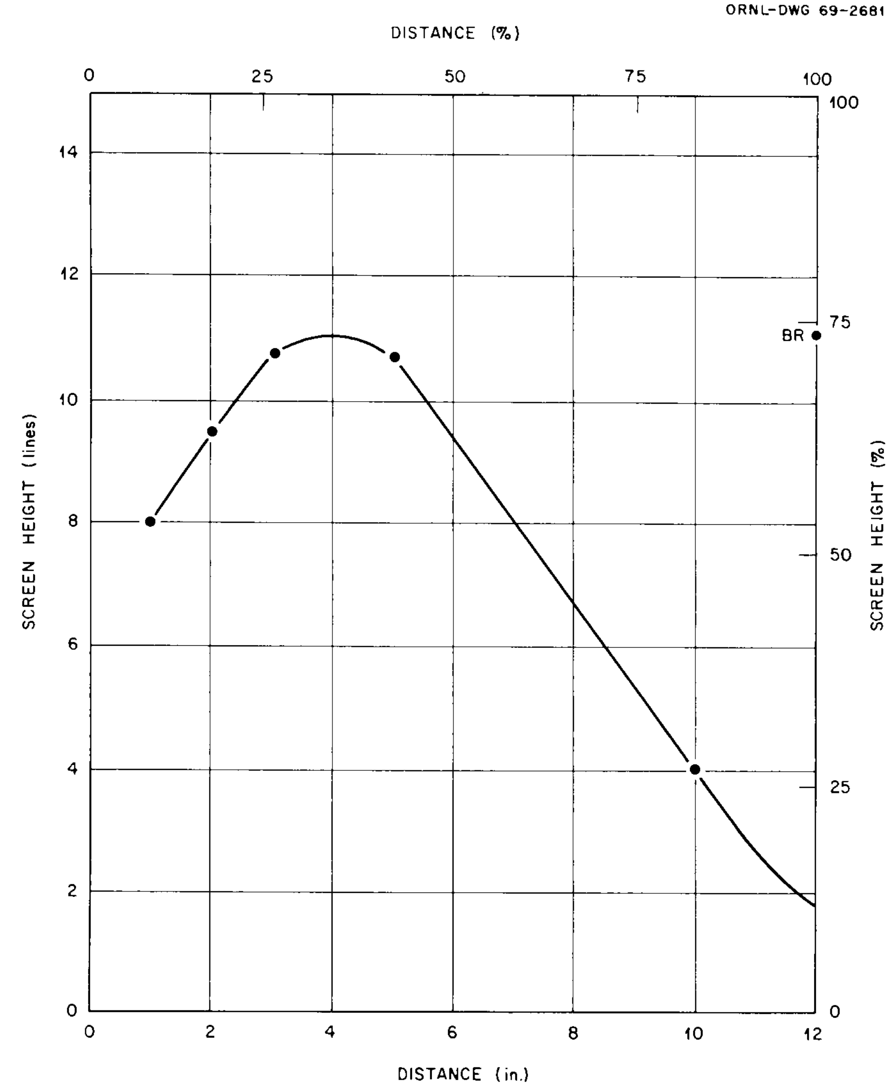


Fig. 1.22. Longitudinal-Wave DAC Curve.

F.2 Shear-Wave Inspection

The ultrasonic equipment for shear-wave inspection after heat treatment was calibrated essentially in the same manner as described in D.2, and the DAC curves shown in Fig. 1.23 were derived from this calibration procedure. It will be noted that the shear-wave DAC curves shown in Fig. 1.23 differ appreciably from those shown in Fig. 1.7. The fact that the curves plotted for the second ultrasonic inspection were made using a Reflectoscope UR-600 and those for the third inspection using a Reflectoscope UM-721 was probably a contributing factor. The use of 10-W SAE oil couplant for the second ultrasonic inspection and the use of a water-soap solution couplant for the third inspection were the only other major variations in the tests.

No "recordable" shear-wave indications were found during this inspection.

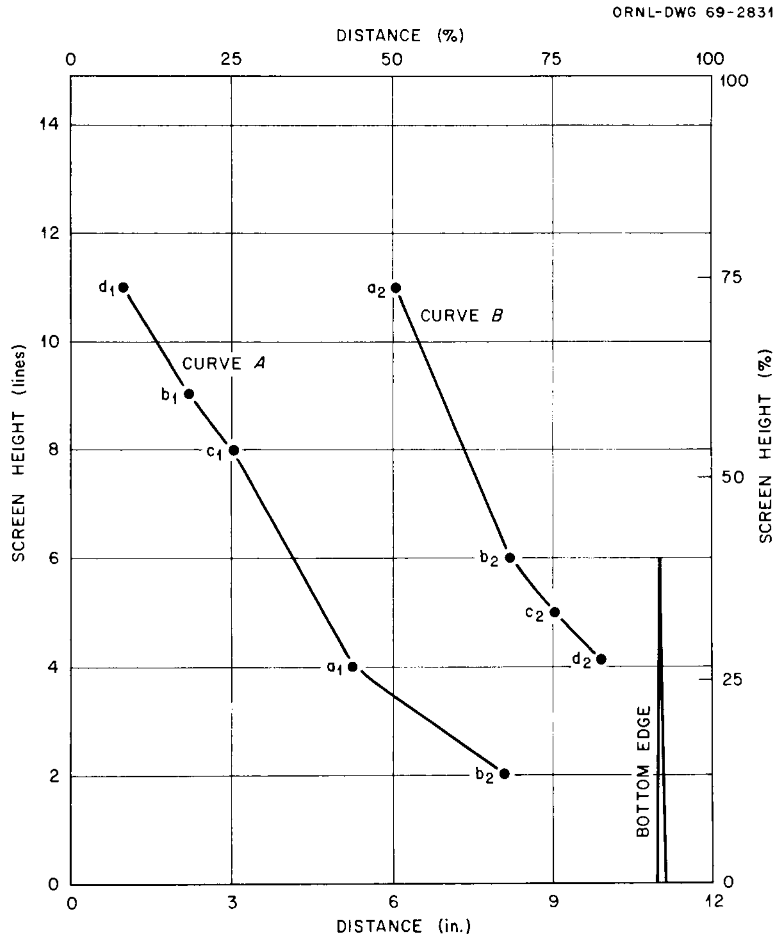


Fig. 1.23. Shear-Wave DAC Curves.

G. LAYOUT, IDENTIFICATION, AND CUTTING

The cutting plan for plate 03 was scribed on the top surface as shown in Fig. 1.24, in order to avoid interference with the thermocouple holes on the bottom surface. In accordance with a plan devised before plate 01 was sectioned, each of the resulting sections was stamped with the recognized HSST bench mark and an alignment mark. The arrow in the bench mark indicates the principal rolling direction and, unless otherwise indicated, points to the top ingot end. Plate number and plate section letter designations are stamped in the quadrants of the semicircle. The intersection of the two perpendicular lines is the point of the coordinates indicated. This system is explained in detail in a guide[4] which has been prepared for use by HSST program participants. These points (bench mark and alignment mark) thus established are described in terms of Cartesian coordinates, with the origin at the top left corner on the top surface when the plate is oriented as it was during the rolling operation. This usually places the origin at the top ingot end, the Y axis parallel to the principal rolling direction, and the X axis transverse to the rolling direction. Thickness would then be measured along the Z axis (Z = 0000 is the top surface).

[4]"A Guide for Material Control and Data Control for the Heavy Section Steel Technology Program," available through the office of the HSST Program Director.

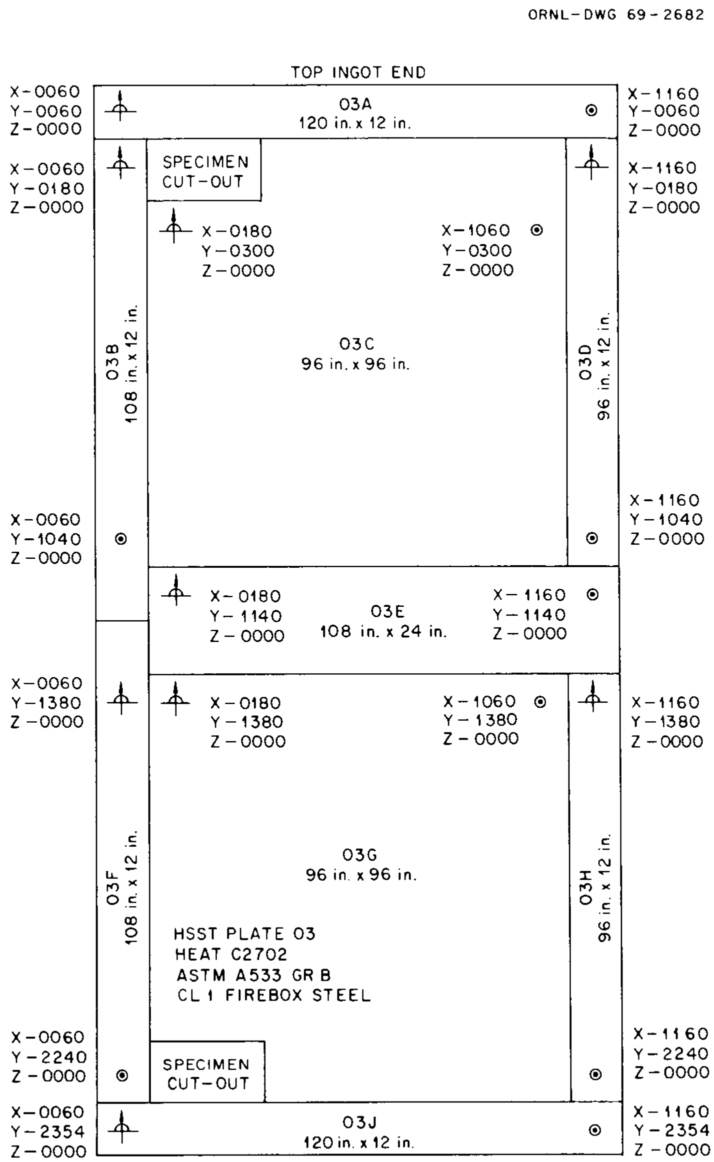


Fig. 1.24. Cutting Plan for Plate 03.

The first three digits of any coordinate point represent whole inches, and the fourth digit represents additional eighths of an inch from the appropriate zero plane. Through the application of this system location of all points in the plate can be established with respect to the origin, even after the plate is cut into sections or possibly subdivided further.

The plate was charged into the furnace and preheated to about 500°F. Immediately on withdrawal from the furnace, the plate sections were cut using a semiautomatic oxyacetylene burning apparatus.

H. STRESS RELIEF AFTER SECTIONING

With the plate sections still hot from preheating and cutting, each was loaded on the furnace car as shown in Fig. 1.25 and charged into the furnace for a post-gas-cut stress relief. Furnace couples only were used to record the temperatures for this heat treatment. Curves showing the spread in the thermocouple readings for this heat treatment are given in Fig. 1.26. Following a 12-hr hold period in the stress-relieving range of 1025 ± 25°F, the plates were cooled in the furnace.

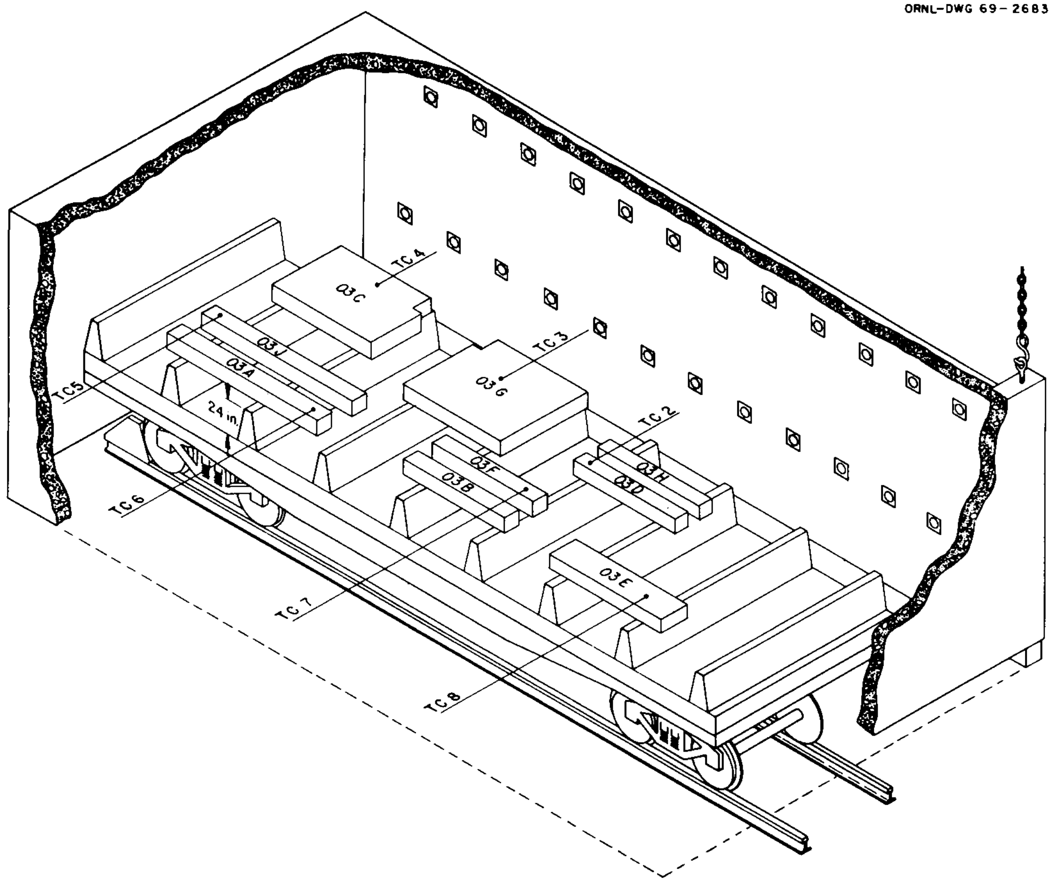


Fig. 1.25. Location of Thermocouples and Orientation of Plate Sections in the Stress-Relieving Furnace.

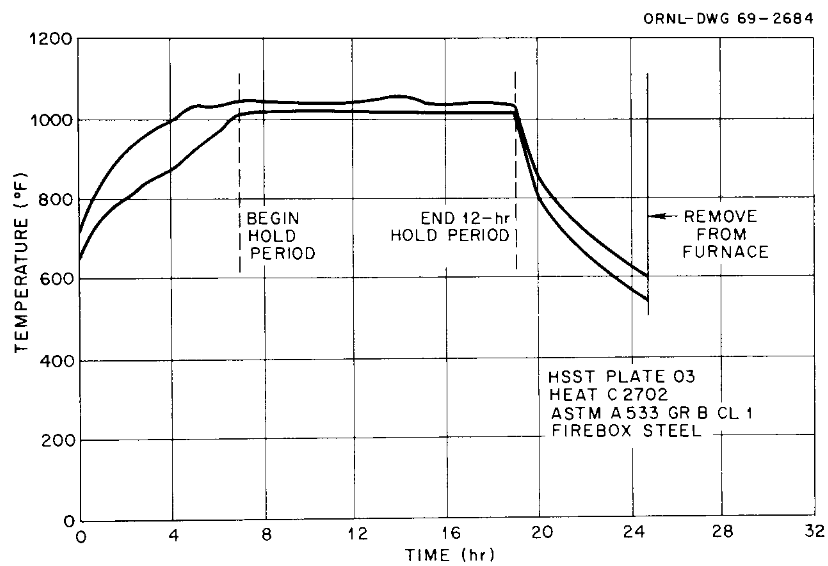


Fig. 1.26. Spread in Thermocouple Readings During Stress-Relief Heat Treatment After Cutting.

When the highest thermocouple reading had dropped below 600°F, the furnace car was withdrawn and the plate sections continued to cool in air to ambient temperature. Plate sections *3B, D, F,* and *H* were shipped directly to a program participant and the remainder to the HSST storage facility in Oak Ridge.

I. RESULTS OF QUALIFICATION AND DEVELOPMENT TESTING

As noted in Part A of this report, the purchase order for plate 03 specified that the plate be supplied in the as-rolled, stress-relieved condition for heat treatment by the purchaser. In order to assure that the physical properties of the plate, after heat treatment, would meet the original specification requirements, certain qualification tests were performed using the materials from the locations shown in Fig. 1.1. The plate qualification tests were made using tensile and Charpy V-notch specimens taken from the top and bottom 1/4 *T* locations in the test material. These specimens were subjected to a Data Trac heat-treatment cycle that simulated the heat treatment the full-size plate was originally scheduled to receive.

Contractually, the physical properties of the tensile specimens had to meet the requirements for ASTM A-533 grade B class 1 steel; the Charpy V-notch tests were required for information purposes only. The results of the plate qualification tests performed by Lukens are listed in Table 1.1.

In addition to the plate qualification tests which were required by the specification, Lukens performed some additional testing which they described as "development tests." Specimens for the development work were also removed from the peripheral material shown in Fig. 1.1. The development specimens, consisting of tensile and Charpy V-notch specimens, were prepared from material taken from the 1/4 *T* and 1/2 *T* locations and program heat treated as follows:

1. Normalized at 1800°F for a 12-hr hold and air cooled.
2. Austenitized at 1700°F for a 4-hr hold and cooled to simulate a water quench.
3. Reaustenitized at 1650°F for a 4-hr hold and cooled to simulate a water quench.
4. Tempered at 1225°F for a 4-hr hold and cooled to simulate a water quench.
5. Stress relieved at 1125°F for an 80-hr hold period and furnace cooled.

Table 1.1. Results of First Series of Plate Qualification Tests Performed by Lukens on HSST Plate 03

Location in Ingot	Through-Gage Location	Specimen Orientation	Yield Strength (ksi)	Ultimate Tensile Strength (ksi)	Percent Elongation	Percent Reduction of Area
			Tensile Tests			
Top	1/4 *T*	L	67.9	93.5	26	62.2
Top	1/4 *T*	L	60.4	92.5	27	67.0
Bottom	1/4 *T*	L	64.6	92.5	27	64.0
Bottom	1/4 *T*	L	71.5	93.6	28	66.3

Location in Ingot	Through-Gage Location	Specimen Orientation	Range and Average Readings for Set of CVN Specimens (ft-lb)			
			−20°F	0°F	+10°F	Room Temperature
			Charpy V-Notch Tests			
Bottom	1/4 *T*	L	18–28	26–41	44–51	76–89
			23	33	47	82

Table 1.2. Results of First Series of Development Tests Performed by Lukens on HSST Plate 03

Location in Ingot	Through-Gage Location	Specimen Orientation	Yield Strength (ksi)	Ultimate Tensile Strength (ksi)	Percent Elongation	Percent Reduction of Area
			Tensile Tests			
Top	1/4 *T*	L	71.0	92.0	24	62.0
Top	1/2 *T*	L	63.8	89.0	22	49.0
Bottom	1/4 *T*	L	63.9	86.9	25	66.9
Bottom	1/2 *T*	L	65.8	89.5	25	67.0
Top	1/4 *T*	T	69.6	94.4	24	59.2
Top	1/2 *T*	T	69.7	93.4	17	39.4

Location in Ingot	Through-Gage Location	Specimen Orientation	Readings for Set of CVN Specimens (ft-lb)		
			Room Temperature	+10°F	+50°F
			Charpy V-Notch Test		
Top	1/4 *T*	L	71, 66, 72, 67 66 av	8, 12, 8, 14 10 av	51, 54, 42, 50 49 av
Top	1/2 *T*	L		23, 18, 35, 38 28 av	
Bottom	1/4 *T*	L	97, 77, 81, 74 84 av		
Bottom	1/2 *T*	L		21, 41, 37, 35, 38, 46, 54, 40 39 av	
Top	1/4 *T*	T		13, 10, 17, 15 14 av	
Top	1/2 *T*	T		29, 27, 37, 35 32 av	

The results of the first series of development tests are listed in Table 1.2.

In addition to the development testing listed above, Lukens prepared transverse macroetch test specimens from the quarter-width locations at the top and bottom ingot ends of the plate. Transverse sulfur prints were also prepared from the same locations. Figures 1.27 and 1.28 show the macroetch tests, and Fig. 1.29 shows the sulfur prints. It will be noted from Fig. 1.29 that some sulfide segregation is present at the top ingot end of the plate; however, Lukens advised that in their opinion the general distribution was very good for a heavy-gage plate.

All of the above qualification and development tests were performed by Lukens while it was still considered that the plate would be heat treated as prescribed in the original purchase order (73Y-49288V). During negotiations prior to issuing the purchase order for heat treatment of the plates, Lukens advised that the heat treating procedure which they usually applied to A-533 Grade B steels to obtain class 1 properties consisted in the following:

1. Normalize at 1675° for a 12-hr hold and air cool.
2. Austenitize at 1575°F for a 12-hr hold.
3. Quench in agitated water.

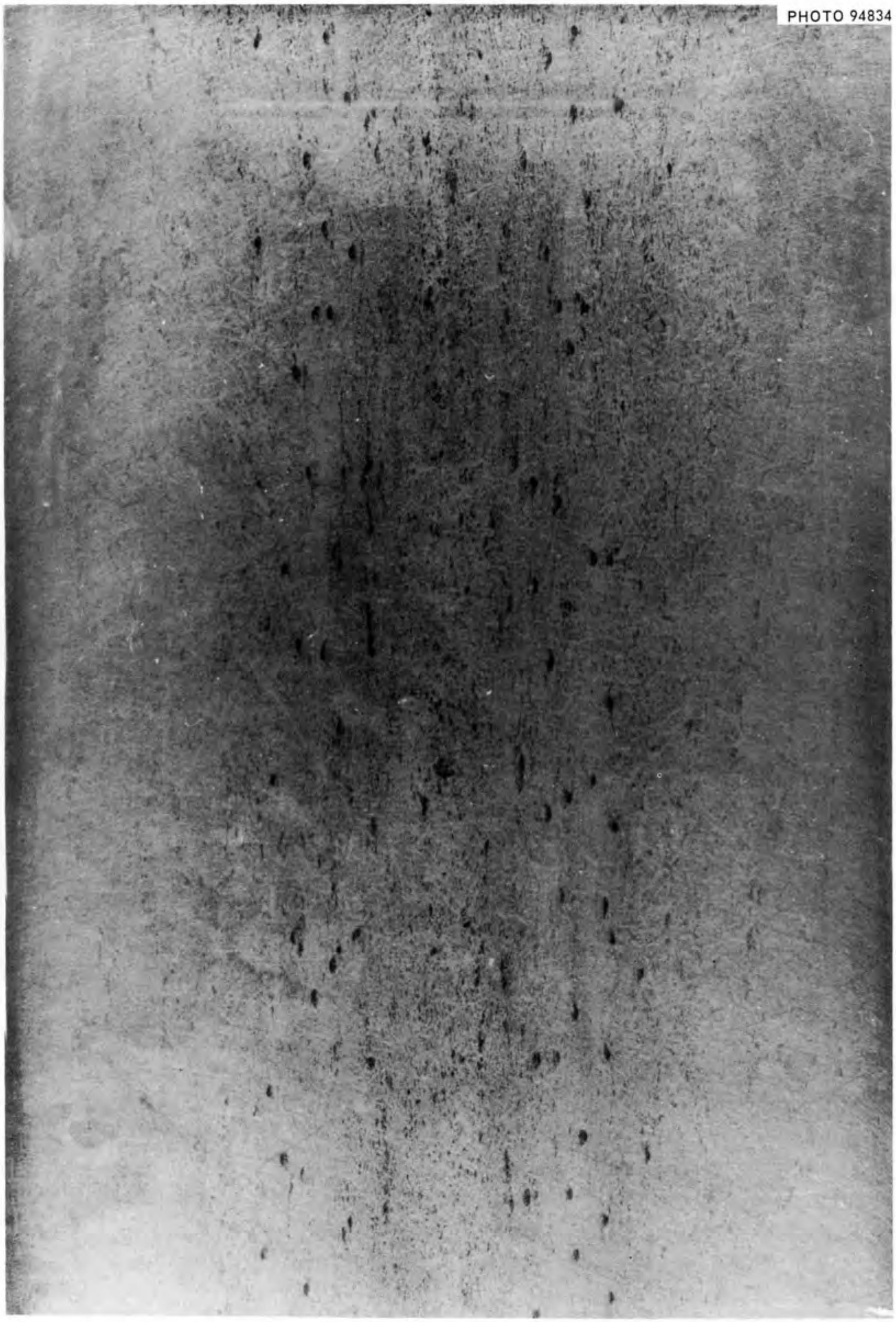


Fig. 1.27. Transverse Macroetch Specimen Taken from the Quarter-Width Position at the Top Ingot End of Heat C-2702.

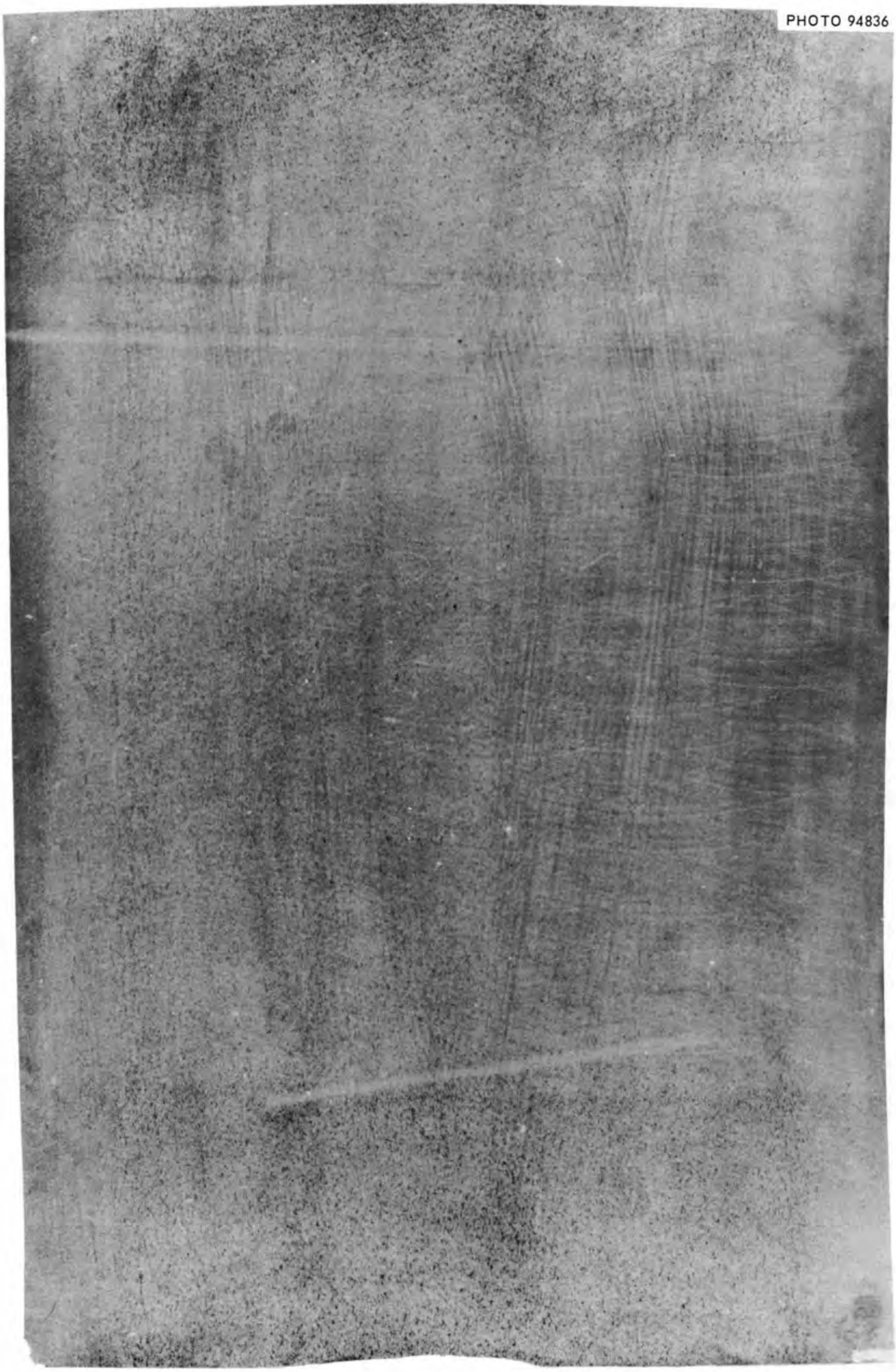


Fig. 1.28. Transverse Macroetch Specimen Taken from the Quarter-Width Position at the Bottom Ingot End of Heat C-2702.

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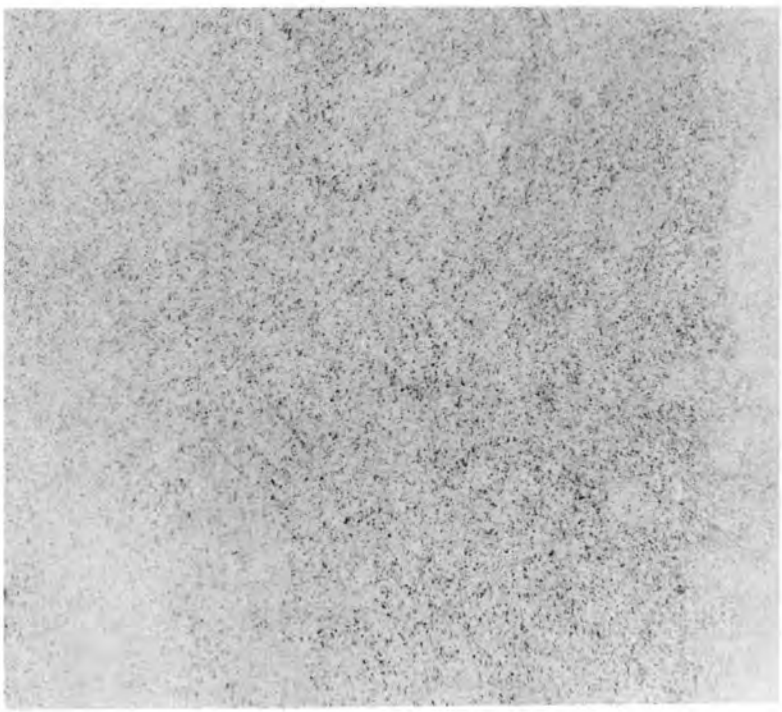
TOP TRANSVERSE, QUARTER WIDTH



BOTTOM TRANSVERSE, QUARTER WIDTH

Fig. 1.29. Sulfur Prints. Top: top transverse, quarter width; bottom: bottom transverse, quarter width.

4. Temper at 1225°F for a 12-hr hold and furnace cool to 600°F.
5. Stress relieve (before flame cutting) at 1125°F for a 40-hr hold and furnace cool to 600°F.
6. Stress relieve (after flame cutting) at 1025°F for a 12-hr hold and furnace cool to 600°F.

Since Lukens ultimately was selected as the vendor to heat treat the plate, it was now necessary to perform additional plate qualification tests on the material heat treated in accordance with the procedure to determine the resultant mechanical properties. All plate qualification specimens (and additional development test specimens) were removed from the locations shown in Fig. 1.21. The plate qualification test specimens (tensile and Charpy V notch) were made from material removed from the top and bottom 1/4 *T* positions. Each specimen was made from plate material that had been subjected to the heat treatment cycle actually applied to the plate. The results of the second plate qualification tests are shown in Table 1.3. The results of the second series of development tests are shown in Tables 1.4 and 1.5.

Table 1.3. Results of Second Series of Plate Qualification Tests Performed by Lukens on HSST Plate 03

Location in Ingot	Through-Gage Location	Specimen Orientation	Yield Strength (ksi)	Ultimate Tensile Strength (ksi)	Percent Elongation	Percent Reduction of Area
			Tensile Tests			
Top	Top 1/4 *T*	L	68.2	91.8	23	71.2
Top	Top 1/4 *T*	L	69.0	92.5	24	69.6
Top	Top 1/4 *T*	T	68.9	92.5	23	73.4
Bottom	Top 1/4 *T*	L	67.1	87.5	25	68
Bottom	Top 1/4 *T*	L	64.6	87.5	26	68
Bottom	Top 1/4 *T*	T	64.8	87.5	26	75
Bottom	Top 1/4 *T*	T	64.2	87.0	26	71
Top	Bottom 1/4 *T*	L	69.5	93.0	23	69.4
Top	Bottom 1/4 *T*	L	69.4	92.6	23	69.4
Top	Bottom 1/4 *T*	T	69.3	93.0	21	79.7
Top	Bottom 1/4 *T*	T	69.1	92.1	21	73.9
Bottom	Bottom 1/4 *T*	L	63.6	86.6	26	66.2
Bottom	Bottom 1/4 *T*	L	63.8	86.1	26	67.2
Bottom	Bottom 1/4 *T*	T	65.2	87.6	26	60.4
Bottom	Bottom 1/4 *T*	T	66.0	88.0	24	62.5

Location in Ingot	Through-Gage Location	Specimen Orientation	ft-lb at 10°F, Range of CVN Specimens	30 ft-lb CVN Trans. Temperature (°F)	Actual NDT (°F) Determined by P-2 Drop Weight Specimens	ft-lb at NDT	Temperature (°F) at Lateral Exp.	
							15 mils	30 mils
			Charpy and Drop Weight Tests					
Top	Top 1/4 *T*	L	50 +1 −0	−4	0	32	−33	+1
		T	39 +1	−10		35	−34	0
Top	Bottom 1/4 *T*	L	35 ±5	+2	−20	17	−19	+12
		T	28 ±6 −5	+16		17	−25	+25
Bottom	Top 1/4 *T*	L	29 +11 −14	+11	−10	14	−10	+13
		T	22 +3 −2	+24		18	−13	+28
Bottom	Bottom 1/4 *T*	L	38 +7 −10	+2	−10	16	−10	+9
		T	27 +3 −2	+14		17	−20	+15

Table 1.4. Results of Second Series of Tensile Development Tests Performed by Lukens on HSST Plate 03

Location in Ingot	Through-Gage Location	Specimen Orientation	Yield Strength (ksi)	Ultimate Tensile Strength (ksi)	Percent Elongation	Percent Reduction of Area
Top	Top surface	L	80.3	97.5	24	65.8
Top	Top surface	L	78.9	97.0	23	67.5
Top	Top surface	T	79.7	97.5	24	70.6
Top	Top surface	T	80.5	98.5	24	71.9
Bottom	Top surface	L	76.7	96.5	26	71.7
Bottom	Top surface	L	75.8	96.0	25	70.9
Bottom	Top surface	T	72.0	96.6	25	65.2
Bottom	Top surface	T	74.2	95.0	24	67.2
Top	1/2 *T*	L	71.8	96.0	21	74.2
Top	1/2 *T*	L	71.5	95.0	21	72.2
Top	1/2 *T*	T	70.3	94.6	17	83.9
Top	1/2 *T*	T	71.1	95.0	20	80.7
Bottom	1/2 *T*	L	64.0	86.2	26	66.0
Bottom	1/2 *T*	L	63.9	86.1	26	68.3
Bottom	1/2 *T*	T	62.5	83.7	26	62.9
Bottom	1/2 *T*	T	65.1	84.6	27	63.7
Top	Bottom surface	L	81.7	99.5	23	65.6
Top	Bottom surface	L	81.6	98.0	23	76.0
Top	Bottom surface	T	80.0	99.0	23	71.5
Top	Bottom surface	T	82.1	100.0	23	72.0
Bottom	Bottom surface	L	74.1	94.6	29	70.8
Bottom	Bottom surface	T	74.0	94.6	26	61.9
Bottom	Bottom surface	T	74.1	94.5	26	67.2
Bottom	Bottom surface	T	72.1	94.0	26	67.2

Table 1.5. Results of Second Series of Charpy and Drop Weight Development Tests Performed by Lukens on HSST Plate 03

Location in Ingot	Through-Gage Location	Specimen Orientation	ft-lb at 10°F, Range of 3 CVN Specimens	30 ft-lb CVN Trans. Temperature (°F)	Actual NDT (°F) Determined by P-2 Drop Weight Specimens	ft-lb at NDT	Temperature (°F) at Lateral Exp. 15 Mils	Temperature (°F) at Lateral Exp. 30 Mils
Top	Top surface	L	110 ±0	−184	−110	48	−210	−140
		T	80 ±0	−120		32		−124
Top	1/2 *T*	L	25 ±4	+22	0	20	−8	+37
		T	23 +4 −3	+30		18	−8	+36
Top	Bottom surface	L	109 ±1	−120	−130	22	−134	−108
		T	81 ±1	−105		15	−128	−97
Bottom	Top surface	L	76 +1 −2	−92	−50	48	−123	−81
		T	66 +9 −4	−92		50	−123	−80
Bottom	1/2 *T*	L	51 +7 −8	−10	−20	20	−30	−8
		T	36 ±6	+1		14	−23	+6
Bottom	Bottom surface	L	61 +4 −2	−76	−50	36	−117	−55
		T	66 +5 −4	−70		39	−105	−64

Specimens for homogeneity tests were removed from the 1/4 *T* locations at the top and bottom ingot ends. Each was considered to be satisfactory; no evidence of shelving or mechanical discontinuity was noted.

Figures 1.30 and 1.31 illustrate the through-gage microstructure at the top and bottom ingot ends of the plate. Lukens' metallurgists analyzed the microstructure specimens and concluded that "at the surfaces no banding is apparent, and the structure consists entirely of fine carbides with some degree of acicularity, plus small dispersed proeutectoid ferrite grains. This structure coarsens and becomes less acicular towards the center of the plate, and some banding is noticeable."

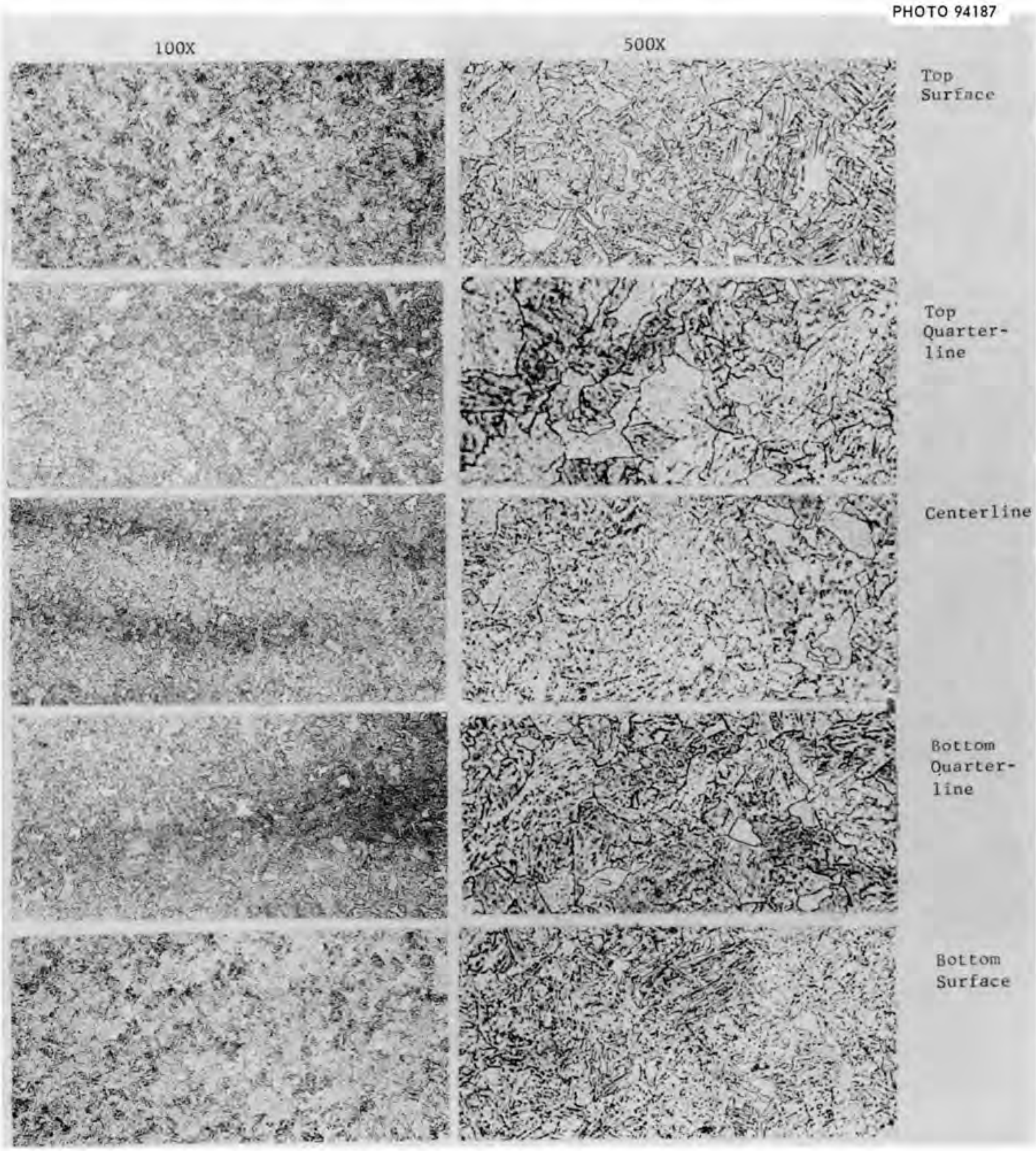


Fig. 1.30. Microstructure at the Top Ingot End of Plate 03, After Heat Treatment. Reduced 21%.

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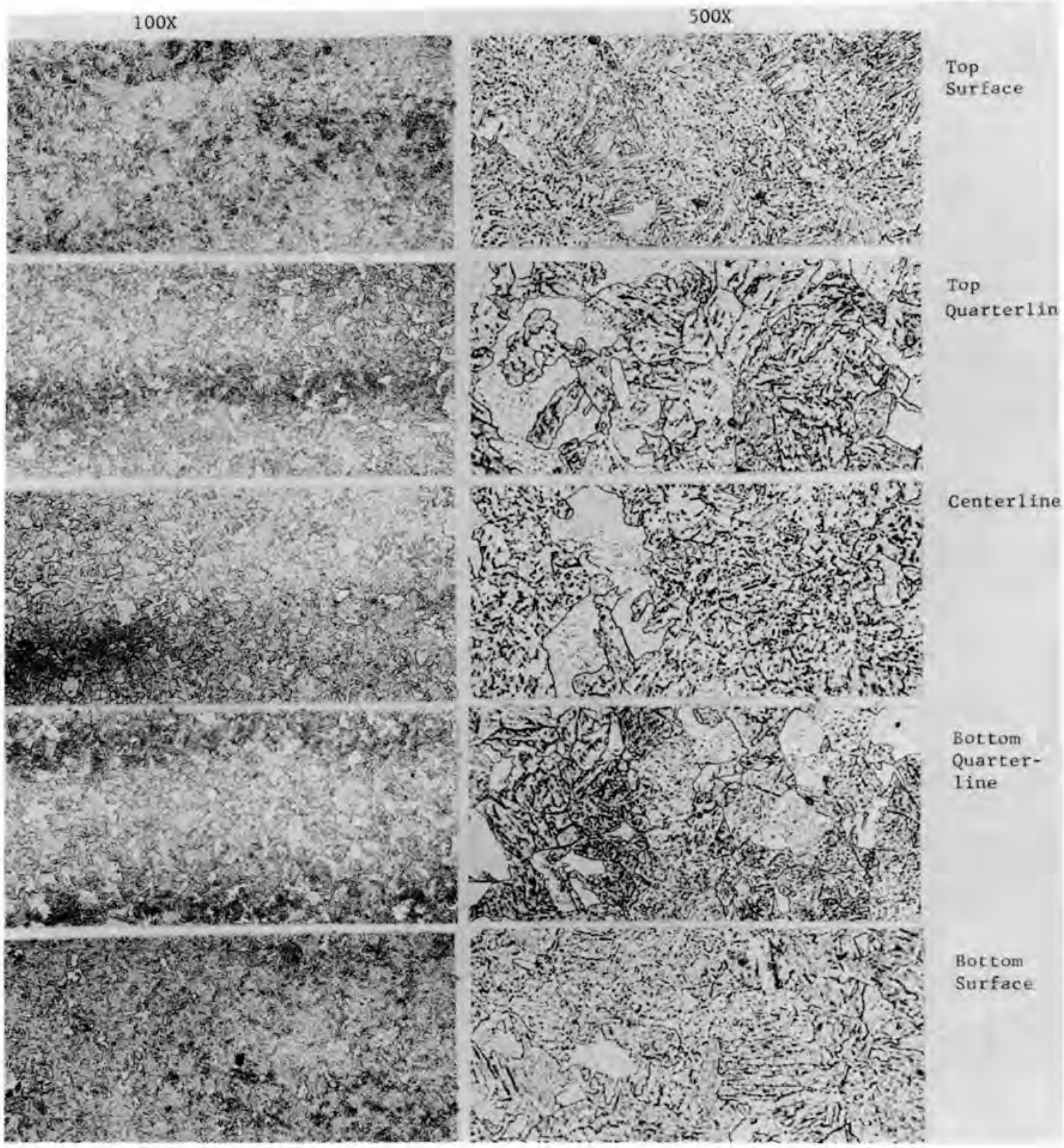

Fig. 1.31. Microstructure at the Bottom Ingot End of Plate 03, After Heat Treatment. Reduced 21%.

2. PLATE 04

J. ROLLING, PRELIMINARY INSPECTION, AND TESTING OF THE FOURTH HSST PLATE

The fourth plate for the HSST program was rolled from slab to plate at Lukens' Coatesville, Pennsylvania, mill in April 1967. Following rolling, the plate was marked at each end so that the top ingot end could be distinguished from the bottom ingot end after the plate was trimmed to pattern size. After trimming, the plate measured 120 in. wide X 240 in. long X 12 in. thick and weighed slightly more than 50 tons. Lukens reported the following information for the fourth plate:

Material Identification

Heat C2748, specification A-533, grade B
Ingot 2
Plate 2

Melting and Casting History

Furnace number – "C"
Furnace type – BEF (basic electric furnace)
Charge materials –cold charge
Tap temperature – 2980°F
Ladle temperature – 2910°F
Deoxidation practice – 0.02% Al and 0.04% V added
Degassing – Yes
Type of degassing process – D.H. (Dortmund and Horder) vacuum lifter type
Teeming practice – top
Teeming time – 7 min
Ingot size – width 108 in., thickness 40 in., height 126 in., weight 136,000 lb
Ingot type – slab
Hot top type – disposable cast refractory, insulating only

Heating and Rolling History

Soaking time – 19 hr 20 min
Soaking temperature – 3 hr 40 min at 2350°F
Rolling practice – slab to 28-in. gage, condition grind, roll to plate; cross-rolling ratio – 1.89:1
Heat-treatment history:
Subcritical – 1150 to 1200°F, cool 100°F/hr to 600°F

The first five illustrations in this portion of the report show heat 2748 at various stages in the rolling process. Figure 2.1 shows the slab being removed from the soaking pit. At this stage the slab is loaded on a car and conducted to a conveyor that will carry the slab to the reducing rolls. In Fig. 2.2 the slab is shown at the entrance side of the reduction rolls before any rolling has begun.

Figure 2.3 shows the slab after it has been through the reduction rolls a few times. Note the burning burlap on the surface of the slab which is used to remove surface oxides. In Fig. 2.4, rolling is about half complete, and the plate is being lifted so that the bottom side can be inspected for surface imperfections. In the last picture of this series, Fig. 2.5, the rolling has been completed and the plate is being conveyed to the cooling area.

Fig. 2.1. Slab of A-533, Grade B, Class 1 Material Being Removed from the Soaking Pit.

Fig. 2.2. Slab of A-533, Grade B, Class 1 Material Immediately Prior to Rolling.

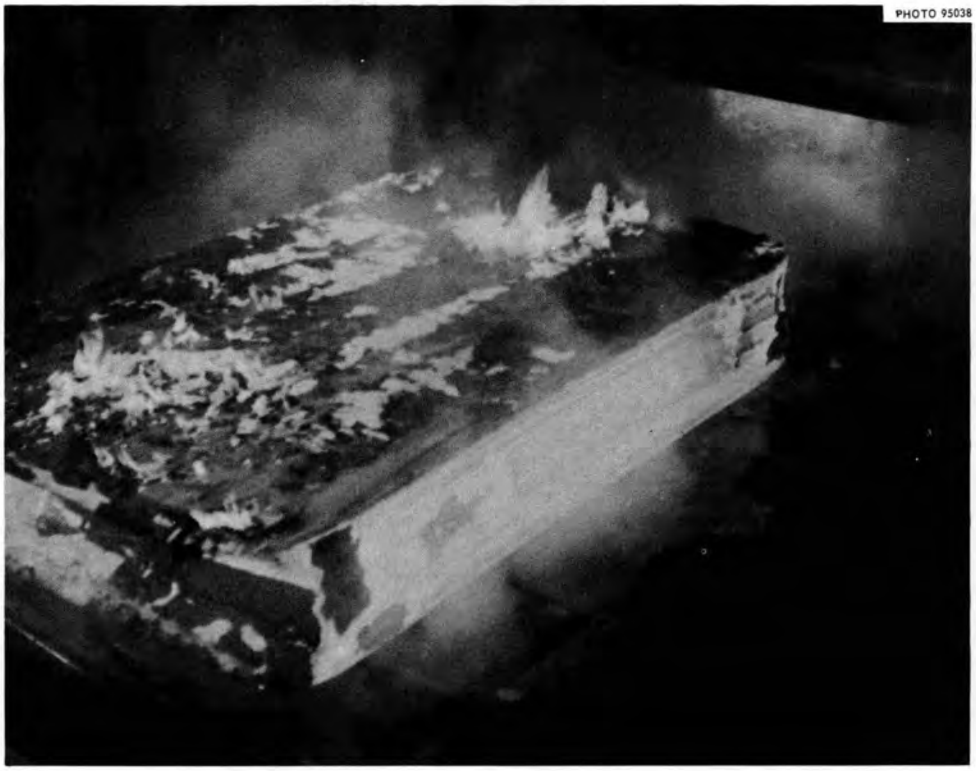

Fig. 2.3. Slab of A-533, Grade B, Class 1 Material After the First Few Passes Through the Reduction Rolls.

Fig. 2.4. Bottom of Slab Being Inspected for Surface Imperfections.

Fig. 2.5. The Fourth HSST Plate Shown Immediately on Completion of Rolling.

Material for plate qualification and development testing was removed from the trim areas as shown in Fig. 2.6. Specimens machined from these areas were processed through Lukens Programmed Testing Procedure,[5] each being subjected to a heat treatment cycle similar to that which the full-size plate was originally scheduled to receive. The plate qualification specimens were:

1. Austenitized at 1550 to 1650°F for a 4-hr hold period.
2. Program cooled at the rate shown in Fig. 1.2 for 12-in.-thick plate.
3. Tempered at 1200 to 1250°F for a 4-hr hold period and air cooled to ambient temperature.
4. Stress relieved at 1125 to 1175°F for a 20-hr hold period, furnace cooled to 600°F, and air cooled to ambient temperature.

The results of the Data Trac processed plate qualification tests, heat treated as shown above, are listed in Table 2.1.

Specimens for check chemical analysis were obtained from the bottom ingot end of the plate at the midwidth 1/4 *T* location. The results of the ladle and check analyses are:

	C	Mn	P	S	Cu	Ni	Cr	Mo	Si	V	Al
Ladle	0.23	1.29	0.010	0.018	0.14	0.60	0.09	0.50	0.24	0.04	0.021
Check	0.28	1.48	0.009	0.015	0.12	0.62	0.14	0.49	0.25		0.030

[5] J. H. Scott, "New Test Method Promises Major Cost Savings in Construction of Big Pressure Vessels," ASME Paper 67-MET-24.

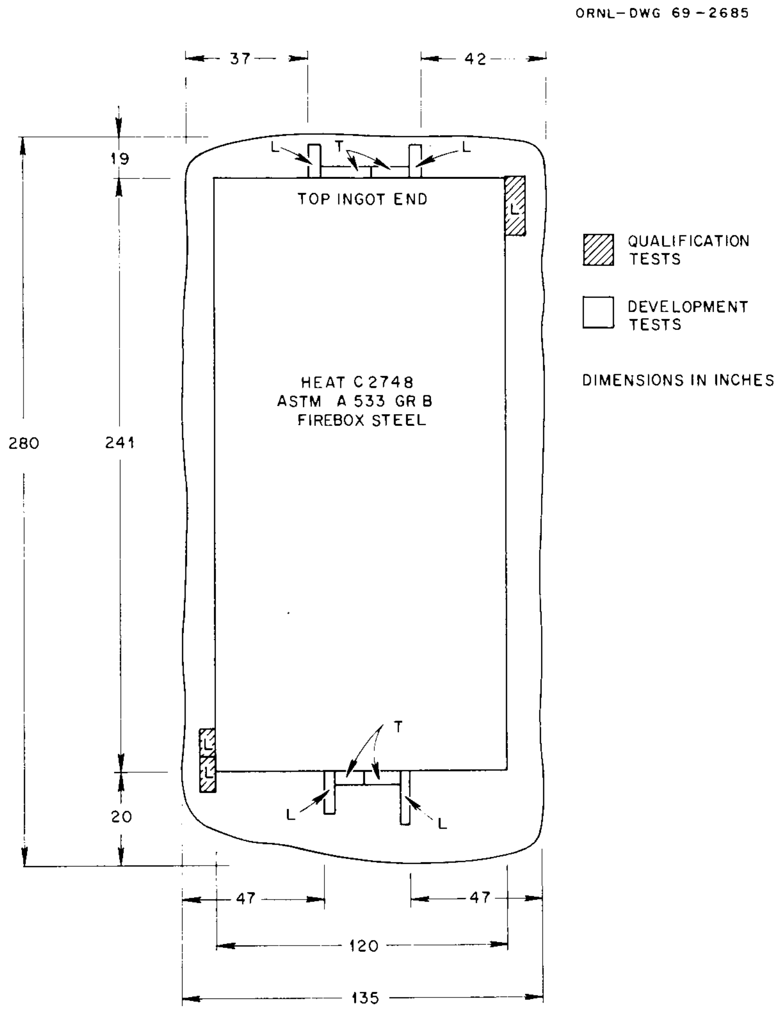

Fig. 2.6. Location of Test Specimens.

Table 2.1. Results of First Series of Plate Qualification Tests Performed by Lukens on the Fourth HSST Plate

Location in Ingot	Through-Gage Location	Specimen Orientation	Yield Strength (ksi)	Ultimate Tensile Strength (ksi)	Percent Elongation	Percent Reduction of Area
			Tensile Tests			
Top	1/4 *T*	L	77.0	95.0	24	66.0
Top	1/4 *T*	L	72.8	94.0	24	64.5
Bottom	1/4 *T*	L	70.1	94.0	25	64.5
Bottom	1/4 *T*	L	72.8	94.5	26	64.5

Location in Ingot	Through-Gage Location	Specimen Orientation	Range and Average Readings for Set of CVN Specimens (ft-lb): +10°F	Range and Average Readings for Set of CVN Specimens (ft-lb): Room Temperature
		Charpy V-Notch Tests		
Bottom	1/4 *T*	L	14, 19, 13, 11 14	54, 45, 47 48

Lukens also conducted a series of "development" tests using the materials designated as such in Fig. 2.6. The development tests included tensile and Charpy V-notch specimens, and each was program heat treated as follows:

1. Normalized at 1800°F for a 12-hr hold and air cooled.
2. Austenitized at 1700°F for a 4-hr hold and cooled to simulate a water quench.
3. Reaustenitized at 1650°F for a 4-hr hold and cooled to simulate a water quench.
4. Tempered at 1225°F for a 4-hr hold and cooled to simulate a water quench.
5. Stress relieved at 1125°F for an 80-hr hold and furnace cooled.

The results of the development tests are listed in Table 2.2.

Macroetch tests and sulfur prints for this heat are shown in Figs. 2.7–2.9. Figure 2.9 shows some sulfide segregation at the top of the plate, but the general distribution appears to be satisfactory. Macro chemical segregation is not evident.

Table 2.2. Results of First Series of Development Tests Performed by Lukens on the Fourth HSST Plate

Location in Ingot	Through-Gage Location	Specimen Orientation	Yield Strength (ksi)	Ultimate Tensile Strength (ksi)	Percent Elongation	Percent Reduction of Area
			Tensile Tests			
Top	1/4 *T*	L	81.9	101.5	24	64.7
Top	1/4 *T*	L	69.7	90.7	25	64.9
Top	1/2 *T*	L	81.0	101.0	25	56.0
Top	1/2 *T*	L	80.8	101.9	21	55.2
Bottom	1/4 *T*	L	71.2	91.4	24	64.1
Bottom	1/4 *T*	L	71.0	90.9	24	65.7
Bottom	1/2 *T*	L	69.6	83.3	26	64.1
Top	1/2 *T*	L	81.2	102.5	21	50.5
Top	1/2 *T*	L	66.8	87.2	14	29.1

Location in Ingot	Through-Gage Location	Specimen Orientation	Range and Average Readings for Set of CVN Specimens (ft-lb)	
			+10°F	+50°F
			Charpy V-Notch Tests	
Top	1/4 *T*	L	32, 12, 12, 40, 21, 32, 28, 14 24 av	54, 33, 49, 42 44 av
Top	1/2 *T*	L	13, 15, 22, 16, 24, 21, 18, 20 19 av	29, 37, 42, 42 37 av
Bottom	1/4 *T*	L	9, 12, 8, 4, 13, 12, 11, 12 11 av	
Bottom	1/2 *T*		10, 33, 16, 11 18 av	45, 35, 37, 36 38 av
Top	1/2 *T*	T	13, 11, 8, 10, 11, 8, 10 10 av	
Bottom	1/2 *T*	T	38, 30, 34, 34 34 av	

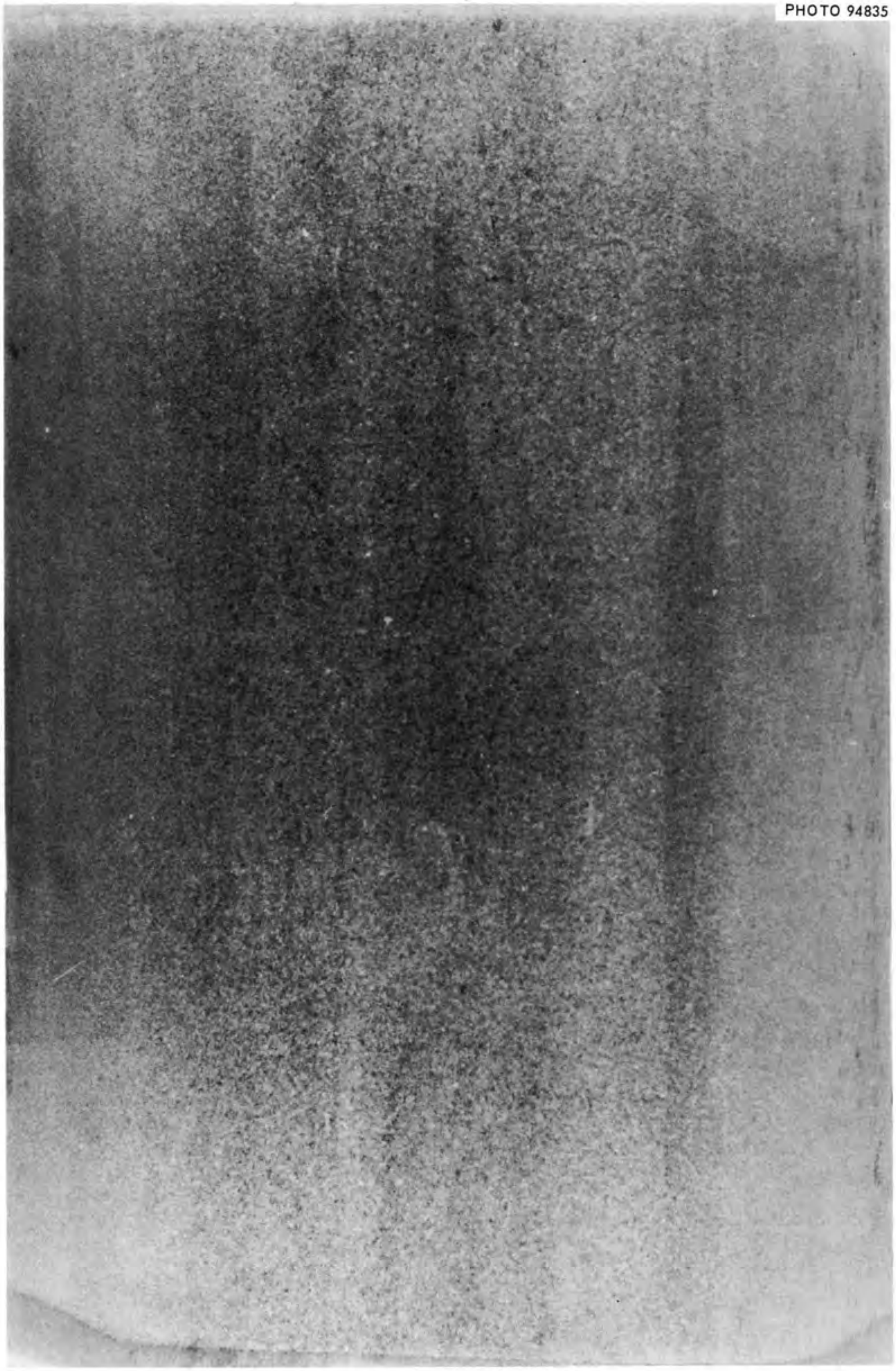

Fig. 2.7. Transverse Macroetch Specimen Taken from Midwidth at the Top Ingot End of Heat C-2748.

Fig. 2.8. Transverse Macroetch Specimen Taken from Midwidth at the Bottom End of Heat C-2748.

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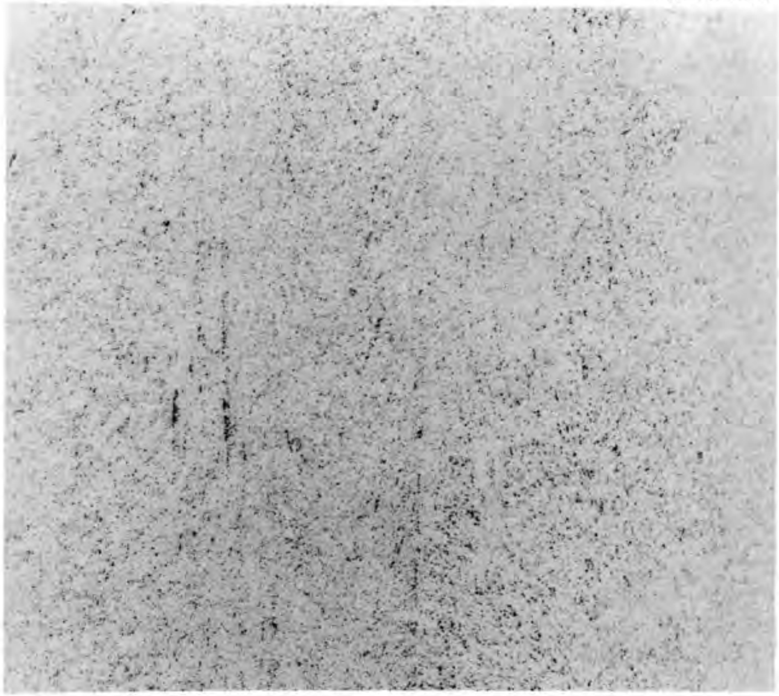
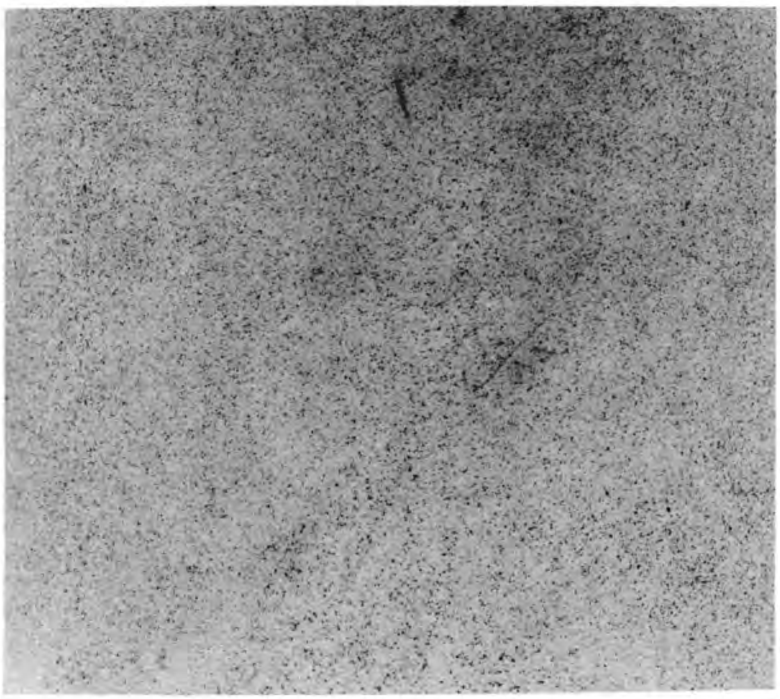


TOP TRANSVERSE, MIDWIDTH



BOTTOM TRANSVERSE, MIDWIDTH

Fig. 2.9. Sulfur Prints. Top: top transverse, midwidth; bottom: bottom transverse, midwidth.

K. FIRST ULTRASONIC INSPECTION OF PLATE

On April 30, 1967, Lukens performed ultrasonic inspection of the plate for information purposes only per ASTM A-435, except that coverage was 100%. They used a UM-700 instrument, water-soap solution couplant, a $1\frac{1}{8}$-in.-diam crystal, and scanned the plate at a frequency of 1 MHz. The plate was in the as-rolled, stress-relieved condition. Plates considered to be rejectable by this specification are those containing indications which cause a complete loss of back-surface reflection not containable within a 3-in.-diam circle, or a circle whose diameter is one-half the plate thickness, whichever is greater.

Three indications were found by this inspection which caused a complete loss of back-surface reflection. Two of these, 1 and 17 (see Fig. 2.10), were of sufficient size to have rendered the plate rejectable, had the rejection criteria been based on A-435. It is noteworthy, however, that each is located at an extreme edge of the plate. The third "recordable" indication, 13, was no larger than crystal size. The remaining indications shown in Fig. 2.10 caused greater than 50% loss of back-surface reflection but less than 100%, and these were recorded for information purposes only.

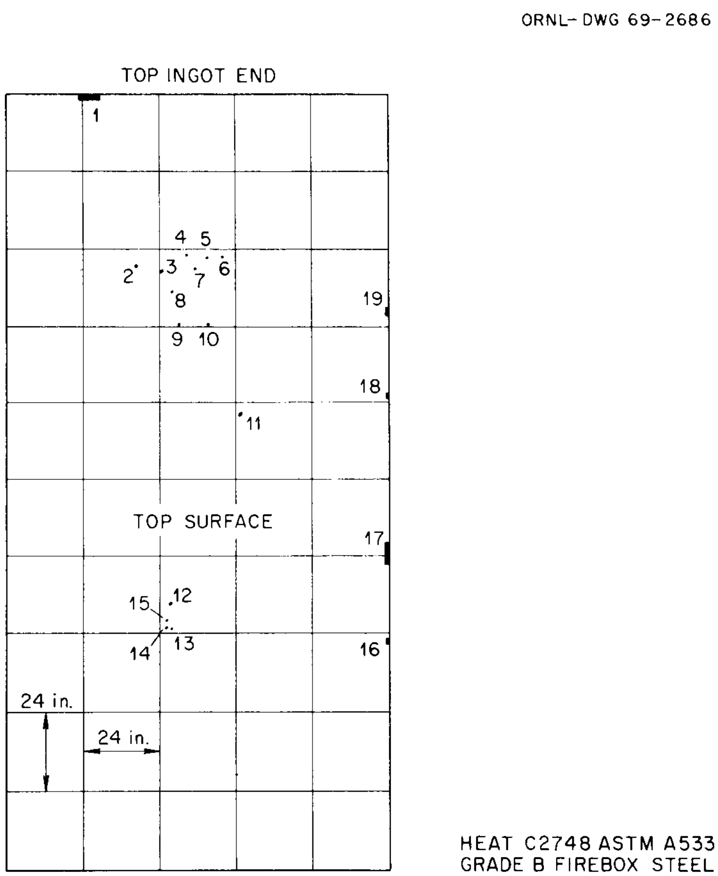


Fig. 2.10. Location of Ultrasonic Indications Found During First UT Inspection.

L. SECOND ULTRASONIC INSPECTION OF PLATE

After Lukens had completed the first ultrasonic inspection of the plate, a contract was negotiated between Lukens and UCCND whereby Lukens would (1) cut plate 04 into four smaller sections, (2) reroll portions of the plate to 8-in. and 4-in. gage, (3) heat treat portions of the as-rolled and rerolled plate to obtain class 2 mechanical properties, and (4) perform ultrasonic inspection on certain of the as-rolled and rerolled plates. The processing sequence for the fourth HSST plate including the rerolled sections is listed in Fig. 2.11. The contract did not require Lukens to ultrasonically inspect the plate before cutting. In order that this information could be made available for comparison with the results after heat treatment, personnel from ORNL ultrasonically inspected the plate in accordance with Attachments 2A and 2B of the PVRC subcommittee report of April 10, 1967, before heat treatment.

The plate top surface was prepared for inspection by buffing with a floor sander until the average surface finish was about 250 rms. Inspection was performed using a UM-721 Reflectoscope and a 2.25-MHz, 1⅛-in.-diam, internally grounded quartz crystal; glycerin couplant was used exclusively. Calibration of the instrument was accomplished essentially as described in D.1. DAC curves very similar to the ones shown in Figs. 1.5 (longitudinal wave) and 1.7 (shear wave) were developed using the calibration block shown in Fig. 1.4. Scanning of the plate was also performed essentially as described in D.1 and D.2.

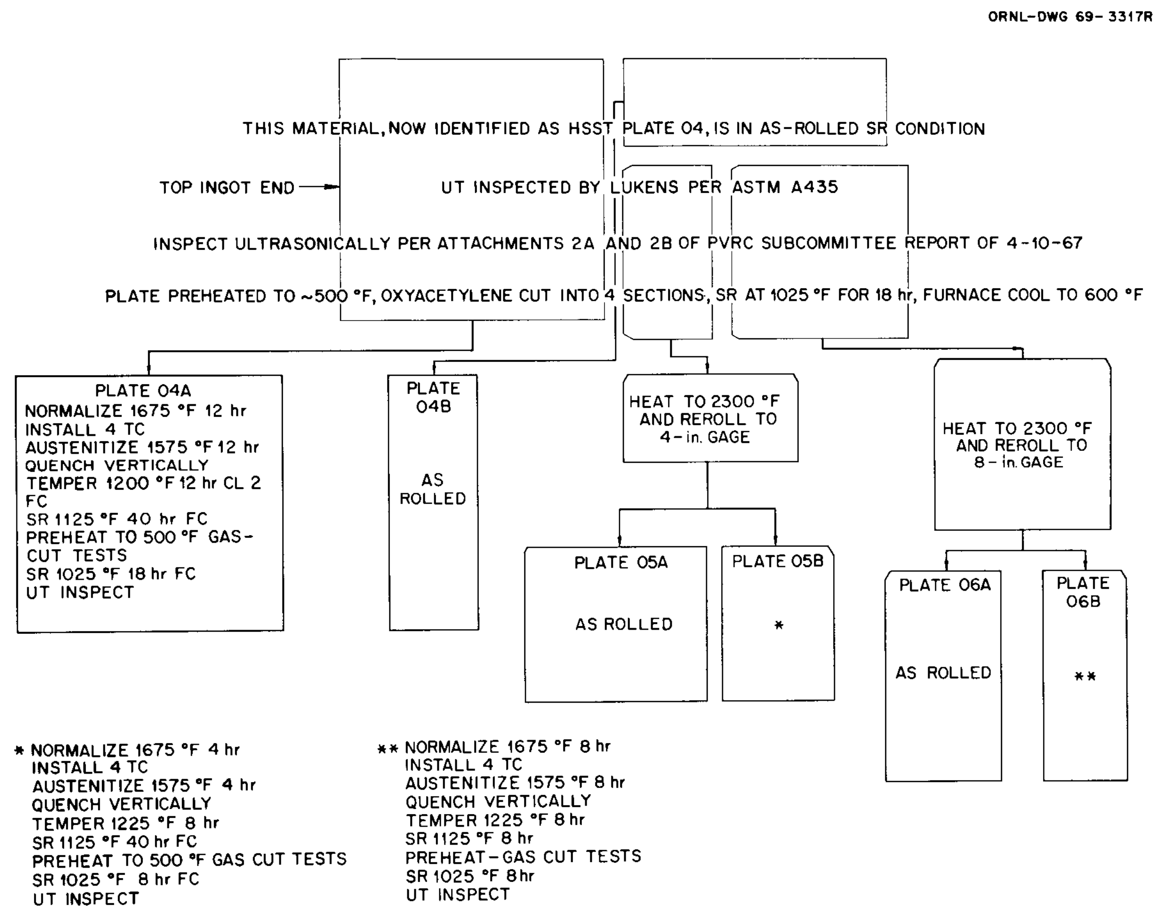


Fig. 2.11. Processing Sequence for the Fourth HSST Plate.

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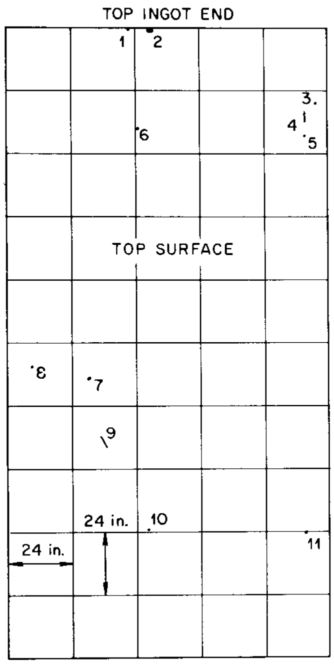

"RECORDABLE" ULTRASONIC INDICATIONS FOUND BY ORNL

INDICATION	DEPTH (in.)	PERCENT OF DAC	PERCENT LOSS OF BACK SURFACE REFLECTION
10	6	115	90
		"NONRECORDABLE"	
1		< 10	90
2		< 10	90
3		< 10	90
4		< 10	90
5		< 10	90
6		< 10	92
7		< 10	93
8		< 10	90
9		< 10	90
11		< 10	90

HEAT C2748
ASTM A533 GRADE B
FIREBOX STEEL

Fig. 2.12. Location of Ultrasonic Indications Found During Second UT Inspection.

As in the case of the previous plate (plate 03) the criteria for "recordable" indications were those causing complete loss of back-surface reflection and/or producing signals equal to or exceeding the height of the DAC curves. Only one indication, 10, shown in Fig. 2.12, was considered to be "recordable" by these standards. This indication produced a signal that exceeded the height of the longitudinal-wave DAC curve, although a faint trace of back-surface signal was still visible. Similarly, a small back-surface signal was visible on the other ten indications, but only a trace of signal was produced under the DAC curve. No "recordable" shear-wave indications were noted.

M. IDENTIFICATION, CUTTING, AND STRESS RELIEVING

On October 26, 1967, the plate was preheated in a natural-gas-fired furnace until the temperature of the plate was about 500°F. The plate was withdrawn from the furnace, and the cutting diagram was scribed on the top surface. The plate was then oxyacetylene cut into four pieces according to the diagram. The two pieces scheduled to be rerolled to 4-in. and 8-in. gage were chamfered at the two corners nearest the top ingot end, so that the original orientation could be maintained after rerolling.

Immediately upon completion of cutting, the plate sections were placed on a furnace car, as shown in Fig. 2.13, and charged into Lukens' furnace 2 and stress relieved for 18 hr at 1025 ± 25°F. Figure 2.14 is a plot of the stress-relief data compiled from the furnace temperature recorder chart. On completion of the 18-hr hold period, the firing units were shut off, and the plate sections were left in the furnace until the furnace couples were recording temperatures below 600°F.

When the plate sections had cooled to ambient temperature, the section which measured 120 × 40 × 12 in. thick (subsequently identified as HSST plate section 04B) was shipped to the HSST storage facility.

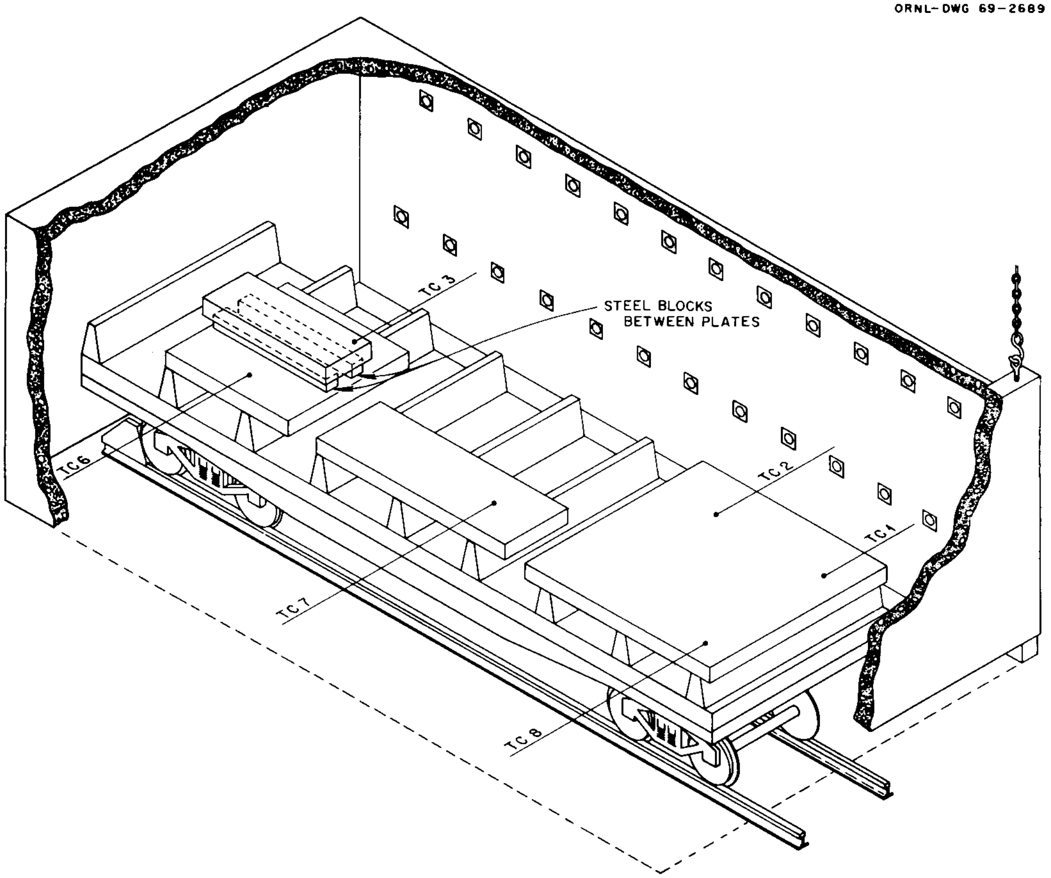

Fig. 2.13. Orientation of Plates in the Stress-Relieving Furnace, After Cutting.

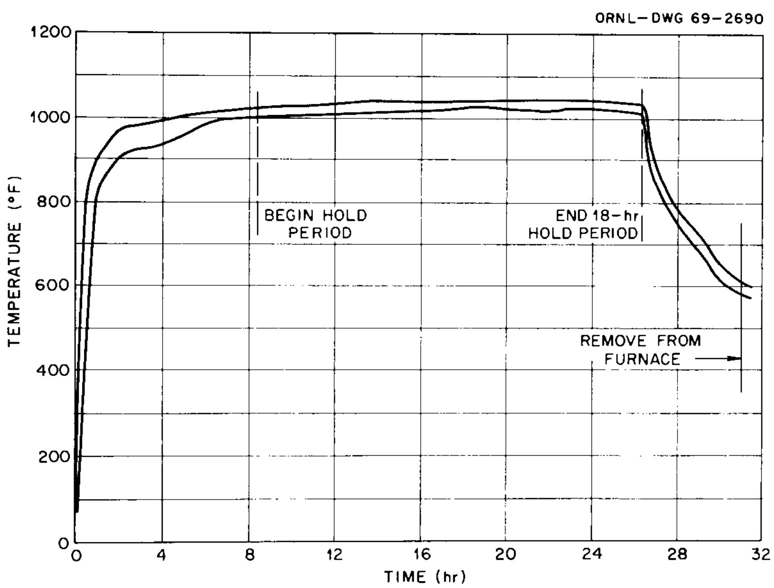

Fig. 2.14. Spread in Thermocouple Readings During the Stress-Relieving Heat Treatment.

N. HEAT TREATMENT HISTORY OF THE TOP HALF OF THE PLATE

The original full-size plate has now been cut into four sections (see Fig. 2.11), and two of these will be rerolled and cut to form two plate sections each. Since each of the resulting six sections will have different fabrication histories, it was necessary to identify each as a separate entity. The top half of the plate, which measured 120 X 120 X 12 in. thick was identified as plate 04A. Hereafter, any reference to plate 04A will apply to this portion only. The remaining portions are numbered 05 and 06, and these will be identified as they are discussed. The only exception to this is plate 04B, which was identified in P and M.

N.1 Normalizing

Plate 04A was placed on a furnace car (see Fig. 2.15) and charged into the furnace at 2:00 PM on December 20, 1967. Only two furnace couples, 1 and 8, were used to record the normalizing temperature profile. After 9 hr the couples were recording temperatures within the specified normalizing range of 1675 ± 25°F, and a 12-hr hold period was started. A chart of the high and low temperature readings is shown in Fig. 2.16. On completion of the hold period, the plate was withdrawn from the furnace and air cooled to ambient temperature. The cooling rate data are not available, since plate-attached thermocouples were not used.

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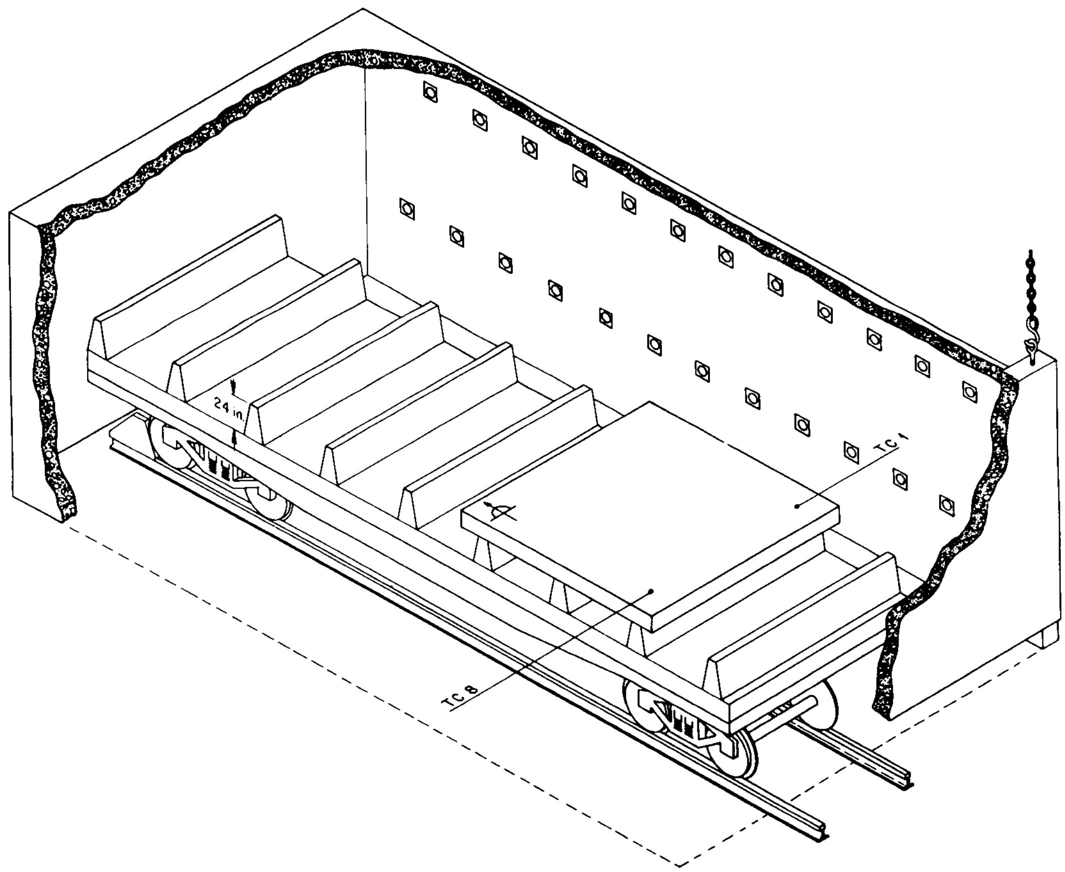

Fig. 2.15. Orientation of Plate 04 in the Furnace for Normalizing.

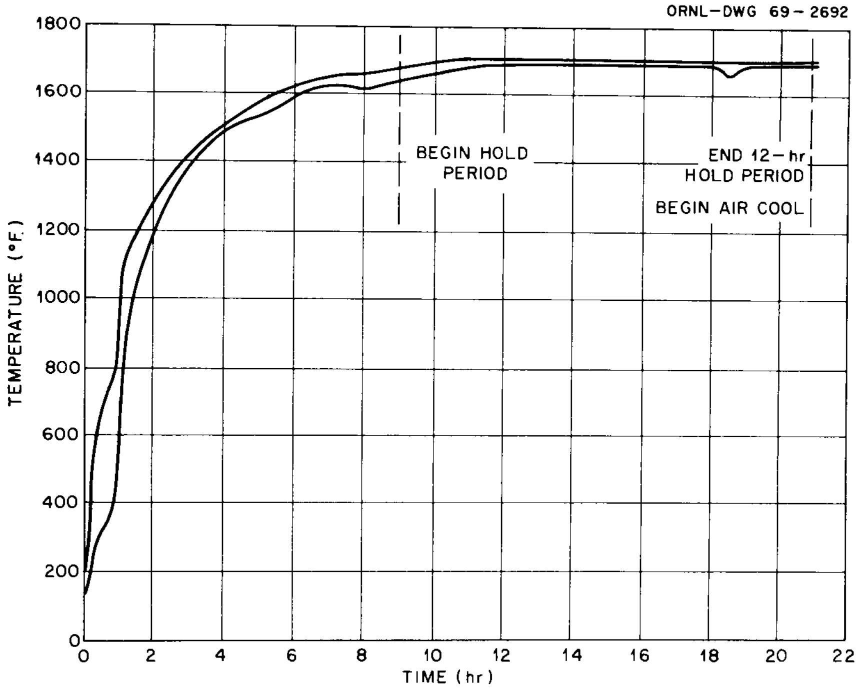

Fig. 2.16. Spread in Thermocouple Readings During the Normalizing of Plate 04.

N.2 Austenitizing and Quenching

On December 26, 1967, plate 04A was equipped with four Honeywell type P measuring junctions containing type K Chromel-Alumel thermocouples. Two of the measuring junctions were installed at 1/2 *T* and two at 1/4 *T* at the locations shown in Fig. 2.17. In each case ¼-in.-diam flat-bottom holes were drilled to the appropriate depths and counterbored for 25% of the hole depth. A measuring junction was inserted in each hole, so that the junction was in intimate contact with the bottom of the hole. The counterbored area was then filled with asbestos packing and tamped until the junction was secured firmly in the hole.

Each measuring junction was provided with a connector assembly located a few inches away from the thermowell. At this point stainless-steel-sheathed Chromel-Alumel thermocouple lead wires were attached, and these extended to a junction box a few feet outside the furnace door. Asbestos-sheathed Chromel-Alumel thermocouple lead wires were used from the junction box to the 12-point Brown-Honeywell recorder. The recorder was wired so that each of the four thermocouples would print three times per 12-point cycle. The plate was then coated with a descaling compound and allowed to dry.

On December 26 at 7:55 PM the plate was charged into the furnace and oriented as shown in Fig. 2.18. It soon became apparent that the thermocouple readings printed by the recorder were too rapid, causing a solid ink band with none of the point numbers distinguishable. The wiring system was then changed so that each couple printed only once per cycle.

At 8:15 the following morning, somewhat more than 12 hr later, the highest plate thermocouple readings were within the austenitizing range of 1575 ± 25°F, and a 12-hr hold period was started. The austenitizing hold period was completed at 8:15 PM, December 27. A chart of the high and low thermocouple readings throughout the heatup and hold periods is shown in Fig. 2.19. The temperature of

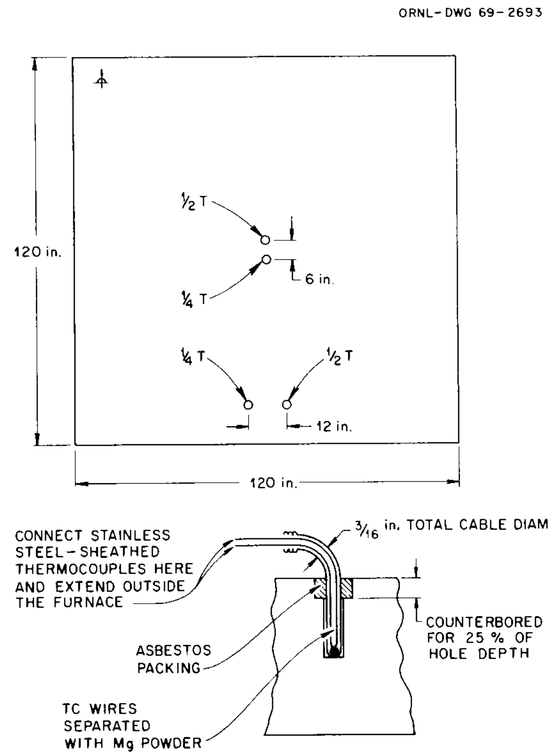

Fig. 2.17. Thermocouple Layout for Plate 04A During the Austenitizing Heat Treatment.

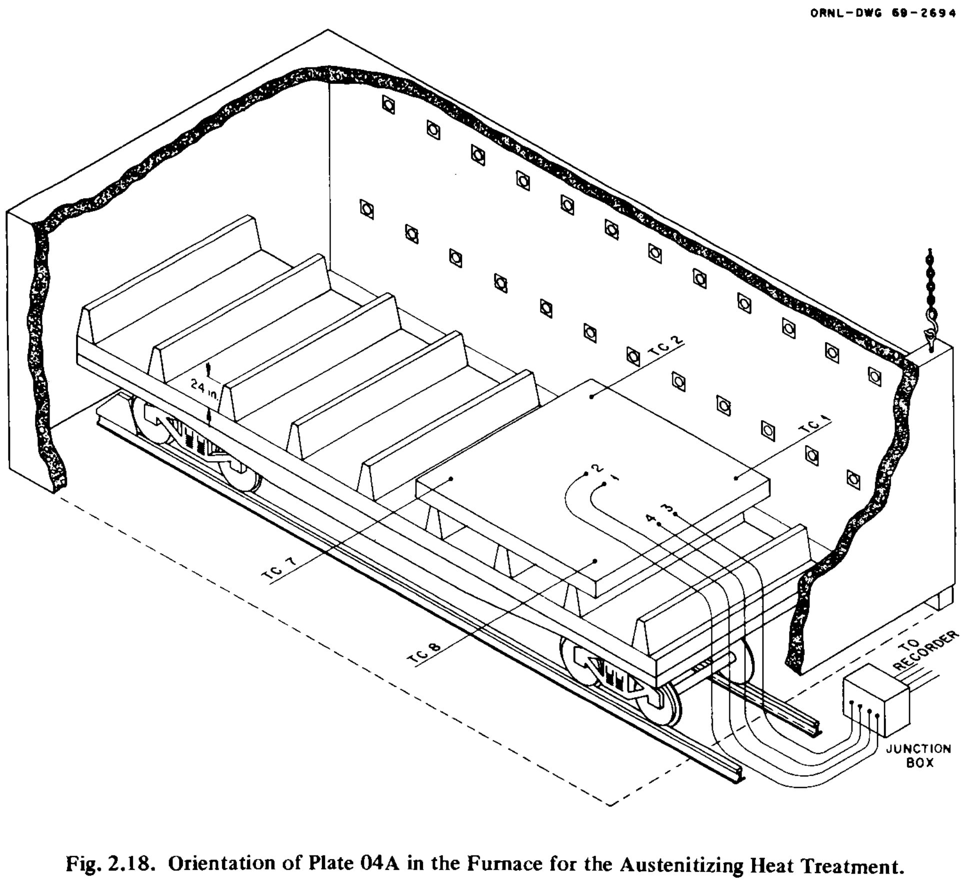

Fig. 2.18. Orientation of Plate 04A in the Furnace for the Austenitizing Heat Treatment.

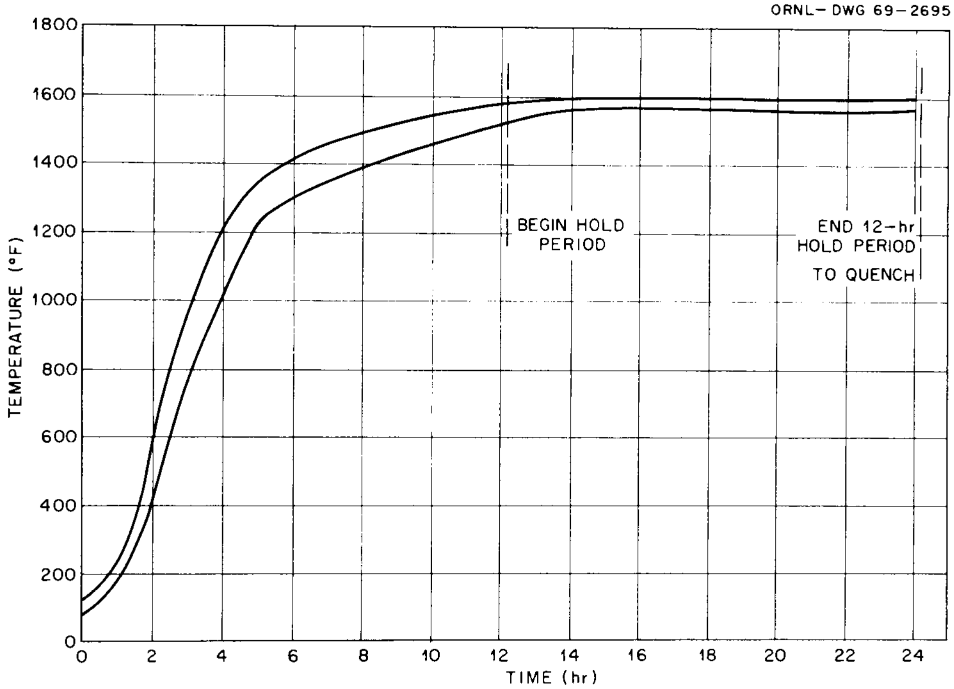

Fig. 2.19. Spread in Thermocouple Readings During the Austenitizing Heat Treatment of Plate 04A.

the water immediately prior to quenching was 50°F. The following sequence of events was recorded:

Furnace door started up	00.00 (12-27-67, 8:15 PM)
Furnace door fully opened	0.15 sec
Car out and stopped	1.17
Pickup started	1.30
Into water	2.55
Quench completed	69.15

The plate was carried from the furnace car to the quench tank with a "peel" and quenched in the flat position. After 24 min the water temperature had risen to 55°F, and the water remained at about this temperature throughout the quench. Near the end of the quench the water temperature began to drop slowly.

It was noted that the quench medium was not being agitated nearly as well after the plate and the lifting rig were submerged. It is probable that the size of the lifting rig – it practically extended over the entire surface of the tank – was sufficient to retard agitation. Assuming this is probable, it could account for the fact that the 1/2 *T* couple near the edge continued to record 1600°F for about 5 min after the plate was submerged.

The plate remained in the water a little more than 69 min, at which time the plate thermocouples were recording temperatures slightly over 200°F.

The cooling rates for the four plate thermocouples are shown in Fig. 2.20. The cooling rates recorded for the thermocouples located at 1/4 *T* are greater than those located at 1/2 *T*, which is to be expected. But the midwidth 1/2 *T* couple cooled at about the same rate as the one at the 1/2 *T* edge position. This may suggest that material 1 *T* or more from an edge is isolated from edge-quench effects.

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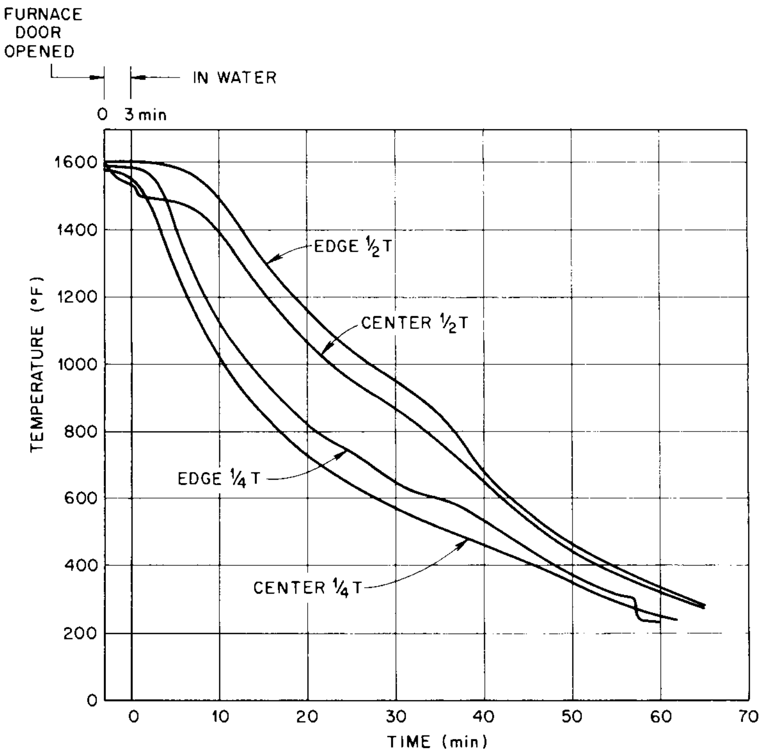

Fig. 2.20. Cooling Curves for Plate 04A.

N.3 Tempering

The plate was removed from the quench tank, reloaded on the furnace car, and returned to the furnace. The position of the plate in the furnace was practically the same as shown in Fig. 2.18. The four thermocouples used during the austenitizing heat treatment were left intact and were used to record the temperature profile for the tempering heat treatment. Each thermocouple was recording in the range of 200°F at the time the plate was charged into the furnace.

The furnace was fired at 9:50 PM, December 27, 1967. About 12 hr later the plate was up to temperature, and a 12-hr hold period was started. Lukens advised that they would try to hold the tempering range to 1200 ± 10°F. However, the chart on which the temperature readings for the plate-attached thermocouples were recorded showed the tempering temperature ranged from about 1210 to 1250°F (see Fig. 2.21). The chart on which the furnace couples recorded, Fig. 2.22, showed the temperature range to be about 1200 ± 10°F.

On completion of the hold period, the firing units were shut off. The plate then remained in the furnace with the furnace door closed and cooled to about 600°F before being removed.

N.4 First Stress Relief

On January 2, 1968, plate 04 again was loaded on a furnace car and charged into the furnace for stress relieving at 1125 ± 25°F for 40 hr. Orientation of the plate in the furnace was approximately as shown in Fig. 2.18. For this heat treatment, furnace couples 1, 2, 7, and 8 were used. Figure 2.23 shows the spread in thermocouple readings throughout the stress-relieving heat treatment.

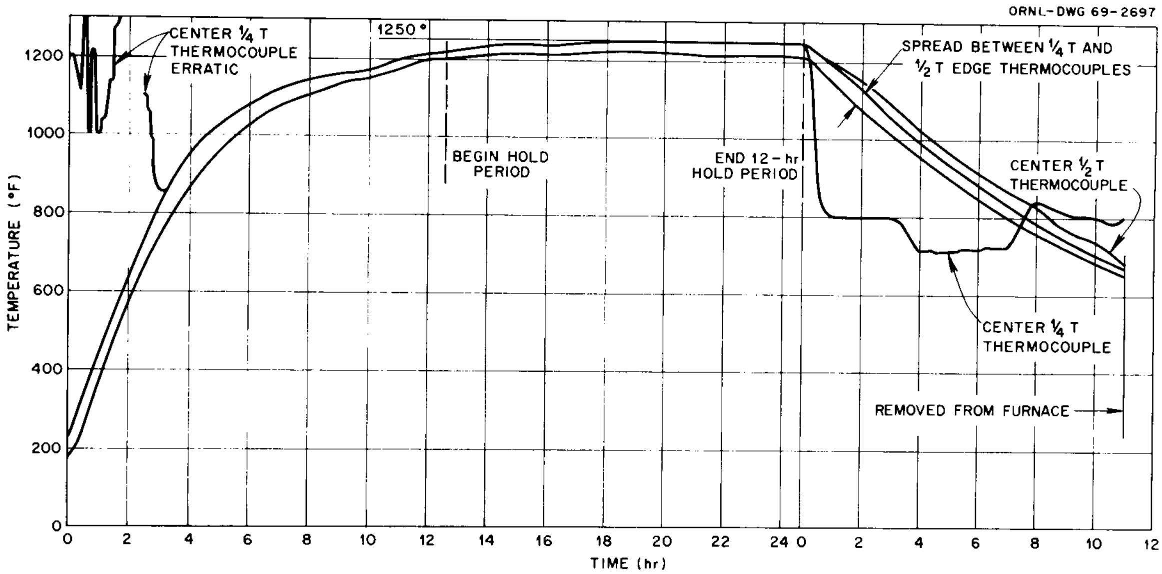

Fig. 2.21. Spread in (Plate) Thermocouple Readings During the Tempering Heat Treatment of Plate 04A.

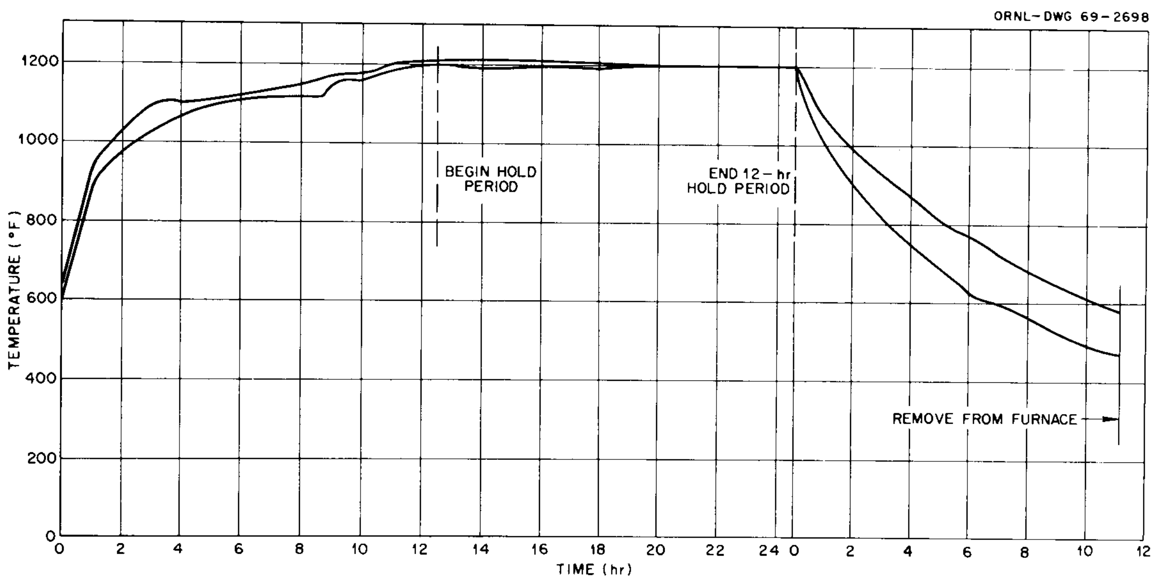

Fig. 2.22. Spread in (Furnace) Thermocouple Readings During the Tempering Heat Treatment of Plate 04A.

N.5 Stress Relief After Cutting of Test Material

Shortly after the stress-relieving heat treatment was completed, plate 04 was placed in a furnace and preheated to about 500°F. On removal from the furnace it was immediately delivered to the cutting area, where specimens for physical testing were removed from the locations noted in Fig. 2.24. Removal of specimen material was accomplished with oxyacetylene cutting equipment.

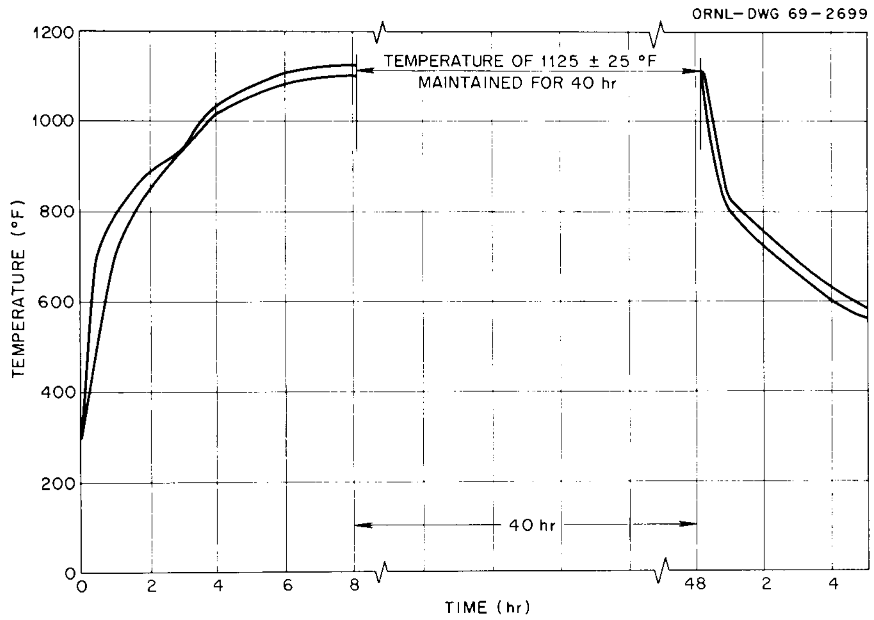

Fig. 2.23. Spread in Thermocouple Readings During the Stress-Relieving Heat Treatment of Plate 04A Before Removal of Test Material.

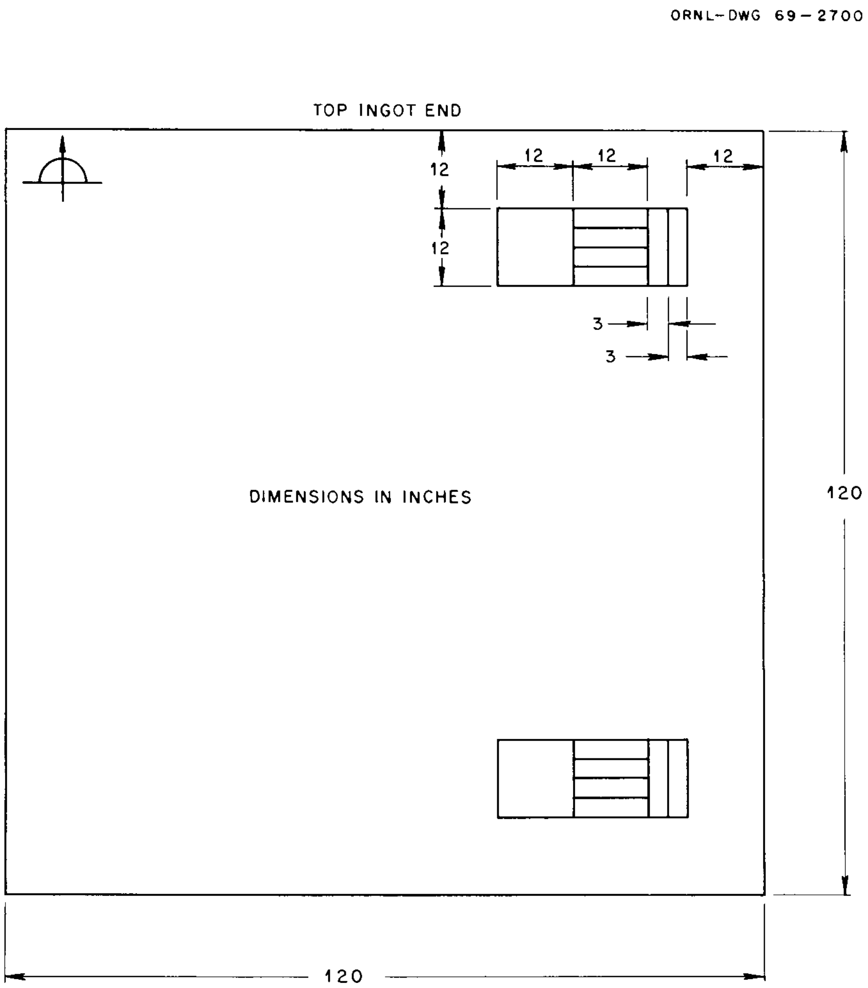

Fig. 2.24. Location of Test Specimens in Plate 04A.

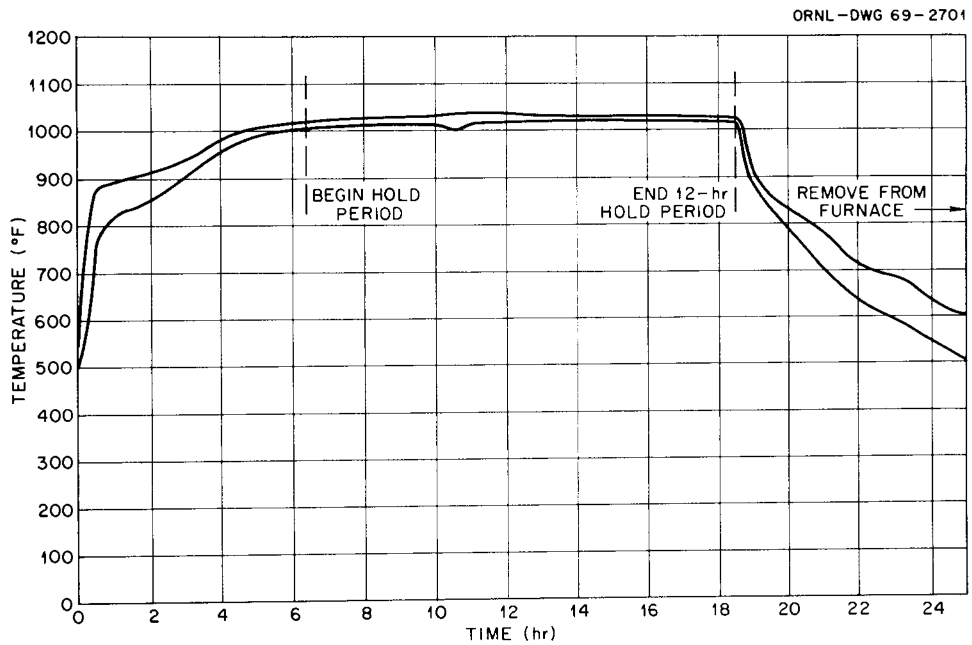

Fig. 2.25. Spread in Thermocouple Readings During the Stress-Relieving Heat Treatment of Plate 04A After Removal of Test Material.

On January 5, 1968, plate 04 was placed in the furnace for a post-gas-cut stress relief at 1025 ± 25°F for a 12-hr hold period. Again, the plate occupied essentially the same position in the furnace as depicted in Fig. 2.18. Four furnace thermocouples 1, 2, 7, and 8 were used to record the stress-relief data, and a plot of those data is shown in Fig. 2.25.

O. ULTRASONIC INSPECTION AFTER HEAT TREATMENT

Plate 04A was prepared for ultrasonic inspection after heat treatment by grit blasting to remove surface oxides and was ground with a floor sander to a surface finish of about 250 rms or better. The plate was then inspected in accordance with Attachments 2A and 2B of the PVRC subcommittee report of April 10, 1967.

This plate and plate 03 (second inspection) were inspected concurrently; therefore, all of the variables described in D.1 and D.2 are applicable to this plate. The longitudinal and shear-wave DAC curves shown in Figs. 1.5 and 1.7 are also applicable to this inspection.

Based on the applicable specification, Attachment 2A, no "recordable" longitudinal-wave indications were noted. There were, however, three indications detected by longitudinal-wave inspection which produced signals greater than 50% of the height of the DAC curve, but neither caused a 100% loss of back-surface reflection. One "traveling" indication was found which produced signals ranging between 10 and 40% of the height of the DAC curve, but caused very little drop in back-surface signal. The location of each of these indications is shown in Fig. 2.26 by the suffix *L*.

Three "recordable" shear-wave indications also shown in Fig. 2.26 and denoted by the suffix *S* were found. The configuration of indications 1*S* and 3*S* is approximately rectangular; each measured about 1 X 1½ in. Indication 2*S* was somewhat similar in shape but larger and covered an area of about 14 in.^{2}. Each of these indications noted in Fig. 2.26 produced signals in excess of the DAC curve.

On completion of ultrasonic inspection, the plate was shipped to the HSST storage facility.

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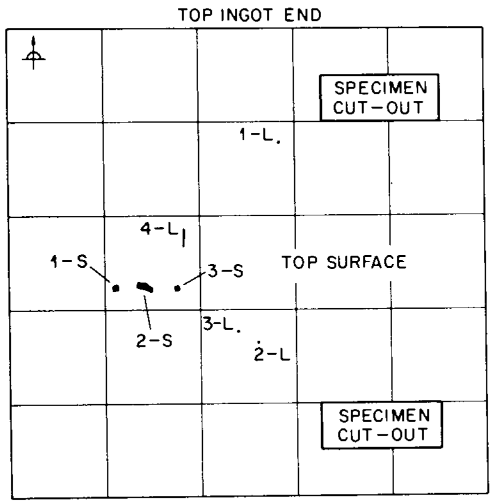

RESULTS OF ULTRASONIC INSPECTION BY LUKENS STEEL CO AFTER HEAT TREATMENT

INDICATION	DEPTH (in.)	PERCENT OF DAC	PERCENT LOSS OF BACK SURFACE REFLECTION
1-L	5¾	60	64
2-L	6	54	28
3-L	6	54	37
4-L	TRAVELING	10-40	10
1-S	5	>100	
2-S	6	>100	
3-S	6½	>100	

NOTE: ONLY THE SHEAR-WAVE INDICATIONS ARE "RECORDABLE"
S SUFFIX DENOTES SHEAR-WAVE INDICATION
L SUFFIX, LONGITUDINAL-WAVE INDICATION

PLATE 04A

Fig. 2.26. Location of Ultrasonic Indications Found in Plate 04A After Heat Treatment.

P. Plate Qualification and Development Testing

Using material removed from the locations shown in Fig. 2.24, Lukens prepared specimens for plate qualification and development testing. Longitudinal and transverse tensile and Charpy V-notch specimens were taken from the top ingot end of the plate at the surface, at 1/4 *T*, and at center-line locations. P-2 specimens for drop weight testing were removed from the top and bottom ingot ends at the top and bottom surfaces, top and bottom 1/4 *T* positions, and at the center line. The materials for testing were removed from the plate after the first stress relief. In order that the test material would be representative of the finished plate, the test blocks were given a second stress relief at 1025°F similar to the one given the plate.

The test specimens were prepared by saw cutting a ⅝-in. discard strip from each of the gas-cut edges. Specimens, in wafer shape, representing the center portions of the plate were saw cut with their center lines parallel to the 1/4 *T* and 1/2 *T* depths. Surface specimens were removed immediately adjacent to the plate surfaces. Specimens from the 1/4 *T* locations were prepared for plate qualification tests; specimens from other locations were for development tests.

Tables 2.3 and 2.4 list the results of the plate qualification tests. The development test results are shown in Tables 2.5 and 2.6. Lukens advised that they did not encounter difficulties in meeting the tensile and yield strength requirements of A-533-65 grade B class 2. However, the notch toughness requirements of paragraph N-331.2 of the ASME Code Section III were not met. This paragraph requires that for room-temperature hydrostatic testing the NDT shall be +10°F or lower, or that the minimum average of three CVN specimens be 30 ft-lb, with one value no lower than 25 ft-lb at +10°F. As noted in Table 2.4, neither of the alternates specified in paragraph N-331.2 is met.

Lukens advised that in their opinion the loss in notch toughness is related to the increasing amount of ferrite in the structure with increasing gage thickness, microsegregation, and hardenability considerations. The need to temper on the low side of the normal range to obtain class 2 properties also impairs toughness.

Nick break test specimens, measuring 3 × 11 × ¾ in. thick, were removed from the top and bottom ingot ends at the 1/4 *T* locations. The specimens were prepared by pressing a notch in the transverse rolling direction and breaking them with a hydraulic press. Figure 2.27 shows the fracture appearance of these specimens.

Table 2.3. Results of Plate Qualification Tests Performed by Lukens on 120 × 120 × 12 in. Thick HSST Plate 04A, ASTM A-533 Grade B Class 2

Location in Ingot	Through-Gage Location	Specimen Orientation	Yield Strength (ksi)	Ultimate Tensile Strength (ksi)	Percent Elongation	Percent Reduction of Area
Top	Top 1/4 *T*	L	78.0	99.5	26	62.9
Top	Top 1/4 *T*	L	77.0	99.0	27	65.0
Top	Top 1/4 *T*	T	76.9	98.5	22	59.8
Top	Top 1/4 *T*	T	77.5	99.5	24	60.6
Bottom	Top 1/4 *T*	L	72.8	94.5	25	64.5
Bottom	Top 1/4 *T*	L		95.0	26	66.4
Bottom	Top 1/4 *T*	T	75.3	97.5	24	60.7
Bottom	Top 1/4 *T*	T	74.8	96.5	24	61.4

Table 2.4. Toughness Data Derived from Plate Qualification Testing of 120 × 120 × 12 in. Thick HSST Plate 04A ASTM A-533 Grade B Class 2

Test Temperature (°F)	Specimen Orientation	ft-lb, CVN	Mils Lateral Exp.	Percent Fibrous	30 ft-lb CVN Transition Temperature (°F)	NDT (°F) Determined by P-2 Drop Weight Specimens
Top 1/4 *T*, top ingot end						
+70	L	47, 52, 47 49 av	43, 45, 43	30		
	T	36, 40, 38 38 av	30, 37, 31	25		
+50	L	36, 46, 47 43 av	32, 33, 35	5		
	T	29, 38, 28 32 av	26, 27	5		
+40	L	35, 36, 31 34 av	29, 31, 24	5		
	T	30, 29, 27 29 av	25, 25, 22	5		
+10	L	15, 20, 22 19 av	14, 16, 18	5		
	T	25, 25, 13 21 av	20, 19, 10	5		
					+38	+40
Bottom 1/4 *T*, top ingot end						
+30	L	12, 25, 15 17 av	11, 22, 18	25		
+10	L	15, 12, 10 12 av	12, 12, 11	10		
						+30
Top 1/4 *T*, bottom ingot end						
+70	L	53, 53, 46 51 av				
	T	37, 33, 48 39 av				

Table 2.4 (continued)

Test Temperature (°F)	Specimen Orientation	ft-lb, CVN	Mils Lateral Exp.	Percent Fibrous	30 ft-lb CVN Transition Temperature (°F)	NDT (°F) Determined by P-2 Drop Weight Specimens
Top 1/4 *T*, bottom ingot end						
+50	L	38, 33, 47 39 av				
	T	25, 40, 28 31 av				
+40	L	40, 35, 36 37 av				
	T	32, 24, 32 29 av				
+10	L	27, 24, 21 24 av				
	T	19, 14, 23 19 av				
					+39	+20
Bottom 1/4 *T*, bottom ingot end						
+50	L	98, 90, 99 96 av	74, 68, 76	90		
+20	L	30, 35, 25 30 av	25, 29, 21	20		
+10	L	26, 22, 21 23 av	24, 20, 19	20		
					+20	+20

Table 2.5. Results of Development Tests Performed by Lukens on 120 × 120 × 12 in. Thick HSST Plate 04A, ASTM A-533 Grade B Class 2

Location in Ingot	Through-Gage Location	Specimen Orientation	Yield Strength (ksi)	Ultimate Tensile Strength (ksi)	Percent Elongation	Percent Reduction of Area
Top	Top surface	L	83.3	103.5	26	69.1
Top	Top surface	L	82.7	102.5	26	68.0
Top	Top surface	T	84.1	104.0	24	64.7
Top	Top surface	T	84.2	104.5	24	66.0
Bottom	Top surface	L	78.2	99.0	26	65.8
Bottom	Top surface	L	77.4	99.0	26	67.3
Bottom	Top surface	T	79.8	100.5	25	67.2
Bottom	Top surface	T	79.3	100.5	26	67.0
Top	1/2 *T*	L	79.3	101.5	26	60.2
Top	1/2 *T*	L		101.2	26	56.0
Top	1/2 *T*	T	80.5	103.0	22	46.8
Top	1/2 *T*	T	80.3	102.5	20	41.4
Bottom	1/2 *T*	L	73.7	97.5	26	61.0
Bottom	1/2 *T*	L	74.0	96.0	26	62.3
Bottom	1/2 *T*	T	75.5	97.5	22	52.0
Bottom	1/2 *T*	T	77.6	97.5	22	45.5

Table 2.6. Toughness Data Derived from Development Testing of 120 × 120 × 12 in. Thick HSST Plate 04A ASTM A-533 Grade B Class 2

Test Temperature (°F)	Specimen Orientation	ft-lb, CVN	Mills Lateral Exp.	Percent Fibrous	30 ft-lb CVN Transition Temperature (°F)	NDT (°F) Determined by P-2 Drop Weight Specimens
Top surface, top ingot end						
+70	L	105, 110, 105 107 av	75, 77, 75	95		
	T	81, 82, 80 81 av	62, 67, 58	95		
+10	L	98, 100, 105 101 av				
	T	66, 50, 75 64 av				
−30	L	71, 74, 76 74 av				
	T	54, 65, 46 55 av				
−100	L	42, 44, 42 43 av	34, 35, 42	60		
	T	26, 24, 24 25 av	20, 18, 18	10		
					−88	−30
Center line, top ingot end						
+100	L	47, 40, 40 42 av				
+70	L	25, 21, 35 27 av	23, 19, 23	25		
	T	25, 28, 27 27 av	21, 28, 21	5		
+50	L	23, 26, 21 23 av	24, 24, 23	5		
	T	21, 24, 22 22 av	16, 22, 21	5		
+10	L	10, 13, 10 11 av	11, 13, 11	5		
	T	10, 11, 20 14 av	10, 11, 15	5		
					+87	+50
Bottom surface, top ingot end						
+10	L	90, 90, 100 93 av				
−80	L	115, 110, 110 112 av	80, 70, 70	95		
−150	L	70, 75, 82 76 av	48, 49, 53	85		
						−80

Table 2.6 (continued)

Test Temperature (°F)	Specimen Orientation	ft-lb, CVN	Mills Lateral Exp.	Percent Fibrous	30 ft-lb CVN Transition Temperature (°F)	NDT (°F) Determined by P-2 Drop Weight Specimens
Top surface, bottom ingot end						
+70	L	110, 105, 101 105 av	78, 77, 55	90		
	T	75, 67, 55 66 av	59, 59, 50	45		
+10	L	75, 79, 78 77 av				
	T	45, 60, 45 50 av				
–50	T	13, 29, 26 23 av	12, 23, 22	15		
–100	L	55, 45, 52 51 av	41, 37, 40	45		
	T	12, 22, 10 15 av	11, 20, 8	15		
–150	L	22, 30, 22 28 av	15, 23, 17	30		
						<–100
Center line, bottom ingot end						
+100	L	60, 52, 55 56 av	51, 44, 48	40		
+70	L	35, 35, 36 35 av	32, 32	5		
	T	30, 31, 27 29 av	29, 30, 34	5		
+30	L	19, 24, 16 20 av	21, 23, 17	5		
	T	13, 14, 15 14 av	13, 15, 18	5		
+10	L	12, 14, 17 14 av	12, 15, 16	5		
	T	14, 15, 11 13 av	13, 14, 12	5		
					+59	+30
Bottom surface, bottom ingot end						
+10	L	72, 62, 60 65 av				
–20	L	21, 54, 55 43 av	20, 37, 42	20		
–50	L	10, 30, 45 28 av				
					–46	–40 to –50

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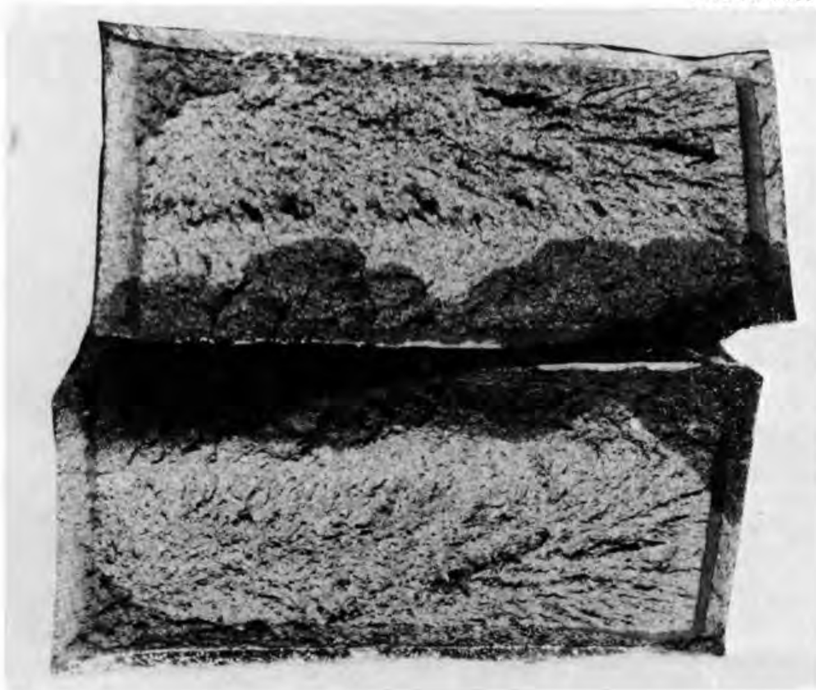
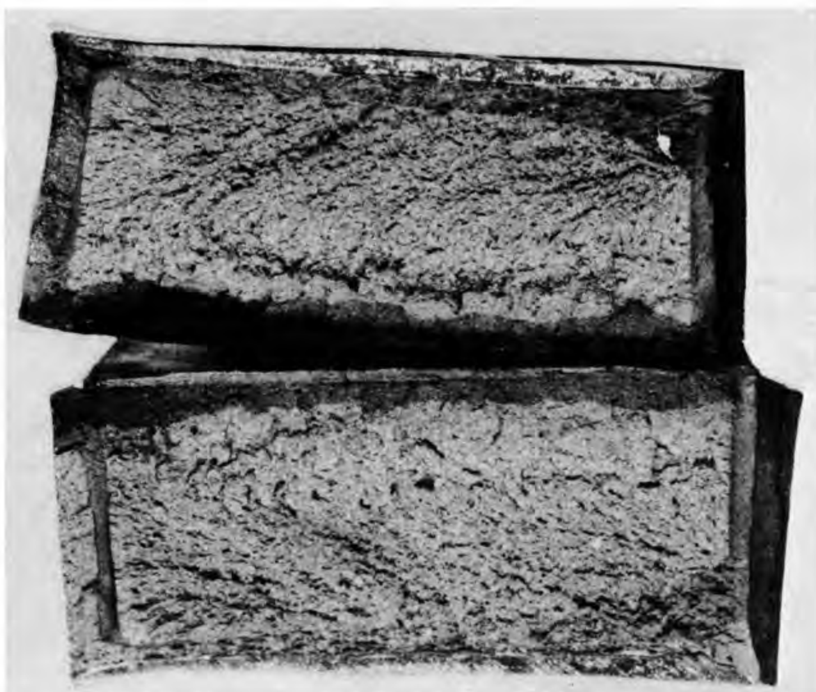


TOP INGOT END



BOTTON INGOT END

Fig. 2.27. Homogeneity Test Specimens from Plate 04A. Top: top ingot end; bottom: bottom ingot end.

Specimens for microscopic examination were prepared from surface, 1/4 *T*, and 1/2 *T* locations from each end of the plate. The micrographic structures from the top ingot end of the plate are shown in Fig. 2.28. The structures shown in Fig. 2.29 are from the bottom ingot end of the plate, or what was originally the midlength zone of the original full-size plate.

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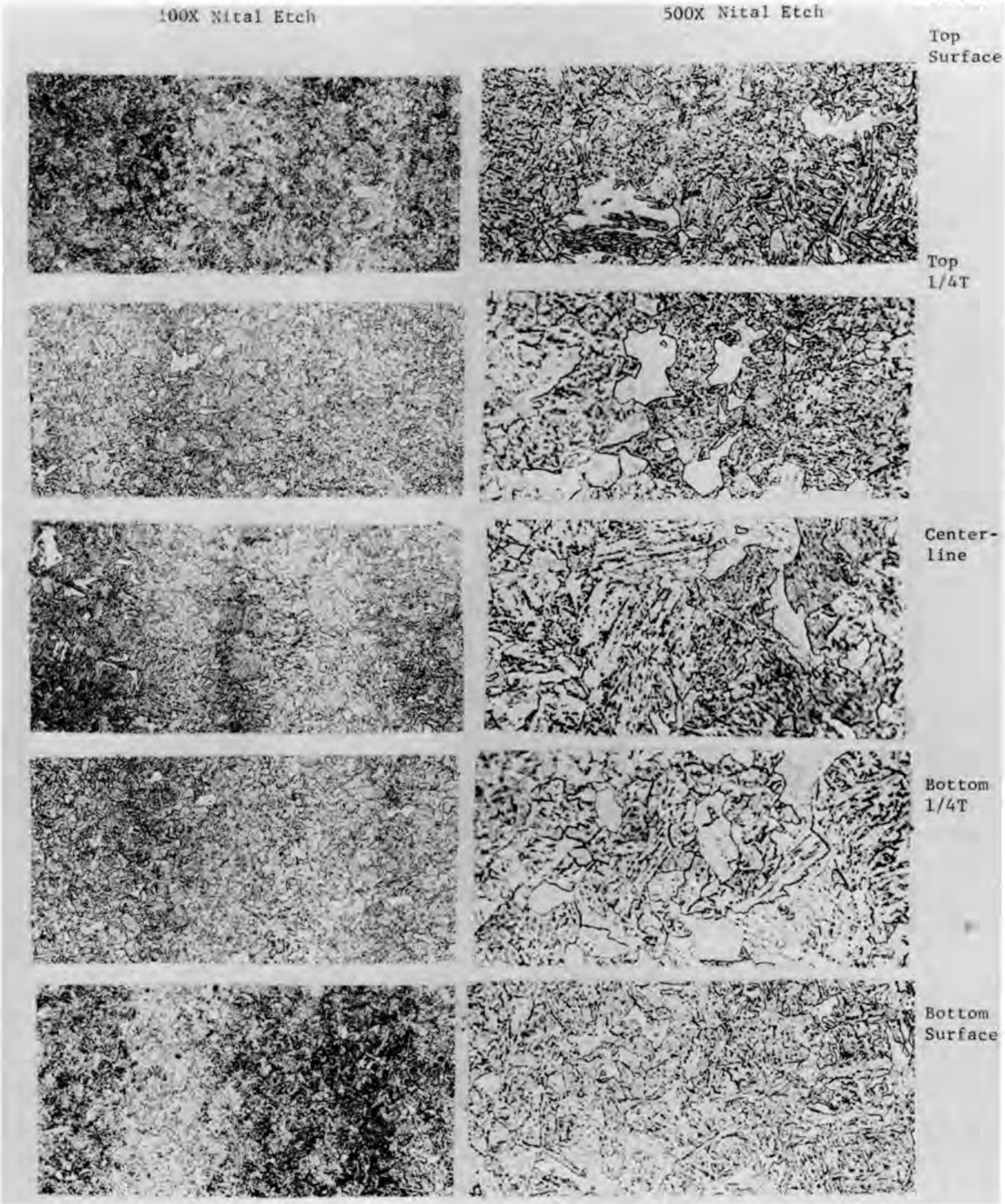

Fig. 2.28. Microstructure at the Top Ingot End of Plate 04A, After Heat Treatment. Reduced 20%.

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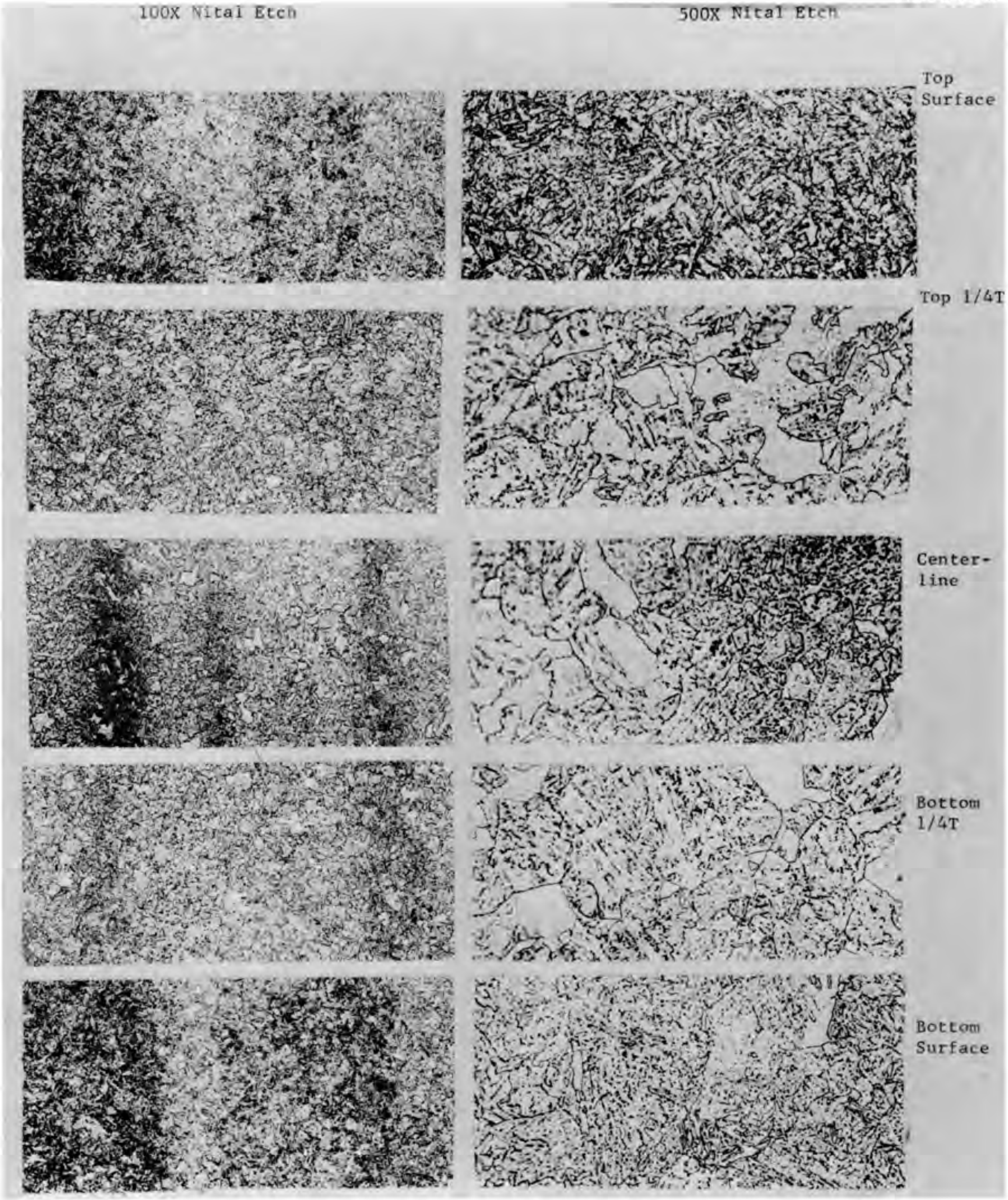

Fig. 2.29. Microstructure at the Bottom Ingot End of Plate 04A, After Heat Treatment. Reduced 20%.

P.1 Retemper of Plate 04A

As noted in the previous section of this report, plate 04A did not meet the toughness requirements of Paragraph N-331.2 of the ASME Code Section III for A-533 grade B class 2 material. Since the plate, in its present condition, did not meet the requirements for either of the classes of A-533 steels, the HSST staff decided to return the plate to Lukens for retempering to class 1 requirements. Before returning the plate to Lukens, a small piece of the material was removed from the bottom ingot end and retained in the HSST storage area.

The plate was returned by rail to Lukens' Coatesville, Pa., mill in May 1969. Late in the evening of June 9, the plate was loaded on a furnace car and charged into furnace 6 for retempering at 1250 ± 25°F for 12 hr. The plate was oriented in the furnace as shown in Fig. 2.30.

Two furnace thermocouples (6 and 7) were used to record the temperature profile throughout the heat-up and hold period. The spread in the thermocouple readings for this heat treatment is shown in Fig. 2.31. On completion of the 12-hr hold period, the plate was withdrawn from the furnace and air cooled to ambient temperature.

About a week after retempering, the plate was preheated to approximately 500°F and additional test material was removed from the location shown in Fig. 2.32. Immediately following removal of the

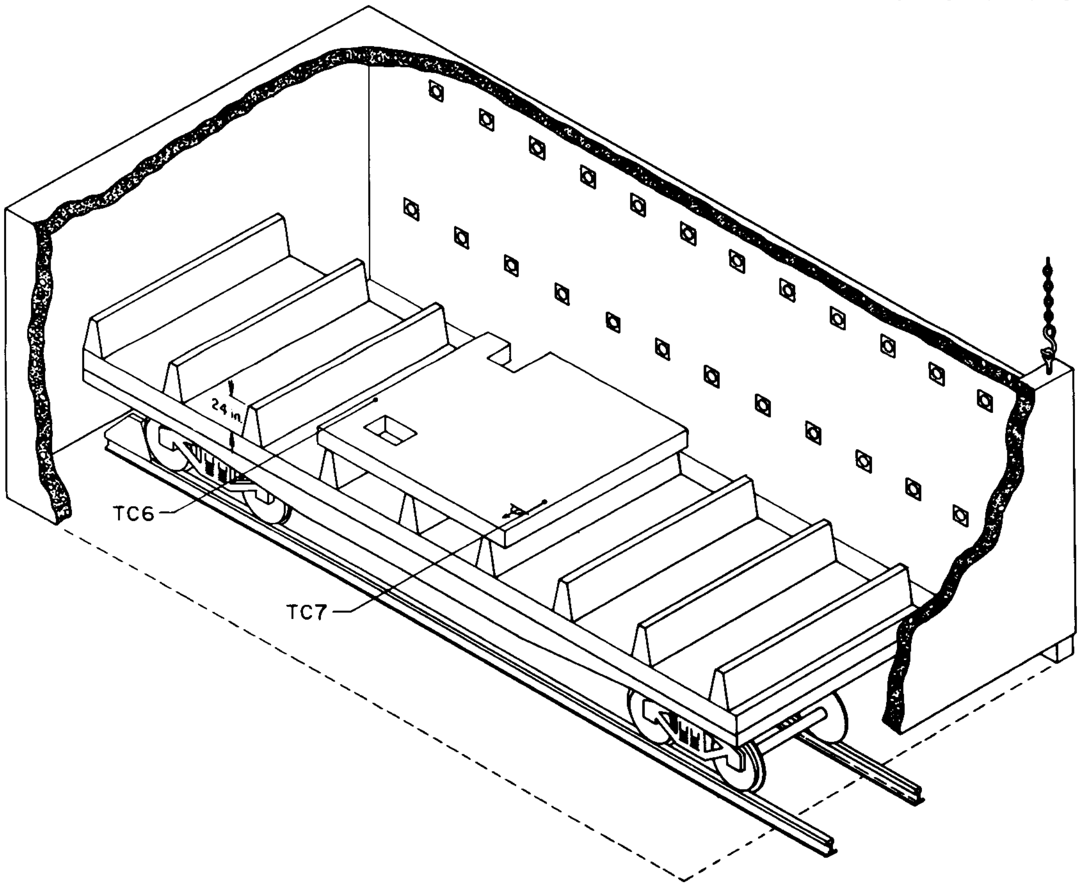

Fig. 2.30. Orientation of Plate 04A in the Furnace for Retempering.

additional test material (by oxyacetylene cutting) the plate was charged into furnace 1 for a 4-hr stress-relieving heat treatment.

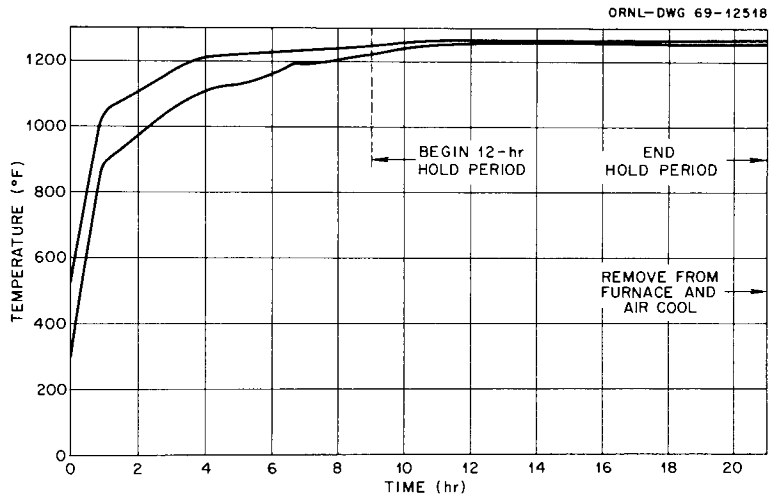

Fig. 2.31. Spread in Thermocouple Readings During Retempering of Plate 04A.

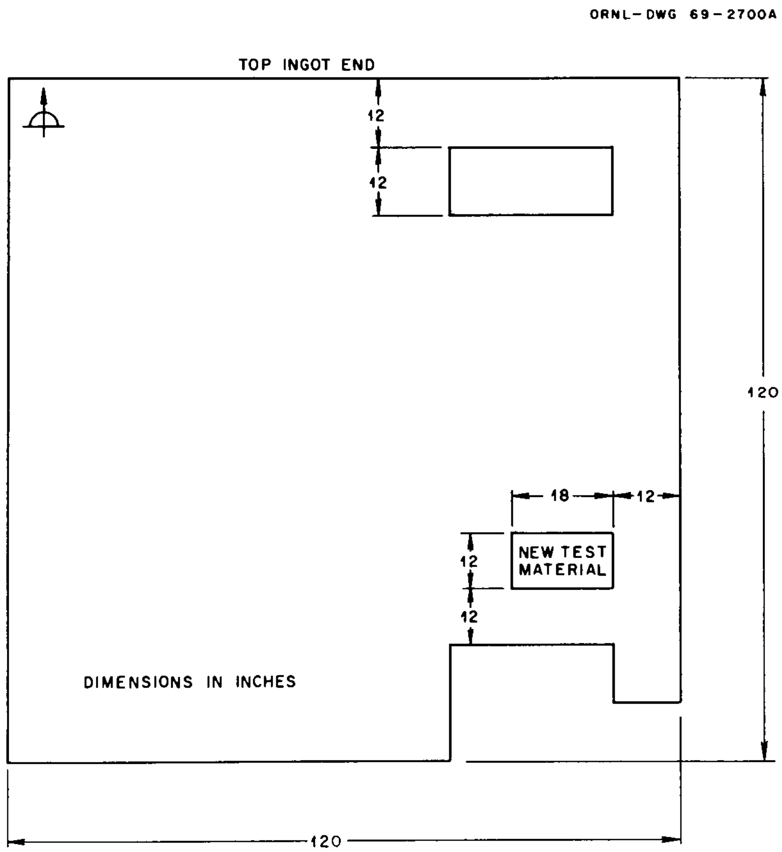

Fig. 2.32. Location of Plate Qualification Material from Retempered Plate 04A.

During the 4-hr stress relief the plate was placed on the end of the car near the rear of the furnace. Four furnace thermocouples (3, 4, 5, and 6) were used to record the temperature profile during this heat treatment. The spread in the thermocouple readings for this cycle is shown in Fig. 2.33.

The test material was not stress relieved with the plate. However, the test specimens were subjected to a similar heat treatment in the laboratory. The results of the plate qualification tests, which meet the requirements for class 1 material are listed in Table 2.7.

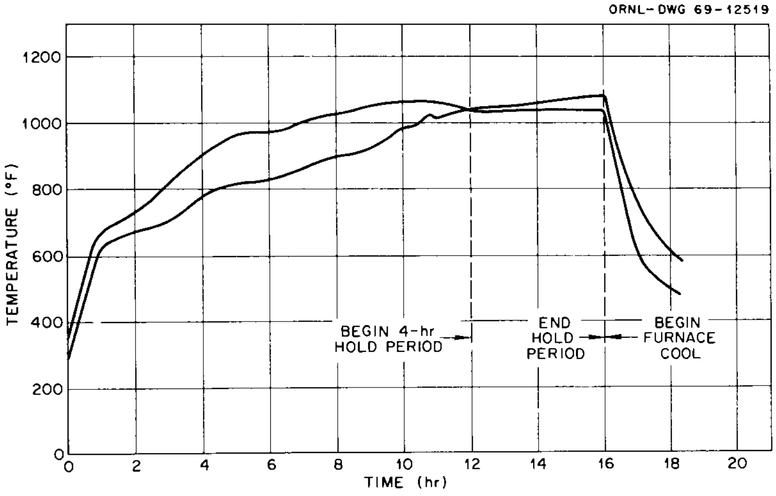

Fig. 2.33. Spread in Thermocouple Readings During Stress-Relieving Heat Treatment of Plate 04A After Retempering.

Table 2.7. Results of Qualification Tests Performed by Lukens on HSST Plate 04A After Retempering to Class 1 Requirements

Through-Gage Location	Specimen Orientation	Yield Strength (ksi)	Ultimate Tensile Strength (ksi)	Percent Elongation	Percent Reduction of Area
1/4 *T*	*T*	64.2	88.6	24	64.9
1/4 *T*	*T*	63.5	88.6	24	62.9

Toughness Data

Specimen Orientation	ft-lb CVN			
	+70°F	+10°F	0°F	−50°F
L	56, 53, 54 54 av	25, 30, 35 30 av	30, 30, 17 26 av	7, 7, 7 7 av
T	37, 38, 38 38 av	24, 20, 24 23 av	15, 13, 15 14 av	9, 9, 7 8 av

3. REROLLING OF PLATE 04 TO FORM PLATES 05 AND 06

Q. REROLLING OF TWO SECTIONS OF THE 12-in.-THICK PLATE TO 4-in. AND 8-in. GAGE

The two remaining portions of the 12-in.-thick plate material (see Figs. 3.1 and 3.2), one measuring 80 X 40 in. and one 80 X 80 in., were prepared for rerolling to 4-in. and 8-in. gage respectively. As noted previously, the top ingot end of each piece was identified by notching the appropriate corners so that the original ingot orientation could be identified after rerolling.

On November 1, 1967, the two pieces of 12-in.-thick material were grit blasted and painted with Pemco, a protective coating. After drying, they were placed in Lukens' furnace 63 for heating prior to rerolling. This furnace was being used for another heating operation prior to charging the 12-in.-thick plates; thus the initial temperature was high. The following table gives the pertinent time-temperature data for the charging and heating cycles, including the last few minutes of the previous heat and the full heating cycle of the two 12-in.-thick pieces.

Table 3.1. Heating of Material Prior to Rerolling

Time, PM	Furnace Temperature (°F)		Furnace TC Readings (°F) (in contact with plates)	Comments
	Zone 1	Zone 2		
3:30	2400	2400		Furnace was being used for regular production work
3:50	2400	2400		This charge removed from furnace
4:00	1700	1700	P_L charged cold	HSST 12-in.-thick plate material charged into furnace
4:30	2100	2000	1700	
5:00	2100	2100	1900	
5:30	2250	2150	2100	
6:00	2350	2200	2200	
7:00	2400	2300	2250	
7:30	2400		2275	
8:00	2400	2350	2300	
8:20	2400	2350	2300	Material to be rerolled to 4 in. thickness removed from furnace
8:35	2300	2300	2300	Material to be rerolled to 8 in. thickness removed from furnace

The plate measuring 80 X 40 X 12 in. thick was the first to be removed from the furnace for rerolling. Furnace 63 is located less than 100 ft from the rolls; therefore, very little time elapsed from the time the piece was removed from the furnace until rerolling began. Both longitudinal (top-to-bottom relative to top and bottom of the ingot) and transverse (side-to-side relative to top and bottom of the ingot) rolling were performed. The plate passed through the rolls 22 times in the longitudinal direction and 17 times in the transverse direction. Lukens' personnel advised that several (the exact number could not be determined) of the passes were merely flattening passes in which no reduction of thickness was taking place. Rerolling was completed in about 10 min, and the finished plate now measured approximately 135 X 72 X 4 in. thick.

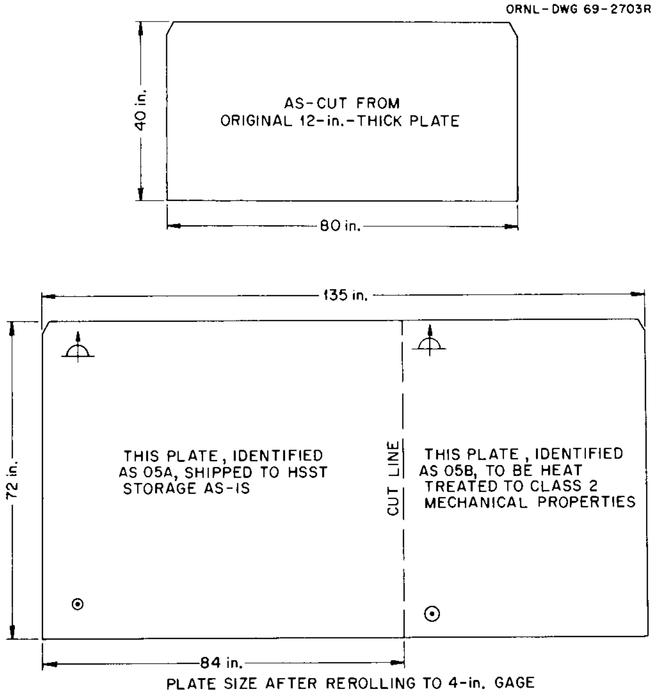

Fig. 3.1. Plate Sections 05A and 05B, Before and After Rerolling.

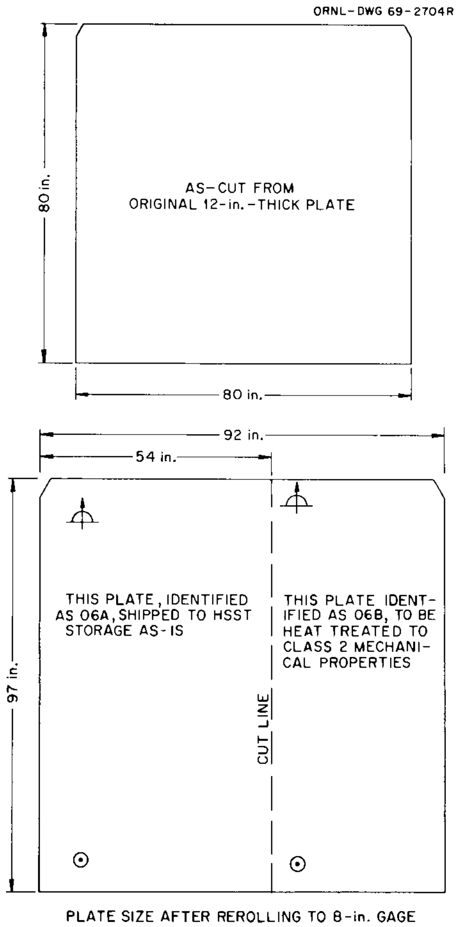

Fig. 3.2. Plate Sections 06A and 06B, Before and After Rerolling.

The original longitudinal-to-transverse rolling ratio for the 12-in.-thick plate was 1.89:1. The total longitudinal-to-transverse rolling ratio for the 4-in.-thick plate was 1.89 X 0.94, or 1.77:1. The 4-in.-thick plate, after rerolling was completed, was transferred to the cooling area and covered with about 4 to 5 in. of sand.

The plate which measured 80 X 80 X 12 in. thick was removed from the furnace as soon as the 4-in.-thick plate was covered for sand cooling. Seven passes were made through the rolls in the longitudinal direction and 14 in the transverse direction. As noted for the previous plate, several of these passes also were for flattening purposes. The finished plate measured about 97 X 92 X 8½ in. thick.

On completion of reduction rolling, the 8½-in. gage plate was conveyed to the flattening rolls, where another effort was made to obtain a more exact flatness. To help maintain flatness, the plate was left on the rolls until it had cooled below the red-heat range. It was then placed on a flat portion of the floor and left uncovered for cooling to ambient temperature. The total longitudinal-to-transverse rolling ratio for the 8½-in.-thick plate was 1.89 X 1.05 or 1.98:1. Soon after cooling, Lukens removed ½ in. from the top surface of the plate by milling.

On November 13, 1967, the two rerolled plates were placed in a furnace and preheated to about 500°F. Following preheating, the plates were taken directly to the cutting area and marked for cutting, as shown in Figs. 3.1 and 3.2. The HSST bench marks and alignment marks were stamped into the plates at the time cut lines were scribed. Cutting was accomplished using oxyacetylene equipment.

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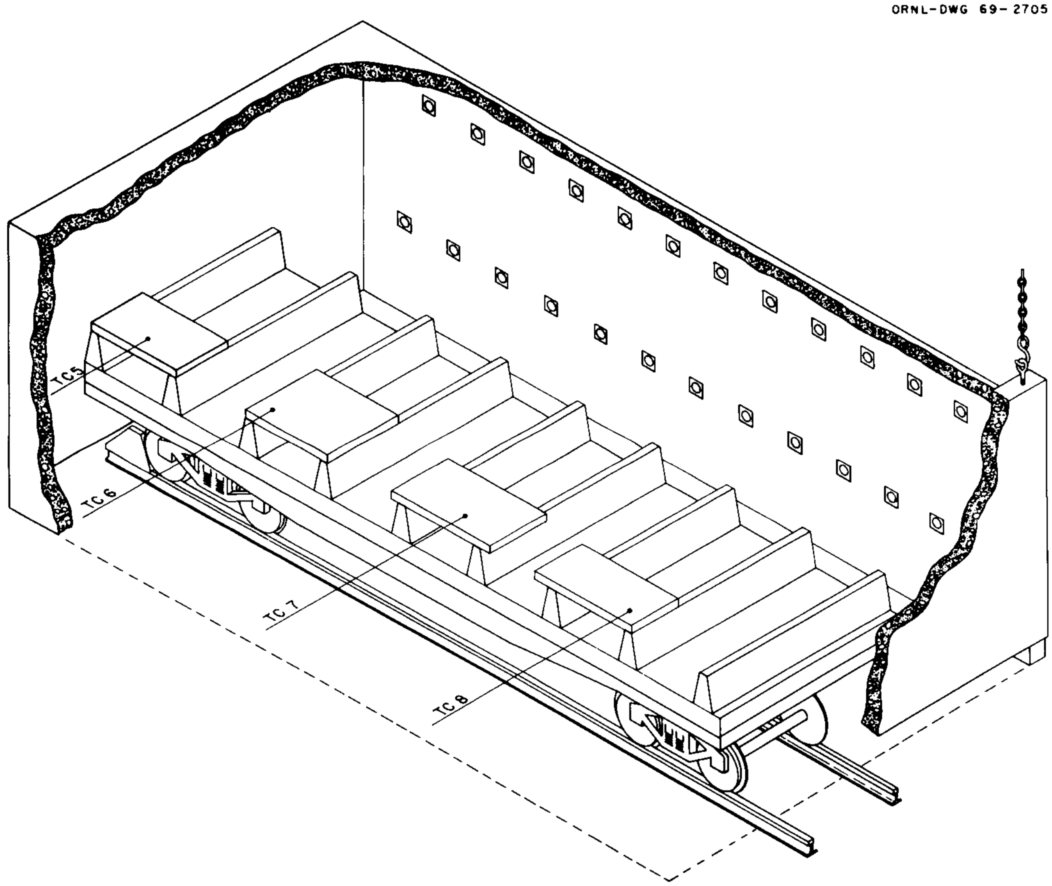

Fig. 3.3. Orientation of Plate Sections in the Furnace for Stress Relieving.

While the plates were still hot from preheating and cutting, they were loaded on a furnace car and charged into the furnace for stress relieving. The plates were oriented in the furnace as shown in Fig. 3.3. Furnace thermocouples only were used to record the heating cycle. The furnace was fired at 3:10 PM, November 13, 1967. Slightly more than 8 hr later the thermocouples showed that the temperature was within the stress-relieving range, and a 12-hr hold period was started. A curve of the data for this heat treatment is shown in Fig. 3.4. After the hold period was completed, the plate sections remained in the furnace for cooling until the thermocouples were recording temperatures below 600°F.

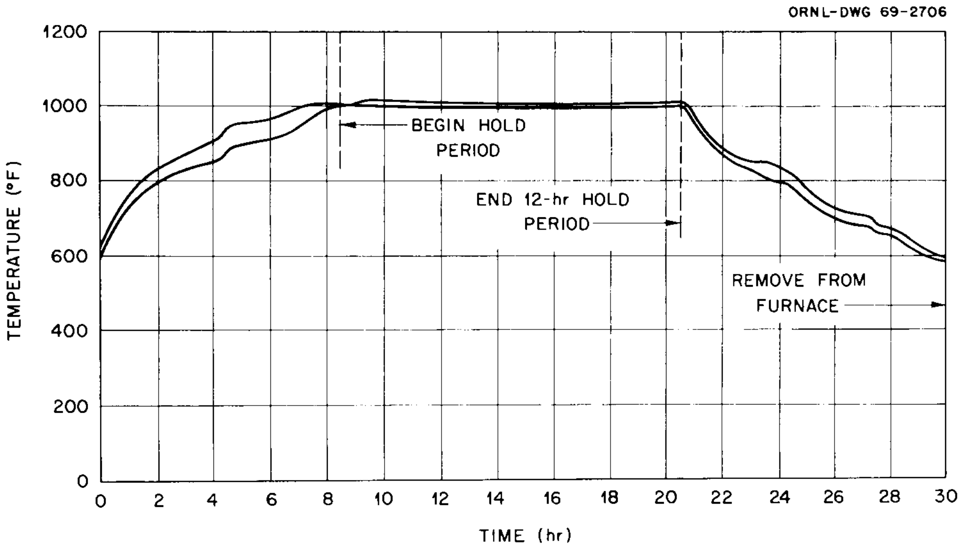

Fig. 3.4. Spread in Thermocouple Readings During Stress-Relieving Heat Treatment of Plate Sections 05A, 05B, 06A, and 06B.

4. HEAT TREATMENT AND TESTING OF PLATES 05 AND 06

R. HEAT TREATMENT AND INSPECTION OF PLATES 05A, 05B, 06A, AND 06B

Plate sections 05A and 06A, with dimensions of 72 X 84 X 4 in. and 97 X 53½ X 8 in., respectively, were grit blasted, visually inspected, and shipped to the HSST storage facility in the as-rerolled, stress-relieved, and descaled condition.

Plate sections 05B and 06B were processed simultaneously at the mill. Accordingly, the processing histories of the two will be treated simultaneously in this document.

R.1 Normalizing of Plate Sections 05B and 06B

Plate sections 05B and 06B were normalized January 4, 1968. They were placed in the furnace in the positions shown in Fig. 4.1. The furnace was heated until the normalizing temperature of 1675 ± 25°F was attained, and the plates were held at this temperature for 4 hr. At this time the furnace door was opened and the 4-in.-thick section (05B) was removed for air cooling. The 8-in.-thick section was recharged into the furnace and allowed to remain an additional 4 hr. In this manner each was held in the normalizing range for

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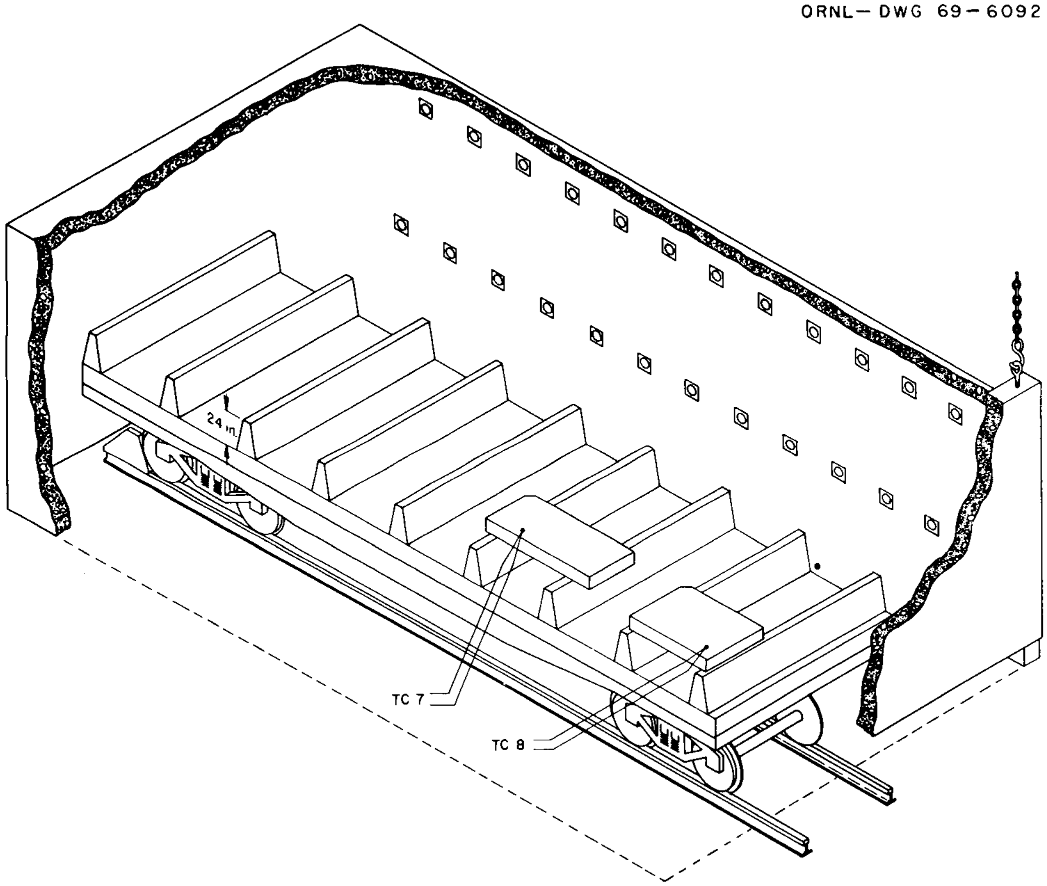

Fig. 4.1. Orientation of Plate Sections 05B and 06B During the Normalizing Heat Treatment.

1 hr per inch of thickness. Following the second 4-hr cycle the 8-in.-thick piece was removed from the furnace and air cooled. The furnace charts for the heat treatment are not available.

R.2 Austenitizing and Quenching of Plate Sections 05B and 06B

About one week later each plate section was grit blasted and four thermocouples were installed at the 1/4 *T* and 1/2 *T* locations shown in Fig. 4.2. Each installation was made using the type of thermocouples described in N.2; installation is as shown in Fig. 2.17.

Each plate section was painted with a scale-retarding compound and allowed to dry before being loaded on the furnace car for the austenitizing heat treatment. Each was oriented in the furnace as shown in Fig.

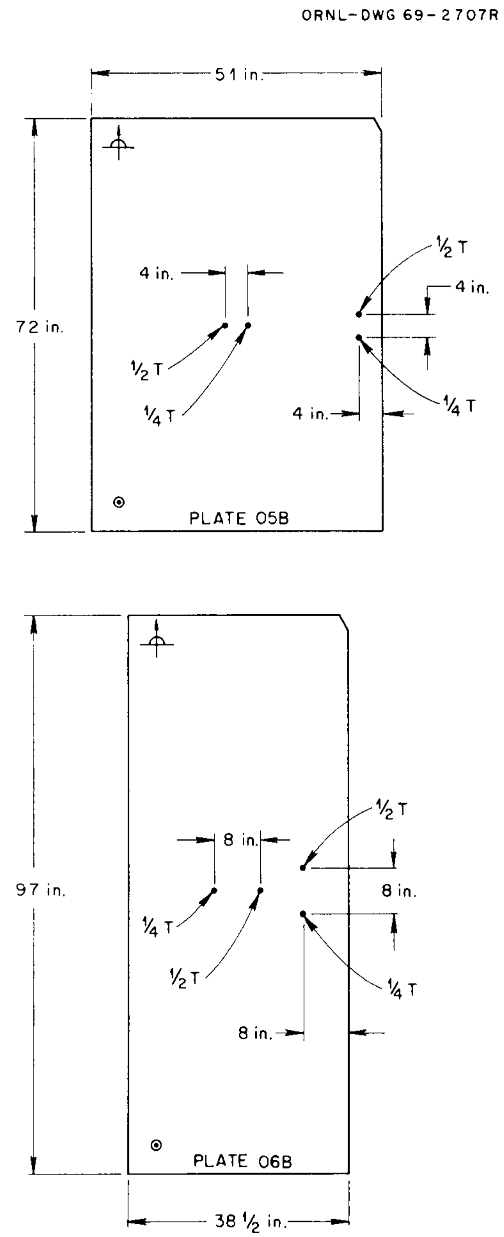

Fig. 4.2. Thermocouple Layout for Plate Sections 05B and 06B During the Austenitizing Heat Treatment.

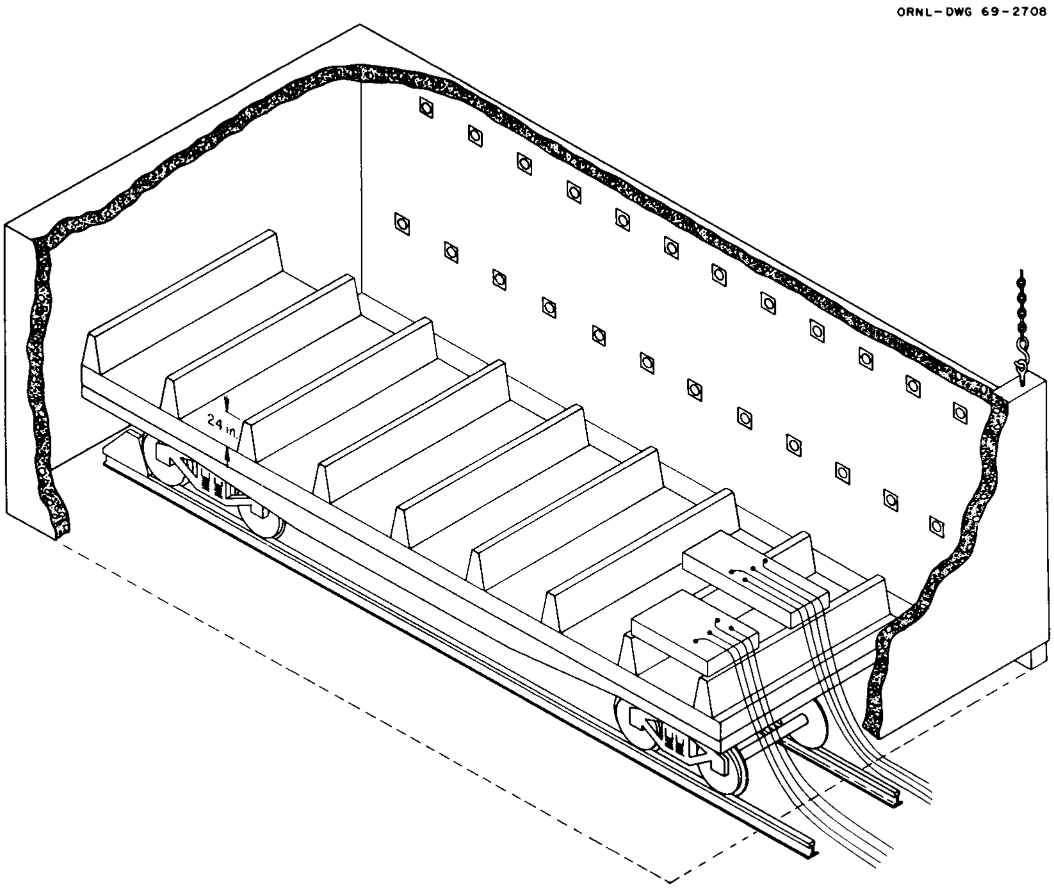

Fig. 4.3. Orientation of Plate Sections 05B and 06B During the Austenitizing Heat Treatment.

4.3. Firing of the furnace began at 12:30 AM, January 10, 1968. At 5:00 AM the highest thermocouple reading was within 1575 ± 25°F, and the hold period was begun. The prescribed hold period for plate section 05B was 4 hr and for plate section 06B, 8 hr, or 1 hr per inch of plate thickness. At 8:00 AM the plate thermocouple readings ranged between 1575 and 1650°F; the furnace couples recorded almost continuously at 1575°F. Lukens' personnel speculated that the Leeds and Northrup 12-point recorder was probably out of calibration. One of their electronics technicians subsequently checked the calibration and concluded that it was recording about 10°F too high.

On completion of the 4-hr hold period, plate section 05B was removed from the furnace. It was lifted for quenching with a triangular-shaped structural member which had four chains suspended from the bottom horizontal member. Steel plates, bent at 90° angles for lifting, were attached to the ends of the four chains. In this manner, practically all of the plate was in contact with the quench medium.

Immediately before the quenching operation began, the temperature of the quench medium was 52°F. The operational sequence was as follows:

Furnace door started up	00:00 (1–10–68, 9:45 AM)
Furnace door fully opened	20 sec
Car out and stopped	55 sec
Pickup started	1 min 5 sec
Into water	1 min 40 sec
Out of water	14 min 35 sec

The temperature of the water remained at about 52°F throughout the quench. The plate temperature was about 150°F on removal from the water. At this time the recorder was calibrated and a 10°F downward adjustment was made.

About 4 hr passed before the 8-in.-thick plate was removed from the furnace. Shortly before quench time the plate thermocouples were recording temperatures between 1590 and 1610°F; the furnace thermocouples were still recording 1575°F. The temperature of the water immediately prior to quench remained at 52°F. The sequence of events for plate section 06B was as follows:

Furnace door started up	00:00 (1–10–68, 1:15 PM)
Furnace door fully opened	20 sec
Car out and stopped	55 sec
Pickup started	1 min 5 sec
Into water	1 min 37 sec
Out of water	36 min 20 sec

No significant temperature change was noted in the quench medium either during or after quenching. All plate thermocouple readings were less than 200°F when the plate was withdrawn from the water.

The curves of the austenitizing heatup and hold periods are shown in Fig. 4.4. Curves of the cooling rates during quenching of plate sections 05B and 06B are shown in Figs. 4.5 and 4.6 respectively.

R.3 Tempering of Plate Sections 05B and 06B

During the time plate section 06B was in the quench tank, the furnace car was left outside, the furnace door remained open, and all firing units were shut off. Consequently, the temperature of both car and furnace dropped to a relatively low value during this interval. On completion of quenching of 06B, both

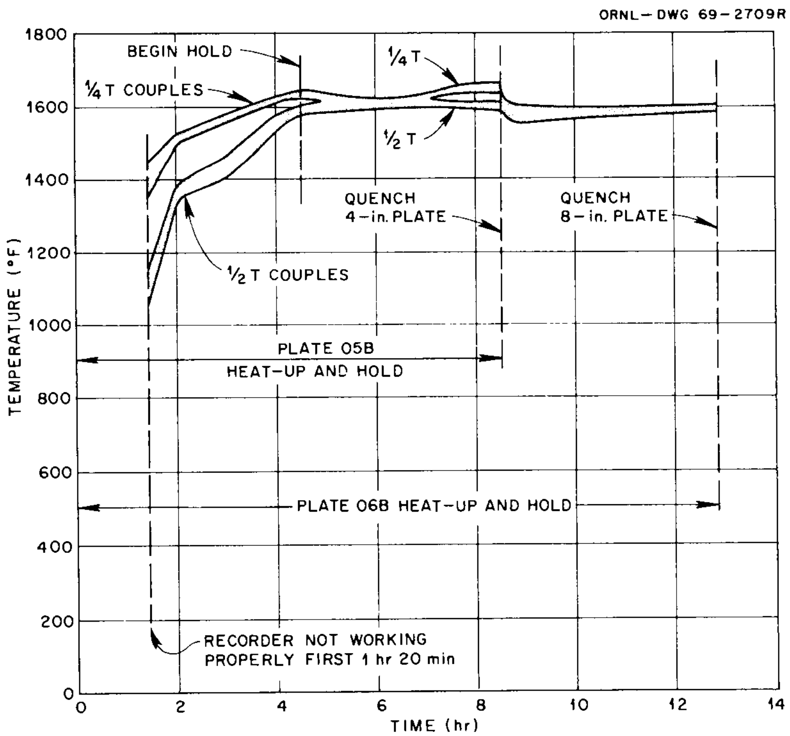

Fig. 4.4. Spread in Thermocouple Readings During the Austenitizing Heat Treatment of Plate Sections 05B and 06B.

plate sections 05B and 06B were reloaded on the furnace car essentially as shown in Fig. 4.3 and charged into the furnace for tempering. All thermocouples were still intact and each was recording.

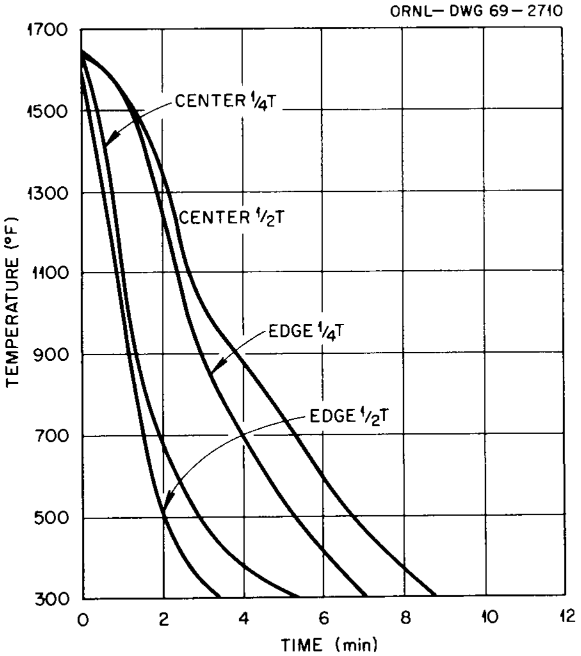

Fig. 4.5. Cooling Curves for Plate Section 05B.

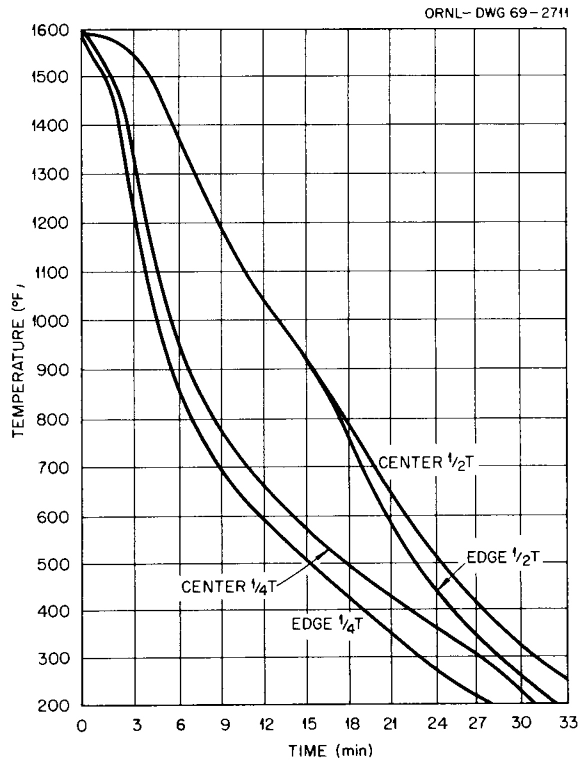

Fig. 4.6. Cooling Curves for Plate Section 06B.

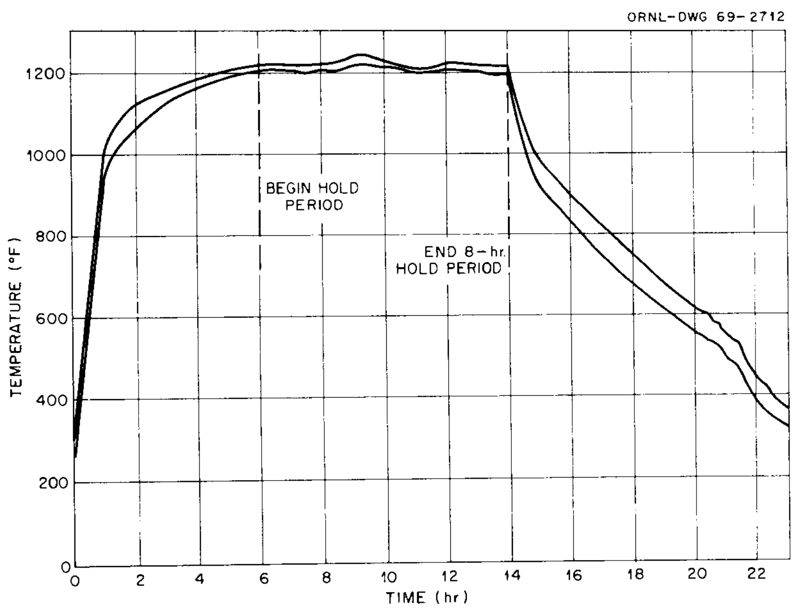

Fig. 4.7. Spread in (Furnace) Thermocouple Readings During the Tempering Heat Treatment of Plate Sections 05B and 06B.

Figure 4.7 shows the heating and cooling rates for the tempering heat treatment as recorded by furnace couples 1 and 8. The heating and cooling rates derived from the plate thermocouples are shown in Fig. 4.8. The specified tempering temperature was 1225 ± 25°F. The temperatures recorded by the furnace couples stayed within this range throughout the hold period. However, as noted by Fig. 4.8, the temperatures recorded by the plate thermocouples were higher than the specified 1250°F maximum.

R.4 Stress Relieving of Plate Sections 05B and 06B

January 13, 1968, the plates were returned to the furnace for a stress-relieving heat treatment at 1125° ± 25°F for 40 hr. Both plates were loaded on the furnace car essentially as shown in Fig. 4.3. Two furnace

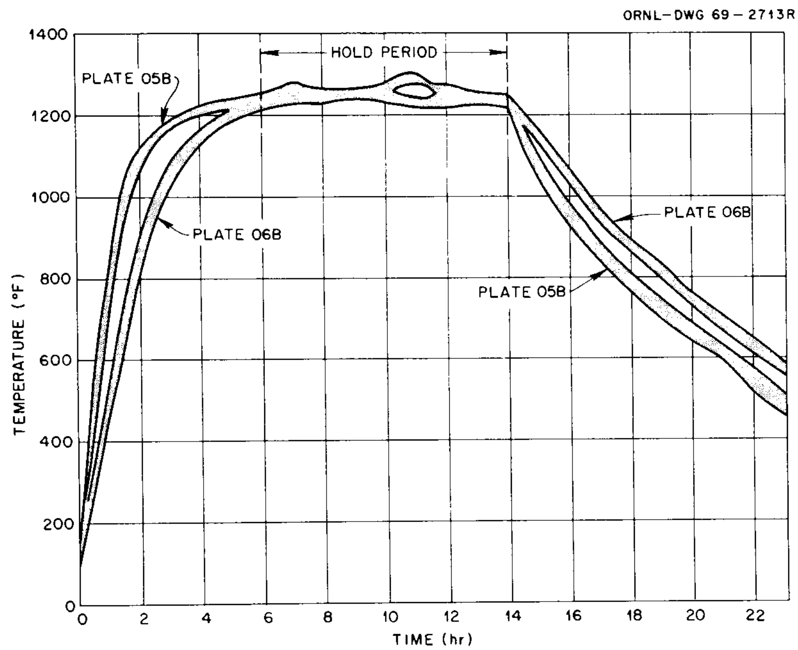

Fig. 4.8. Spread in (Plate) Thermocouple Readings During the Tempering Heat Treatment of Plate Sections 05B and 06B.

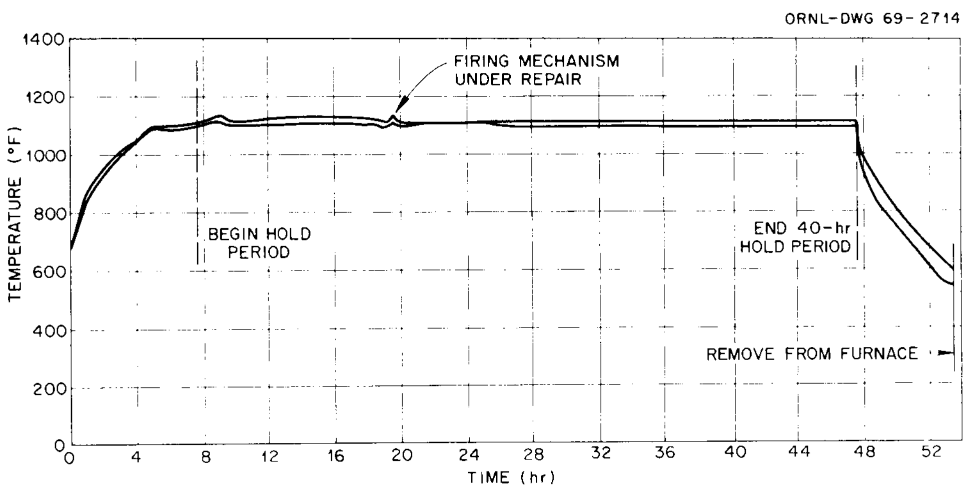

Fig. 4.9. Spread in Thermocouple Readings During the Stress-Relieving Heat Treatment of Plate Sections 05B and 06B.

couples, 1 and 8, were used to record the temperature profile. Some mechanical difficulties were experienced with the firing mechanism during the hold period, and this is reflected in an erratic curve as noted in Fig. 4.9.

After the 40-hr hold period was completed, the plates remained in the furnace for about 6 hr, until the thermocouples were recording less than 600°F.

R.5 Removal of Test Material and Second Stress Relief of Plate Sections 05B and 06B

A few days after the first stress-relieving heat treatment, plate sections 05B and 06B were placed in a furnace and heated to about 500°F. They were then removed from the furnace, and the test material was cut from the locations shown in Fig. 4.10. Cutting was done by the oxyacetylene process.

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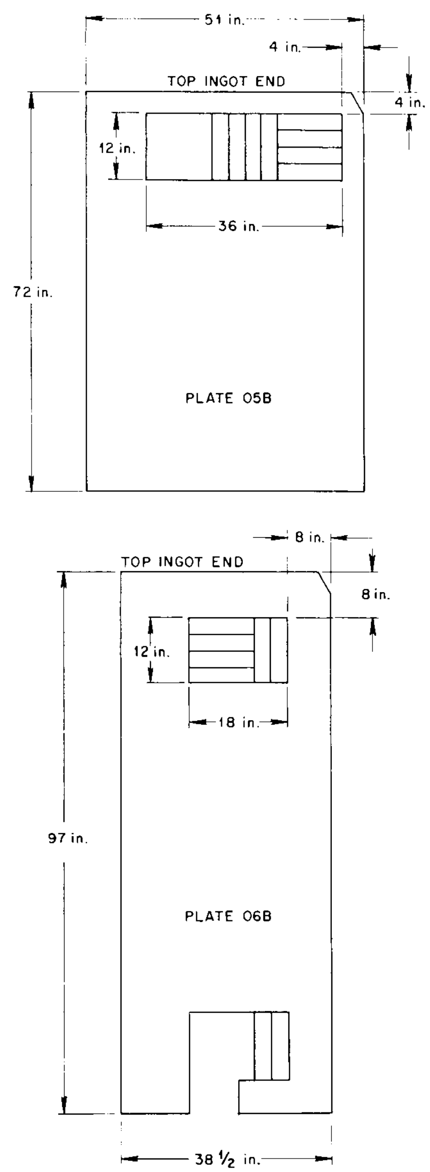

Fig. 4.10. Location of Specimen Cutouts for Plate Sections 05B and 06B.

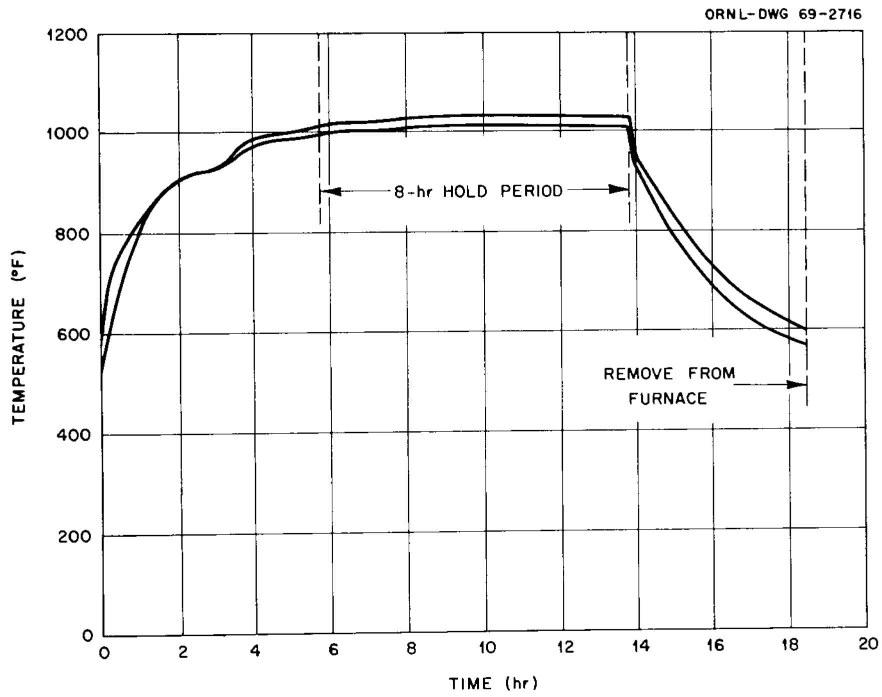

Fig. 4.11. Spread in Thermocouple Readings During the Stress Relieving of Plate Sections 05B and 06B After Removal of Specimen Material.

Shortly after the test material was cut from the plate sections, they were returned to the furnace for the final stress-relieving heat treatment. Again each was oriented in the furnace as shown in Fig. 4.3, and furnace couples 1 and 8 were used to record the temperature profile.

The plate sections were heated for about 6 hr before the stress-relief temperature of 1025°F ± 25°F was attained. Following an 8-hr hold period, each was left in the furnace to cool below 600°F. A record of the heating and cooling data is shown in Fig. 4.11.

S. ULTRASONIC INSPECTION OF PLATE SECTIONS 05B AND 06B

It was noted in a preceding section of this report that plate 03 and plate section 04A were ultrasonically inspected concurrently. Plate sections 05B and 06B were also inspected concurrently with those plates. Consequently, all of the testing parameters listed in D.1 and D.2, longitudinal and shear-wave inspection, respectively, also apply to plate sections 05B and 06B. The longitudinal and shear-wave DAC curves shown in Figs. 1.5 and 1.7 were used for evaluating plate sections 05B and 06B.

Like the previous plates, 05B and 06B were prepared for inspection by grit blasting and grinding to a suitable surface finish, approximately 250 rms.

No "recordable" longitudinal or shear-wave indications were found in plate section 05B.

Plate section 06B, shown in Fig. 4.12, contained three small longitudinal-wave indications which caused a 100% loss of back-surface reflection. Indication 1 produced a signal two lines high on the instrument screen at the 4-in.-depth level. Indications 2 and 3, respectively, produced signals five and seven lines high at this level. No "recordable" shear-wave indications were found in plate section 06B.

At the conclusion of ultrasonic inspection the plates were shipped to the HSST storage facility.

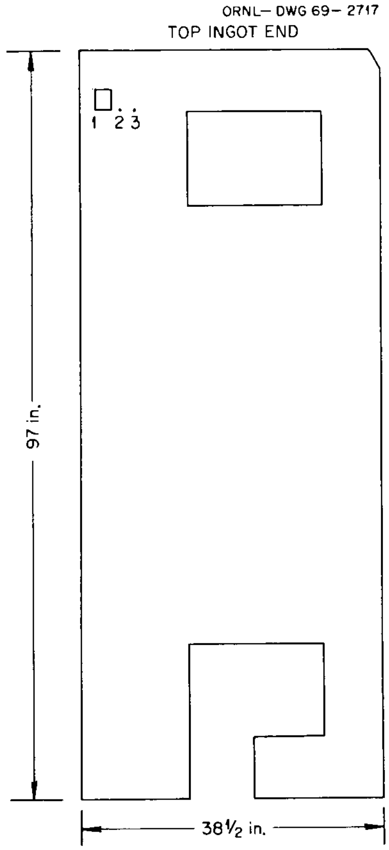

Fig. 4.12. "Recordable" Longitudinal-Wave Indications Found in Plate Section 06B.

T. QUALIFICATION AND DEVELOPMENT TESTING

Specimens for qualification and development testing of plate sections 05B and 06B were secured from the locations shown in Fig. 4.10. The methods used for preparing the specimens and selection of test locations were the same as those described in Part P. The results of the plate qualification tests are listed in Tables 4.1 and 4.2. It can be seen from the results listed in Table 4.1 that the mechanical properties of both

Table 4.1. Results of Qualification Tests Performed by Lukens on HSST Plate Sections 05B and 06B, ASTM A-533 Grade B Class 2

Location in Ingot	Through-Gage Location	Specimen Orientation	Yield Strength (ksi)	Ultimate Tensile Strength (ksi)	Percent Elongation	Percent Reduction of Area
Plate section 05B						
Top	Bottom 1/4 *T*	L	77.5	97.0	26	69.0
Top	Bottom 1/4 *T*	L	76.1	97.0	26	69.0
Top	Bottom 1/4 *T*	T	77.2	100.0	25	68.0
Top	Bottom 1/4 *T*	T	79.4	98.5	25	66 0
Plate section 06B						
Top	Top 1/4 *T*	L	80.0	101.5	24	66.9
Top	Top 1/4 *T*	L	78.8	100.5	24	64.3
Top	Top 1/4 *T*	T	79.0	101.5	22	59.8
Top	Top 1/4 *T*	T	78.7	100.5	23	60.0

plates met the requirements of A-533 grade B class 2. The requirements of the ASME Code Section III, which specify that for a room-temperature hydrotest the NDT shall be +10°F or lower, or that the minimum average of three CVN specimens shall be 30 ft-lb, with one value as low as 25 ft-lb at +10°F, were met in the 4-in.-thick plate (05B), but only the CVN requirement was met in the 8-in.-thick plate (06B). The results of the development tests are listed in Tables 4.3 and 4.4.

The fracture appearance of homogeneity tests taken from the 1/4 *T* location in the plate sections may be seen in Fig. 4.13.

Photomicrographs made from broken Charpy V-notch specimens representing surface, 1/4 *T*, and 1/2 *T* locations in the plate sections are shown in Figs. 4.14 and 4.15.

Table 4.2. Toughness Data Derived from Plate Qualification Testing of HSST Plate Sections 05B and 06B, ASTM A-533 Grade B Class 2

Test Temperature (°F)	Specimen Orientation	ft-lb CVN	Mils Lateral Exp.	Percent Fibrous	30 ft-lb CVN Transition Temperature (°F)	NDT (°F) Determined by P-2 Drop Weight Specimens
Plate 05B, plate top, bottom 1/4 *T*						
+70	L	48, 107, 100 85 av	69, 72, 76	95		
	T	77, 94, 82 84 av	62, 69, 68	85		
+10	L	71, 70, 77 73 av	57, 55, 58	45		
	T	71, 67, 55 61 av	47, 56, 44	25		
−50	L	55, 32, 32 40 av	44, 28, 29	35		
	T	22, 30, 32 28 av	30, 26, 42	20		
					−58	−50
Plate 06B, plate top, top 1/4 *T*						
+70	L	65, 67, 68 67 av	51, 54, 57	45		
	T	54, 57, 59 57 av	46, 47, 49	50		
+30	L	38, 55, 62 52 av	36, 45, 49	30		
+10	L	38, 33, 42 38 av	32, 27, 34	10		
	T	33, 37, 42 39 av	30, 31, 34	20		
−20	L	36, 30, 30 32 av	33, 29, 13	20		
					+3	+30

Table 4.3. Results of Development Tests Performed by Lukens on HSST Plate Sections 05B and 06B, ASTM A-533 Grade B Class 2

Location in Ingot	Through-Gage Location	Specimen Orientation	Yield Strength (ksi)	Ultimate Tensile Strength (ksi)	Percent Elongation	Percent Reduction of Area
Plate section 05B						
Top	Top surface	L	84.1	100.5	25	66.9
Top	Top surface	L	84.5	100.5	26	66.0
Top	Top surface	T	86.3	102.5	23	65.9
Top	Top surface	T	87.5	102.6	23	63.6
Top	1/2 *T*	L	75.2	95.4	25	63.8
Top	1/2 *T*	L	75.2	96.0	27	64.5
Top	1/2 *T*	T	73.6	94.5	27	63.5
Top	1/2 *T*	T	73.8	94.9	24	60.7
Plate section 06B						
Top	Top surface	L	92.4	107.6	22	65.7
Top	Top surface	L	90.6	107.0	22	62.0
Top	Top surface	T	92.4	107.5	24	63.5
Top	Top surface	T	89.8	106.5	23	66.0
Top	1/2 *T*	L	77.1	96.5	24	64.3
Top	1/2 *T*	L	75.9	96.0	24	63.5
Top	1/2 *T*	T	75.9	97.0	23	58.5
Top	1/2 *T*	T	76.8	96.5	21	54.3

Table 4.4. Toughness Data Derived from Development Testing of HSST Plate Sections 05B, ASTM A-533 Grade B Class 2

Test Temperature (°F)	Specimen Orientation	ft-lb CVN	Mils Lateral Exp.	Percent Fibrous	30 ft-lb CVN Transition Temperature (°F)	NDT (°F) Determined by P-2 Drop Weight Specimens
Plate top, top surface						
+70	L	99, 97, 111 103 av	68, 66, 74	90		
	T	108, 107, 105 107 av	79, 78, 72	95		
+10	L	98, 103, 103 101 av	62, 66, 67	65		
	T	97, 100, 103 100 av	63, 74, 75	85		
−100	L	45, 40, 48 44 av				
	T	46, 30, 38 38 av				
−150	L	21, 20, 22 21 av				
	T	18, 13, 16 16 av				
					−119	−100

Table 4.4 Continued

Test Temperature (°F)	Specimen Orientation	ft-lb CVN	Mils Lateral Exp.	Percent Fibrous	30 ft-lb CVN Transition Temperature (°F)	NDT (°F) Determined by P-2 Drop Weight Specimens
Plate top, center line						
+70	L	92, 95, 97 95 av	72, 72, 74	95		
	T	97, 97, 102 99 av	72, 74, 75	95		
+10	L	55, 70, 59 61 av	48, 62, 53	60		
	T	65, 65, 77 69 av	53, 50, 60	55		
−50	L	32, 42, 42 39 av	29, 37, 33	35		
	T	34, 25, 16 25 av	29, 25, 18	15		
					−58	−50
Plate top, top surface						
+70	L	108, 101, 101 106 av	74, 75, 71	95		
	T	72, 80, 81 78 av	40, 41, 52	85		
+10	L	100, 102, 104 102 av	64, 65, 70	95		
	T	79, 82, 82 81 av	53, 56, 70	80		
−100	L	32, 40, 36 36 av	24, 31, 27	25		
−100	L	40, 40, 32 37 av	25, 28, 24	15		
					−110	−100
Plate top, center line						
+70	L	79, 77, 64 73 av				
	T	48, 51, 50 50 av				
+20	L	56, 26, 55 46 av	45, 21, 44	25		
+10	L	41, 43, 30 35 av	32, 34, 27	25		
	T	28, 44, 41 38 av	28, 37, 36	20		
−20	L	15, 44, 38 32 av	29, 31, 30	20		

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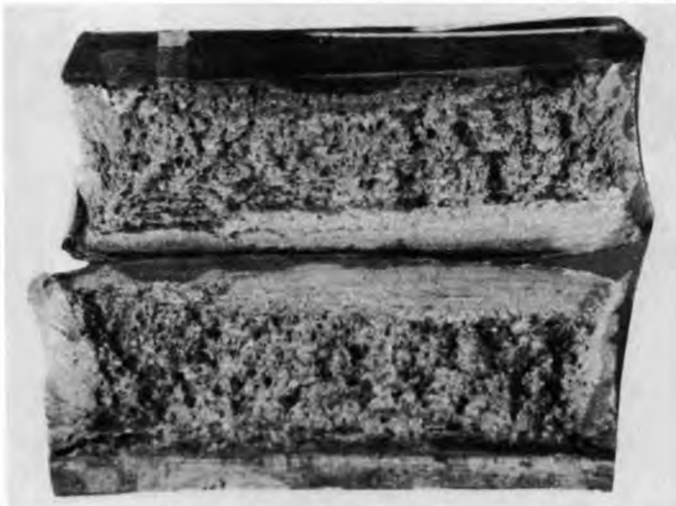
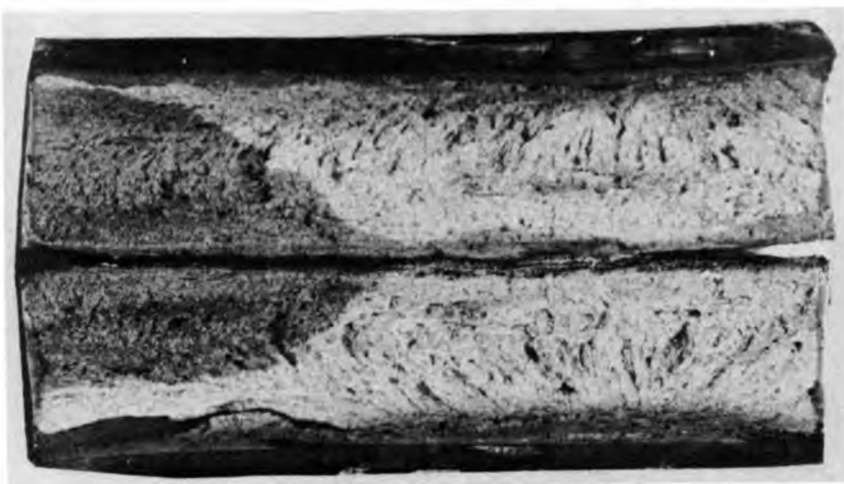


TOP INGOT END PLATE SECTION 05B



BOTTOM INGOT END PLATE SECTION 06B

Fig. 4.13. Homogeneity Test Specimens from Plate Sections 05B and 06B.

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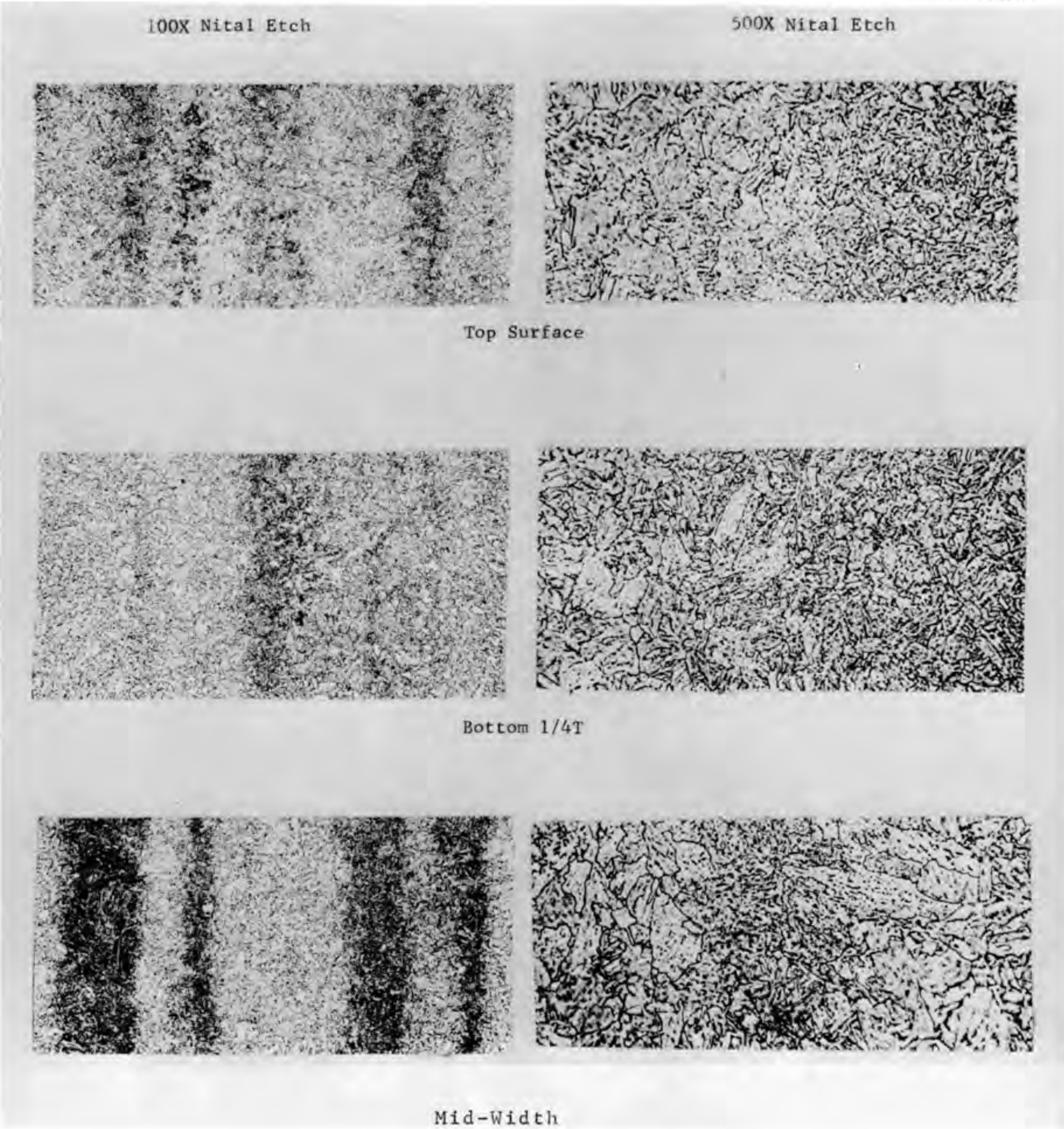


Fig. 4.14. Microstructure of Plate Section 05B. Reduced 20%.

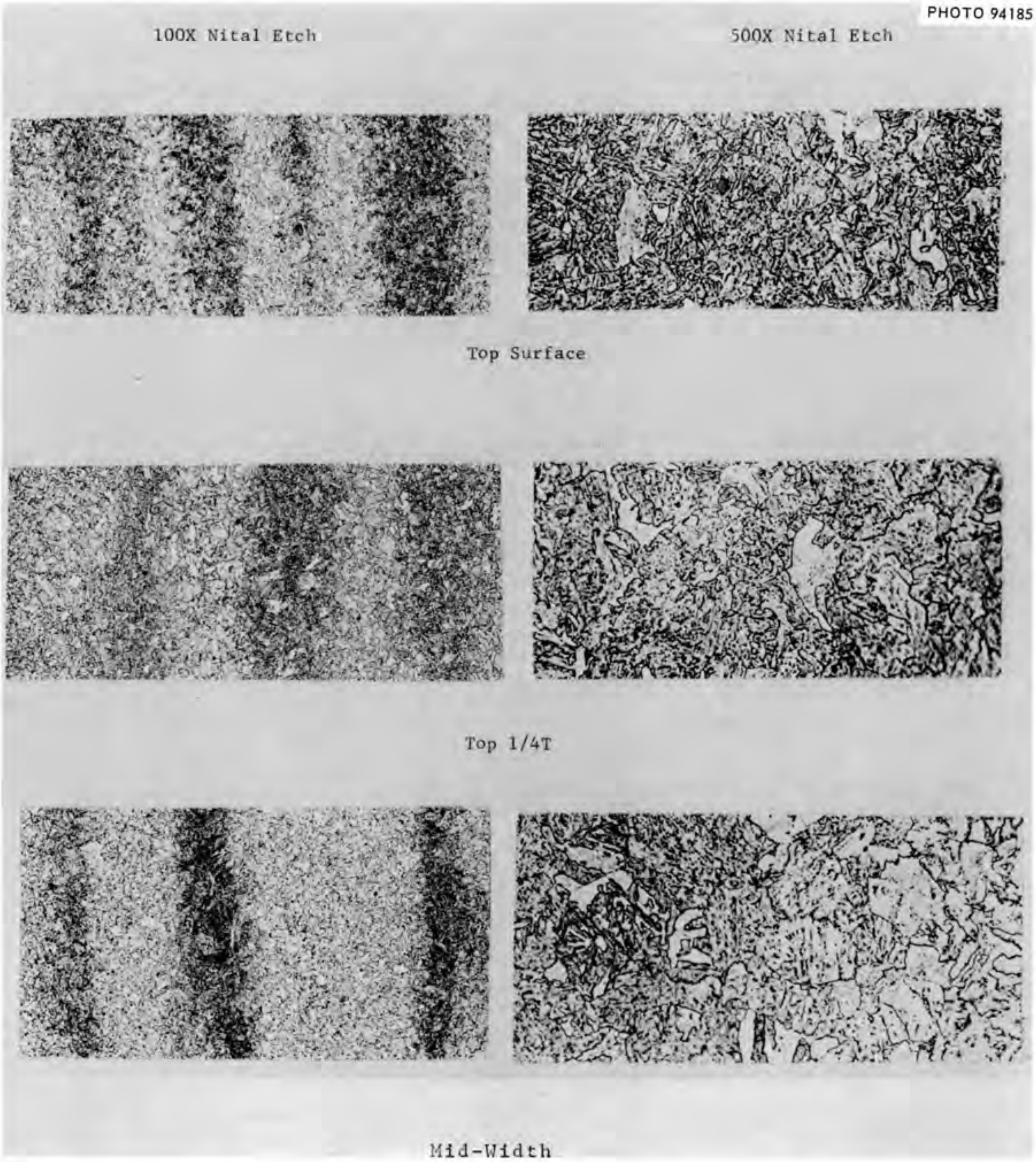


Fig. 4.15. Microstructure of Plate Section 06B. Reduced 20%.

APPENDIX

UNION CARBIDE CORPORATION
NUCLEAR DIVISION
OAK RIDGE, TENNESSEE 37830

PURCHASE ORDER

Acting Under U. S. Government Contract W7405 eng 26 With the U. S. Atomic Energy Commission

REQUISITION NO	DELIVER BY	REFER QUESTIONS TO	PLANT	PURCHASE ORDER NO.	C/N	DATE
A-6161	5-26-67	A. F. Johnson	Y-12	73Y-49288V		2-22-67

SHIP TO: U. S. Atomic Energy Commission, c/o Union Carbide Corporation - Nuclear Division
MARK ALL PACKAGES WITH PLANT AND ORDER NUMBER AND CONSIGN:

PARCEL POST TO: POST OFFICE BOX Y OAK RIDGE, TENN 37830
RAIL FREIGHT VIA AND TO DESTINATION (As Coded): 1. SOUTHERN RAILWAY TO BLAIR, TENNESSEE 2. LOUISVILLE AND NASHVILLE RAILWAY TO OAK RIDGE, TENN.

Motor Freight, Air Express, or Railway Express to Oak Ridge, Tennessee; Air Freight to Knoxville, Tennessee

F.O.B. (As Coded): 2 — 1. DESTINATION 2. SHIPPING POINT 3. SHIPPING POINT-FRT. ALLOWED 4.

SHIPPING POINT: Coatesville, PA

VENDOR PAYEE CODE: L24350

Lukens Steel Company
Suite 104, 1172 West Galbraith Road
Cincinnati, Ohio 45231

ATTENTION: Mr. Eugene D. Hug

TRANSPORTATION TERMS (As Coded): 1 — 1. ACCOUNT OF GOVERNMENT DO NOT INSURE DECLARE VALUE SO AS TO OBTAIN LOWEST POSSIBLE TRANSPORTATION RATE 2. ACCOUNT OF SELLER-PREPAID. 3. OTHER (SEE BELOW)

SHIP VIA (As Coded): B — A. MOTOR FREIGHT B. RAIL FREIGHT C. RAIL EXPRESS D. AIR FREIGHT* E. AIR EXPRESS F. PARCEL POST G. AIR PARCEL POST H. SELLER'S TRUCK I. SELLER'S OPTION J. KNOX CONT CARRIER K. BUS L. AS SHOWN M. UCN TRUCK N. 0-20# PARCEL POST 21-45# RAIL EXP. OVER 45# MTR. FRT. *EXCLUDES AIR FREIGHT FORWARDERS

You are required to follow the provisions of DMS Regulation 1 and all other applicable regulations and orders of BDSA in obtaining controlled materials and other products and materials needed to fill this order.
DO E-2 (CERTIFIED FOR NATIONAL DEFENSE USE UNDER DMS REGULATION 1) [ ]
DMS ALLOTMENT NO. E-2 (CERTIFIED FOR NATIONAL DEFENSE USE UNDER DMS REGULATION 1) [x] 1st QUARTER, 1967

DISCOUNT (As Coded): 5 — 0 NET 1 1% 2 2% 3 3% 4 1/4% 5 1/2% 6 5% 7 6% 8 10% 9 OTHER
PAYMENT TERMS — DISCOUNT PERIOD: DISCOUNTS ARE TAKEN IN ACCORDANCE WITH STANDARD POLICY (SEE PAYMENTS ARTICLE OF TERMS AND CONDITIONS) UNLESS NOTED BELOW: [ ] OTHER DISCOUNT PERIOD

FURNISH THE FOLLOWING ITEMS IN ACCORDANCE WITH TERMS AND CONDITIONS DESIGNATED L 8-1-66 ATTACHED HERETO AND WITH THE SPECIFICATIONS AND/OR DRAWINGS REFERRED TO HEREIN AND MADE A PART HEREOF.

ITEM NO.	WORK ORDER (ACCT. T/E SUB) / CATALOG NUMBER / DESCRIPTION	ORDERED QUANTITY	UNIT	UNIT PRICE $ ¢	TOTAL PRICE $ ¢
	443565-120				
001	Steel Plate, ASME Case 1339, Electric Furnace Melt, Vacuum Degassed, Stress Relieved and Descaled, Controlled Cooling, 12" Thick x 120" x Approximately 240" Long (200" minimum), manufactured in accordance with Combustion Engineering, Inc., specification entitled "Purchase Specification for 80,000 PSI Tensile Strength (SA-302-GR B Modified) Plate for Heat Treatment by the Purchaser" designation: Spec. No. PBF12(a), dated July 29, 1964, except as follows:	196,000 (2	LB EA)		
	Part 1.1 - Change sentence to read: "This specification is for the purchase of steel plate to be used in test programs related to pressure vessels for nuclear service."				
	Part 1.2 - Change sentence to read: "Plate furnished to this specification shall conform to the requirements of ASME Case 1339, except				

AFJ:ms

THE BLOCK CHECKED BELOW IS APPLICABLE TO THIS ORDER. IF BLOCK "A" IS CHECKED, THE SELLER SHALL SIGN AND COMPLETE IN THE SPACE PROVIDED.

[X] A — TO THE SELLER
Please sign and return one copy as acceptance of this order at once. All of the agreements of the parties relating to the subject matter are contained in this Purchase Order.

ACCEPTED (FIRM NAME) | BY (NAME AND TITLE) | DATE

[ ] B — TO THE SELLER
This Purchase Order is issued to accept Seller's proposal dated ______ Request No. ______ and constitutes the sole contractual agreement between the parties.

NO TENNESSEE SALES OR USE TAX IS PAYABLE BY THE SELLER ON MATERIAL COVERED BY THIS ORDER BY REASON OF EXEMPTION CERTIFICATE AUTHORIZED FOR USE BY THE BUYER BY THE DEPARTMENT OF REVENUE, STATE OF TENNESSEE.

BILLING INSTRUCTIONS (REFER TO PURCHASE ORDER TERMS AND CONDITIONS)
1. [ ] INVOICE NOT REQUIRED - DO NOT MAIL
2. [X] FURNISH ORIGINAL INVOICE TO:
UNION CARBIDE CORPORATION - NUCLEAR DIVISION ACCOUNTS PAYABLE DEPARTMENT P.O. BOX P, OAK RIDGE, TENNESSEE 37830

UNION CARBIDE CORPORATION
NUCLEAR DIVISION
J. A. Elkins
PURCHASING

PAGE OF	INSPECTION (As Coded) 1. ROUTINE 2. SPECIAL	REQUISITIONED BY	DELIVER TO	WANTED BY
3		W. B. Pike (2)	S. R. Ashton, 9201-3	6-1-67

											TOTAL AMOUNT OF ORDER
2	4	04	01	6	4	1	003	65	1	2	36,641.20

UCN-2163
(1286 1-67)

UNION CARBIDE CORPORATION
NUCLEAR DIVISION
P. O. BOX M, OAK RIDGE, TENNESSEE 37831

PURCHASE ORDER CONTINUATION PAGE

PURCHASE ORDER NO. 73Y-49288V

ITEM NO.	DESCRIPTION	ORDERED QUANTITY	UNIT	UNIT PRICE $. ¢	TOTAL PRICE $. ¢
	nickel shall be .40 - .70% in the ladle analysis."				
	Part 1.3 - Delete.				
	Part 2.2 - Change sentence to read: "Plates shall be furnished in the stress relieved and descaled condition, except that the manufacturer shall apply special treatments to gas cut edges."				
	Part 4.3 - Add the following sentence: "The holding time for the quenched and tempered samples shall be twenty (20) hours."				
002	Each plate shall be stamped on two edges with heat number and identification markings.	1	LOT		
003	Check analysis (per plate)	2	EA		
	Note 1: In addition to conformance with the referenced specifications, the Seller shall not make any repairs to the required plates for this order during the rolling process except those considered normal to production practice. In cases where repairs are made, the Seller shall maintain a sketch record of the location of each repair and furnish the sketches to the Company at time of shipment and the plates shall be identified accordingly.				
	Note 2: The Seller shall provide the Company with data described on the attached form Appendix I, "Material History of Heavy Section Steels", for each heat. It is to be noted this requirement is for information purposes only.				
	Note 3: The Seller shall notify the Company 72 hours in advance of the date scheduled for the rolling operations in order that the Company's representative(s) may be present to witness these operations.				
	Note 4: Lukens Data Trac shall be used in lieu of 3T testing.				
	Note 5: Prices as above, subject to adjustment to conform with Seller's price at time of shipment; any increase not to exceed 10% of above prices.				

UCN-2164

UNION CARBIDE CORPORATION
NUCLEAR DIVISION
P. O. BOX M, OAK RIDGE, TENNESSEE 37831

PURCHASE ORDER CONTINUATION PAGE

PURCHASE ORDER NO. 73Y-49288V

ITEM NO.	WORK ORDER ACCT. T/E SUB NO.	CATALOG NUMBER	R/A DESCRIPTION	ORDERED QUANTITY	UNIT	UNIT PRICE $ ¢	TOTAL PRICE $ ¢
	In the event Seller's price at time of shipment is in excess of the price stated in this order, the Seller shall submit adequate evidence of the basis of the increase in price, and shall certify to the Company that the price charged in not in excess of its posted price or that charged its customers in like circumstances.						
	CONFIRMING TELEPHONE ORDER OF 2-24-67, A. F. JOHNSON TO MR. HUG. DO NOT DUPLICATE.						

ATTACHMENT 2A

DATE: AUGUST 4, 1966
SHEET: 1 of 4

ULTRASONIC TEST SPECIFICATION NUMBER 1

(Longitudinal Wave Pulse Echo Testing of Plate)

1.0 SCOPE:

1.1 This specification covers the examination procedure and recording requirements for the pulse echo ultrasonic inspection of rolled carbon and alloy steel plates, 4" through 13" in thickness, of fully killed firebox or higher quality by the longitudinal (normal) beam method. It was developed to detect discontinuities parallel to the rolled surfaces.

1.2 This test shall be applied 1) when the plate is in the flat condition and 2) after the plate has been hot formed, quenched and tempered.

2.0 APPARATUS:

2.1 The test shall be performed using ultrasonic equipment of the pulse-echo longitudinal beam type which shall provide linear presentation, within ± 5% to at least 75% of full screen height.

2.2 The transducer shall be 1-1/8" diameter or 1" square.

2.3 Other search units may be used for evaluating and pin-pointing indications.

3.0 PROCEDURE:

3.1 The inspection shall be conducted in an area free from operations that interfere with proper performance of the test.

3.2 Unless otherwise specified, ultrasonic inspection shall be made on either major surface of the plate.

3.3 The plate surface shall be sufficiently clean and smooth to maintain a good sonic coupling between the transducer and plate surface during scanning. This may involve suitable means of scale removal. Local rough surfaces shall be conditioned by grinding. Any specified identification which is removed when grinding to achieve proper surface smoothness shall be restored.

ATTACHMENT 2A

DATE: AUGUST 4, 1966
SHEET: 2 of 4

ULTRASONIC TEST SPECIFICATION NO. 1

3.0 PROCEDURE: (continued)

3.4 The test shall be performed by one of the following methods:

Direct contact, immersion or liquid column coupling. A suitable couplant such as water, soluble oil or glycerine shall be used.

3.5 A nominal test frequency of 2¼ Mc is recommended. Thickness, grain size or microstructure of the material and nature of the equipment or method may require a higher or lower test frequency. Transducers shall be used at their rated frequency. A clean, easily interpreted trace pattern shall be produced during the inspection.

3.5.1 Each flat plate will be stamped with a bench mark located near the plate identification stamping and all indication locations referenced to this mark. This mark shall be located such that when the plate is cut to size and formed into a shell segment the mark will remain on the vessel.

3.6 Scanning

3.6.1 Scanning shall be continuous over 100% of the plate surface.

3.6.2 When a discontinuity condition is observed which approaches the Distance Amplitude Curve (D.A.C.), the transducer shall be positioned to display the maximum indication so that the discontinuity can be evaluated by comparison with the D.A.C.

4.0 ULTRASONIC EXAMINATION USING FLAT BOTTOM HOLE CALIBRATION:

4.1 The following calibration and recording procedures shall be used:

4.2 Reference Block - A reference specimen shall be used to calibrate the equipment and establish recording criteria. Two (2) reference blocks shall be utilized: one (1) 7½" thick to apply to plate thicknesses from 6" to 9" inclusive; one (1) 11" thick to apply to plate thicknesses in excess of 9" and not exceeding 13". The material shall be acoustically

ATTACHMENT 2A

DATE: AUGUST 4, 1966
SHEET: 3 of 4

ULTRASONIC TEST SPECIFICATION NO. 1

4.0 ULTRASONIC EXAMINATION USING FLAT BOTTOM HOLE CALIBRATION: (continued)

4.2 (continued)

similar to the plate undergoing examination. Acoustic similarity is presumed when comparison of the back reflection signals between the reference specimen and actual plate without change in instrument setting shows a variation of 25% or less.

4.2.1 The reference blocks shall conform to figure 1 (later).

4.3 All reference blocks used on this program shall be prepared by one supplier and ultrasonic response shall not vary by more than 5 percent from block to block.

5.0 CALIBRATION PROCEDURE:

5.1 Place the transducer over the hole producing the highest indication and adjust the sensitivity to approximately 75% of full scale. Without changing the instrument settings, place the transducer over each hole and mark on the oscilloscope face the location and amplitude of the reflection from each flat bottom hole. Connect these points with a smooth curve. This is the D.A.C. and is the reference level for examination and reporting.

5.2 Place the transducer over a sound area of the reference block and note the back reflection amplitude using a calibrated attenuator or similar device if necessary. Record this amplitude and attenuator setting.

5.3 Place the transducer on a sound area of the plate to be examined in an area having a satisfactory surface condition. The instrument sensitivity may be adjusted so that the first back reflection equals that amplitude from the reference plate. Any change in sensitivity from that established on the reference block shall be recorded and reported in terms of decibels of attenuation or % of screen height change in the reflection.

ATTACHMENT 2A

DATE: AUGUST 4, 1966
SHEET: 4 of 4

ULTRASONIC TEST SPECIFICATION NO. 1

5.0 CALIBRATION PROCEDURE:
(continued)

5.4 Sensitivity adjustment shall be made only as described in 5.2 and 5.3 or when performing a recalibration procedure which will be done at least once per hour, or at any time the equipment is moved, turned on or after any power interruption.

6.0 RECORDING:

6.1 Any indication exceeding the D.A.C. shall be recorded.

6.1.1 Record the loss of back reflection amplitude associated with any such indications.

6.2 Any complete loss of back reflection shall be recorded.

6.3 Any travelling indication shall be recorded.

6.4 In addition to the above, each plate shall be tested and the results recorded in accordance with A.S.M.E. Code Case 1338-2.

7.0 REPORTS:

7.1 All indications listed in 6.0 above shall be mapped and reported on a report form. A sample form is enclosed as figure 2 (later).

ATTACHMENT 2B

DATE: AUGUST 4, 1966
SHEET: 1 of 3

ULTRASONIC TEST SPECIFICATION NUMBER 2
(Shear Wave Pulse Echo Testing of Plate)

1.0 SCOPE:

1.1 This specification covers the examination procedure and recording levels for ultrasonic shear wave inspection of steel plates. It was developed to detect discontinuities at an angle to the rolled surfaces.

1.2 This test shall be applied 1) while the plate is in the flat and 2) after the plate has been hot formed, quenched and tempered.

2.0 TEST CONDITIONS:

2.1 The inspection shall be conducted in an area free from operations that interfere with proper performance of the test.

2.2 Pits, ripples, rust, scratches, dirt, loose scale and surface blemishes from rolled-in scale shall be removed to the extent necessary. Any specified identification which is removed to achieve proper surface smoothness shall be restored.

3.0 APPARATUS:

3.1 The test shall be performed using an ultrasonic, pulsed, reflection-type instrument with operating frequencies suitable for the test. The instrument shall provide linear presentation, within ± 5% up to at least 75% of full screen height.

3.2 The search unit shall be a 45 degree (in steel) shear wave type with an active transducer length of no more than one inch. Search units of other sizes and angles may be used for additional exploration and evaluation.

4.0 TEST FREQUENCY:

4.1 The ultrasonic frequency selected for the test shall be nominally 2¼ Mc. One Mc transducer may be used when the plate exhibits an excessively high noise level when using 2¼ Mc.

ATTACHMENT 2B

DATE: AUGUST 4, 1966
SHEET: 2 of 3

ULTRASONIC TEST SPECIFICATION NO. 2

5.0 CALIBRATION REFERENCE STANDARD:

5.1 Reference Block - A reference specimen shall be used to calibrate the equipment and establish recording criteria. Two (2) reference blocks shall be utilized: one (1) 7½" thick to apply to plate thicknesses from 6" to 9" inclusive, one (1) 11" thick to apply to plate thicknesses in excess of 9" and not exceeding 13". The material shall be acoustically similar to the plate undergoing examination.

Acoustic similarity is presumed when comparison of the back reflection signals between the reference specimen and actual plate without change in instrument setting shows a variation of 25% or less.

5.1.1 The reference blocks shall conform to figure 1 (later).

5.2 All reference blocks used on this program shall be prepared by one supplier and ultrasonic response shall not vary by more than 5 percent from block to block.

6.0 CALIBRATION PROCEDURE:

6.1 A Distance Amplitude Curve (D.A.C.) shall be established using the series of side drilled holes in the reference block as reflectors. The hole nearest the test surface shall establish the first and last points on the curve. The first pcint shall be established using the direct reflection (<½ node) from this hole and the last point shall be established by the indirect reflection from this hole (more than a half node but less than a full node). Any other two holes may be used to complete the curve. See figure 2 (later).

6.1.1 The highest point on the D.A.C. shall be set to 75% of full screen amplitude.

6.2 In order to compensate for variations in surface and attenuation, without changing instrument settings, the back reflection amplitude of a longitudinal transducer on a sound area of the test block shall be determined and recorded using a calibrated attenuator, if necessary. On each new plate or when recalibration is necessary, the

ATTACHMENT 2B

DATE: AUGUST 4, 1966
SHEET: 3 of 3

ULTRASONIC TEST SPECIFICATION NO. 2

longitudinal transducer shall be placed on a sound area of the plate undergoing examination and with instrument gain control, adjust the back reflection to the original amplitude.

7.0 INSPECTION PROCEDURE:

7.1 Scanning shall be done over 100% of the plate surface by use of a suitable couplant such as water, oil, or glycerine. Scanning shall be performed by placing the search unit near one edge with the sound beam directed toward the same edge and moving the search unit in a direction perpendicular to the edge to a location two plate thicknesses beyond the plate center. This scanning procedure shall be repeated along all four edges of the plate with a minimum overlap of 10% with each pass.

7.2 The search unit shall be positioned to obtain a maximum reflection from the observed discontinuity. Record those indications which exceed the D.A.C.

7.3 Each plate shall be stamped with a bench mark in the area of the plate identification stamping such that all discontinuity indications can be located and reported in reference to this mark and, when testing is performed after forming, subsequent results may be related to the previous test.

8.0 REPORT:

8.1 Indications described in 7.2 shall be recorded and mapped on a report form. A sample form is enclosed as figure 3 (later).

UNION CARBIDE CORPORATION
NUCLEAR DIVISION
OAK RIDGE, TENNESSEE 37830

PURCHASE ORDER

Acting Under U. S. Government Contract W7405 eng 26 With the U. S. Atomic Energy Commission

REQUISITION NO	DELIVER BY	REFER QUESTIONS TO	PLANT	PURCHASE ORDER NO.	C/N	DATE
A-6841		A. F. Johnson	Y-12	73Y-73710V	A	9-25-67

SHIP TO: U. S. Atomic Energy Commission, c/o Union Carbide Corporation - Nuclear Division

MARK ALL PACKAGES WITH PLANT AND ORDER NUMBER AND CONSIGN:

PARCEL POST TO — POST OFFICE BOX — OAK RIDGE, TENN. 37830

RAIL FREIGHT VIA AND TO DESTINATION (As Coded) 1. SOUTHERN RAILWAY TO BLAIR, TENNESSEE 2. LOUISVILLE AND NASHVILLE RAILWAY TO OAK RIDGE, TENN.

Motor Freight, Air Express, or Railway Express to Oak Ridge, Tennessee; Air Freight to Knoxville, Tennessee

F.O.B. (As Coded) 1. DESTINATION 2. SHIPPING POINT 3. SHIPPING POINT-FRT. ALLOWED 4.

SHIPPING POINT

VENDOR PAYEE CODE: L24350

Lukens Steel Company
Suite 104, 1172 West Galbraith Road
Cincinnati, Ohio 45231

ATTENTION:

TRANSPORTATION TERMS (As Coded): 1 ACCOUNT OF GOVERNMENT. DO NOT INSURE. DECLARE VALUE SO AS TO OBTAIN LOWEST POSSIBLE TRANSPORTATION RATE; 2. ACCOUNT OF SELLER-PREPAID; 3. OTHER (SEE BELOW)

SHIP VIA (As Coded): A. MOTOR FREIGHT; B. RAIL FREIGHT; C. RAIL EXPRESS; D. AIR FREIGHT*; E. AIR EXPRESS; F. PARCEL POST; G. AIR PARCEL POST; H. SELLER'S TRUCK; I. SELLER'S OPTION; J. KNOX CONT CARRIER; K. BUS; L. AS SHOWN; M. UCN TRUCK; N. 0-20# PARCEL POST 21-45# RAIL EXP. OVER 45# MTR. FRT.; P. UNIT PARC'L SER. *Excludes Air Freight Forwarders

You are required to follow the provisions of DMS Regulation 1 and all other applicable regulations and orders of BDSA in obtaining controlled materials and other products and materials needed to fill this order.
DO E-2 (CERTIFIED FOR NATIONAL DEFENSE USE UNDER DMS REGULATION 1) — DMS ALLOTMENT NO. E-2 (CERTIFIED FOR NATIONAL DEFENSE USE UNDER DMS REGULATION 1) — QUARTER, 196

DISCOUNT (As Coded): 0 NET; 1 1%; 2 2%; 3 3%; 4 2½%; 5 1½%; 6 ½%; 7 6%; 8 10%; 9 OTHER

PAYMENT TERMS — DISCOUNT PERIOD: DISCOUNTS ARE TAKEN IN ACCORDANCE WITH STANDARD POLICY (SEE PAYMENTS ARTICLE OF TERMS AND CONDITIONS) UNLESS NOTED BELOW: OTHER DISCOUNT PERIOD

FURNISH THE FOLLOWING ITEMS IN ACCORDANCE WITH TERMS AND CONDITIONS DESIGNATED
ATTACHED HERETO AND WITH THE SPECIFICATIONS AND/OR REFERRED TO HEREIN AND MADE A PART HEREOF.

ITEM NO	WORK ORDER (ACCT / T/E / SUB NO)	CATALOG NUMBER / DESCRIPTION	ORDERED QUANTITY	UNIT	UNIT PRICE $ ¢	TOTAL PRICE $ ¢
	443565-120	CHANGE PURCHASE ORDER TO READ AS FOLLOWS:				
		Using Company-furnished Alloy Steel Plate (Plate No. 4, 240" x 120" x 12", Heat C-2748-2, rolled on Company's Purchase Order 73Y-49288V), the Seller shall perform the following operations, per the attached Processing Sequence sheets, revised 9-22-67, and Sketches I through XI dated 7-21-67. Material - Firebox ASTM A-302-66 Grade B Nickel, modified up-graded to ASTM A-533-65, Grade B, Class 2, Firebox Quality.				
001		Plate marked "A", Sketch I - 1 PC 120" x 120" x 12". Estimated Net Weight - 48,954#. Operations per Item 5 of Processing Sequence sheets.	1	LOT		
•		Using Slab "B", Sketch I - 80" x 40" x 12". Operations per Item 6 of Processing Sequence sheets to reroll plate to approximate size - 137" x 70" x 4".				

AFJ:ms

THE BLOCK CHECKED BELOW IS APPLICABLE TO THIS ORDER. IF BLOCK "A" IS CHECKED, THE SELLER SHALL SIGN AND COMPLETE IN THE SPACE PROVIDED.

[X] A TO THE SELLER
Please sign and return one copy as acceptance of this order at once to the above address, P.O. Box M. All of the agreements of the parties relating to the subject matter are contained in this Purchase Order.

[ ] B TO THE SELLER
This Purchase Order is issued to accept Seller's proposal dated ________ Request No. ________ and constitutes the sole contractual agreement between the parties.

ACCEPTED (FIRM NAME)	BY (NAME AND TITLE)	DATE

NO TENNESSEE SALES OR USE TAX IS PAYABLE BY THE SELLER ON MATERIAL COVERED BY THIS ORDER BY REASON OF EXEMPTION CERTIFICATE AUTHORIZED FOR USE BY THE BUYER BY THE DEPARTMENT OF REVENUE, STATE OF TENNESSEE.

BILLING INSTRUCTIONS (REFER TO PURCHASE ORDER TERMS AND CONDITIONS)
1. [ ] INVOICE NOT REQUIRED - DO NOT MAIL
2. [ ] FURNISH ORIGINAL INVOICE TO:
UNION CARBIDE CORPORATION - NUCLEAR DIVISION ACCOUNTS PAYABLE DEPARTMENT P.O. BOX P, OAK RIDGE, TENNESSEE 37830

UNION CARBIDE CORPORATION
NUCLEAR DIVISION
[signature]
PURCHASING

PAGE OF	INSPECTION (As Coded) 1 ROUTINE 2 SPECIAL	REQUISITIONED BY	DELIVER TO	WANTED BY
1 3	2 Inspec. Engr.	W. B. Pike (2)	R. B. Clarke, 9204-1	

INV. REQ.	SUP SQ	COMM CODE	TYP TRN	LO TH	PLT	FP CST	NO. OF ITEMS	PRO TYP	NG. REQS	TYP REQ	TOTAL AMOUNT OF ORDER $ ¢	INC.	DEC.
2	4	04	01	6	4	1	008	65	1	2	105 00		X

UCN-2163 (1236 5-67)

UNION CARBIDE CORPORATION

NUCLEAR DIVISION

P. O. BOX M, OAK RIDGE, TENNESSEE 37831

PURCHASE ORDER CONTINUATION PAGE

PURCHASE ORDER NO. 73Y-73710V

ITEM NO.	WORK ORDER (ACCT. / T/E / SUB NO.) · CATALOG NUMBER · R/A	ORDERED QUANTITY	UNIT	UNIT PRICE $. ¢	TOTAL PRICE $. ¢
002	Plate "BA", approximate size - 1 PC 82" x 70" x 4". Estimated Net Weight - 6505#	1	LOT		
003	Plate "BB", approximate size - 1 PC - 55" x 70" x 4". Estimated Net Weight - 4363#	1	LOT		
	Using Slab "C, Sketch I - 80" x 80" x 12". Operations per Item 7 of Processing Sequence sheets. Reroll plate to approximate size - 95" x 95" x 8 1/2". Machine top and bottom surface to 8" gauge.				
004	Plate "CA", approximate size - 1 PC 55" x 95" x 8". Estimated Net Weight - 11,842#	1	LOT		
005	Plate "CB", approximate size - 1 PC 40" x 95" x 8". Estimated Net Weight - 8612#	1	LOT		
006	Plate "D", per Sketch I, approximate size - 1 PC 40" x 120" x 12". Estimated Net Weight - 16,315#. Operations per Item 8 of Processing Sequence sheets.	1	LOT		
007	Ship all large size test pieces, properly identified per plate, heat and location	1	LOT		
008	"Reporting Requirements", per Appendix I, dated 9-19-67	5	COPY		

Note 1: The above operations are to be under the direction of Seller's E. K. Martini and S. G. Johnson and witnessed by the Company's inspector. The Seller shall notify the Company's Purchasing Division five (5) days prior to the beginning of all operations and shall permit access by Company's engineering and inspection personnel to observe, assist and perform additional inspection necessary to secure a true history of the plates being rolled and their heat treatment.

Note 2: All sizes and weights shown are approximate. Rerolled plate sizes will be furnished untreated with no opportunity of replacement rolling.

Note 3: All plates are to be shipped to the Company, Oak Ridge, Tennessee. Plate "A" via Rail Freight; balance via Motor Freight as work specified is completed on each plate.

Note 4: Government Property Clause dated May 22, 1967, applies to this order.

UNION CARBIDE

UNION CARBIDE CORPORATION
NUCLEAR DIVISION
P. O. BOX M, OAK RIDGE, TENNESSEE 37831

PURCHASE ORDER CONTINUATION PAGE

PURCHASE ORDER NO. 73Y-73710V

Change Notice A

ITEM NO.	WORK ORDER ACCT.	T/E	SUB NO.	CATALOG NUMBER	R/A		ORDERED QUANTITY	UNIT	UNIT PRICE $ ¢	TOTAL PRICE $ ¢
						ORIGINAL TOTAL OF ORDER				
						DECREASE				
						REVISED TOTAL OF ORDER				

Reason: To revise and clarify Purchase Order and Processing Sequence sheets:

1. Grit blast and UT inspect plate prior to starting heat treating and rolling operations. (Processing Sequence Items 1 and 2)
2. Change conditioning of plate from 75 RMS to approximate 250 RMS (Processing Sequence Item 7.F.)
3. Add Items 007 and 008 to Purchase Order.

PROCESSING SEQUENCE

Revised 9-22-67
Purchase Order 73Y-73710V

Union Carbide Plate No. 4, Melt C-2748-2, 240 × 120 × 12 in. Plate, ASTM A-302 Grade B Ni Modified Up-Graded to ASTM A-533 Grade B Class 2, Firebox Quality

1. Grit blast.
2. Ultrasonic inspect by Company's representatives.
3. Preheat, gas cut hot, and stress relieve at 1025 ± 25°F for 1–1½ hr per in. of thickness and furnace cool to 600°F and identify as per Sketch I.
4. Plate shall be marked to assure identity of top and bottom surfaces, heat number, and top and bottom as related to ingot orientation and to longitudinal direction of rolling throughout all operations.
5. Slab C-2748-2A, 120 × 120 × 12 in.
   A. Drill four holes in plate per Sketch II.
   B. Normalize 1675 ± 25°F for 12 hr, air cool.
   C. Grit blast.
   D. Install four thermocouples in drilled holes.
   E. Paint with special paint; Lukens to procure from Combustion Engineering.
   F. Austenitize 1575 ± 25°F for 12 hr.
   G. Water quench, obtain cooling rate from four thermocouples, record water temperature at start and finish of quench.
   H. Temper at 1200°F for 1–1½ hr per in. of thickness, furnace cool to 600°F to meet A-533 grade B class 2 mechanical properties (minimum temperature to be 1150°F).
   I. Stress relieve 40 hr at 1125 ± 25°F, furnace cool to 600°F
   J. Preheat, gas cut hot, and cut tests per Sketch III. Stress relieve at 1025 ± 25°F for 1–1½ hr per in. of thickness, furnace cool to 600°F. Tests to be tensile, bend, homogeneity, CVN transition curve, NDT actual temperature determination per ASTM E-208 (see S. G. Johnson).
   K. Press flatten plate if required.
   L. Grit blast.
   M. Ultrasonic test 100% coverage longitudinal and shear wave, one face only, from top surface, per attachments 2A and 2B of PVRC subcommittee report of 4-10-67, "Midvale" or "Combustion" reference block shall be used for primary calibration; in presence of S. G. Johnson.
   N. Ship to Company.
6. Slab C-2748-2B, 80 × 40 × 12 in.
   A. Notch slab as per Sketch IV.
   B. Grit blast slab.
   C. Paint with Pemco.
   D. Heat to 2350°F in No. 63 furnace and reroll to 4-in. gage to make plate–80 in. × pro × 4 in. approx (80 × 137 × 4), roll 40 in. dimension to 70 in., and 80 in. dimension to 137 in. – 70 in. dimension is the major rolling direction.
   E. Sand cool.
   F. Lay out plate in Green Anneal Building per Sketch V. Notify S. G. Johnson. Identify per Sketch V. Preheat, gas cut hot, and stress relieve 1025°F minimum for 1–1½ hr per in. of thickness, furnace cool to 600°F. As-rolled edges, do not cut.

G. Hold C-2748-2BB at Green Anneal Building. Approx 70 X 55 in.

H. Ship C-2748-2BA to Company. Approx 70 X 82 in.

I. Plate C-2748-2BB. Drill holes per Sketch VI.

J. Normalize 1675 ± 25°F for 4 hr. Air cool.

K. Grit blast.

L. Install thermocouples per S. G. Johnson.

M. Paint with special paint; Lukens to procure from Combustion Engineering.

N. Austenitize 1575 ± 25°F for 4 hr.

O. Water quench, obtain cooling rate from four thermocouples, record water temperature at start and finish of quench.

P. Temper at 1200°F for 1–1½ hr per in. of thickness and furnace cool to 600°F, to meet ASTM A-533 grade B class 2, minimum temper temperature to be 1150°F.

Q. Stress relieve for 40 hr at 1125 ± 25°F, furnace cool to 600°F.

R. Preheat, gas cut tests hot as per Sketch VII, stress relieve at 1025 ± 25°F for 1–1½ hr per in. of thickness, furnace cool to 600°F, tests to be tensile, homogeneity, CVN transition curve, NDT actual temperature determination per ASTM E-208 (see S. G. Johnson).

S. Grit blast.

T. Ultrasonic test 100% longitudinal and shear wave, one face only, from top surface, per attachments 2A and 2B of PVRC subcommittee report of 4-10-67, "Midvale" or "Combustion" reference block shall be used for primary calibration, in the presence of S. G. Johnson.

U. Ship to Company.

7. Slab C-2748-2C, 80 X 80 X 12 in.

   A. Notch slab per Sketch VIII.

   B. Grit blast.

   C. Paint with Pemco.

   D. Heat to 2350°F in No. 63 furnace and reroll to 8½-in. gage to produce plate 95 in. X pro X 8½ in. approx (95 X 95 X 8½), mark mill order 95 X 8 X pro.

   E. Sand cool.

   F. Condition plate to 8-in. gage nominal; top surface to have approx 250 rms finish.

   G. To Green Anneal Building, lay out plate per Sketch IX, identify per Sketch IX.

   H. Preheat, gas cut hot, and stress relieve 1025°F minimum for 1–1½ hr per in. of thickness, furnace cool to 600°F. As-rolled edges, do not cut.

   I. Ship approx 55 X 95 in. pc. C-2748-2CA to Company.

   J. Approx. 40 X 95 pc., C-2748-2CB to Green Anneal Building.

   K. Drill holes as per Sketch X + VI.

   L. Normalize 1675 ± 25°F, 8 hr, air cool.

   M. Grit blast.

   N. Install thermocouples per Sketch X.

   O. Paint with special paint; Lukens to procure paint from Combustion Engineering.

   P. Austenitize 1575 ± 25°F, 8 hr.

   Q. Water quench, obtain cooling rate at four thermocouples, record water temperature at start and finish of quench.

R. Temper at 1200°F for 1–1½ hr per in. of thickness, furnace cool to 600°F, to meet A-533 grade B class 2 (minimum temper to be 1150°F).

S. Stress relieve 40 hr at 1125 ± 25°F, furnace cool to 600°F.

T. Preheat, gas cut test hot, as per Sketch XI, stress relieve at 1025 ± 25°F for 1–1½ hr per in. of thickness, furnace cool to 600°F. Tests to be tensile, homogeneity, bend, CVN transition curve, NDT actual temperature determination per ASTM E-208 (see S. G. Johnson).

U. Grit blast.

V. UT test 100% of surface longitudinal and shear wave, one face only, from top surface, per attachments 2A and 2B of PVRC subcommittee report of 4-10-67, "Midvale" or "Combustion" reference block shall be used for primary calibration, in the presence of S. G. Johnson.

W. Ship to Company.

8. Slab C-2748-2D, 40 × 120 × 12 in.

A. Identify and hold at Green Anneal Building.

B. Mark mill order No. in bold letters. Mark U.S. Government property.

C. Ship to Company.

Note 1: Longitudinal-to-transverse rolling ratio on rerolled plates maintained same as original ingot to 12-in. plate of 3.1/1.0.

Note 2: The above operations are to be under the direction of seller's E. K. Martini and S. G. Johnson and witnessed by Company's inspector. Seller shall notify Company's Purchasing Division five days prior to the beginning of all operations and shall permit access by Company's engineering and inspection personnel to observe, assist, and perform additional inspection necessary to secure a true history of the plates being rolled and their heat treatment.

Note 3: Sketches mentioned have been incorporated in the text of this report.

REPORTING REQUIREMENTS

Purchase Order 73Y-73710V
Purchase Order 73Y-73721V
Appendix I
Dated 9-19-67

General

The seller shall provide a report which *summarizes all* operations performed on the parent plate, these plates, or pieces of plates. The operations shall be presented in chronological order with the date each operation was commenced and completed.

I. Heat Treat Information

A. The seller shall provide detailed information on all heat treating operations. As a minimum the reports shall contain the following:

1. Identity of plate (heat number, size, thickness, etc.)
2. Name of heat treatment (austenitize, temper, etc.)
3. A drawing showing the location of all thermocouples on the plate, the type of thermocouples, and method of installation.
4. A drawing showing position of plate in furnace, orientation with respect to top ingot end and top surface, and method of support.
5. A brief description of heat treating operation including heating rate, time to reach heat treating temperature, holding time and temperature, method of cooling, cooling rate, and temperature of plate when it is removed from the furnace or quench tank.

6. The actual furnace charts and thermocouple charts or exact copies. Sufficient information shall be added to make them meaningful.

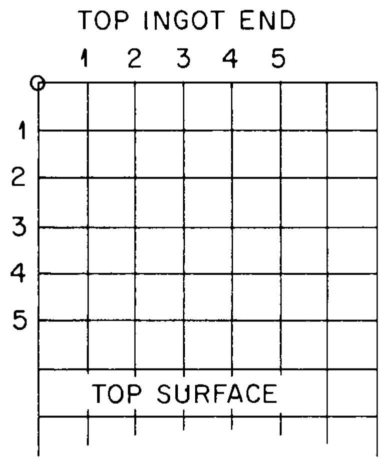
   In general, the heat treating reports shall be complete to the extent that it would be possible to duplicate the heat treatment (in all respects) at a later date.

II. Chemical and Physical Properties Information

A. The seller shall provide a report of chemical analyses, physical properties including the results of the other tests required by the P.O. (e.g., CVN transition, NDT actual temperature determination). The location of the test coupons, with respect to the parent plate, shall be shown by means of sketches and necessary supporting information. The heat treating operations performed on the material for the test specimens shall be described.

III. Nondestructive Testing Information

A. The seller shall provide reports of ultrasonic inspections. As a minimum, the reports shall contain:
   1. Test instrument, make, and model.
   2. Type of calibration block and condition of same; for example, as-rolled, Q&T, etc.
   3. Discussion of the calibration of the UT instrument for longitudinal and shear-wave inspections including copies of the longitudinal-wave and shear-wave DAC curves.
   4. Identification of plate including its condition (as-rolled, Q&T, approximate rms finish, etc.)
   5. Search unit, size, frequency, couplant, and such additional supporting information to adequately describe the inspection.
   6. The plate shall be layed out for ultrasonic inspection with the top surface facing up and with the origin of the grid system at the top ingot end of the plate; for example:



   7. A general drawing (on a grid where each space represents 12 or 24 in.) showing each recordable indication by number and an enlarged view drawn on a grid to a scale of no less than 3 in. = 12 in.
   8. For each *recordable* indication, the report shall give the number assigned to the indication, type of test (longitudinal or shear wave), size of indication, depth from top surface, percent of DAC and percent of loss of back-surface reflection.
   9. Summary comments as considered necessary to adequately describe results.

UNION CARBIDE CORPORATION
NUCLEAR DIVISION
OAK RIDGE, TENNESSEE 37830

PURCHASE ORDER

Acting Under U. S. Government Contract W7405 eng 26 With the U. S. Atomic Energy Commission

REQUISITION NO.	DELIVER BY	REFER QUESTIONS TO	PLANT	PURCHASE ORDER NO.	C/N	DATE
A-6618		A. F. Johnson	Y-12	73Y-73721V	A	9-25-67

SHIP TO: U. S. Atomic Energy Commission, c/o Union Carbide Corporation - Nuclear Division
MARK ALL PACKAGES WITH PLANT AND ORDER NUMBER AND CONSIGN:
PARCEL POST TO — POST OFFICE BOX — OAK RIDGE, TENN. 37830
RAIL FREIGHT VIA AND TO DESTINATION (As Coded) 1. SOUTHERN RAILWAY TO BLAIR, TENNESSEE 2. LOUISVILLE AND NASHVILLE RAILWAY TO OAK RIDGE, TENN.
Motor Freight, Air Express, or Railway Express to Oak Ridge, Tennessee; Air Freight to Knoxville, Tennessee

F.O.B. (As Coded) 1. DESTINATION 2. SHIPPING POINT 3. SHIPPING POINT-FRT. ALLOWED 4.
SHIPPING POINT

VENDOR PAYEE CODE: L24350

Lukens Steel Company
Suite 104, 1172 West Galbraith Road
Cincinnati, Ohio 45231

ATTENTION:

TRANSPORTATION TERMS: (As Coded) 1 ACCOUNT OF GOVERNMENT. DO NOT INSURE. DECLARE VALUE SO AS TO OBTAIN LOWEST POSSIBLE TRANSPORTATION RATE 2. ACCOUNT OF SELLER-PREPAID. 3. OTHER (SEE BELOW)

SHIP VIA (As Coded): A. MOTOR FREIGHT B. RAIL FREIGHT C. RAIL EXPRESS D. AIR FREIGHT* E. AIR EXPRESS F. PARCEL POST G. AIR PARCEL POST H. SELLER'S TRUCK I. SELLER'S OPTION J. KNOX CONT CARRIER K. BUS L. AS SHOWN M. UCN TRUCK N. 0-20# PARCEL POST 21-45# RAIL EXP. OVER 45# MTR. FRT. P. UNIT PARC'L SER. *Excludes Air Freight Forwarders

PRIORITY: You are required to follow the provisions of DMS Regulation 1 and all other applicable regulations and orders of BDSA in obtaining controlled materials and other products and materials needed to fill this order. DO E-2 (CERTIFIED FOR NATIONAL DEFENSE USE UNDER DMS REGULATION 1) DMS ALLOTMENT NO. E-2 (CERTIFIED FOR NATIONAL DEFENSE USE UNDER DMS REGULATION 1) QUARTER, 196

DISCOUNT (As Coded) — PAYMENT TERMS — DISCOUNT PERIOD: DISCOUNTS ARE TAKEN IN ACCORDANCE WITH STANDARD POLICY (SEE PAYMENTS ARTICLE OF TERMS AND CONDITIONS) UNLESS NOTED BELOW.

FURNISH THE FOLLOWING ITEMS IN ACCORDANCE WITH TERMS AND CONDITIONS DESIGNATED
ATTACHED HERETO AND WITH THE SPECIFICATIONS AND/OR REFERRED TO HEREIN AND MADE A PART HEREOF.

ITEM NO.	WORK ORDER (ACCT / T/E / SUB. NO.)	DESCRIPTION	ORDERED QUANTITY	UNIT	UNIT PRICE	TOTAL PRICE
	443565-120	CHANGE PURCHASE ORDER TO READ AS FOLLOWS:				
		Using Company-furnished Alloy Steel Plate (Plate No. 3, 240" x 120" x 12", Heat C-2702-2, rolled on Company's Purchase Order 73Y-49288V), the Seller shall perform the operations as outlined on the attached Processing Sequence sheets, revised 9-22-67. Material - ASTM A-302-66 Grade B Nickel modified (ASTM A-533-65, Grade B, Class 1, Firebox Quality).				
001			1	LOT		
002		Ship all large size test pieces, properly identified per plate, heat and location.	1	LOT		
003		Reporting Requirements, per Appendix I, dated 9-19-67.	5	COPY		

AFJ:ms

THE BLOCK CHECKED BELOW IS APPLICABLE TO THIS ORDER. IF BLOCK "A" IS CHECKED, THE SELLER SHALL SIGN AND COMPLETE IN THE SPACE PROVIDED.

[X] A — TO THE SELLER
Please sign and return one copy as acceptance of this order at once to the above address, P.O. Box M. All of the agreements of the parties relating to the subject matter are contained in this Purchase Order.

[ ] B — TO THE SELLER
This Purchase Order is issued to accept Seller's proposal dated ______ Request No. ______ and constitutes the sole contractual agreement between the parties.

ACCEPTED (FIRM NAME)	BY (NAME AND TITLE)	DATE

NO TENNESSEE SALES OR USE TAX IS PAYABLE BY THE SELLER ON MATERIAL COVERED BY THIS ORDER BY REASON OF EXEMPTION CERTIFICATE AUTHORIZED FOR USE BY THE BUYER BY THE DEPARTMENT OF REVENUE, STATE OF TENNESSEE

BILLING INSTRUCTIONS (REFER TO PURCHASE ORDER TERMS AND CONDITIONS)
1 [ ] INVOICE NOT REQUIRED - DO NOT MAIL
2 [ ] FURNISH ORIGINAL INVOICE TO:
UNION CARBIDE CORPORATION - NUCLEAR DIVISION ACCOUNTS PAYABLE DEPARTMENT P.O. BOX P, OAK RIDGE, TENNESSEE 37830

AFJ.
UNION CARBIDE CORPORATION
NUCLEAR DIVISION
PURCHASING

PAGE	OF	INSPECTION (As Coded) 1 ROUTINE 2 SPECIAL	REQUISITIONED BY	DELIVER TO	WANTED BY
1	2	2 Inspect. Engr.	W. B. Pike (2)	R. B. Clarke, 9204-1	

INV. REQ.	SUP. SO	COMM. CODE	TYP. TRN.	LO TM	PLT	FF CST	NO. OF ITEMS	PRO. TYP.	NO. REQS.	TYP. REQ.	TOTAL AMOUNT OF ORDER	INC.	DEC.
2	4	04	01	6	4	1	003	65	1	2	000.00		

UCN-2163 (1236 5-67)

☐	PURCHASE ORDER NO. 73Y-73721V
☒	CHANGE NOTICE NO. A

UNION CARBIDE CORPORATION
NUCLEAR DIVISION
P.O. BOX M, OAK RIDGE, TENNESSEE 37830

PURCHASE ORDER CONTINUATION PAGE

Acting Under U. S. Government Contract W7405 eng 26 With the U. S. Atomic Energy Commission

Note 1: The above operations are to be under the direction of Seller's E. K. Martini and S. G. Johnson and witnessed by the Company's inspector. The Seller shall notify the Company's Purchasing Division five (5) days prior to the beginning of all operations and shall permit access by Company's engineering and inspection personnel to observe, assist and perform additional inspection necessary to secure a true history of the plates being rolled and their heat treatment.

Note 2: Government Property Clause dated May 22, 1967, applies to this order.

NO CHANGE IN TOTAL AMOUNT OF ORDER.

Reason: To revise and clarify Purchase Order and Processing Sequence Sheets and to add Items 002 and 003 to Purchase Order.

PROCESSING SEQUENCE

Revised 9-22-67
Purchase Order 73Y-73721V

Union Carbide Plate No. 3, Melt C-2702-2, 12 X 120 X 240 in. Plate, ASTM A-302 Grade B Ni Modified (ASTM A-533 Grade B Class 1, Firebox Quality)

1. Plate shall be marked to assure identity of top and bottom surfaces, heat number, and top and bottom as related to ingot orientation and to longitudinal direction of rolling throughout all operations.
2. Melt C-2702-2, 240 X 120 X 12 in.
   A. Grit blast.
   B. UT test 100% of surface longitudinal and shear wave, one face only, from top surface, per attachments 2A and 2B of PVRC subcommittee report of 4-10-67, "Midvale" or "Combustion" reference block shall be used for primary calibration, in the presence of S. G. Johnson.
   C. Mark with four punch marks for dimensional measurements after normalizing.
   D. Normalize. 1675 ± 25°F for 12 hr, air cool.
   E. Check, record, and report dimensional measurements.
   F. Grit blast.
   G. Re-mark with four punch marks for dimensional measurements after heat treatment.
   H. Drill and attach twenty-four (24) thermocouples per Company's sketch JW-6-5-67.
   I. Paint with special paint; Lukens to procure from Combustion Engineering.
   J. Austenitize 1575 ± 25°F for 12 hr.
   K. Water quench, obtain cooling rate from 24 thermocouples, horizontal immersion. Record water temperature at start and finish of quench.
   L. Temper at 1200°F (1150°F minimum) for 1–1½ hr per in. of thickness, furnace cool to 600°F, to meet A-533 grade B class 1 mechanical properties.
   M. Stress relieve 40 hr at 1125 ± 25°F, furnace cool to 600°F.
   N. Preheat, gas cut test specimens hot, per sketch I dated 9-21-67, stress relieve 1025 ± 25°F for 1–1½ hr per in. of thickness, furnace cool to 600°F after cutting. Information only – tests to be transverse tensile, bend, homogeneity, CVN transition curve (no guarantee), NDTT determination per ASTM E-208.
   O. Check, record, and report dimensional measurements.
   P. Grit blast.
   Q. UT test 100% of surface longitudinal and shear wave, one face only, from top surface, per attachments 2A and 2B of PVRC subcommittee report of 4-10-67, "Midvale" or "Combustion" reference block shall be used for primary calibration, in the presence of S. G. Johnson.
   R. Preheat, gas cut 50 linear feet to Company's sketch (to follow), stress relieve 1025 ± 25°F for 1–1½ hr per in. of thickness, furnace cool to 600°F. Plates shall be identified as to heat number, location, and orientation of plates in accordance with a code to be supplied by Company prior to any cutting operation.
   S. Ship all plates to Company.

Note: The above operations are to be under the direction of seller's E. K. Martini and S. G. Johnson and witnessed by Company's inspector. Seller shall notify Company's Purchasing Division five days prior to the beginning of all operations and shall permit access by Company's engineering and inspection personnel to observe, assist, and perform additional inspection necessary to secure a true history of the plates being rolled and their heat treatment.

ORNL-4313-2
UC-80 — Reactor Technology

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