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FINAL REPORT

STRUCTURAL AND METALLURGICAL EVALUATION OF THE 260-SL-3 CHAMBER

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ABSTRACT

Twelve 0.60-in. (0.52 cm) thick, 18% nickel, 200 Grade, maraging steel test panels were removed from the 260-in. (6.6 m)-dia motor case to evaluate the structural and metallurgical characteristics of selected areas of the "as fabricated" production case. The areas investigated include: (1) measurement of a case thin spot, (2) structural and metallurgical evaluation of production automatic welds, defective welds, and nondestructive test indications in welds, and (3) structural and metallurgical evaluation of case hot spots that occurred during motor postfiring heatsoak. The program results showed that the material and fabrication process controls developed prior to the start of fabrication were successfully incorporated in the production of the 260-in. (6.6 m)-dia case. These production process controls resulted in acceptable case material properties.

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I. SUMMARY

The metallurgical evaluation of the 260-SL-3 chamber was initiated in May 1969 under Contract NAS3-12039 to evaluate the structural and metallurgical characteristics of selected areas of the production chamber (SN 001) fabricated with 18% nickel, 200 Grade, maraging steel. The program scope was divided into seven tasks as follows: (1) Task I - review of inspection reports, (2) Task II - sectioning of the 260-SL-3 chamber, (3) Task III - metallurgical evaluation of standard production welds, (4) Task IV - metallurgical evaluation of defective welds (including a radiographic high-density area, two ultrasonic indications, and a magnetic particle indication), (6) Task VI - measurement of a thin spot, and (7) Task VII - metallurgical evaluation of hot spots.

After all 12 test panels were removed from the chamber cylinder section, the test panels of Tasks IV and V were inspected using radiographic, ultrasonic, and magnetic particle inspection techniques. The results of these inspections were: (1) the scattered, spherical, porosity (Task IV) and the high-density indication (Task V) were observed, (2) the ultrasonic and magnetic particle indications (Task IV) were not observed, (3) there were no indications that had not been previously reported, and (4) existing defects showed no apparent change resulting from two proof tests and two motor firing pressurization cycles.

The structural and metallurgical material properties of Tasks III, IV, V, and VII were determined using: (1) standard metallographic analysis and hardness measurement techniques, (2) standard 0.25-in. (0.635 cm)-dia tensile specimens, (3) V-notched and precracked Charpy impact fracture toughness specimens (except Task VII), and (4) slow-notch-bend fracture toughness specimens.

The microstructural characteristics of the welds, heat-affected zones, and parent material of the production chamber were found to be satisfactory and normal for the 18% nickel alloy and fabrication history of the sections examined. Typically, the microstructural examination of welds showed porosity

I. Summary (cont)

and crack-free deposits of normal, high quality, gas-tungsten arc fusion sections with satisfactory geometry. One porosity pore was observed in one microstructural examination plane of the Task IV porosity test panel. The high-density indication (Task V) in the heat-affected zone adjacent to an area of multiple weld repair appeared to be an unusual band of reverted austenite caused by the extensive weld repair in the area.

The minimum thickness of the thin area as determined by ultrasonic techniques was 0.010 in. (0.254 mm) more than the actual 0.565-in. (1.43 cm) minimum thickness. Rockwell C hardness values in the thin area were normal; they varied from 48 to 50.

Average 0.2% offset yield strengths of 260-SL-3 chamber parent material and welds evaluated in this program ranged from 230,000 to 252,000 psi (158,590 to 173,750 N/cm^2) and 194,000 to 225,000 psi (133,760 to 155,140 N/cm^2), respectively. Weld strength was typically lower than parent metal yield strength and is the result of the initial selection of wire chemistry to obtain lower strength and higher toughness in the welds. Repair welding further reduced the yield strength, e.g., average strength of welds repaired four and seven times were 207,000 psi (142,730 N/cm^2) and 194,000 psi (133,760 N/cm^2), respectively.

Precracked Charpy impact and slow-notch-bend fracture toughness values obtained from the test panels indicate that the fracture toughness of the parent material and welds were within the range expected for the production chamber. The parent material and weld precracked Charpy impact values ranged from 509 to 1103 in.-lb/in.^{2} (8.9 to 19.3 J/cm^2) and 911 to 1785 in.-lb/in.^{2} (15.9 to 31.2 J/cm^2), respectively. Average slow-notch bend fracture toughness values obtained from three parent plates and welds ranged from 159 to 227 in.-lb/in.^{2} (2.8 to 4.0 J/cm^2) and 251 to 453 in.-lb/in.^{2} (4.4 to 7.9 J/cm^2), respectively.

I. Summary (cont)

The evaluation of the two hot areas of the chamber showed that the yield strength had been reduced to the minimum value of 137,000 psi (94,460 N/cm^2) from the normal unaffected value of 244,000 psi (168,240 N/cm^2).

On the basis of evaluations accomplished in this program, it is concluded that: (1) the production chamber showed adequate structural and metallurgical characteristics within the range expected, (2) repetitive repair of 18% nickel steel welds significantly reduces the tensile properties and increases the fracture toughness properties of the weld in the locally repaired area, and (3) the hot areas of the chamber were exposed to a temperature gradient of about 1200°F (922°K) near the OD surface to 1700°F (1200°K) near the ID surface.

II. INTRODUCTION

Two 260-in. (6.6 m)-dia motor chambers and two nozzle support (shell) structures were fabricated with the 18%, 200 Grade, maraging steel in the 260-in. (6.6 m)-dia Motor Feasibility Demonstration Program, accomplished under NASA Contract NAS3-6284. Prior to the start of fabrication of the maraging steel motor hardware, extensive material and process investigations were accomplished to assure that material properties and fabrication processes were understood and that the application of this knowledge would result in a successful fabrication program.

The 260-SL-3 motor chamber (SN 001) was used initially in the 260-SL-1 motor firing, then, the chamber was rehabilitated and used in the 260-SL-3 motor firing. Hot spots on the chamber cylinder section that developed during the 260-SL-3 motor postfiring heat soak rendered the cylinder section unacceptable for any further use in a motor firing. This provided an opportunity to obtain material for evaluation of the "as fabricated" chamber.

II. Introduction (cont)

The evaluations accomplished in this program are intended to investigate specific characteristics of the production chamber; i.e., production automatic welds, defective welds, welds with NDT indications, a chamber thin spot, and the cylinder section hot spots. The type of specimens used in this investigation were specifically established to provide data that could be directly compared with much data developed in the previous material and process evaluation program and to the test specimens that were included with the chamber during the production maraging heat-treatment.

Previously, investigations of the 18%, 200 Grade, maraging steel have been limited to specimen testing of simulated production conditions and to burst tests of subscale pressure vessels simulating production conditions. The results of the investigations accomplished in this program will be useful in defining the material properties and characteristics that could be expected in similar large motor case production. Specifically, the results obtained from the investigation of the actual production hardware will provide considerable insight into the design parameters that should be used in the design of any future 260-in. (6.6 m)-dia motor chamber fabrication with the 18%, 200 Grade, maraging steel.

III. TECHNICAL DISCUSSION

A. PROGRAM OBJECTIVES

The objective of this program was to evaluate structural and metallurgical characteristics of selected areas of the 260-SL-3 (SN 001) chamber. The objective was fulfilled by accomplishing the following:

1. Evaluating structural and metallurgical characteristics of typical standard production automatic chamber weld.

III.A. Program Objectives

2. Evaluating the structural and metallurgical effects of weld process variables (defective welds) encountered during fabrication of the chamber.

3. Thoroughly examining areas with defect indications detected in previous nondestructive tests to determine if the defects had changed since the previous inspection and to quantitatively assess the effects of the defects.

4. Determining the thickness and hardness in a chamber cylinder section thin spot.

5. Evaluating structural and metallurgical effects in areas subjected to local heating during Motor 260-SL-3 postfiring heat soak.

B. TECHNICAL APPROACH

1. Program Background

a. 260-SL Chamber (SN 001) History

The 260-SL chamber (SN 001) was fabricated by the Sun Shipbuilding and Dry Dock Company, Chester, Pennsylvania, during the period from April 1964 to March 1965. The structural integrity of the motor case was verified with a hydrostatic proof-test (Reference 1)* at the Sun Shipbuilding Company before delivery. The chamber was subjected to a proof pressure of 737 +5, -0 psig (508 +3, -0 N/cm^2 gage) (1.1 times the MEOP) and maintained at the proof pressure for 120 sec.

*References used throughout this report are listed on page 38.

III.B. Technical Approach (cont)

Then, the chamber was shipped by barge to the Aerojet's Dade County Plant (DCP) for preparation for the 260-SL-1 motor firing. The chamber processing included cleaning, installation of internal insulation and liner, installation of the insulated chamber in the cast, cure, and test facility, propellant casting, and motor assembly. The motor processing was initiated April 1965 and was concluded in September 1965.

The motor was statically test fired (Reference 2) in September 1965. Review of the pressure, strain gage, and thermocouple data recorded during the motor firing indicated that structural integrity of the chamber was maintained throughout the firing. However, postfiring heat soak before motor quench resulted in heating of the chamber sufficient to slightly discolor the exterior paint in small local areas coincidental with propellant web burnout regions. Interior and exterior hardness indications measured at each discolored area and laboratory investigation to determine the maximum temperature that occurred in each area indicated that the chamber strength was not affected in the areas of local heating.

Subsequently, the chamber (SN 001) was selected for use in the 260-SL-3 motor firing. The structural integrity of the chamber for use in the SL-3 motor was established by hydrostatically proof testing the chamber. Radiographic, magnetic particle, and ultrasonic inspections were accomplished on the cylinder longitudinal welds before the proof test.

The case was successfully proof tested (Reference 3) to 706 psig (487 N/cm^2 gage) for 80 sec in the cast, cure, and test facility in September 1966. Then, the chamber was prepared for the 260-SL-3 motor firing. The processing included cleaning; installation of internal insulation and liner; installation in the cast, cure, and test facility; propellant casting; and motor assembly during the period from September 1966 to June 1967.

III.B. Technical Approach (cont)

Motor 260-SL-3 was statically fired in June 1967 (Reference 4). The motor case successfully withstood the motor firing; however, a postfire quench system failure resulted in 10 hot areas in the cylinder. The size of the hot areas ranged from about 3-in. (8.62 cm)-dia to 60 by 17-in. (15.2 by 43.0 cm). The extent of paint degradation ranged from a slight discoloration to complete decomposition of the paint. Also, surface contour inspections showed that significant distortion had occurred at two areas. Hardness indications taken in the hot areas indicated a strength reduction to about 155,000 psi (106,870 N/cm^2).

b. Chamber (SN 001) Design and Fabrication Description

The following limited description of the chamber design, structural material, and fabrication approach will provide a baseline, or reference, for defining the material property data and characteristics developed in this program.

The structural material used in fabrication of the 260-SL motor chamber was 18% nickel maraging steel with 0.2% offset yield strength between 200,000 and 235,000 psi (137,900 and 162,030 N/cm^2). The material was produced from small ingots weighing about 26,000 lb, (11,800 kg), vacuum-arc remelted from air-melted ingots, to achieve high material quality and reliable structural integrity. The chemical composition of the weld filler wire was selected to produce the lowest 0.2% offset yield strength (200,000 to 220,000 psi) (137,900 to 151,690 N/cm^2) consistent with minimum strength requirements to obtain the best possible fracture toughness and inherent resistance to defect propagation in the pressure vessel welds. The weld filler wire selected was an 18% nickel alloy similar to the parent material except that the molybdenum content was lower than that specified for the parent material and the titanium content was higher. The chemical composition and other characteristics of the production vacuum-arc remelted steel plates and weld filler wire are shown in the procurement specifications contained in Appendix A.

III.B. Technical Approach (cont)

The minimum material yield strength value [(200,000 psi) (137,900 N/cm^2)] was assumed for structural design of the chamber. A reduction in allowable strength of 5% throughout the pressure vessel was established to allow for weld efficiency combined with weld mismatch, resulting in 190,000 psi (131,000 N/cm^2) as the minimum design yield strength. The maximum weld mismatch allowed was 10% of the minimum thickness for all welds, except for the longitudinal welds in the cylinder, where the allowable mismatch was 5% of the minimum thickness. Additional design criteria included a minimum safety factor of 1.3 at yield. These criteria resulted in a minimum cylinder membrane thickness of 0.60 in. (1.52 cm).

All production welds except weld repair were performed in the down-hand position using automatic welding equipment with 0.062-in. (1.57 mm) dia weld wire. The down-hand technique was selected to provide the welding operator the greatest amount of puddle control and to minimize the occurrence of lack of fusion, porosity, and other defects in the weldment. The automatic equipment used in this program was a Linde HWM-2 automatic arc voltage control welding head, a Linde HW-27 (gas lens type) welding torch and a Miller 600 power source. The tungsten welding electrode was 0.150-in. (0.381 cm) dia (2% thoriated).

The welding procedures used resulted in a heat input of approximately 30,000 joules/in. (11,800 J/cm). The initial root pass was accomplished at 5 in./min (12.7 cm/min) travel. Subsequent weld passes were made at a travel of 8 in./min (20.3 cm/min) and a wire feed of 60 in./min (152.4 cm/min) with the welding equipment regulated at about 375 amp and 11.0 volts. About 12 passes were required to complete the weldment in 0.61-in. (1.56 cm) nominal thickness material.

III.B. Technical Approach (cont)

All chamber welding was accomplished from the outside with a simple U-groove edge preparation as shown in Figure 1. Grooved back-up bars were provided as an integral part of the assembly and welding tooling to provide back-side argon gas-shielding to protect the root of the weld from oxidation. The weld groove was filled with low-to-intermediate heat input multiple stringer-type weld bead with interpass temperature maintained below 200°F (367°K). Surface scale was removed from the face of the weld by grinding between each pass to minimize the occurrence of excessive porosity.

Prior to the start of chamber fabrication, extensive material and process evaluations (Reference 5) were accomplished using production material, equipment, and fabrication processes to investigate and define material process variables that could be expected during actual motor case fabrication. This effort resulted in the detection of material and process problems and the implementation of corrective action on these problems before the start of fabrication. The material and process evaluation areas of investigation included: (1) parent plate, (2) forged material, (3) evaluation of the effects of cold forming on the tensile and fracture-toughness properties of plate, (4) plate welding, (5) evaluation of the effects of cold-straightening on the tensile and fracture toughness of welded joints, (6) maraging response of the material and demonstration of the maraging system, (7) evaluation of the effects of the hydrostatic test fluid on the material stress-corrosion characteristics, and (8) fabrication and burst test of two 36-in. (91.5 cm) dia process evaluation test chambers.

Although the material and process evaluation program preceding chamber fabrication was extensive, some difficulties and discrepancies did occur during case fabrication. These difficulties included welding problems (e.g., weld burnthrough, areas of multiple weld repair, and weld defects) and nondestructive indications.

III.B. Technical Approach (cont)

2. Specimen Test Procedures

The specimen types and configurations and specimen test procedures used in this program were identical to the test specimens and specimen test procedures used in the 260-in. (6.6 m) Motor Program Material and Process Evaluation Program (Reference 5) and in the certification of the chamber production maraging heat-treatment (Reference 6). The same specimen types were used so that the data developed in this program would be directly comparable with previous data.

Tensile, slow-notch bend, and precracked Charpy impact tests were used to evaluate the tensile properties and fracture toughness of the plate and weld materials. The dimensions of these test specimens are shown in Figure 2. All tests were conducted at room temperature.

a. Tensile Tests

Tensile properties of specimens removed from the motor chamber (SN 001) were determined using a 0.250-in. (0.635 cm) dia threaded round specimen in accordance with requirements of ASTM-E8-68. The tensile specimens were taken from the center region of the 0.6 in. (1.52 cm) plate thickness. Where specific gage center locations were required, i.e., welds and heat-affected zones, specimen blanks were swab-etched to locate the microstructural zones.

The room temperature tensile tests were conducted in accordance with Federal Test Method Standard 151, using a strain rate of 0.005 in./in./min. (0.127 mm/mm/min). Load and strain were recorded during the tensile tests and the resulting load-strain diagram was used to determine the 0.2% offset yield strength. Elongation was measured over a 1-in. (2.54 cm) gage length.

III.B. Technical Approach (cont)

b. Precracked Charpy Impact Tests

Precracked Charpy impact tests were made on a subsize Charpy machine designed by Man Labs, Incorporated, with a capacity of 24 ft-lb (42.5 J). A Man Labs fatigue-cracking machine was used to automatically precrack the Charpy impact specimens to the desired crack depth.

Impact specimens were machined to standard 0.394 by 0.394 by 2.10 in. (1.0 by 1.0 by 5.33 cm) dimensions from the center region of the 0.6 in. (1.52 cm) plate thickness. Specimen notches were oriented through the plate thickness. Specimen blanks were swab-etched prior to notching to locate the desired microstructural zones.

The energy (W/A) required to propagate a crack per unit area of fracture surface was calculated by dividing the impact energy by the cross-sectional fracture area and was expressed in units of in.-lb/in.^{2} (J/cm^2).

c. Slow-Notch-Bend Fracture Toughness Tests

Slow-notch-bend specimen dimensions (Figure 2) were the same as those used in the previous 260-in. (6.6 m) Motor Feasibility Demonstration Program. Specimen width was full plate thickness, about 0.6 in. (1.52 cm). Specimen depth was 0.75 in. (1.9 cm) and specimen length was 4.12 in. (10.50 cm). As in the Charpy impact specimens, notches were oriented through the plate thickness.

Two analytical procedures were used in computing the plane strain fracture toughness parameter, G_c, strain energy release rate: the spring constant method and the Bueckner method. The spring constant equation is as follows: $G_{N_c} = 1/2\ (P/B)^2\ d\ (B/M)/da$ (Aerojet Computer Program 16112) that required obtaining a load (P) from a load-deflection (P-e) curve

III.B. Technical Approach (cont)

for the test specimen and the quantity d (B/M)/da from a previously developed calibration curve relating the reciprocal of the bar spring constant, M, to crack depth, a.

Load-deflection curves were developed from bend tests of instrumented, fatigue precracked notched bars. The load (P) is the load at which the curve deviates from linearity and is referred to as the proportional limit load. In this study the lack of a well defined deviation from linearity in the load-deflection curve was frequently encountered making accurate definition of the proportional limit load difficult. This difficulty was particularly associated with the tougher material conditions tested such as welds and hot spot regions.

The quantity d(B/M)/da is the slope of the calibration curve for the value of the spring constant (M) calculated for the deflection value (e), from the load-deflection curve, associated with the proportional limit load value (P), using the following:

$$M = \frac{L}{eB}$$

The test specimen width, B, and span, L, are normally constant for a given test series. In developing the calibration curve, test bars are machined from material representative of the material to be subsequently tested. Where several material conditions may exist it is difficult to properly describe all the material behavior from calibrations based on a calibration curve for one condition. In this study the calibration curve was derived from calibration specimens taken from the Panel No. 11 unaffected parent metal region. The development of calibration curves for the tougher material conditions found in the welds and hot spot regions and re-dimensioning the test specimen would probably be necessary to obtain valid fracture toughness data for these regions.

III.B. Technical Approach (cont)

The Bueckner equation is as follows:

$$G_{Ic} = \frac{(1 - \gamma^2)}{E} \quad F_n^{\ 2}\ h\ f(a/D)$$ (Aerojet Computer Program 16107)

where $F_n = 3\ PL/Bh^2$, σ = Poisson's ratio, E = Youngs modulus, h = depth below the notch and $f(a/D) = 0.0126 + 1.9762\ (a/D) - 2.1713\ (a/D)^2$. The experimental data required are again the proportional limit load (P) and measured values of the machined-notch-plus-fatigue-crack-depth, (a). The same difficulties of determining the proportional limit load described for the spring constant method apply in the Bueckner analysis. Two values of load were used in the Bueckner analysis, i.e., one using the best estimate of the proportional limit load (P_L) and the second using the well defined maximum load (P_M).

The fatigue crack depth must be measured for each specimen to determine the a-value to be used in the Bueckner calculation. The procedure in measuring crack depth was the same as used in the previous 260-in. (6.6 m) Motor Feasibility Demonstration Program. Three fatigue crack depths were measured on each specimen, one at the specimen center and one each, 0.0156 in. (0.040 cm) to each side of the center. The average of the three measurements was used in the calculation of G_{Ic}. Difficulty was encountered in growing planer fatigue cracks of uniform and controlled depth, invalidating some data groups.

d. Metallographic Procedures

Conventional metallographic procedures were followed during the program. Inclusion ratings were established by examining the specimens in the "as-polished" condition. Grain size determinations were made with a 10% chromic and electrolytic etch to define the prior austenitic grain size

III.B. Technical Approach (cont)

that was rated in accordance with ASTM E112-61. General microstructure evaluations were performed using Marble's etchant to emphasize the martensitic microstructure and, in conjunction with Knolls etchant, to determine the presence of banding or severe alloy segregation.

C. RESULTS AND DISCUSSION OF RESULTS

1. Review of Inspection Reports (Task I)

Existing chamber material and fabrication records (log books) maintained on the motor chamber (SN 001) during fabrication, during its use in the 260-SL-1 motor, and during reuse in the 260-SL-3 motor were reviewed to confirm the exact characteristics of the 12 test panels planned for study in this program. On the basis of review of the inspection reports, the 12 test panels shown in Table 1 were selected for evaluation. The locations of the test panels on the chamber cylinder section are shown in Figure 3. The chamber cylinder section weld and parent plate designations, e.g., girth weld WG-6, longitudinal weld W2CA, and parent plate 2CA, that are used throughout the text are shown in Figure 3.

The review of inspection reports confirmed the location and characteristics of the test panels originally planned for evaluation with the exception of test panel No. 1. Test panel No. 1, Metallurgical Evaluation of Standard Productions Welds (Table 1) was originally planned to be obtained from the cylinder section longitudinal weld W3CA. The location of test panel No. 1 was revised to longitudinal weld W4CB because the review of inspection reports showed that the originally planned area of weld W3CA did not have sufficient evaluation area that was free of interference from any type of weld repair.

III.C. Results and Discussion of Results (cont)

The location of test panel No. 2, selected for evaluation of a girth weld burnthrough where the turning rolls stopped, could not be verified by inspection records contained in the chamber log book. This area was observed during fabrication of the chamber (SN 001) and was selected as a location for installation of strain gages to be monitored during the SL-1 (Reference 1) and SL-3 (Reference 3) chamber hydrostatic proof tests. The area of weld burnthrough was not recorded in the chamber log book because the burnthrough and subsequent successful repair did not represent a nonconformance to established requirements.

2. Sectioning of the 260-SL-3 Chamber (Task II)

The cutting lines defining the exact size, shape, and location of each of the 12 test panels were marked on the chamber cylindrical section exterior surface with indelible ink. Each test panel was oriented by establishing dimensions from a reference point on the panel to a reference point on the chamber (Figure 4). Both the panel number and orientation marks were placed on each test panel with a metal stamp.

The panels were removed from the cylinder section without difficulty, and well within the heat-affected zone allowance, by using the Arc-Air carbon arc cutting technique. Temperature-indicating paint used on the first five panels to be removed showed that the heat-affected zone of the cut was well within a 1-in. (2.54 cm) band from the center of the cut. Exterior paint discoloration did not exceed 0.25 in. (0.61 cm) from the cut on any of the test panels.

III.C. Results and Discussion of Results (cont)

Test panel No. 6 was located over an inert sliver. This panel was removed by first cutting through the maraging steel, then cutting through the sliver with a chain saw. The sliver was removed from the panel by making 2-in. (5.08 cm) on-center cuts across the sliver with a chain saw to as close to the metal as possible, without contacting the metal. The 2-in. (5.08 cm) sections of sliver were then pried away from the test panel. Very little force was required to break the small sections of sliver.

The 12 test panels were cut from the chamber with the internal motor insulation in place. The insulation was removed by heating the exterior surface of the test panel with a steam generator to approximately 250°F (394°K) to degrade insulation bond strength, and then pulling the insulation away from the panel.

Panels 1, 11, and 12 were left with the exterior paint and interior insulation bonding agent on the surfaces as the next planned operations on these panels were to lay out and machine test specimens. However, panels 2 through 10 were grit-blasted to the metal base to prepare the panels for subsequent nondestructive inspections. The grit-blasting was accomplished with care so that the panel number and panel orientation marks would not be removed. The hose pressure was maintained at 60 psig (41.4 N/cm^2 gage) or less, to minimize metal removal and roughening of the panel surfaces.

The metal surfaces of the test panel were covered with soft film corrosion preventive compound for protection during shipment of the test panels from the Aerojet's Dade County Plant in Florida to the Sacramento Facility.

III.C. Results and Discussion of Results (cont)

3. Metallurgical Evaluation of Standard Production Welds (Task III)

Test panel No. 1, Standard Production Weld, was evaluated to determine the mechanical properties and metallurgical characteristics that were obtained in actual production chamber welds. Also, the data from this test panel will be used as a baseline for comparison with other welds evaluated in this program.

Before the start of testing, the weld process and defect characteristics in the evaluation area of weld W4CB were defined by a review of the chamber fabrication nondestructive inspection and process records. The results of this review are shown in Table 2. Weld seam W4CB in the area is a typical production automatic weld, free of any discrepant process or defect characteristic. The weld was accomplished from the exterior only as shown in Figure 5.

Layout of the tensile, precracked Charpy impact (PCI), slow-notch-bend (SNB), and metallographic test specimens on test panel No. 1 is shown in Figure 6. Weld filler wire heat No. 08950 was used in the production of weld seam W4CB. The test panel parent metal and weld heat-affected zone (HAZ) test specimens were obtained from plate heat 3960832-A (plate 4CB). Available parent plate and weld filler wire material characterization data (Reference 7) and production maraging heat-treat specimen data (Reference 6) are listed in Table 3. Average tensile, PCI, and SNB specimen data obtained from test panel No. 1 are listed in Table 4.

It is apparent from a comparison of the characterization and heat-treat data (Table 3) vs the test panel No. 1 mechanical property data (Table 4) that strength and toughness values of the production parent

III.C. Results and Discussion of Results (cont)

plate and weld were within the range of values that had been expected, for the production component. Average yield strength values for test specimens heat-treated with the chamber and the test panel No. 1 are, respectively:

Parent Plate - 233,000 vs 243,000 psi (160,650 vs 167,550 N/cm^2)
Weld, Transverse - 226,000 vs 221,000 psi (155,830 vs 152,380 N/cm^2)

The similarity between the plate fracture toughness (G_{Nc}) data and the G_{Nc} values obtained from the previous chamber heat-treat coupons is also evident in a comparison of Tables 3 and 4. The average G_{Nc} values for plate material obtained in this program and from the previous heat-treat coupons are 227 vs 239 in.-lb/in.^{2} (3.97 vs 4.18 J/cm^2), respectively.

An apparent discrepancy exists (Tables 3 and 4) when comparing the panel No. 1 heat-affected zone (G_{Ic}, P_L) values with the G_{N_c} value obtained in the previous material characterization program (Reference 6); i.e., 253 vs 468 in.-lb/in.^{2} (4.43 vs 8.19 J/cm^2), respectively. However, it has been shown (Reference 5, page 127 through 135) that actual chamber maraging generally produced higher strength and lower toughness than was obtained in the material characterization program. Therefore, the spread between the characterization data and the test panel data obtained from the maraged chamber is in the direction that is expected based on the previous 260-In. (6.6 m)-Dia Motor program evaluations (References 5 and 6).

Quantitative comparison of the panel No. 1 G_{Ic} data in this program with the data in the previous 260-In. (6.6 m)-Dia Motor Program cannot be accomplished because the previous program data are based primarily on G_{Nc} toughness values. However, a qualitative comparison of weld, HAZ, and parent plate can be accomplished by using the G_{Ic} (Pm) toughness value calculated using maximum load. Weld and HAZ are shown (Table 4) to be about equal

III.C. Results and Discussion of Results (cont)

toughness [357 and 356 in.-lb/in.^{2} (6.25 and 6.23 J/cm^2)], respectively, and about 20% tougher than the parent plate [294 in.-lb/in.^{2} (5.14 J/cm^2)]. Previous heat treat specimen data (Table 3) show the weld to be at least 15% tougher than the parent plate.

Examination of the microstructure of the standard production weld in test panel No. 1 showed a sound weld deposit with only a few isolated spherical pores. The segregated dendritic structure typical of aged, multiple pass welds in 18% nickel maraging steels was observed in the center of the weld (Figure 7).

The hardness traverse values measured at the OD, center, and ID surfaces of the weld of test panel No. 1 are plotted in Figure 8. The hardness values, in R_c, range between 44 and 48. Tabulation of the hardness indications are provided in Table 5.

4. Metallurgical Evaluation of Defective Welds (Task IV)

The Task IV evaluation of defective welds includes test panels No. 2 through 5. These panels include an area of weld burnthrough, areas of four and seven overlapping manual weld repairs, and an area of multiple scattered spherical porosity.

Initially, the four test panels were nondestructively inspected using radiographic, magnetic particle, and ultrasonic inspection techniques. These inspection techniques were used in the production inspection of the chamber SN 001. The inspections were accomplished in accordance with specific process specifications that identify the equipment and material requirements as well as the minimum inspection sensitivity (Reference 8).

III.C. Results and Discussion of Results (cont)

The nondestructive inspection results are discussed below:

a. Test Panel No. 2 - Weld Burnthrough

Radiographic inspection showed two spherical gas pores within specification limits. Magnetic particle inspections and both shear wave and longitudinal wave inspections did not reveal any defects.

b. Test Panel No. 3 - Multiple Weld Repair Area

Radiographic inspection revealed no rejectable defects. Also, magnetic particle and ultrasonic inspection revealed no defect indications.

c. Test Panel No. 4 - Multiple Weld Repair Area

Radiographic inspection showed one spherical gas pore well within specification limits. The magnetic particle and ultrasonic inspections showed no defects.

d. Test Panel No. 5 - Weld Porosity

Radiographic inspection of panel No. 5 showed a cluster of 21 spherical gas pores with diameters of 0.010 to 0.050 in. (0.254 to 1.270 mm) in about 1.5 in. (3.81 cm) of weldment length. Average pore diameter was 0.02 to 0.025 in. (0.508 to 0.635 mm) with a distance of closest approach of 0.01 in. (0.254 mm). Neither magnetic particle nor ultrasonic inspection detected any defects.

III.C. Results and Discussion of Results (cont)

The average tensile data and SNB and PC1 fracture toughness data obtained from test panels No. 2 through 5 are tabulated in Table 6.

One of the significant aspects of the Task IV effort was to determine the tensile properties obtained in the production manual weld repairs. Manual weld repairs are less amenable to process controls than are automatic welds by nature of the process. The heat input in manual welds is typically a function of the welding operator technique. Manual weld repairs were evaluated in the previous material and process evaluation program (Reference 5, pages 90 through 96). Also, specimens representing seven manual overlapping repairs were prepared and placed in the furnace during the production heat-treatment of chamber SN 001. Average ultimate and yield strength (Reference 6, Figure 88) of these heat-treated coupons were 194,000 psi (133,760 N/cm^2) and 187,000 psi (128,940 N/cm^2), respectively. The average tensile data for test panel No. 4 (Table 6); i.e., 201,900 psi (139,210 N/cm^2) ultimate strength and 194,400 psi (134,040 N/cm^2) yield strength show that the actual production area of seven repairs was better than expected from the heat treat coupon test results. As result of this program, the yield strength in the area of seven repairs is 26,600 psi (18,340 N/cm^2) lower than the transverse yield strength of the production automatic weld (Table 4). Also, data in Table 6 show that the average yield strength in the panel No. 4 area of seven multiple weld repairs is 21,500 psi (8,620 N/cm^2) lower than the panel No. 3 area of four multiple weld repairs.

Average weld plane stress (W/A) fracture toughness values of test panels No. 2 through 5 varied from 1180 to 1575 in.-lb/in.^{2} (20.65 to 27.56 J/cm^2) (Table 6). These values agree with the 1305 in.-lb/in.^{2} (22.85 J/cm^2) value obtained in the standard automatic weld (Table 4). Average weld plane strain (G_{Ic}) fracture toughness values calculated using the maximum load varied from 312 to 453 in.-lb/in.^{2} (5.46 to 7.93 J/cm^2) (Table 6) and also agree with the 357 in.-lb/in.^{2} (6.25 J/cm^2) obtained in the production automatic weld (Table 4).

III.C. Results and Discussion of Results (cont)

The tensile and fracture toughness properties obtained in this program are discussed further in Sections III.C.8. and 9.

Metallographic examinations were made in one plane transverse to the weld in each test panel No. 2 through 5, except that two planes were examined in test panel No. 5.

Photomacrographs of the weld areas taken in the metallographic sections transverse to repair welds of test panels No. 2 through 5 are shown in Figure 9. The microstructural characteristics of the parent material regions were normal. The weld- and heat-affected zones were generally more extensive and wider than observed in unrepaired welds, i.e., the production automatic weld (test panel No. 1). The burnthrough region in panel No. 2 appeared as a ID - OD weld repair. The panel No. 3 repair cannot be distinguished from an unrepaired weld. Panel No. 4 and 5 repairs were extensive and involved both ID and OD surfaces. Very little evidence of the porosity associated with the panel No. 5 weld was apparent in the two sections examined. One pore is evident in the typical panel No. 5 section shown in Figure 9. The welds were generally sound and all but panel No. 5 were free from cracks, porosity, or other defects.

After completion of the microstructural examinations, microhardness was measured (Table 7). The microhardness values were in the range expected and did not reveal any abnormal conditions.

5. <u>Evaluation of NDT Indications (Task V)</u>

The Task V test panels of prior nondestructive test indications (test panels No. 6 through 9) include an area of radiographic high-density indication associated with an area of multiple weld repair and areas of ultrasonic and magnetic particle indications (see Table I). Initially, test panels No. 6 through 9 were inspected using radiographic, ultrasonic, and magnetic particle inspection techniques to confirm the existence and location of the prior NDT indications.

The nondestructive inspections accomplished in this program revealed characteristic indications only in test panel No. 6 (radiographic high-density indication). The radiographic film of test panel No. 6 indicated the exact location on the test panel where test specimens should be ob tained. The test specimen locations on test panels No. 7 through 9 were specified in accordance with the characteristic locations obtained from the chamber SN 001 fabrication log book.

Microstructural examinations and hardness transverses were accomplished on six planes, each, of test panels No. 6 through 9 prior to mechanical property testing, except for panel No. 6. Only three planes were examined on panel No. 6 prior to mechanical property testing to conserve as much of the "flaw" area as possible for specimen testing.

a. Examination of Test Panel No. 6; High-Density Indication

The radiographic high-density indication is about 2.5 in. (6.35 cm) long by 0.06 in. (1.52 mm) wide located at the junction of the weld nugget and the parent material, parallel to the weld contour. Magnetic particle inspections showed an indication identical in size and location as the "more dense" area shown radiographically. The magnetic particle indication was observed with clarity on the back (ID) surface of the panel.

III.C. Results and Discussion of Results (cont)

The location of the three initial section planes on test panel No. 6 and the locations of the microstructural examinations on these planes are shown in Figure 10. The layout of specimens in the high-density area and all six planes of microstructural examinations are shown in Figure 11. Photographs of the macro and microstructure on the six planes of examinations are provided in Figures 12 through 16. No foreign material, cracks, porosity, seams, or other defects were observed in the sections. However, an unusual condition was observed (planes 1 and 2, Figures 12 and 14) in the heat-affected zone where the radiograph had shown a crescent of dense material. The condition is a band 0.030 to 0.050 in. (0.76 to 1.27 mm) in width perpendicular to the plate surfaces and extending through the plate thickness. The microstructure within the band showed what is interpreted to be an area of extensive austenite reversion. The phases present are normal and are found in all heat-affected zones adjacent to welds. But the extent of the transition zone from unaffected parent [maximum exposure temperature 900 to 950°F (756 to 784°K)] to resolution annealed and transformed material [minimum temperature of exposure 1350°F (1006°K)] is much more in the test panel No. 6.indication areas than in "normal" areas of test panel No. 6 (Figure 13, photos 6-1(4) and 6-3) or others, e.g., test panel No. 8, Figure 17.

Although austenite reversion is normally detected by magnetic particle examinations, and was in test panel No. 6, detection by radiographic inspections has not been reported. The unique orientation and extent of the particular reverted zone might account for its being radiographically detectable. During abrasive grinding and polishing of section planes 1 and 2, loose abrasive particles accumulated over the austenite band that duplicates the type of indication that would be obtained in magnetic particle inspection (austenite is weakly magnetic compared with the surrounding martensitic structures). It is therefore expected that the indication noted by nondestructive inspections of test panel No. 6 was caused by a band of reverted austenite. The abnormal dimensions and extent of the band were probably a result of the extensive repair welding accomplished in the area.

III.C. Results and Discussion of Results (cont)

Microhardness traverses were made through the indication and also, outside the indication. A photograph of the hardness traverse made on plane 1 through the indication is shown in Figure 18. Panel No. 6 hardness traverses are shown as typical values in Figures 19 and 20.

After completion of the microstructural examinations, the flaw region was laid out for mechanical property determinations (Figure 11). Centers of test gages or notch planes were located in the flaw. The test results are tabulated in Table 8 with pertinent data to compare the performance with normal material. Two tensile specimens were located to include the flaw in the gage center. One specimen failed in the flaw region and the other failed in the weld, about 0.5 in. (1.27 cm) from the flaw (Figure 12) with similar tensile properties and at about the same strength and reduction in area values as obtained in repair weld specimens. However, tensile elongation was about 25% lower than normal repair welds. Comparing the flaw region properties with parent metal from the same heat (panel No. 4, plate 2CA, Table 8) shows flaw region strength levels to be about 10% lower. The parent material in test panel No. 6 from the Plate 2CB opposite the flaw showed tensile properties similar to those for the same heat from test panel No. 4, Plate 2CB (Table 8), indicating that local heat treatment anomalies were not responsible for the condition.

Toughness comparisons are difficult because of the limited tests that could be performed in the small area and the problem of confining the crack to the flaw region. The single precracked Charpy impact value indicates a toughness level associated with heat-affected zones, i.e., higher than parent metal. In the single notched bend specimen the fatigue crack growth from the machined notch deviated by 0.2 in. (0.51 cm) from the plane of the notch and was not uniform in depth. Hence, the calculated G_{Ic} value is questionable.

III.C. Results and Discussion of Results (cont)

From the metallurgical examination it is expected that the flaw region of the test panel No. 6 would behave in a manner similar to heat-affected zones as encountered adjacent to repair welds, that is, with slightly reduced strength and slightly increased toughness.

Representatives of International Nickel Company, Incorporated, Republic Steel Corporation, and Allegheny Ludlum Steel Corporation were contacted to determine if they had radiographically detected any reverted austenite bands. None could recall detecting localized austenite regions; however, the orientation of the flaw and its association with a weld would not normally be experienced by the producer of basic materials. It is expected that it would not be difficult to reproduce the structure, establish its detectability, and completely describe its local phase and compositional characteristics.

b. Examinations of Test Panels No. 7, 8, and 9

Sections transverse to the welds in test panel No. 7, 8, and 9 were made on six planes (Figure 21). The microstructural characteristics of the weld, heat-affected zone, and parent metal were examined and found to be normal for the alloy and fabrication history of the sections. Microstructures were similar to that found in the standard automatic production weld (Task III). The macrostructural features of normal, high quality fusion weld sections are shown in Figures 22 through 30 for test panels No. 7, 8, and 9. Satisfactory geometry, porosity, and crack free weld deposits were obtained and evidence of any condition that might have caused the prior ultrasonic and ghost-type magnetic particle indications was not observed.

III.C. Results and Discussion of Results (cont)

The results of the hardness traverses accomplished on the test panels No. 7, 8, and 9 are shown as typical values in Figures 31 and 32. Figure 31 shows typical mid-thickness microhardness traverses with typical standard automatic weld (test panel No. 1) microhardness values for comparison. The hardness values obtained are within the range expected and any abnormal conditions were not observed. The Knoop microhardness measurements converted to R_c are tabulated in Tables 9 through 11, respectively.

After completion of the microstructural examinations, tensile, PC1 and SNB specimens of test panels No. 7, 8, and 9 were prepared and tested. The test results are shown in Tables 12 through 14, respectively. The 0.2% offset yield strength values of the unrepaired welds are comparable with the values of test panel No. 1 standard production automatic weld [average 222,100 psi (153,140 N/cm^2) vs 221,000 psi (152,380 N/cm^2), respectively]. Also, the average plane stress (W/A fracture toughness) was very similar to the standard production automatic weld [1190-in.-lb/in.^{2} (20.82 J/cm^2) vs 1305 in.-lb/in.^{2} (22.84 J/cm^2)], respectively. Test panels No. 7, 8, and 9 average plane strain fracture toughness (G_{Ic}) values calculated using the Bueckner analysis and maximum load showed reasonable correlation with the standard production automatic weld [279 vs 357 in.-lb/in.^{2} (4.88 vs 6.25 J/cm^2)], respectively. However, the difficulty encountered in growing the Task V planer fatigue cracks resulted in crack depths deeper than desired (refer to Sections III.B.2. and III.C.9.).

6. Measurement of a Thin Spot (Task VI)

A thin area in the chamber cylinder section was observed during final visual inspection of the chamber SN 001 prior to the SL-1 hydrostatic proof test. The thin area resulted from an electric arc burn when an electric cable short circuited against the exterior of the case. Inspection

III.C. Results and Discussion of Results (cont)

records reported the thickness to be 0.560 in. (1.42 cm) after blending the thin area by grinding. Thickness measurements obtained by ultrasonic techniques prior to strain gage installation in the thin area for SL-1 and SL-3 hydrostatic proof tests were 0.560-in. (1.422 cm) and 0.552 in. (1.402 cm), respectively.

The thickness in the thin area of test panel No. 10 (Table 1) was determined using the Sperry Reflectroscope equipment similarly used to determine the thickness prior to the SL-3 proof test. Initially, the thin area [about 0.675 in. (1.714 cm)-dia] was located using the Sperry UM-700 Reflectoscope; and, the thickness was determined to be 0.575-in. (1.460 cm). As a cross-check, the thickness was again inspected ultrasonically with the Bronson Sonoray-30 Unit and was found to be 0.570-in. (1.448 cm). After completion of the ultrasonic thickness inspections, the test panel was sectioned through the thin area. Then, the thickness was inspected using a standard micrometer with pointed anvils. The thickness measurements obtained in and adjacent to the thin area are shown in Figure 33. The minimum thickness of 0.565-in. (1.435 cm) obtained with the micrometer is 0.005-in. (0.127 mm) and 0.010-in. (0.254 mm) less than that determined ultrasonically with the Bronson Sonoray-30 and UM-700 Reflectoscope equipment, respectively. Also, the minimum micrometer indication was 0.005-in. (0.127 mm) more than the thickness measurement determined ultrasonically during production final inspection and prior to SL-1 proof test.

The Rockwell C (R_c) microhardness values measured through the thickness of the thin area are shown in Figure 34 and are compared with the standard production weld traverses taken along the ID, OD, and mid-thickness across the weld. The Knoop hardness values converted to Rockwell C through the thin area are provided in Table 15. The Rockwell C values varied from 48 to 50 and did not indicate any adverse effect on the parent metal from the electric arc burn.

III.C. Results and Discussion of Results (cont)

7. Metallurgical Evaluation of Hot Spots (Task VII)

The hot areas on the chamber cylinder ranged from slight paint discoloration to complete deterioration of the paint. A typical area is shown in Figure 35. Prior to SL-3 motor firing, the exterior surface of the chamber was covered with two coats of zinc chromate primer (MIL-P-8585) and two coats of white lacquer (TT-L-32).

The hot spot test panels No. 11 and 12 (Table 1) were removed from the chamber cylinder section such that both the heat-affected and unaffected areas were contained in each panel (Figures 36 and 37). A limited hardness survey using a portable hand-operated hardness tester was made on the test panels to identify the heat-affected and unaffected area of the panels. A layout of the test specimens in both the heat-affected and unaffected areas and the surface hardness indications are shown in Figures 38 and 39.

Test panels No. 11 and 12 were examined by metallographic analyses and hardness traverses within and without the hot spot regions. The microhardness traverses (Table 16, Figures 40 and 41) indicate decreases in hardness levels from R_c 47/49 in the unaffected regions to R_c 31/39 in the hot areas. Microstructural changes were most evident in test panel No. 11. The photomacrograph of Figure 42 shows a section through the hot area of panel No. 11. Figure 43 shows microstructural features at various positions in the section. The upper-left region 22 of Figure 43 shows that recrystallization and grain growth has occurred, particularly in segregate bands, near the ID surface. Microstructural changes of this type were observed to a depth of about 0.030 in. (0.76 mm) in regions that reached the highest temperatures. In the cooler regions, recrystallization had not occurred as indicated by the severely distorted and elongated grain structure characteristic of the original

III.C. Results and Discussion of Results (cont)

plate (compare Figure 43 with Figure 44). However, over-aging had occurred as evidenced by the significant hardness drop. In the section examined from test panel No. 12, evidence of recrystallization and grain growth was not observed (Figure 45); however, the hardness traverses and mechanical property test results indicate that microstructural conditions similar to those observed in test panel No. 11 would be found at some location within the hot area.

Grain size measurements showed that in test panel No. 12, the average grain size was ASTM 6-8. Test panel No. 11 was finer-grained, measuring ASTM 7-8 or finer in the unaffected portions. In the segregate bands near the hot area ID surface, where grain growth had occurred, the grain size was ASTM 6. Inclusion ratings obtained in examination of test panels No. 11 and 12 are shown in Table 17.

To estimate the range of temperature exposure of the metal wall within the hot spot regions, data from Decker and Floreen (Reference 9) were plotted in Figure 46. The hardness range for the panels No. 11 and 12 hot areas indicate that the minimum exposure temperature was 1200°F (922°K). The occurrence of recrystallization and grain growth near the ID surface in panel No. 11 indicated that temperatures reached 1700°F (1200°K) in this region. Therefore, it is estimated that the metal wall in the hot regions experienced temperatures of about 1700°F (1200°K) near the ID, to 1200°F (922°K) near the OD surfaces. The exposure time was probably not long.

The mechanical properties of the normal and hot regions are compared in Table 18. Strength reductions occurred about 30 and 40% in tensile ultimate and yield strength, respectively, on the basis of mid-plate, 0.252-in. (0.640 cm)-dia specimen tests. The qualitative toughness values, calculated using the Bueckner analysis and maximum loads, indicate greater toughness in the hot spot regions as compared with the normal, unaffected material.

III.C. Results and Discussion of Results (cont)

Softening occurs in the 18% nickel maraging steel from the formation of austenite from martensite when the alloy is exposed to the temperature range between the normal aging temperature, about 900°F (755°K), and the transformation temperature, about 1350°F (1006°K) (References 9, 10, and 11). The reversion to austenite is in accordance with the equilibrium diagram for the iron-nickel system. Martensite, a non-equilibrium form produced by cooling from the austenite region above 1350°F (1006°K), is stable at room and moderate temperatures but with higher temperature becomes increasingly unstable and reverts to the equilibrium state, austenite plus ferrite. The reversion reactions are time-temperature dependent and are of practical concern in the temperature range of 950 to 1350°F (785 to 1006 °K). The austensite formed during the reversion reaction is enriched in nickel and hence, stable upon subsequent cooling to room temperature and can only be eliminated by heating above the transformation temperature, 1350°F (1006°K), i.e., solution annealing. Subsequent cooling will then produce the soft martensitic form that can be hardened by aging treatments. Apparently, over-aging with austentite reversion, to some degree, and resolution annealing occurred in the hot regions of test panels No. 11 and 12.

8. Tensile Properties

The results of room temperature tensile tests performed on samples removed from SL-3 chamber test panels No. 1 through 9, 11, and 12 are presented in Table 19. The average tensile ultimate and yield strengths of the parent plate materials are given in Table 20 and compared with the heat-treatment test coupon and characterization test data for the same plates, heats, and grain orientations. These data are presented in bar chart form in Figure 47. The SL-3 specimen tests results, with an ultimate strength level of 240,000 to 255,000 psi (165,480 to 175,822 N/cm^2) and a yield strength level of 220,000 to 245,000 psi (152,000 to 169,000 N/cm^2), are about 5,000 psi (3,450 N/cm^2)

III.C. Results and Discussion of Results (cont)

higher than the heat-treat coupon results and about 15,000 psi (10,340 N/cm^2) higher than the characterization test results. The SL-3 data confirm the difference previously observed between tensile values of specimens heat-treated using laboratory time-temperature cycles (characterization data) and those heat-treated with the chamber in the large maraging furnace that involved long heat-up and cool-down periods (Reference 5). The observed difference in strength was previously reported to be 6,000 to 17,000 psi (4,140 to 11,720 N/cm^2), (Reference 5, Figure 177).

The average tensile ultimate and yield strengths of weld joints are given in Table 21. Weld properties should be grouped as non-repaired and repaired for comparison purposes. Welds in test panels No. 7, 8, and 9 were not repair welds and hence, had strengths equivalent to the standard, automatic production weld of test panel No. 1, and, equivalent to the heat-treat coupon results. The repair welds of test panels No. 3 and 4 had strengths below the production weld but slightly above the strengths for repair heat-treat coupons.

The test panel No. 5 repair area was characterized by a large amount of spherical porosity. The primary effect of such porosity is not on strength but on localized ductility. Specimen No. 5-2 (Table 19), with extensive porosity, demonstrated nominal repair weld strength but extreme decreases in elongation, 3 from 12%, and reduction area, 5 from 50%. However, these ductility values are for a 0.25-in. (0.635 cm) test section in the center of a 0.6-in. (1.52 cm) thick plate and therefore may not be representative of other positions through the thickness or of the performance that might be obtained in a full plate thickness specimen.

III.C. Results and Discussion of Results (cont)

The test panel No. 2 weld was a burnthrough caused by an interruption of the welding head circumferential traverse and a dwell of the arc. However, the strength reduction was not as much as observed in the multiple repair welds of test panels No. 3 and 4. Panel No. 2 had one repair. Panels No. 3 and 4 had four and seven repairs, respectively. Strength level is then observed to decrease with increasing repairs [test panel No. 2 - 218,000 and 210,000 psi (150,310 and 144,800 N/cm^2); test panel No. 3 - 211,000 and 207,000 psi (145,480 and 142,730 N/cm^2); test panel No. 4 - 201,000 and 194,000 psi (138,590 and 133,760 N/cm^2)]. The limited data (Reference 6, Figure 89) indicate a similar trend in repair welds for two weld filler wire heats.

A graphical comparison of weld joint tensile strength for SL-3 specimens, heat-treat coupons, and characterization tests is presented in bar chart form (Figure 48).

9. Fracture Toughness Properties

The results of the precracked Charpy impact tests of test panels No. 1 through 9 are shown in Table 22. Characterization data are included for comparison purposes. Impact specimens were not included during motor case heat-treatment; hence, an estimate of the impact level expected in the motor case was made on the basis of limited data presented (Reference 5, page 128). Generally, the SL-3 average parent material precracked Charpy impact level was 13% lower than the characterization data, which would be expected because the actual SL-3 strength level was about 15% higher than the characterization strength level. An estimated average impact toughness value for heat-treat coupon impact specimens would be 15% lower than the characterization level. Therefore, the SL-3 parent plate precracked Charpy

III.C. Results and Discussion of Results (cont)

impact levels are within the range expected. These limited data also indicate that the average impact levels decrease with increasing strength level, within the range of the heats tested; and, that transverse values are lower than longitudinal values (Figure 49). These observations agree with those reported (Reference 12, Figure 40, and Reference 5, Figure 15).

Weld precracked Charpy impact toughness values were in the range expected, averaging about 15% more than parent material. Heat-affected zone precracked impact toughness values were too limited in quantity to evaluate.

Slow-notch-bend test results for test panels No. 1 through 9, 11, and 12 are presented in Table 23. Average slow-notch-bend test results are presented for plate material in Table 24 and for weld joints in Table 25.

A qualitative comparison of weld toughness was attempted using the well defined maximum load (P_m) and the Bueckner analysis (Section III.B.2.). These calculations are included in the weld toughness summary (Table 26) to enable comparison of unrepaired welds with repair welds. The unrepaired welds have G_{Ic} values in the range of 250 to 380 in.-lb/in.^{2} (4.38 to 6.65 J/cm^2) (test panels No. 1, 7, 8, 9), while repair welds have G_{Ic} values in the range of 310 to 450 in.-lb/in.^{2}(5.42 to 7.88 J/cm^2) (test panels No. 2, through 5). The trend of decreased toughness with increased strength shown in these results is in good agreement with the corresponding panel weld strength level trend.

Where fatigue cracks of the desired depth, uniformity, and flatness were obtained in normal parent material specimens (panels No. 1, 11, and 12), good correlation of the SL-3 specimen test results with heat-treat coupon test results was obtained (Table 27). Correlation was also obtained between the G_{Ic} values calculated using spring constant and Bueckner methods for these panels.

IV. CONCLUSIONS

The tensile properties, fracture toughness properties, and material microstructural examinations obtained from investigation of test panels from the SL-3 (SN 001) 260-in. (6.6 m) motor chamber cylinder section were representative of the characteristics that were expected on the basis of results of material characterization and process evaluations accomplished prior to the start of chamber fabrication. The results of the investigations in this program show that acceptable parent material and weld properties were obtained and that future chamber fabrication using the same material and fabrication techniques should produce similar results.

The general trend of strength increase and reduction of fracture toughness resulting from the extended heat-up and cool-down portions of the production maraging temperature-time cycle (as compared with the rapid heating and cooling of the prior material characterization) was confirmed by the results obtained in this program. As an example, the 0.2% offset yield strength of chamber cylinder plate 4CB (test panels No. 1 and 5) varied from 239,000 to 243,000 psi (164,790 to 167,550 N/cm^2). The yield strengths of plate 4CB heat-treat coupons maraged with the chamber and material characterization specimens were 235,000 psi (162,030 N/cm^2) and 225,000 to 227,000 psi (155,140 to 156,520 N/cm^2), respectively. Any future material characterization preceding 18% Ni maraging steel chamber fabrication should be accomplished using the long heat-up and cool-down part of the maraging cycle that would be representative of the actual production heat-treatment.

The 18% nickel steel weld strength and fracture toughness are significantly influenced by subsequent weld repairs. The welding heat input of manual weld repair reduces the strength and increases the toughness of the weld in comparison with the unrepaired weld. On the basis of data developed in this program, each additional repair further reduces the strength and increases the toughness. The effect of manual weld repair is generally dependent on

IV. Conclusions (cont)

operator skill and technique. Average strength reductions of 2.5, 5, and 9% could be expected in areas of 1, 4, and 7 overlapping manual repairs, respectively.

The average yield strength of 215,000 psi (148,240 N/cm^2) in the test panel No. 5 area of porosity was within the range expected for one weld repair. A single 0.25-in. (0.635 cm)-dia tensile specimen failed at an area of significant amount of pores located within the gage length of the specimen. The yield strength was lower [207,000 psi (142,730 N/cm^2)] than any other specimen from the same area and both elongation and reduction of area were severely reduced. However, general conclusions regarding the effect of porosity on the mechanical properties of the weld cannot be made because the properties obtained in an 0.25-in. (0.635 cm)-dia specimen from the center of the plate thickness are not necessarily representative of the properties that would be obtained in a full plate thickness specimen from the same area.

Qualitative analysis by microstructural examination of the radiographically detected "high-density" indication in the heat-affected zone adjacent to an area of multiple weld repair shows that the indication was caused by a band of reverted austenite about 0.030 to 0.050-in. (0.076 to 0.127 cm) in width oriented essentially perpendicular to the plate surface and extending through the plate thickness. The band of reverted austenite was probably caused by the extensive manual repair accomplished in the area. The electron microprobe analysis and X-ray diffraction would be required to quantitatively identify the chemical composition and phases present in the "high-density" band. The tensile properties in the "high-density" area were about 10% lower than normal parent metal from the same heat. The "high-density" area evaluated (or any similar area) would be expected to exhibit properties similar to the heat-affected zone adjacent to an area of multiple weld repair, except that the tensile elongation would be significantly lower.

IV. Conclusions (cont)

The prior ultrasonic and magnetic particle indications were not observed in test panels No. 7, 8, and 9. The mechanical properties of the weld were similar to the standard automatic weld. Microstructural examinations in the area of the prior indications did not reveal any condition that would lead to conclusions as to the cause of the prior indications.

Measurement of the thin spot at an area of an electric-arc burn in panel No. 10 by two ultrasonic systems resulted in a measured thickness of 0.010-in. (0.254 mm) more than the thickness determined with a micrometer with pointed anvils. It should not be concluded that the accuracy obtained in this investigation is necessarily representative of that obtained in any ultrasonic inspection of 0.60-in. (1.524 cm) thick steel because the accuracy is dependent on the equipment used and the calibration of the equipment. There was no apparent effect on the plate material hardness caused by the electric-arc burn.

The mechanical property data, microhardness data, and microstructural examinations obtained in the hot areas of panels No. 11 and 12 showed that the material had experienced a temperature gradient varying from about 1700°F (1200°K) at the ID surface to about 1200°F (922°K) at the OD surface. A band about 0.030-in. (0.762 mm)-thick from the ID surface showed grain growth characteristics typical of resolution annealed material. The material through the thickness of the hot-spot area varied from resolution annealed to significantly over-aged conditions.

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5. Aerojet Report NASA CR-72126, 260-Inch-Diameter Motor Feasibility Demonstration Program, Vol. V: 260-SL Motor Chamber and Nozzle Shell Fabrication of 18 Percent-Nickel Steel, Appendix B: "Material and Process Evaluation Program," dated 8 April 1966

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7. Aerojet Report NASA CR-72126, 260-Inch-Diameter Motor Feasibility Demonstration Program, Vol. V: 260-SL Motor Chamber and Nozzle Shell Fabrication of 18 Percent-Nickel Maraging Steel, Appendix C: "Material Characterization Reports," dated 8 April 1966

8. Aerojet Report NASA CR-72126, 260-Inch-Diameter Motor Feasibility Demonstration Program, Vol. V: 260-SL Motor Chamber and Nozzle Shell Fabrication of 18 Percent-Nickel Maraging Steel, Appendix A: "Program Specifications," dated 8 April 1966

9. Decker and Floreen, "Effect of Overheating Aged 18% Nickel Maraging Steel," Transaction - ASM, Vol. 55, page 526 (1962)

10. Anon., "Problems in the Load Carrying Applications of High-Strength Steels," DMIC Report 210, Batelle Memorial Institute, pp 180, dated October 1964

11. Anon., "18% Nickel Maraging Steels," Data Bulletin, The International Nickel Company, Inc., pp 6, dated November 1964

12. Aerojet Report ML-TDR-64-115, Evaluation of High Nickel Steel for Application in Large Booster Motor Fabrication, Air Force Materials Laboratory, Research and Technology Division, Air Force System Command, dated April 1964

TABLE 1

STRUCTURAL AND METALLURGICAL EVALUATION TEST PANELS

Panel No.	Location	Location Reference	Characteristic Description	Characteristic Location
1	Longitudinal weld W4CB; 7 in. (17.8 cm) through 37 in. (94.0 cm) aft of WG-8 at 270°.	Log Book, Vol. I, Section E	Production automatic weld.	N/A
2	Girth weld WG-8, 6.5 in. (16.5 cm) through 36.5 in. (92.7 cm) from W3CB, 180 - 270° quadrant.	Report NAS3-6284 HTR-1	Weld burnthrough where turning rolls stopped.	Girth weld WG-8, 21.5 in. (54.6 cm) from W3CB.
3	Longitudinal weld W3CA, from WG-7 through 30 in. (76.2 cm) aft of WG-7 at 0°.	SDAR 0125	Four overlapping weld repairs. Panel includes 2 separate areas of 4 repairs each.	4 repairs - 6 in.(15.2 cm) from WG7 4 repairs - 11 in.(27.9 cm) from WG7 1 repair - 17 in.(43.2 cm) from WG7 3 repairs - 22 in.(55.9 cm) from WG7
4	Longidudinal weld W2CA, 68 in. (172.7 cm) through 98 in. (248.9 cm) aft of WG-9, at 0°.	SDAR 0106	Seven overlapping weld repairs. Panel includes 1 area of 7 repairs, 2 separate areas of 4 repairs each, and one area of 3 repairs.	4 repairs - 75 in.(190.5 cm) from WG9 4 repairs - 83 in.(210.8 cm) from WG9 7 repairs - 88 in.(223.5 cm) from WG9 3 repairs - 95 in.(241.3 cm) from WG9
5	Girth weld WG-8; 113 in. (287.0 cm) through 143 in. (287.0 cm) from weld W4CA, 0-90° quadrant.	SDAR 0116	Multiple scattered spherical porosity-max. cavity dia - 0.050 in. (1.27 mm); avg. cavity dia = 0.025 (0.64 mm) in.; min. cavity separation - 0.010 in. (0.25 mm)	Worst porosity located 128.5 in. (326.4 cm) from weld W4CA.
6	Longitudinal weld W2CB; 28 in. (71.1 cm) through 58 in. (147.3 cm) aft of WG-9; at 180°.	SDAR 0131	High density indication in HAZ along area of weld repair. MPI indication in same area of chamber I.D.	High density indication located 43.5 in. (110.5 cm) aft of WG-9.

TABLE 1

STRUCTURAL AND METALLURGICAL EVALUATION TEST PANELS

Panel No.	Location	Location Reference	Characteristic Description	Characteristic Location
7	Girth weld WG-8, 49 through 87 in. (221.0 cm) from 0° in the 0-270° quadrant.	Log Book, Vol. I, Section K	Shear wave ultrasonic indications varying from 60% to 100% amplitude.	60-100% amplitude, 60 to 72 in. (152.4-182.9 cm) 100% amplitude, 72 to 84 in. (182.9-213.4 cm) from 0°.
8	Girth weld WG-10, 23 (58.4 cm) through 61 in. (154.9 cm) from W5CA; 0-90° quadrant.	Log Book, Vol. I, Section K	Shear wave ultrasonic indications at 80% amplitude.	80% amplitude, 36 to 48 in. (91.4-121.9 cm) from 90° in WG-10.
9	Longitudinal weld W1CB, 37.5 to 67.5 in. (95.2-171.4 cm) aft of WG-6 , 270°.	Log Book, Vol. 1, Section E IRN 596	Ghost type MPI indication on I.D. and O.D. at area of weld repair. MPI records after hydrostatic proof test indicate no indications found in this area.	MPI indication located in area approximately 50 to 60 in. (127.0-152.4 cm) aft of WG6.
10	Plate 5C-B, 4.5 (11.4 cm) through 15 in. (38.1 cm) from WG-11 and 142.5 (362.0 cm) through 157.5 in. (400.0 cm) from W5CB, 0-270° quadrant.	SDAR 0179 and Report NAS3-7998-HTR-1	Thin spot in cylinder resulting from electric arc burn. Min. thickness reported in inspection records is 0.560 in. (14.22 mm). Min. thickness measured during SL-3 hydrotest instrumentation is 0.552 in. (14.02 mm).	Cylinder plate 5C-B, 7.5 in. (19.05 cm) from WG-11 and 150 in. (381.0 cm) from W5CB.
11	Plate 2CA, 3.0 in. (7.6 cm) fwd of WG-9 through 42 in. (106.7 cm) aft of WG-9 and 87 (226.0 cm) through 117 in. (297.2 cm) from W2CA, 0-90° quadrant.	Report NASA CR-72284	Parent plate hot spot resulting from SL-3 post-firing heat soak. R_c hardness readings in heat affected area vary from 51.5 at the edge to 33.0 at the center.	Heat affected area is located 16 in. (40.6 cm) aft of WG-9 and 102 in. (259.1 cm) from W2CA in 0-90° quadrant.
12	Plate 1C-A, 12 in. (30.5 cm) through 82 in. (208.3 cm) aft of WG-6 and 19 in. (48.3 cm) through 49 in. (124.5 cm) from W1CA, 90-180° quadrant.	Report NASA CR-72284	Parent plate hot spot resulting from SL-3 post-firing heat soak. R_c hardness readings in heat affected area vary from 39.5 to 50.5.	Heat affected area is located 13 in. (33.0 cm) aft of WG-6 and 34 in. (86.4 cm) from W1CA.

TABLE 2

WELD SEAM W4CB CHARACTERISTICS

WELD PROCESS - GAS TUNGSTEN ARC (TIG)

Filler Wire	-	.062-in (1.57 mm)-dia
Electrode	-	2% thoria tungsten; 0.156-in. (0.39 cm)-dia
Torch Gas	-	argon; 30 ft^3/hr (0.84 m^3/hr) flow
Back-Up Gas	-	argon; 30 ft^3/hr (0.84 m^3/hr) flow
Total Weld Passes	-	12
Root Pass	-	330 AMPS; 10.5 volts; 5 in/min (3.45 cm/min) travel; 60 in/min (41.4 cm/min) wire feed
Filler Passes	-	370-372 AMPS; 10.9-11.1 volts; 8 in/min (5.5 cm/min) travel; 60 in/min (41.4 cm/min) wire feed

WELD CHARACTERISTICS

Weld Seam Root Gap (Fit-Up) - 0.002 in (0.05 mm), 2 through 6-in (1.4 through 4.1 cm), aft of girth weld WG-8.

Weld Seam Mismatch (Fit-Up) - 0.008 in (0.2 mm), 2 through 6-in (1.4 through 4.1 cm), and 0.006 in (1.5 mm), 17 through 26-in (11.7 through 17.9 cm), aft of girth weld WG-8.

Weld Repairs - No repairs.

Magnetic Particle Inspection (ID & OD) - No indications.

Ultrasonic Inspection (Longitudinal & Shear Modes) - No indications.

Radiographic Inspection - scattered spherical porosity within specification limits.

Radiographic Inspection Scattered Porosity Acceptance Limits -
Diameter of cavity - T/5 (0.060 in (1.52 mm) max.).
Distance between cavities - 10D (0.15 in (0.4 cm) min.)
No. cavities per inch of weld - 2
Elongated cavity - unacceptable.

NASA CR 72676

TABLE 3

PLATE 4CB AND WELD WIRE 08950 CHARACTERIZATION AND HEAT TREAT AVERAGE DATA

Specimen	Characterization Data				Heat-Treat Data		
	F_{tu} psi(N/cm^2)	F_{ty} psi(N/cm^2)	G_{N_c} in.-lb/in.^{2} (J/cm^2)	W/A in.-lb/in.^{2} (J/cm^2)	F_{tu} psi(N/cm^2)	F_{ty} psi(N/cm^2)	G_{N_c}(1) in.-lb/in.^{2} (J/cm^2)
Plate 4CB	233,000 (160,650)	224,000 (154,450)	428 (7.49)	1210 (21.18)	245,000 (168,930)	233,000 (160,650)	239 (4.18)
Plate 4CB, HAZ	-	-	468 (8.19)	1656 (28.98)	-	-	-
Weld, Long.	218,000 (150,310)	210,000 (144,800)	-	-	-	0	-
Weld, Trans.	217,000 (149,620)	212,000 (146,170)	398 (6.96)	898 (15.72)	233,000 (160,650)	226,000 (155,830)	-

NOTES: (1) Calculated using Spring Constant Method, Proportional Limit Load (P_L)

Units: F_{tu} = Tensile ultimate strength
F_{ty} = 0.2% offset yield strength
G_{N_c} = Plane strain fracture toughness
W/A = Plane stress fracture toughness

TABLE 4

TEST PANEL NO. 1 AVERAGE MECHANICAL PROPERTY DATA

Location	Tensile Ultimate psi(N/cm^2)	Tensile yield-0.2% psi(N/cm^2)	W/A in.-lb/in.^{2} (J/cm^2)	G_{N_c} (Spring Constant) in.-lb/in.^{2} (J/cm^2) PL(1)	G_{I_c} (Bueckner) in.-lb/in.^{2}(J/cm^2) P_L(2)	P_M(3)
Plate 4CB	251,000 (173,060)	243,000 (167,550)	971 (16.99)	227 (3.97)	174 (3.04)	294 (5.14)
Plate 4CB, HAZ	-	-	972 (17.01)	-	253 (4.43)	356 (6.23)
Weld, Long.	224,000 (154,440	215,000 (148,240)	-	-	-	-
Weld, Trans.	225,000 (155,140)	221,000 (152,380)	1305 (22.84)	-	182 (3.18)	357 (6.25)

NOTES: (1) Calulated using Spring Constant Method, Proportional Limit Load.
(2) Calculated using Bueckner Analysis, Proportional Limit Load.
(3) Calculated using Bueckner Analysis, Maximum Load.

UNITS: W/A = Plane stress fracture toughness.
G_{N_c},G_{I_c} = Plane strain fracture toughness.

TABLE 5

HARDNESS MEASUREMENTS TRANSVERSE TO WELD W4CA IN PANEL NO. 1

(Knoop Hardness Converted to Rockwell C) (1)

Position		Hardness, R_c		
Inch	(mm)	0.060 inch (1.524 mm) from I.D. Surface	Plate Mid-Thickness	0.060 inch (1.524 mm) from O.D. Surface
0	0	P 44	P 45	P 44
0.040	1.016	45	44.5	45.5
0.080	2.032	47.5	44	45.5
0.120	3.048	44	44	48
0.160	4.064	47.5	45.5	47.5
0.200	5.080	47.5	46	47.5
0.240	6.096	45.5	46	48.5
0.280	7.112	46.5	46.5	45.5
0.320	8.128	47	45.5	48
0.360	9.144	48	44.5	48
0.400	10.160	49	46.5	50
0.440	11.176	48	44.5	50
0.480	12.192	46.5	W 45	44
0.520	13.208	47	43.5	49.5
0.560	14.224	47	44.5	44.5
0.600	15.240	47	44.5	46
0.640	16.256	W 46	43.5	W 47
0.680	17.272	45	44	47
0.720	18.288	45	42.5	46.5
0.760	19.304	45.5	43.5	46.5
0.800	20.320	46	43	46.5
0.840	21.336	44.5	43	44.5
0.880	22.352	45	43.5	46
0.920	23.368	44.5	44.5	46.5
0.960	24.384	45	45	47.5
1.000	25.400	46.5	44	45.5
1.040	26.416	46	44	44.5
1.080	27.432	46.5	P 47	44
1.120	28.448	45.5	46	P 45
1.160	29.464	P 48	46	46
1.200	30.480	48	46.5	46
1.240	31.496	44.5	46.5	46
1.280	32.512	47.5	46.5	46.5
1.320	33.528	45	46.5	46.5
1.360	34.544	45.5	46	47.5
1.400	35.560	44.5	46.5	46
1.440	36.576	45	46.5	46.5
1.480	37.592	46.5	46.5	47
1.520	38.608	46	46.5	46.5

TABLE 5 (cont)

HARDNESS MEASUREMENTS TRANSVERSE TO WELD W4CA IN PANEL NO. 1

(Knoop Hardness Converted to Rockwell C)[1]

Position		Hardness, R_c		
Inch	(mm)	0.060 inch (1.524 mm) from I.D. Surface	Plate Mid-Thickness	0.060 inch (1.524 mm) from O.D. Surface
1.560	39.624	46	46.5	46.5
1.600	40.640	47.5	46.5	45.5
1.640	41.656	47.5	47.5	45.5
1.680	42.672	45	47.5	47
1.720	43.688	45	47.5	48
1.760	44.704	44.5	46.5	48
1.800	45.720	48.5	46	47
1.840	46.736	48.5	47	47
1.880	47.752	48	45.5	45
1.920	48.768	48	44.5	45
1.960	49.784	47.5	45	46.5
2.000	50.800	45	45	48
2.040	51.816	45	46	47
2.080	52.832	48	46.5	46.5
2.120	53.848	47.5	46	48
].160	54.864	47.5	45.5	45.5
2.200	55.880	46.5	-	44.5
2.240	56.896	45	-	-
2.280	57.912	46	-	-

Note: (1) Knoop hardness obtained with 500 gm load.

TABLE 6

TEST PANELS NO. 2 THROUGH 5 AVERAGE MECHANICAL PROPERTY DATA

Location	Orient.	Tensile Ultimate psi(N/cm^2)	Tensile Yield - 0.2% psi(N/cm^2)	W/A, in.-lb/in.^{2} (J/cm^2)	G_{N_c} (Spring Constant) in.-lb/in.^{2} (J/cm^2) P_L(1)	G_{I_c} (Bueckner) in.-lb/in.^{2} (J/cm^2) P_L(2)	P_M(3)
Panel 2, Weld	Trans.	217,800 (150,170)	210,200 (144,930)	1350 (23.62)	253 (4.43)	239 (4.18)	453 (7.93)
3CB	Trans.	242,400 (167,130)	234,300 (161,550)	700 (12.25)	-	-	-
4CA	Trans.	241,400 (166,440)	233,300 (160,860)	720 (12.60)	-	-	-
Panel 3, Weld	Trans.	211,000 (148,480)	206,900 (142,660)	1300 (22.75)	122 (2.14)	125 (2.19)	312 (5.46)
3CA	Long.	239,000 (164,790)	229,500 (158,240)	890 (15.58)	-	-	-
Panel 4, Weld	Trans.	201,900 (139,210)	194,400 (134,040)	1180 (20.65)	189 (3.31)	137 (2.40)	412 (7.21)
2CB	Long.	247,500 (170,650)	236,400 (163,000)	1050 (18.38)	-	-	-
2CA	Long.	250,500 (172,720)	244,400 (168,510)	747 (13.07)	-	-	-
Panel 5, Weld	Trans.	221,100 (152,450)	213,800 (147,420)	1575 (27.56)	NV(4)	175 (3.06)	440 (7.70)
4CB	Trans.	248,500 (171,340)	239,400 (165,070)	945 (16.54)	-	-	-

NOTES:
(1) Calculated using Spring Constant Method, Proportional Limit Load.
(2) Calculated using Bueckner Analysis, Proportional Limit Load.
(3) Calculated using Bueckner Analysis, Maximum Load.
(4) Test invalid, Spring Constant beyond calibration curve range.

UNITS:
W/A = Plane stress fracture toughness.
G_{N_c}, G_{I_c} = Plane strain fracture toughness.

TABLE 7

KNOOP MICROHARDNESS MEASUREMENTS ON TRANSVERSE SECTION OF REPAIR WELDS IN PANELS 2, 3, 4, AND 5

Position	Panel 2 OD	Panel 2 MID	Panel 2 ID	Panel 3 OD	Panel 3 MID	Panel 3 ID	Panel 4 OD	Panel 4 MID	Panel 4 ID	Panel 5 OD	Panel 5 MID	Panel 5 ID
1										P 43.5		
2										45.0	P 45.0	
3										43.5	46.0	
4										45.0	46.5	
5										42.5	45.5	
6										44.0	45.5	
7										45.5	45.0	
8										44.0	45.5	
9										44.0	46.5	
10									P 47.5	44.0	45.5	P 44.0
11									47.5	45.0	45.5	43.0
12		P 48							47.5	44.0	46.5	44.5
13	P 47	45	P 45				P 47		47.5	42.5	47.5	44.5
14	47.5	48	45				48		48.5	HAZ 41.0	46.5	44.0
15	46.5	46	45			P 45.5	48	P 50	48.5	42.0	46.5	44.5
16	46.5	43	45.5	P 46.0	P 46.5	46.0	HAZ 47.5	49	47	43.0	46.0	45.5
17	46	45	46.5	46.5	46.0	46.0	46.5	47	45.5	44.0	46.0	45.5
18	47	46	45.5	46.5	46.0	46.0	44	47.5	HAZ 45.5	44.0	46.0	44.5
19	HAZ 47.5	45.5	45.5	46.5	46.5	46.0	44	HAZ 48	44	W 44.0	HAZ 42.5	44.5
20	46	45.5	45	46.5	46.0	45.5	48	48	43	44.0	42.0	45.5
21	47.5	45	46	46.0	45.5	45.5	46	47	43	44.0	43.0	45.5
22	47	45	47	46.0	45,5	45.5	W 46	44.5	42	43.5	42.5	44.5
23	47	45.5	HAZ 47	47.5	46.5	45.5	44.5	46	40	43.0	42.5	HAZ 44.0
24	47	45.5	47	45.0	47.0	45.5	47	W 43	38.5	42.5	W 45.0	44.0
25	47	45	47	45.0	47.0	46.5	47	43	41	44.0	46.0	44.0
26	47.5	45.5	47	45.5	46.0	46.5	47	40	47	44.5	46.0	42.0
27	W 47	HAZ 44.5	46	46.0	46.5	46.5	47	46.5	49	44.0	45.0	W 47.5
28	48	45	46	HAZ 46.5	46.5	HAZ 44.5	47	47	49	43.0	45.0	46.5
29	48	45.5	46	46.5	HAZ 46.0	45.0	46	45	W 49	43.5	45.0	46.5
30	44	45	46	46.5	46.0	44.5	46	44.5	49	43.0	45.5	45.0
31	44	45	W 46	W 46.0	46.0	44.5	44.5	43	48	43.0	42.5	45.0
32	42	W 45	46	45.5	46.0	44.5	43	43	48	44.0	43.0	45.0
33	43	44	45	45.0	46.0	W 44.5	43	43	47.5	42.5	41.0	44.5
34	43	44	46.5	45.0	46.0	44.5	44	43	47.5	42.0	41.5	43.5

TABLE 7

KNOOP MICROHARDNESS MEASUREMENTS ON TRANSVERSE SECTION OF REPAIR WELDS IN PANELS 2, 3, 4, AND 5

Position	Panel 2 OD	Panel 2 MID	Panel 2 ID	Panel 3 OD	Panel 3 MID	Panel 3 ID	Panel 4 OD	Panel 4 MID	Panel 4 ID	Panel 5 OD	Panel 5 MID	Panel 5 ID
35	41	40	46	44.5	W 46.0	44.5	44	43	47.5	42.5	42.5	43.5
36	38	38	46.5	45.5	44.0	44.5	46	43	47.5	43.5	42.5	43.5
37	37.5	43	46	44.0	44.0	44.0	44.5	47	47	43.5	42.0	44.0
38	39	43	45	CL 44.5	44.0	44.5	44.5	44	47	CL 43.5	42.0	CL 44.0
39	CL 39	CL 43	CL 47	44.5	42.5	CL 44.5	CL 44.5	CL 43	CL 48	42.5	45.0	44.0
40	39	43	45.5	45.0	CL 41.5	45.5	44.5	42	49	42.5	CL 43.0	45.0
41	41	43	45.5	45.0	41.0	45.5	44	42	49	42.5	42.5	45.5
42	40	43	44.5	45.0	41.5	45.5	46	40	47.5	42.5	42.5	44.5
43	44	43	44.5	45.0	42.5	46.5	47	40	50	43.0	43.0	44.5
44	44	43	45	45.0	43.5	46.5	45.5	40	50	43.5	43.5	44.5
45	44.5	43	45	45.0	42.5	46.5	44	42	41	44.5	43.5	45.5
46	46	43	45	45.0	HAZ 45.0	HAZ 42.5	45	42	41	44.5	44.0	45.5
47	46	41	45	HAZ 45.5	45.0	42.5	45.5	42	43	42.5	44.0	45.0
48	48	HAZ 42	HAZ 45	45.0	42.5	42.5	45.5	38.5	41	41.5	43.5	44.5
49	47.5	38	46	45.5	45.0	P 44.0	45.5	40	41	43.0	43.5	45.0
50	46	38	47.5	P 46.0	P 45.0	44.0	45.5	40	HAZ 43	44.0	43.5	44.0
51	46	39	46.5	46.5	46.0	44.5	45.5	41	44.5	44.5	44.0	HAZ 42.5
52	HAZ 47	42	46.5	46.5	46.0	47.0	45.5	43	44	45.0	44.5	42.5
53	45.5	P 44	47	46.5	44.5	47.0	46	43	44	43.5	44.0	40.0
54	46.5	44.5	P 47	46.5	46.0	47.0	46	HAZ 43	P 47.5	44.0	HAZ 43.5	32.5
55	47	45.5	47	44.5	46.0	46.0	46.5	44	47.5	44.5	41.5	38.0
56	47	47	45.5	46.5	45.5	46.5	HAZ 47	41	47.5	43.5	43.5	40.0
57	47	45.5	47	46.5	46.0	46.5	48	39	47.5	44.0	43.5	41.5
58	46.5	46	45	46.5	46.0	46.5	48	P 40	47.5	45.0	P 43.0	P 43.5
59	P 46.5	45	45	47.0	46.0	46.5	48	44	48	HAZ 46.0	45.5	42.5
60	46.5	45	45	47.0	46.5	46.5	46	45	48	47.5	45.5	43.5
61	47	45	46	46.5	46.5	47.0		46		46.5	45.5	46.0
62	46.5	45	44	46.5	46.5	47.0		47		P 45.0	45.5	44.5
63	47	45	45			46.5		47		46.5	46.0	47.5
64	47	45	45					50		45.5	46.0	45.0
65		46.5	45.5							45.5	46.5	45.5
66		46								45.5	46.5	46.0
67		46								45.5	46.5	46.0
68		46								47.0	46.5	46.0
69		46									46.5	45.5
70											46.5	46.0
71												45.5
72												45.5
73												46.0
74												

NOTES: 1. Distance between adjacent position equals 0.040 in.
2. Knoop (500 gm load) hardness converted to Rockwell C.
3. P - Parent Metal, HAZ - Heat Affected Zone, W - Weld
CL - Weld Centerline (approximate)

TABLE 8

EFFECT OF RADIOGRAPHICALLY DETECTED "FLAW" ON MECHANICAL PROPERTIES OF PLATE, PANEL NO. 6

Material: 18 Ni Marage Steel, Grade 200, 0.6 (1.524 cm) Plate

Test: +75°F

1. Tensile Properties

				Heat Treat Coupons				Specimens from SL-3			
Panel No.	Plate No.	Heat	Test Region	F_{tu}, psi (kN/cm^2)	F_{ty}, psi (kN/cm^2)	Elong. % in 1 in.	Red. in. Area %	F_{tu}, psi (kN/cm^2)	F_{ty}, psi (kN/cm^2)	Elong. % in 1 in.	Red. in. Area %
6	2CA	24999	Flaw in HAZ					222* (153) 216**(149)	220*(152) -	7.5* 7.5**	50* 44**
4	2CA	24000	Sound Parent	249(171)	243(168)	11	52	251 (173)	244 (168)	13.5	55
6	2CB	3960829	Sound Parent	235(162)	224(154)	11	60	243 (168)	235 (162)	11	57
4	2CB	3960829	Sound Parent	235(162)	224(154)	11	60	247 (170)	236 (163)	12	56

NOTES: *Broke in flaw in HAZ.
**Broke in weld ~ 0.5 inch from flaw.

2. Toughness Properties

				W/A in.-lb in.^{2}		Fracture Touchness, in.-lb/in.^{2} (J/cm^2)			
Panel No.	Plate No.	Heat	Test Region	Character Data	SL-3 Data	Character Data G_{N_c}	Heat Treat G_{N_c}	G_{N_c}	G_{I_c}
6	2CA	24999	Flaw in HAZ	-	827(14.5)	-	-	212 (3.7) 335* (5.9)	201 (3.5)
4	2CA	24999	Sound	723(12.7)	747(13.0)	277(4.9)	232(4.1)	-	-
11	2CA	24999	Parent	723(12.7)	-	277(4.9)	232(4.1)	259**(4.5)	235**(4.1)

NOTES: *Normal HAZ value estimated as 130% of sound parent value (based on Panel No. 1 test results).
**Longitudinal values calculated as 117% of transverse test value.

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TABLE 9

KNOOP MICROHARDNESS MEASUREMENTS TRANSVERSE TO WELD IN PANEL NO. 7[1]

Plane Section	1			2			3			4			5			6		
	OD	Mid	ID	OD	Mid	ID	OD	Mid	ID	OD	Mid	ID	OD	Mid	ID	OD	Mid	ID
Panel	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c
7	48	48.5	47	48	48	47	48	48	47	47	47	46	48	48	51	46	47	48
	48	48.5	50	49	48	46	46	47	48	48	48.5	46	48	48.5	50	46	48	48
	48	49	48	48.5	47	48	46	46	47	47	48	45	48	48.5	49	47	46	47
	49	48	48	48	47	46	46.5	47	48.5	48.5	47.5	46	47.5	49	51	46	47.5	47.5
	44.5	48	45.5	48	46.5	44.5	46	47	49	48	46	47	47.5	48.5	50.5	47.5	48.5	48
	48	48.5	46	49	47	45	46	47	48	49	47	47	47.5	50.5	49	48	48	48
	49	48	48	47	46	45	46	47.5	47.5	49	47.5	45.5	47	48.5	48	48	48.5	49
	48	46	44	48.5	47	44	45	46	45	48.5	47	45.5	48	50	49.5	47	47	47
	49	47	46	48	46.5	48	46	47	46	50	47	46	48.5	48	48	49	47	48
	46	46	45	49	45	46.5	46.5	49.5	46	48	47	48	47	49	48	50.5	47	48
	48	48	44	48.5	47	46	48	48	47	48	47	45.5	46.5	48.5	46.5	49	46.5	46
	45.5	46.5	45	49.5	45	44	47	47	46.5	47	47	49	48	47	48	47	46	48.5
	48.5	45	45	46.5	46	44.5	46.5	46	47	46.5	47.5	50	49	45.5	50	47	47	48.5
	49	45	45.5	48.5	45.5	44	45.5	46	45.5	48	45.5	50	48.5	47	50	48	46	49
	48	44.5	42	48	44.5	44	45	42.5	43.5	48	45	49	45.5	46	47.5	48	46	48
	46.5	44	42	50.5	46	46.5	46	43.5	45	49	44	48	46	48.5	47.5	47	46	48
	47	38.5	45	47	46.5	47	46	41.5	46	48	45.5	47	48	47	48.5	46	44.5	47
	46	36.5	43.5	46	44	48	47	43	46	48	43	49	44	45	48.5	46	42	48.5
	47.5	40	42.5	46	44.5	45.5	46	43	46	48	43	47.5	47	43.5	48	48	42.5	46.5
	46.5	40	44.5	49	44	45.5	47	43.5	44	46	43	47.5	45	42.5	48	47	42.5	48.5
	47	41	43	48.5	42.5	45.5	46.5	42.5	42.5	48.5	43.5	47.5	46.5	42	47	49	41	48
	48	42.5	42.5	47	42	46	46	41	47.5	47	43.5	46	45	42.5	49.5	45	42	48
	48	42	42	47	42	48	46	41	48	47	44	48	48	43	46.5	46.5	44	46
	47.5	42	44	47	44.5	49	48	41.5	49	48.5	45	48.5	47	44.5	48.5	46	41	48
	48	41.5	46.5	47	45	48.5	48	44.5	46	48.5	44.5	50.5	46.5	44	48.5	46.5	42.5	48
	47.5	42	44.5	49	45.5	48.5	46.5	42.5	44.5	48.5	46.5	48	46	44	48	44	44	49.5

TABLE 9

KNOOP MICROHARDNESS MEASUREMENTS TRANSVERSE TO WELD IN PANEL NO. 7[1]

Plane Section	1			2			3			4			5			6		
	OD	Mid	ID	OD	Mid	ID	OD	Mid	ID	OD	Mid	ID	OD	Mid	ID	OD	Mid	ID
Panel	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c
7	50	42	44.5	47.5	45	50	47	44	46	49	44.5	47	48.5	43.5	48	46	46	48
	47.5	42.5	44	47.5	44	51	45.5	44	46	47.5	45.5	48	46.5	46.5	47	49	47.5	48
	49	42	46	46	44.5	50.5	45	45.5	46	48.5	45.5	47.5	46	48	46	46.5	45.5	49.5
	48	44	44.5	47.5	49	50.5	45	44	46.5	50	46	47.5	44.5	46.5	48	47.5	46	49.5
	48	44.5	46.5	47	50	48	47	45	47	49	46	47	46	45	48	48	46.5	46.5
	47	44	46	48	48	48	48	43	47	49	46	47.5	45	45.5	48.5	47	48	48.5
	46	45.5	48	48.5	49.5	49.5	45	47	47.5	49	47	47	46.5	48	48	50.5	47	48
	48.5	47	45	48.5	48.5	49.5	46	46	48	48	47.5	47	46	48	48	46	47	50
	48	46	47	49	48	48.5	45.5	47.5	48	49	47	47.5	46	47.5	48.5	45.5	49	48
	47	46	48	48	48.5	48.5	47.5	48	48	48	48	47.5	44.5	47	48.5	46	48	49
	46.5	46	46	48.5	48	48.5	48.5	49	49	48	47	48	45	47.5		47	48.5	48.5
	47.5	46.5	45	48	48	49.5	46	48	48	48	47.5	47	45	48.5		45	48.5	48.5
	48.5	45.5	48.5	48	49.5	49	46.5	48.5	49	48	48	48	44.5	48		46	48.5	48.5
	49	46	50	48	48	49.5	47	48		47	46	46	46	48		46	48	48.5
	48	48	47	47	48	49	46	48.5		48.5	47.5	47	46	48.5		46	49	49.5
	47	48	46.5	48	49	49	47	48		48.5	46.5	48	46	48		46	49.5	49.5
	48	49	47	46.5	50	49	46	48.5		47.5	47.5	46.5	48	48.5		46	50	49
	48.5	47.5	45.5	46	49.5	48.5	45	48		48	48	47.5	46	48.5		44	48	48.5
	47	47	46	46.5	49	49	47	48.5		48	48	48	45.5			44.5	48.5	49
	46.5	47			49	49.5	47.5			47.5	46.5	47	46			44	48	49
					49		46			48	47		45					
							46											

Note: (1) Knoop hardness obtained with 500 gm load.

TABLE 10

KNOOP MICROHARDNESS MEASUREMENTS TRANSVERSE TO WELD IN PANEL NO. 8[(1)]

Plane Section	1			2			3			4			5			6		
	OD	Mid	ID	OD	Mid	ID	OD	Mid	ID	OD	Mid	ID	OD	Mid	ID	OD	Mid	ID
Panel	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c
8	49.5	50.5	50.5	48	48.5	48.5	49.5	49	50	47	47	50	47.5	50	50.5	47.5	49	49
	49	50.5	51	49.5	49	48.5	47	50	50.5	48.5	47	49	48	49	50	48	48.5	47.5
	48	50.5	50.5	49	49	48	48.5	50.5	51	48.5	47	50	46	49	50	47.5	44	49
	48.5	50.5	51	50	50	49	48.5	49	52	48	47	50	47.5	49	50.5	48	42	48
	47.5	50	50.5	49.5	48.5	49	47	49	50.5	48	48	50	47	48	49	47.5	40.5	48.5
	49	50	50	49	49	49	46	48.5	50.5	48.5	47	49	46	48.5	48.5	48	40	49
	49.5	50	50	48	48	49	48	49	50	48	46.5	50	46	49	50.5	47	41	50
	49	50	50	48.5	49	49	48	50	49	50.5	48.5	50	47.5	49	50	47.5	42.5	50
	50	49	50	48	48.5	48	47	49	49	50	48	50	47.5	48	50	46	45	49
	48	48	48	47.5	49	50	47	47	50.5	49.5	47	49	48	48.5	48.5	48	46	48.5
	50	47	48	47	49	48.5	48	46	48	50	48	49	48	48	48	48.5	48	47.5
	48	46.5	47	48.5	49	48	46.5	40	48	51	48	48.5	46	48	49	46	47	42.5
	46	48.5	45.5	49	47	48	45	45	49	48.5	48	48.5	49	45	49.5	45.5	44	45.5
	47	47	49	46	41	48	43	46	48	48	43	50	48.5	45.5	47	45	46	43
	49	46	46	47.5	44	48	47	45.5	48	47.5	43	50	45.5	48	49	49.5	45	44
	48	45	49	48	46	48	47	45	47	48	46.5	48	46	44	47	47	45	40
	48	44.5	48.5	46	48	48.5	45.5	43.5	46	49	44	50	48	45.5	49.5	50.5	42	44.5
	48	47	48	48	46	51	45.5	40	46	46.5	40	48.5	46	45	48.5	45	44.5	44.5
	47.5	47	47	46.5	45	49.5	46.5	42	45	47.5	42	48	45	42.5	47	48.5	42	46
	47	47	46	46.5	44.5	50.5	47	44.5	45	48	46	48	45	44.5	47	42.5	43	44
	50	48.5	46	48	44.5	50	45.5	46	44	48	47.5	46	45.5	43	47	47	45	44
	50	48	45.5	48	42	48.5	47	45.5	44.5	49	47	46	47.5	42.5	47.5	45.5	43	45.5
	48	47	47	47	43	48.5	47	44.5	46.5	46.5	44.5	48	47	44	48	45	43	44.5
	46	48	46	46	43.5	48.5	45	44.5	48.5	48	46	48	47	44	46.5	46.5	44.5	49
	45	47	48	48.5	46	48	47	47	49	47.5	47	48	47.5	44.5	49	45.5	46	41

TABLE 10

KNOOP MICROHARDNESS MEASUREMENTS TRANSVERSE TO WELD IN PANEL NO. 8[1]

Plane Section	1			2			3			4			5			6		
	OD	Mid	ID	OD	Mid	ID	OD	Mid	ID	OD	Mid	ID	OD	Mid	ID	OD	Mid	ID
Panel	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c
8	46	43	45	48	47	49	46	46.5	47	48.5	48	50.5	46	46	49.5	45.5	42	41
	47	48	45.5	48.5	43	50.5	46.5	45.5	47	47.5	48	50	46	46	46.5	44.5	42.	46
	49	48	46	47	44.5	48.5	47	45.5	49	48.5	43	49	46.5	48	48	46.5	45	42.5
	49	50.5	47.5	48.5	44.5	48.5	48.5	46	47.5	48	46.5	48.5	47	47	48	49	42	47
	49	50.5	48	49	47	49	48	48	47	48.5	45	48	47	45	48	47	46	44
	48.5	51	44.5	50	47	50	47.5	48.5	49	48	45.5	48	45.5	43.5	45	47.5	46.5	42
	48	51.5	47	48	48	49	47	48.5	51	50	49	48	48	47.5	48.5	47	46.5	46.5
	47	51	48	50.5	48.5	46	48	50	50	49	48.5	49	48.5	48	49.5	46	46.5	47
	48	51	48.5	48.5	48	48.5	47	49	50.5	48	49	49	47	47.5	51	46.5	49	47
	48.5	50.5	50	48	48	50.5	48	49	50.5	44.5	50	49	47.5	48.5	49.5	45.5	48.5	48.5
	48	50	48	49.5	49	49	48	50	51	48.5	50	48.5	48	50	50.5	49	47	49
	48	50	51.5	47	48.5	48.5	48	50	50.5	48	50	48	48	49	51	46.5	47	49.5
	49	50	50.5	47.5	48.5	48	48.5	51	49.5	49	49	48	48	49	50.5	47	48	48
	48.5	50	50	46	48	48.5		50	50	48.5	50.5	49.5	46	49.5	50.5	46	50	47.5
	49	50.5	49.5	47	49	49.5		49	50	49	50	49	46.5	50.5	51	45.5	49	48
	49	50.5	49	47	50	49		48.5	49.5	48	49.5	49.5	47	48	51.5	48.5	50.5	47.5
	48.5	50.5	50	48	48.5	48.5			50.5	49.5	49.5	48.5	47	51	51	46	46	50
	48		49.5	47	48	48.5			49.5	48.5	50	49	48.5	49	51	46.5	48.5	49.5
			49.5	45	48	48.5				48	48	50	48.5	48.5	53	46	48.5	48.5
				46.5	48	49				47	48	48.5	47	49	50.5	46	48.5	
				48	47.5	49				47		47	48	49.5	50.5	46.5	48	
				46.5		49				47		47.5	47	48.5	51.5	46		

Note: (1) Knoop hardness obtained with 500 gm load.

TABLE 11

KNOOP MICROHARDNESS MEASUREMENTS TRANSVERSE TO WELD IN PANEL NO. 9[1]

Plane Section	1			2			3			4			5			6		
Panel	OD R_c	Mid R_c	ID R_c	OD R_c	Mid R_c	ID R_c	OD R_c	Mid R_c	ID R_c	OD R_c	Mid R_c	ID R_c	OD R_c	Mid R_c	ID R_c	OD R_c	Mid R_c	ID R_c
9	50.5	53	53	48.5	48.5	47	50.5	52	49	48.5	*49	*50.5	50.5	51	50	50.5	51	49
	51.5	52.5	51.5	49	48	48	50	51	48	50	50	50	52	51	51	48.5	50	49.5
	51.5	52	51	47.5	47.5	46.5	50	50.5	49	51	49.5	50	52	51	50.5	50.5	50	49
	51	52	52	48	47	48	49.5	50.5	48.5	51	49.5	48.5	52.5	50.5	51	49.5	50.5	48.5
	49	52	51.5	49	48	47.5	49.5	52	48.5	50	48.5	48.5	50	52	49.5	50.5	49	49.5
	50	51	52	49.5	48	47	48.5	52	48.5	50.5	50	50	52.5	51	50	50.5	50	49.5
	52	52	51.5	49.5	48	48.5	49	51	48	50	50	49	52	50.5	50	50	49.5	48.5
	49	52	52	50	48.5	48.5	49.5	51.5	46	50.5	51	48.5	50.5	52	49.5	50	50	48.5
	48.5	52	51	48	49.5	48	47	51	48	50	50.5	50.5	52	51	50	48	49.5	50
	51	51	51	48.5	48.5	48	48.5	49	47	45	50.5	48	52	50.5	50	49	48.5	48.5
	49.5	50	51	48.5	49.5	48	46	49.5	48	41	49	40.5	50	50	49.5	48	48	48
	47	49	50.5	48	51	48.5	46	49	47	44.5	49	41	48.5	50.5	49	48.5	48	48
	48	49	48	47	51	48.5	48	48.5	48.5	43	49.5	38	48	51	49.5	47	46	48
	48	49	50	47.5	50.5	48.5	48	48	48.5	44	48	41	47	52	50	47	46.5	45.5
	48.5	50	48	48	50.5	48	45	47	45.5	46	46	41	50.5	47	46	47	46.5	48
	46.5	48.5	50.5	49	49	47	49.5	46	44.5	47	48	38	49	46	44	44.5	47	48
	49.5	48	52	48	45	49	47	47.5	44.5	48	48	41	48	48	48.5	44	45	48.5
	48.5	48	50.5	48.5	45	48	48	46	44.5	46	45	37	48	45	45.5	45	46	48
	48.5	48	48.5	48.5	43	49	47	47	44	46.5	44	38.5	45	43	48	46	45	48
	48.5	46	47.5	48	43	49.5	48.5	46	44	48.5	42.5	39	44	43	47.5	46	45.5	48
	48	47	48.5	49	40	46.5	48	43	44	49	42	36.5	43.5	44	47	44.5	44.5	48
	47.5	47	48	48	42	48	49	46	46	48	39.5	38.5	46	45.5	48.5	43.5	46.5	47.5
	47.5	48	48	48	41.5	47	48	47	45	46.5	41	36	45.5	46	48.5	44	46	48
	50	45	45.5	47	42	47	48.5	47	47	48.5	43	38.5	44.5	44	47	46	48	45.5
	48.5	47	48.5	44	41	46.5	50	47.5	44	46	44.5	36.5	46	43	47.5	44.5	46	37.5
	48.5	46	48.5	47	40	48	48	48	45	45	42.5	41	47	43.5	48	44.5	47	37

TABLE 11

KNOOP MICROHARDNESS MEASUREMENTS TRANSVERSE TO WELD IN PANEL NO. 9 (1)

Plane Section	1			2			3			4			5			6		
	OD	Mid	ID	OD	Mid	ID	OD	Mid	ID	OD	Mid	ID	OD	Mid	ID	OD	Mid	ID
Panel	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c	R_c
9	50	59	49	46	40	46.5	48	49	44.5	48	44.5	38	45.5	44.5	48	46	46.5	37
	48	48.5	51	47	41	48	47.5	47.5	44	46	45.5	39.5	50	44.5	48.5	46	44	37
	48	48	50	47.5	52	48	48	46.5	45	46	43.5	36	49	44.5	47	45	41	39
	48	42	52	47	44.5	48.5	50	50	45.5	47	38	38.5	46.5	44.5	46	47	44.5	42
	50.5	50.5	50.5	48	44.5	49	48.5	51	46	47	48	38	49.5	48.5	48	48	45	48
	50.5	49	50.5	49	48	46.5	48.5	50.5	48	49.5	49	39	48.5	43.5	47	50.5	49	48
	50	50.5	52	49	48	49	46.5	50.5	48	48	46	37	52	42	50	50	50	49
	49.5	50	51.5	49	48	49	48	51	46.5	48	47	40	52	48.5	45	48	50	49
	50	50.5	52	51	48.5	48.5	49.5	50.5	46	48	47.5	42	49.5	50.5	48.5	49	49.5	49.5
	50	49	52.5	49.5	49	50.5	49	51.5	46	46	48	42	49.5	51	48.5	49	48.5	49
	50.5	50.5	52	49.5	48.5	51	49	52	46	47	48	48	51	51	47.5	49	50.5	48.5
	50.5	51.5	52	50	49.5	50	49	52	48	48.5	45.5	39	50	50.5	48.5	49	52	48.5
	49.5	52	51.5	49.5	49	49	48	52.5	49	49	48	42	52	52	48.5	49	48.5	49
	50	53	52	48.5	48.5	47.5	50	51.5		47	46	49	52.5	50.5	49	50.5	50.5	49
	52	53	51.5	48.5	49	49	48.5	51		47	48	50.5	52	52	52	50	50.5	49
	51	52.5	52	50	49	48.5	49.5	50.5		48.5	48.5	50.5	50	51.5	52	49	49	49
	50	51	51.5	50	49	49	49.5	51		47	48.5	51	51.5	51.5	50	50	50.5	48
	49.5	52.5	50	48.5	49	49	50.5			48	48.5	51	51	51	50.5	50	50	47.5
	51	53	51	50	48	48.5				48	48.5	49	51	51.5	52	49.5	48	44.5
	49.5	52.5	51	50	47	48.5					49	51	52	50	51	49.5	48	47.5
		52	51.5	48.5	44.5	48					48	51	51	49	51			48
			51.5	48	45.5	48.5							48.5	51				
														50				

Note: (1) Knoop hardness obtained with 500 gm load.

TABLE 12

TEST PANEL NO. 7, 8, AND 9 TENSILE TEST DATA

Panel No.	Spec. No.	Plate or Weld No.	Specimen Location	Specimen Orient.	Tensile Strength k lb/in.^{2} (kN/cm^2) F_{tu}	Tensile Strength k lb/in.^{2} (kN/cm^2) F_{ty}	Elong. in 1-in. %	Reduc. in Area %
7	1	WG8	Weld	Trans.	225.1 (155.2)	222.0 (153.1)	11.1	54.8
	2	WG8	Weld	Trans.	224.0 (154.5)	220.0 (151.7)	8.6	50.5
	3	WG8	Weld	Trans.	226.3 (156.0)	221.2 (152.5)	11.1	57.4
	4	WG8	Weld	Trans.	225.5 (155.5)	221.4 (152.7)	11.0	51.7
	5	WG8	Weld	Trans.	227.3 (156.7)	224.2 (154.6)	9.6	54.1
	6	3CB	Parent	Trans.	241.4 (166.4)	231.3 (159.5)	9.6	48.1
8	1	WG10	Weld	Trans.	227.3 (156.7)	224.7 (154.9)	11.0	54.1
	2	WG10	Weld	Trans.	227.2 (156.6)	225.3 (155.3)	9.0	48.1
	3	5CB	Parent	Trans.	247.5 (170.6)	239.8 (165.3)	11.0	47.0
9	1	W1CB	Weld	Trans.	217.6 (150.0)	215.2 (148.4)	9.5	53.1
	2	W1CB	Weld	Trans.	227.1 (156.6)	225.1 (155.2)	11.1	50.5
	3	1CB	Parent	Long.	255.7 (176.3)	245.4 (169.2)	11.0	51.1

TABLE 13

TEST PANELS NO. 7, 8, AND 9 PRECRACKED CHARPY IMPACT TEST RESULTS

Panel No.	Plate or Weld No.	Specimen Location	Specimen Orient.	W/A[(1)] in.-lb/in.^{2} (J/cm^2)		Average W/A, in.-lb/in.^{2} (J/cm^2) SL-3 Case	Average W/A, in.-lb/in.^{2} (J/cm^2) Charac. Data
7	3CB	Parent	Trans.	686 (12.00)		686 (12.00)	715 (12.51)
7	WG8	Weld	Trans.	1385 (24.24)	1310 (22.92)	1325 (23.19)	-
				1262 (22.08)	1360 (23.08)		
				1308 (22.89)			
8	5CB	Parent	Trans.	509 (8.91)		509 (8.91)	615 (10.76)
8	WG10	Weld	Trans.	1003 (17.55)	980 (17.15)	991 (17.34)	-
9	1CB	Parent	Long.	654 (11.44		654 (11.44)	739 (12.93)
9	W1CB	Weld	Trans.	828 (14.49)	1679 (29.38)	1253 (21.93)	1074 (18.80)

NOTE: (1) Test: Standard V-notch fatigue Precracked Charpy Impact; +75°F.

TABLE 14

FRACTURE TOUGHNESS OF PANELS NO. 7 THROUGH 9

Plate No.	Weld or Plate No.(4)	Specimen Location	Specimen Orient.	Characterization Data G_{Nc}(1)†	H.T. Coupons G_{Nc}(1)†	Specimens from 260-SL-3 G_{Nc}(1)†	Specimens from 260-SL-3 G_{Ic}(2)†	Specimens from 260-SL-3 G_{Ic}(3)†
7	3CB	Parent	Trans.	279 (4.88)	275* (4.81)	NV	134 (2.34)	-
7	WG8	Weld	Trans.	356 (6.23)	435 (7.61)	NV	171 (2.99)	281 (4.92)
8	5CB	Parent	Trans.	258 (4.52)	-	NV	103 (1.80)	-
8	WG10	Weld	Trans.	356 (6.23)	435 (7.61)	NV	176 (3.08)	306 (5.36)
9	1CB	Parent	Long.	220 (3.85)	198 (3.46)	NV	82 (1.44)	- -
9	W1CB	Weld	Trans.	218 (3.82)	435 (7.61)	NV	112 (1.96)	251 (4.39)

NOTES: * Calculated as 85% longitudinal values.
NV Test invalid, spring constant beyond calibration curve range.

(1) G_{N_c} calculated using Spring Constant Method, Proportional Limit Load.

(2) G_{I_c} calculated using Bueckner Method, Proportional Limit Load.

(3) G_{I_c} calculated using Bueckner Method, Maximum Load.

(4) Weld data average of minimum of two specimens.

† G_{Nc}, G_{Ic}–in.-lb/in.^{2} (J/cm^2)

TABLE 15

RESULTS OF MICROHARDNESS MEASUREMENTS ON A SECTION THROUGH THE THICKNESS OF PANEL NO. 10

(Knoop hardness converted to Rockwell C)[1]

Distance from O.D. Surface, in. inch	(mm)	Hardness R_c
0.004	0.102	48.5
0.008	0.203	49
0.012	0.305	50
0.016	0.406	50
0.020	0.508	49
0.024	0.610	49
0.028	0.711	48.5
0.032	0.813	49
0.036	0.914	49
0.040	1.016	49
0.044	1.118	49
0.048	1.219	48.5
0.052	1.321	49
0.056	1.422	48.5
0.060	1.524	48.5
0.080	2.032	49
0.100	2.540	49
0.120	3.048	48.5
0.140	3.556	48.5
0.160	4.064	48.5
0.180	4.572	48
0.200	5.080	48
0.220	5.588	48
0.240	6.096	48
0.260	6.604	48
0.280	7.112	48
0.300	7.620	48.5
0.320	8.128	48
0.340	8.636	48
0.360	9.144	48
0.380	9.652	48
0.400	10.160	49
0.420	10.668	48
0.440	11.176	48
0.460	11.684	48
0.480	12.192	48
0.500	12.700	48
0.520	13.208	48
0.540	13.716	48
0.560	14.224	48
0.580	14.732	48

Note: (1) Knoop hardness obtained with 500 gm load.

TABLE 16

RESULTS OF MICROHARDNESS MEASUREMENTS ON SECTIONS THROUGH NORMAL AND HOT SPOT REGIONS OF PANEL NO. 11 AND 12

(Knoop hardness converted to Rockwell C, 0.040 inch (0.122 cm) between measurement

Panel No. 11						Panel No. 12					
Normal			Hot Spot			Normal			Hot Spot		
OD	Mid	ID	OD	Mid	ID	OD	Mid	ID	OD	Mid	ID
48	49	47	35	35	35	48	49	48	37.5	37.5	36.5
47	48	46	35	35	35	48	48.5	49	37.5	37.5	35
48	48	48	35	35	34.5	48	48	49	38	37.5	35
48	48	48	35	36	35	48	48	48.5	38.5	37.5	35
48	48	48.5	35	34.5	35	49	48	48	38.5	37.5	34.5
48	48	48	35	33	35	48	47	48	38	37.5	34.5
48	48	47	34.5	33	34.5	49	48	48	38.5	37.5	34.5
48	48	47	35	32	35	49	48.5	48	38.5	38	34.5
48	48	47	35	32	35	49	48.5	48	38	38	34
48	48	48	35	32	35	48.5	48	48	38.5	38	34.5
48	48	48	35	32	35	48.5	48	48	38.5	38	34
47	48	48	35.5	32	35	48.5	48	48	38.5	38	34
48	48	48	36	32	35	48.5	48	48	38.5	38	34
48	48	48	36	31	35	48.5	48	49	38.5	38	34
48	48	49	35.5	32	35	48	48	48	39	38	34
47	48.5	48	36	31	35	48	48	48	39	37.5	34
48	48	48	36.5	32	35	49	48	48	39	37.5	34
48	48.5	49	37.5	31	35	49	48	48	39	37.5	34
48	48	49	36.5	31	35	49	48	48	39	37.5	34
49	48	48.5	37.5	32	35	48.5	48	48	39.5	37	34
48.5	48	47	37.5	31	35	48.5	48	48.5	39.5	37	33.5
48.5	48	48	36.5	31	36	48	48	48	39.5	37.5	33.5
48	48	48	37	31	35	48	48	48	38.5	37.5	33.5
48	48	48	37	31	35	48	48	48	39.5	37	33.5
48.5	48	48	37.5	31	35	48	48.5	48	39.5	37	33.5
48	48	48	37	31	35	48	48.5	48	39.5	37	34
48	48		36.5	30.5	35				39.5	37.5	34
			36.5	31	35				39.5	37.5	34
			37	31	35				39.5	37.5	33.5
			38	33	35				39.5	37	34
			37.5	35	35				39	37	34.5
			38	35	35				39	37	34.5
			37.5	36	35				39	37	34.5
			38	36	35				39	37.5	34.5
			38	36.5	35				39	37.5	34.5
			38.5	35.5	35				39	37.5	35
			38.5	35	35				39	38	35.5
			39	36	35				39	37.5	36
			39	36	35				39	37.5	36
			38.5	37.5	35				39	37.5	37

Note: (1) Knoop hardness obtained with 500 gm load.

TABLE 17

TASK VII INCLUSION RATING

Specimen	TYPE A Sulfide Type		TYPE B Alumina Type Tin		TYPE C Silicate Type		TYPE D Globular Oxides	
	Thin	Heavy	Thin	Heavy	Thin	Heavy	Thin	Heavy
12U	<1		<1	<1	<1			<1
12A	<1		<1	<1	<1		<1	
11U	<1		<1	<1	<1			<1
11A	<1		<1	<1	<1			<1

NOTES:
- 11 = Test Panel No. 11
- 12 = Test Panel No. 12
- A = Heat-Affected Area (Hot Spot)
- U = Unaffected Area

TABLE 18

EFFECT OF SHORT TIME TEMPERATURE EXPOSURE ON MECHANICAL PROPERTIES OF 260 MOTOR CASE PLATE

Material: 18N, Marage Steel, Grade 200, 0.6 inch plate, S/N SL-3 motor case

Tests: 0.250 in.(0.635 cm)-dia. tensile rounds, +75°F (296k)
notched slow bend toughness, +75°F (296k)

Panel No.	Region	Tensile Strength - psi (kN/cm²) F_{tu}	F_{ty}	% Elong. in 1 in.	Reduction in Area, %	Average Hardness R_c	Toughness(1) G_{I_c} in.-lb/in.² (J/cm²)
11	Normal	257 (177)	252 (174)	10	46	48	228 (3.99)
11	Hot Spot	180 (124)	139 (96)	15	62	35	337 (5.90)
12	Normal	248 (171)	244 (168)	12	54	48	174 (3.04)
12	Hot Spot	181 (125)	137 (94)	17	67	37	367 (6.42)

NOTE: (1) Calculated using Bueckner Analysis and maximum load.

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TABLE 19

RESULTS OF ROOM TEMPERATURE TENSILE TESTS OF SL-3 CHAMBER SPECIMENS

Panel No.	Spec No.	Plate or Weld No.	Heat No.	Specimen Location	Specimen Orient.	Tensile Strength (1) Ftu	Tensile Strength (1) Fty	Elong. in 1 in. (2.54cm) %	Red. in Area %	Remarks
1	1	W4CB	08950	Weld	Long.	225.3(155.3)	214.1(147.6)	13.0	57.4	
	2	W4CB	08950	Weld	Long.	222.4(153.3)	215.4(148.5)	12.4	52.3	
	3	W4CB	08950	Weld	Trans.	224.2(154.6)	220.2(151.8)	12.2	56.8	
	4	W4CB	08950	Weld	Trans.	224.8(155.0)	221.8(152.9)	10.0	47.8	
	5	4CB	3960832	Parent	Long.	250.5(172.7)	243.4(167.8)	10.7	51.3	
2	1	WG8	(63343) (09035)	Weld	Trans.	217.2(149.8)	208.1(143.5)	12.4	56.6	
	2	WG8	(09620)	Weld	Trans.	218.4(150.6)	212.4(146.4)	12.0	55.9	
	3	3CB	3960819	Parent	Trans.	242.4(167.1)	234.3(161.5)	10.4	49.7	
	4	4CA	25126	Parent	Trans.	241.4(166.4)	233.3(160.9)	11.5	52.5	
3	1	W3CA	(63343) (08436)	Weld	Trans.	211.1(145.6)	206.1(142.1)	13.0	59.4	
	2	W3CA	(08950)	Weld	Trans.	210.8(145.3)	207.7(143.2)	14.0	61.5	
	3	3CA	3951218	Parent	Long.	238.5(164.4)	229.5(158.2)	12.0	54.5	
	4	3CA	3951218	Parent	Long.	239.5(165.1)	229.5(158.2)	12.2	53.9	
4	1	W2CA	63343	Weld	Trans.	207.4(143.0)	196.4(135.4)	-	55.1	Broke outside
	2	W2CA	63343	Weld	Trans.	196.4(135.4)	192.4(132.6)	12.8	57.1	gage
	3	2CB	3960829	Parent	Long.	247.5(170.6)	236.4(163.0)	12.0	55.8	
	4	2CA	24999	Parent	Long.	250.5(172.7)	244.4(168.5)	13.5	55.2	
5	1	WG8		Weld	Trans.	221.8(152.9)	212.5(146.5)	12.2	48.9	
	2	WG8	(63343)	Weld	Trans.	212.3(147.1)	207.2(142.9)	3.2	5.2	Extensive
	3	WG8	(09035)	Weld	Trans.	224.2(154.6)	215.1(148.3)	12.6	53.1	porosity

TABLE 19

RESULTS OF ROOM TEMPERATURE TENSILE TESTS OF SL-3 CHAMBER SPECIMENS

Panel No.	Spec. No.	Plate or Weld No.	Heat No.	Specimen Location	Specimen Orient.	Tensile Strength (1) F_{tu}	Tensile Strength (1) F_{ty}	Elong. in 1 in. (2.54cm) %	Red. in Area %	Remarks
	4	WG8	(09620)	Weld	Trans.	223.2(153.9)	214.1(147.6)	11.5	48.7	
	5	WG8		Weld	Trans.	223.2(153.9)	220.2(151.8)	12.2	51.3	
	6	4CB	3960832	Parent	Trans.	248.5(171.3)	239.4(165.1)	11.7	53.1	
6	1	2CA	24999	HAZ Flaw	Long.	216.2(149.1)	- -	7.6	44.4	Broken in weld away from flaw
	2	2CA	24999	HAZ Flaw	Long.	222.2(153.2)	220.2(151.8)	7.5	49.7	Broke in flaw
	3	2CB	3960829	Parent	Long.	243.4(167.8)	235.4(162.3)	11.1	57.4	
7	1	WG8		Weld	Trans.	225.1(155.2)	222.0(153.1)	11.1	54.8	
	2	WG8	(63343)	Weld	Trans.	224.0(154.4)	220.0(151.7)	8.6	50.5	
	3	WG8	(09035)	Weld	Trans.	226.3(156.0)	221.2(152.5)	11.1	57.4	
	4	WG8	(09620)	Weld	Trans.	225.5(155.5)	221.4(152.6)	11.0	51.7	
	5	WG8		Weld	Trans.	227.3(156.7)	224.2(154.6)	9.6	54.1	
	6	3CB	3960819	Parent	Trans.	241.4(166.4)	231.3(159.5)	9.6	48.1	
8	1	WG10	(63343) (09035)	Weld	Trans.	227.3(156.7)	224.7(154.9)	11.0	54.1	
	2	WG10	(09620)	Weld	Trans.	227.2(156.6)	225.3(155.3)	9.0	48.1	
	3	5CB	50187-3	Parent	Trans.	247.5(170.6)	239.8(165.3)	11.0	47.0	
9	1	W1CB	63343	Weld	Trans.	217.6(150.0)	215.2(148.4)	9.5	53.1	
	2	W1CB	63343	Weld	Trans.	227.1(156.6)	225.1(155.2)	11.1	50.5	
	3	1CB	24997	Parent	Long.	255.7(176.3)	245.4(169.2)	11.0	51.1	
11	A	2CA	24999	Parent	Trans.	258.6(178.3)	254.5(175.5)	11.0	48.7	
	B	2CA	24999	Parent	Trans.	253.5(174.8)	250.5(172.7)	10.5	47.9	
	C	2CA	24999	Parent	Trans.	256.5(176.8)	250.5(172.7)	8.0	37.3	
	D	2CA	24999	Parent	Trans.	258.5(178.2)	253.5(174.8)	10.9	47.7	
	E	2CA	24999	Parent	Trans.	258.5(178.2)	251.5(173.4)	10.0	46.5	

TABLE 19

RESULTS OF ROOM TEMPERATURE TENSILE TESTS OF SL-3 CHAMBER SPECIMENS

Panel No.	Spec No.	Plate or Weld No.	Heat No.	Specimen Location	Specimen Orient.	Tensile Strength(1) Ftu	Tensile Strength(1) Fty	Elong. in 1 in. (2.54 cm) %	Red. in Area %	Remarks
11	1	2CA	24999	Parent	Trans.	191.0(131.7)	142.3(98.1)	14.1	58.1	1200-1500°F
	2	2CA	24999	Hot Spot	Trans.	193.2(133.2)	142.2(98.0)	15.2	57.6	exposure
	3	2CA	24999	Hot Spot	Trans.	183.5(126.5)	145.9(100.6)	15.2	62.0	estimated
	4	2CA	24999	Hot Spot	Trans.	172.2(118.7)	134.7(92.9)	15.3	63.3	
	5	2CA	24999	Hot Spot	Trans.	159.3(109.8)	130.7(90.1)	15.7	66.5	
12	A	1CA	24996	Parent	Long.	248.5(171.3)	246.5(170.0)	11.2	53.1	
	B	1CA	24996	Parent	Long.	246.5(170.0)	240.5(165.8)	11.6	54.5	
	C	1CA	24996	Parent	Long.	248.5(171.3)	244.5(168.6)	11.8	54.5	
	D	1CA	24996	Parent	Long.	248. (171.3)	241.5(166.5)	11.0	52.0	
	E	1CA	24996	Parent	Long.	247.5(170.6)	243.5(167.9)	12.2	56.5	
12	1	1CA	24996	Parent	Long.	175.2(120.8)	139.7(96.3)	15.9	67.7	1200-1500°F
	2	1CA	24996	Hot Spot	Long.	177.0(122.0)	131.9(90.9)	15.0	70.1	exposure
	3	1CA	24996	Hot Spot	Long.	184.2(127.0)	122.4(84.4)	18.0	65.5	estimated
	4	1CA	24996	Hot Spot	Long.	178.2(122.9)	132.1(91.1)	16.7	67.1	
	5	1CA	24996	Hot Spot	Long.	189.6(130.7)	157.3(108.4)	18.0	62.1	

Material: 18 Ni. Marage Steel, Grade 200, 0.6 in. (1.524 cm) plate.
Welds: TIG automatic or manual (repairs).
Heat Treatment: Solution anneal 1650-1700°F (1170-1200°K), weld, age 900°F (760°K) 8 hrs.
Test: 0.250 in. (0.635 cm) dia rounds, +75°F (297°K)

NOTES: (1) F_{tu} - Ultimate tensile strength, ksi (k N/cm^2)
F_{ty} - 0.2% tensile yield strength, ksi (k N/cm^2)

TABLE 20

AVERAGE TENSILE PROPERTIES OF SL-3 CHAMBER PLATES

Material: 18 Ni Marage Steel, Grade 200, 0.6 in. (1.524 cm) plate
Test: 0.250 in. (0.635 cm) dia rounds, +75°F (297 K)

Panel No.	Plate No.	Heat(1)	Spec. Orient.	Characterization Data		Heat Treat Coupons(2)		Specimens From SL-3	
				F_{tu}*	F_{ty}*	F_{tu}*	F_{ty}*	F_{tu}*	F_{ty}*
1	4CB	3960832	Long.	234(161)	225(155)	245(169)	235(162)	251(173)	243(168)
5	4CB	3960832	Trans.	235(162)	227(156)	245(169)	235(162)	249(172)	239(165)
2	3CB	3960819	Trans.	231(159)	221(152)	236(163)	226(156)	242(167)	234(161)
7	3CB	3960819	Trans.	231(159)	221(152)	236(163)	226(156)	241(166)	231(159)
4	2CB	3960829	Long.	230(158)	220(152)	235(162)	224(154)	248(171)	236(163)
6	2CB	3960829	Long.	230(158)	220(152)	235(162)	224(154)	243(168)	235(162)
3	3CA	3951218	Long.	228(157)	220(152)	237(163)	229(158)	240(165)	230(158)
4	2CA	24999	Long.	237(163)	230(158)	249(172)	243(168)	251(173)	244(168)
11	2CA	24999	Trans.	243(168)	237(163)	249(172)	243(168)	257(177)	252(174)
12	1CA	24996	Long.	243(168)	236(163)	252(174)	245(169)	248(171)	244(168)
9	1CB	24997	Long.	233(161)	225(155)	248(171)	242(167)	256(176)	245(169)
2	4CA	25126	Trans.	231(159)	222(153)	236(163)	226(156)	241(166)	233(161)
8	5CB	50187-3	Trans.	242(167)	233(161)	245(169)	236(163)	248(171)	240(165)

NOTES: (1) Suppliers: Heats 39xxxxx Republic Steel
2xxxx Allegheny Ludlum
5xxxx Cameron Iron Works

(2) Heat treat coupon orientation not stipulated, assumed to be longitudinal when comparing with transverse data.

UNITS: *F_{tu} - Ultimate tensile strength, ksi (kN/cm^2)
F_{ty} - 0.2% tensile yield strength, ksi (kN/cm^2)

TABLE 21

AVERAGE TRANSVERSE TENSILE PROPERTIES OF SL-3 CHAMBER FUSION WELD JOINTS

Material: 18 Ni Marage Steel, Grade 200, 0.6 in. (1.524 cm) plate
Test: 0.250 in. (0.635 cm) dia rounds, +75°F (297K)

Panel No.	Weld	Joint Feature	Filler Wire Heat	Characterization Data F_{tu} (1)	Characterization Data F_{ty} (2)	Heat Treat Coupons F_{tu} (1)	Heat Treat Coupons F_{ty} (2)	Specimens from SL-3 F_{tu} (1)	Specimens from SL-3 F_{ty} (2)
1	WACB	Std.Prod.	08950	217(150)	212(146)	233(161)	226(156)	225(155)	221(152)
2	WG8	Burn Thru	(63343) (09035) (09620)	218(150)	210(145)	231(159) 196*(135)	222(153) 189*(130)	218(150)	210(145)
3	W3CA	Repair	(63343) (08436) (08950)	216(149)	211(145)	233(161) 198*(136)	226(156) 192*(132)	211(145)	207(143)
4	W2CA	Repair	63343	217(150)	211(145)	233(161) 194*(134)	224(154) 187*(129)	201(138)	194(134)
5	WG8	Repair Porosity	(63343) (09035) (09620)	218(150)	210(145)	231(159) 196*(135)	222(153) 189*(130)	223(154) 213**(147)	215(148) 207**(143)
7	WG8	Ultrasonic Indication	(63343) (09035) (09620)	218(150)	210(145)	231(159)	222(153)	226(156)	221(152)
8	WG10	Ultrasonic Indication	(63343) (09035) (09620)	218(150)	210(145)	231(159)	222(153)	227(156)	225(155)
9	W1CB	Magnetic Particle Indication	63343	217(150)	211(145)	233(161)	224(154)	222(153)	220(152)

NOTES: * Repair weld properties calculated as 85% of automatic weld properties based upon NASA CR72126 Vol. V Figs. 88, 89
** Extensive porosity in specimen gage section

Units: (1) F_{tu} - Ultimate tensile strength, ksi (kN/cm^2)
(2) F_{ty} - 0.2% tensile yield strength, ksi (kN/cm^2)

TABLE 22

PRECRACKED CHARPY IMPACT TEST RESULTS OF SL-3 CHAMBER SPECIMENS

Panel No.	Weld or Plate No.	Specimen Location	Specimen Orient.	W/A in.-lb/in.^{2} (J/cm^2)	Avg W/A, in.-lb.in.^{2}(J/cm^2) SL-3 Case	Avg W/A, in.-lb.in.^{2}(J/cm^2) Charac. Data
1	4CB	Parent	Long.	938(16.4), 974(17.0), 1001(17.5)	970(17.0)	1210(21.2)
1	4CB	HAZ	Long.	1009(17.6), 940(16.4), 967(16.9)	970(17.0)	-
1	W4CB	Weld	Trans.	1267(22.2), 1323(23.2), 1324(23.2)	1305(22.8)	-
2	4CA	Parent	Trans.	725(12.7), 705(12.3)	720(12.6)	771(13.5)
2	3CB	Parent	Trans.	675(11.8), 720(12.6)	700(12.2)	715(12.5)
2	WG8	Weld	Trans.	1409(24.6), 1295(22.7)	1350(23.6)	-
3	3CA	Parent	Long.	850(14.9), 928(16.2)	890(15.6)	1280(22.4)
3	W3CA	Weld	Trans.	1418(24.8), 1184(20.7)	1300(22.8)	1320(23.1)*
4	2CB	Parent	Long.	998(17.5), 1103(19.3)	1050(18.4)	1263(22.1)
4	2CA	Parent	Long.	752(13.2), 742(13.0)	747(13.1)	723(12.6)
4	W2CA	Weld	Trans.	911(15.9), 1450(25.4)	1180(20.6)	1074(18.8)
5	4CB	Parent	Trans.	998(17.5), 891(15.6)	945(16.5)	906(15.8)
5	WG8	Weld	Trans.	1368(23.9), 1785(31.2)	1575(27.6)	-
6	2CA	HAZ (Flaw)	Long.	827(14.5)	827(14.5)	-
6	2CB	Parent	Long.	921(16.1)	921(16.1)	1263(22.1)
7	3CB	Parent	Trans.	686(12.0)	686(12.0)	715(12.5)
7	WG8	Weld	Trans.	1385(24.2), 1310(22.9), 1262(22.1)	1325(23.2)	-
8	5CB	Parent	Trans.	509(8.9)	509(8.9)	615(10.8)
8	WG10	Weld	Trans.	1003(17.6), 980(17.2)	991(17.3)	-
9	1CB	Parent	Long.	654(11.4)	654 (11.4)	739(12.9)
9	W1CB	Weld	Trans.	828(14.5), 1679(29.4)	1253(21.9)	1074(18.8)

TABLE 22

PRECRACKED CHARPY IMPACT TEST RESULTS OF SL-3 CHAMBER SPECIMENS

	W/A, in.-lb/in.^{2} (J/cm^2) Range	Average
Weld	828-1679 (14.5-29.4)	1292 (22.6)
Heat Affected Zone	827-1009 (14.5-17.6)	936 (16.4)
Parent	509-1103 (8.9-19.3)	830 (14.5)

Material: 18% Ni. Marage Steel, Grade 200.
Test: Standard V notch fatigue precracked Charpy Impact, +75°F (297°K)

NOTES: *Value for filler metal heat 08436 only.

TABLE 23

PLANE STRAIN FRACTURE TOUGHNESS OF SL-3 CHAMBER PLATE AND FUSION WELD JOINTS

Material: 18 Ni Marage Steel, Grade 200, 0.6 in. (1.524 cm) Plate
Test: Notched Slow Bend, +75°F (297K)

Specimen No.	Specimen Location	Specimen Orientation	Crack Depth (1) -in.(cm)	G_{Nc} (Spring Constant)(2)† P_L(4)	G_{Ic} (Bueckner) (3)† P_L(4)	G_{Ic} (Bueckner) (3)† P_M(4)
1-1	Panel 1,	Trans.	.412 (1.046)	83 (1.4)*	148 (2.6)	423 (7.4)
1-2	Weld		.429 (1.090)	101 (1.8)*	242 (4.2)	299 (5.2)
1-3	W4CB		.317 (0.805)	181 (3.2)*	257 (4.5)	349 (6.1)
				-	182 (3.2) avg.	357 (6.2) avg.
1-4	Panel 1,	Long.	.307 (0.780)	374 (6.5)*	295 (5.2)	322 (5.6)
1-5	HAZ		.288 (0.732)	300 (5.2)	222 (3.9)	389 (6.8)
1-6	4CB		.312 (0.792)	290 (5.1)*	243 (4.2)	356 (6.2)
				300 (5.2) avg.	253 (4.4) avg.	356 (6.2) avg.
1-7	Panel 1,	Long.	.238 (0.604)	185 (3.2)	95 (1.7)	229 (4.0)
1-8	Parent		.269 (0.683)	269 (4.7)	169 (3.0)	290 (5.1)
1-9	4CB		.354 (0.899)	240 (4.2)*	259 (4.5)	362 (6.3)
				227 (4.0) avg.	174 (3.0) avg.	294 (5.1) avg.
2-1	Panel 2,	Trans.	.357 (0.907)	237 (4.1)*	266 (4.6)	431 (7.5)
2-2	Weld - WG8		.302 (0.767)	253 (4.4)	212 (3.7)	472 (8.3)
				253 (4.4) avg.	239 (4.2) avg.	453 (7.9) avg.
3-1	Panel 3,	Trans.	.330 (0.838)	116 (2.0)	121 (2.1)	319 (5.6)
3-2	Weld - W3CA		.333 (0.846)	129 (2.2)	130 (2.3)	306 (5.4)
				123 (2.1) avg.	125 (2.2) avg.	312 (5.5) avg.
4-1	Panel 4,	Trans.	.304 (0.772)	163 (2.8)	132 (2.3)	331 (5.8)
4-2	Weld - W2CA		.276 (0.701)	215 (3.8)	141 (2.5)	493 (8.6)
				189 (3.3) avg.	137 (2.4) avg.	412 (7.2) avg.
5-1	Panel 5,	Trans.	.333 (0.846)	199 (3.5)*	191 (3.3)	392 (6.9)
5-2	Weld - WG8		.374 (0.950)	126 (2.2)*	159 (2.8)	487 (8.5)
				-	175 (3.1) avg.	440 (7.7) avg.

TABLE 23

PLANE STRAIN FRACTURE TOUGHNESS OF SL-3 CHAMBER PLATE AND FUSION WELD JOINTS

Specimen No.	Specimen Location	Specimen Orientation	Crack Depth (1) -in. (cm)	G_{Nc} (Spring Constant) (2)† P_L (4)	G_{Ic} (Bueckner) (3)† P_L (4)	G_{Ic} (Bueckner) (3)† P_M (4)
6-1	Panel 6,2CA HAZ Flaw	Long.	.326 (0.828)	212 (3.7) avg.	201 (3.5) avg.	395 (6.9) avg.
6-2	Panel 6, Parent 2CB	Long.	.376 (0.955)	106 (1.8)*	136 (2.4) avg.	228 (4.0) avg.
7-1	Panel 7,	Trans.	.383 (0.973)	114 (2.0)*	154 (2.7)	274 (4.8)
7-2	Weld		.352 (0.894)	171 (3.0)*	198 (3.5)	256 (4.5)
7-3	WG8		.409 (1.039)	93 (1.6)*	183 (3.2)	322 (5.6)
7-4			.269 (0.683)	324 (5.7)*	199 (3.5)	378 (6.6)
7-5			.413 (1.049)	85 (1.5)*	149 (2.6)	272 (4.8)
					177 (3.1) avg.	300 (5.2) avg.
7-6	Panel 7, Parent 3CB	Trans.	.318 (0.808)	159 (2.8)*	134 (2.3) avg.	149 (2.6) avg.
8-1	Panel 8,	Trans.	.362 (0.919)	125 (2.2)	163 (2.8)	394 (6.9)
8-2	Weld WG10		.359 (0.912)	162 (2.8)*	189 (3.3)	217 (3.8)
				125 (2.2) avg.	176 (3.1) avg.	306 (5.4) avg.
8-3	Panel 8, Parent 5CB	Trans.	.339 (0.861)	105 (1.8)*	103 (1.8) avg.	120 (2.1) avg.
9-1	Panel 9,	Trans.	.382 (0.970)	97 (1.7)*	131 (2.3)	293 (5.1)
9-2	Weld W1CB		.398 (1.011)	60 (1.0)*	92 (1.6)	209 (3.6)
					112 (2.0) avg.	251 (4.4) avg.
9-3	Panel 9, Parent 1CB	Long.	.330 (0.838)	89 (1.6)*	82 (1.4) avg.	102 (1.8) avg.
11-A	Panel 11, Parent 2CA	Trans.	.243 (0.618)	252 (4.4)*	221 (3.9)	221 (3.9)
11-B	Outside		.233 (0.591)	253 (4.4)*	204 (3.6)	210 (3.7)
11-C	Hot Spot		.268 (0.681)	166 (2.9)	183 (3.2)	215 (3.8)
11-D			.234 (0.594)	333 (5.8)	272 (4.8)	287 (5.0)
11-E			.211 (0.536)	244 (4.3)	188 (3.3)	200 (3.5)
11-F			.270 (0.686)	174 (3.0)	190 (3.3)	242 (4.2)
11-G			.252 (0.640)	180 (3.2)	179 (3.1)	223 (3.9)
11-H			.240 (0.610)	238 (4.2)	220 (3.8)	248 (4.3)
11-J			.245 (0.622)	145 (2.5)	139 (2.4)	216 (3.8)
				211 (3.7) avg.	200 (3.5) avg.	228 (4.0) avg.

TABLE 23

PLANE STRAIN FRACTURE TOUGHNESS OF SL-3 CHAMBER PLATE AND FUSION WELD JOINTS

Specimen No.	Specimen Location	Specimen Orientation	Crack Depth (1) -in. (cm)	G_{Nc} (Spring Constant)(2)† P_L(4)	G_{Ic} (Bueckner)(3)† P_L(4)	G_{Ic} (Bueckner)(3)† P_M(4)
11-2	Panel 11, Parent 2CA	Trans.	.244 (0.620)	115 (2.0)	105 (1.8)	302 (5.3)
11-3	Inside		.241 (0.612)	135 (2.4)	120 (2.1)	291 (5.1)
11-4	Hot Spot		.257 (0.653)	136 (2.4)	140 (2.4)	343 (6.0)
11-5			.243 (0.617)	129 (2.2)	114 (2.0)	406 (7.1)
11-6			.273 (0.693)	90 (1.6)*	97 (1.7)	330 (5.8)
11-7			.252 (0.640)	83 (1.4)	83 (1.4)	324 (5.7)
11-8			.253 (0.643)	115 (2.0)*	107 (1.9)	339 (5.9)
11-9			.240 (0.610)	105 (1.8)	96 (1.7)	359 (6.3)
				117 (2.0) avg.	108 (1.9) avg.	337 (5.9) avg.
12-A	Panel 12, Parent 1CA	Long.	.247 (0.627)	153 (2.7)	144 (2.5)	180 (3.2)
12-B	Outside Hot		.255 (0.648)	153 (2.7)	158 (2.8)	204 (3.6)
12-C	Spot		.275 (0.698)	164 (2.9)	189 (3.3)	268 (4.7)
12-D			.219 (0.556)	200 (3.5)	158 (2.8)	166 (2.9)
12-E			.252 (0.640)	150 (2.6)	137 (2.4)	149 (2.6)
12-F			.252 (0.640)	177 (3.1)*	166 (2.9)	166 (2.9)
12-G			.253 (0.643)	140 (2.4)	134 (2.3)	148 (2.6)
12-H			.234 (0.594)	167 (2.9)	139 (2.4)	142 (2.5)
12-J			.231 (0.587)	142 (2.5)	124 (2.2)	142 (2.5)
				159 (2.8) avg.	150 (2.6) avg.	174 (3.0) avg.
12-1	Panel 12, Inside		.288 (0.732)	225 (3.9)*	262 (4.6)	464 (8.1)
12-2	Hot Spot		.260 (.660)	143 (2.5)*	136 (2.4)	374 (6.5)
12-3			.270 (.686)	122 (2.1)*	123 (2.2)	346 (6.0)
12-4			.256 (.650)	146 (2.6)*	132 (2.3)	349 (6.1)
12-5			.230 (.584)	144 (2.5)*	107 (1.9)	367 (6.4)
12-6			.251 (.638)	122 (2.1)*	105 (1.8)	372 (6.5)
12-7			.280 (.711)	96 (1.7)*	103 (1.8)	319 (5.6)
12-8			.272 (.691)	123 (2.2)*	125 (2.2)	309 (5.4)
12-9			.241 (.612)	143 (2.5)*	117 (2.0)	405 (7.1)
					134 (2.3) avg.	367 (6.4) avg.

TABLE 23

PLANE STRAIN FRACTURE TOUGHNESS OF SL-3 CHAMBER PLATE AND FUSION WELD JOINTS

NOTES: (1) Values of G for crack depths greater than 0.275 in. (0.698 cm) of questionable validity.

(2) Spring constant method, calibration specimens Panel 11, constants $Q = 1.158 \times 10^{-5}$, $R = -4.353 \times 10^{-5}$, $S = 8.701 \times 10^{-5}$, AGC computer Program No. 16112

(3) Bueckner Method, AGC Computer Program No. 16107

(4) P_L = load at proportional limit, P_M = maximum load

Units: †, G_{Nc}, G_{Ic} - in.lb/in.^{2} (J/cm^2)

* Specimen spring constant reciprocal values beyond range of calibration curve, calculated values not valid. Not used in calculation of average.

TABLE 24

AVERAGE PLANE STRAIN FRACTURE TOUGHNESS OF SL-3 CHAMBER PLATES

Panel No.	Plate No.	Heat No.	Spec. Orient.	Charact. Data G_{N_c} (1)	Heat-Treat Coupons G_{N_c} (1)	Specimens from SL-3 G_{N_c} (1)	Specimens from SL-3 G_{I_c} (2)
1	4CB	3960832	Long.	428(7.5)	239(4.2)	227(4.0)	174(3.0)
6	2CB	3960829	Long.	344(6.0)	-	*106(1.8)	136(2.4)
7	3CB	3960819	Trans.	279(4.9)	**275(4.8)	*159(2.8)	134(2.3)
9	1CB	24997	Long.	220(3.8)	198(3.5)	*89(1.6)	82(1.4)
11	2CA	24999	Trans.	223(3.9)	**197(3.4)	220(3.8)	200(3.5)
12	1CA	24996	Long.	204(3.6)	153(2.7)	159(2.8)	150(2.6)
8	5CB	50187-3	Trans.	258(4.5)	-	*105(1.8)	103(1.8)

Material: 18% Ni. Marage Steel, Grade 200, 0.6 in. (1.524 cm) Plate.
Test: Notched Slow Bend, +75°F (297°K)

NOTES: *Spring constant values beyond range of calibration curve, calculated values not valid.

**Traverse heat-treat coupon value calculated as 85% of longitudinal value

(1) G_{N_c}, calculated using spring constant method, proportional limit load.

(2) G_{I_c}, calculated using Buechner method, proportional limit load.

UNITS: † G_{N_c}, G_{I_c} - in.-lb/in.^{2} (J/cm^2)

TABLE 25

AVERAGE PLANE STRAIN FRACTURE TOUGHNESS OF SL-3 CHAMBER FUSION WELD JOINTS

Material: 18% Ni Marage Steel, Grade 200, 0.6 in. (1.524 cm) Plate.
Test: Notched Slow Bend, + 75°F (297 K).

Panel No.	Weld	Joint Feature	Filler Wire Heat	Characterization Data $G_{Nc}^{(1)\dagger}$	Heat Treat Coupons $G_{Nc}^{(1)\dagger}$	Specimens from SL-3 $G_{Nc}^{(1)\dagger}$	Specimens from SL-3 $G_{Ic}^{(2)\dagger}$	Specimens from SL-3 $G_{Ic}^{(3)\dagger}$
1	WACB	Std. Prod.	08950	398 (7.0)	435 (7.6)	NV	182 (3.2)	357 (6.2)
2	WG8	Burn Thru	63343 09035 09620	356 (6.2)	412 (7.2)*	253 (4.4)	239 (4.2)	453 (7.9)
3	W3CA	Repair	63343 08436 08950	290 (5.1)	412 (7.2)*	123 (2.2)	125 (2.2)	312 (5.5)
4	W2CA	Repair	63343	218 (3.8)	412 (7.2)*	189 (3.3)	137 (2.4)	412 (7.2)
5	WG8	Repair Porosity	63343 09035 09620	356 (6.2)	412 (7.2)*	NV	175 (3.1)	440 (7.7)
7	WG8	Ultra. Ind.	63343 09035 09620	356 (6.2)	435 (7.6)	NV	171 (3.0)	300 (5.2)
8	WG10	Ultra. Ind.	63343 09035 09620	356 (6.2)	435 (7.6)	NV	176 (3.1)	306 (5.4)
9	W1CB	Mag.Part. Ind.	63343	218 (3.8)	435 (7.6)	NV	112 (2.0)	251 (4.4)

Notes: *Repair value for 63343 filler heat treat coupon used for comparison of test data from repair welds

NV-Test invalid, spring constant beyond calibration curve range

TABLE 25

AVERAGE PLANE STRAIN FRACTURE TOUGHNESS OF SL-3 CHAMBER FUSION WELD JOINTS

Notes: $G_{Nc}^{(1)}$ Calculated using Spring Constant Method, Proportional Limit Load

$G_{Ic}^{(2)}$ Calculated using Bueckner Method, Proportional Limit Load

$G_{Ic}^{(3)}$ Calculated using Bueckner Method, Maximum Load

Units: † G_{Nc}, G_{Ic}, -- in-lb/in^2 (J/cm^2)

TABLE 26

AVERAGE PLANE STRAIN FRACTURE TOUGHNESS OF REPAIRED AND UNREPAIRED SL-3 CHAMBER FUSION WELD JOINTS

Panel No.	Weld No.	Joint Feature	Average G_{I_c} (1)†
1	W4CB	Standard Production Automatic Weld	357(6.2)
7	WG8	Unrepaired Weld	300(5.2)
8	WG10	Unrepaired Weld	306(5.4)
9	W1CB	Unrepaired Weld	251(4.4)
2	WG8	Burn Through	453(7.9)
5	WG8	Porosity, Repaired, Manual	440(7.7)
3	W2CA	Multiple (4) Repairs Manual	312(5.5)
4	W2CA	Multiple (7) Repairs, Manual	412(7.2)

Material: 18% Ni. Maraging Steel, Grade 200, 0.6 in. (1.524 cm) Plate
Test: Notched Slow Bend, +75°F (297°K)

NOTES: (1) Calculated as qualitative value using Bueckner method and maximum load, specimen-crack dimensions not considered valid for toughness-strength levels of welds.

UNITS: †G_{I_c} - in. lb/in.^{2} (J/cm^2)

TABLE 27

COMPARISON OF AVERAGE PLANE STRAIN FRACTURE TOUGHNESS OF SL-3 CHAMBER PLATES

Material: 18% Ni Marage Steel, Grade 200, 0.6 in (1.524 cm) Plate
Test: Notched Slow Bend, + 75°F (297 K)

Panel No.	Plate No.	Heat No.	Specimen Orientation	G_{Nc} (1)† Characterization Data	G_{Nc} (1)† Heat Treat Coupons	G_{Nc} (1)† SL-3 Specimens	G_{Ic} (2)† SL-3 Specimens
1	4CB	3960832	Long	428 (7.5)	239 (4.2)	227 (4.0)	174 (3.0)
11	2CA	24999	Trans	223 (3.4)	197 (3.4)(3)	211 (3.7)	200 (3.5)
12	1CA	24996	Long	204 (3.6)	153 (2.7)	159 (2.8)	150 (2.6)

Notes: (1) Calculated using Spring Constant Method, Proportional Limit Load
(2) Calculated using Bueckner Method, Proportional Limit Load
(3) Transverse heat treat coupon value calculated as 85% of longitudinal value

Units: G_{Nc}, G_{Ic} -- in-lb/in^2 (J/cm^2)

COMPARISON OF AVERAGE PLANE STRAIN FRACTURE TOUGHNESS OF SL-3 CHAMBER PLATES
TABLE 27

NASA CR 72676

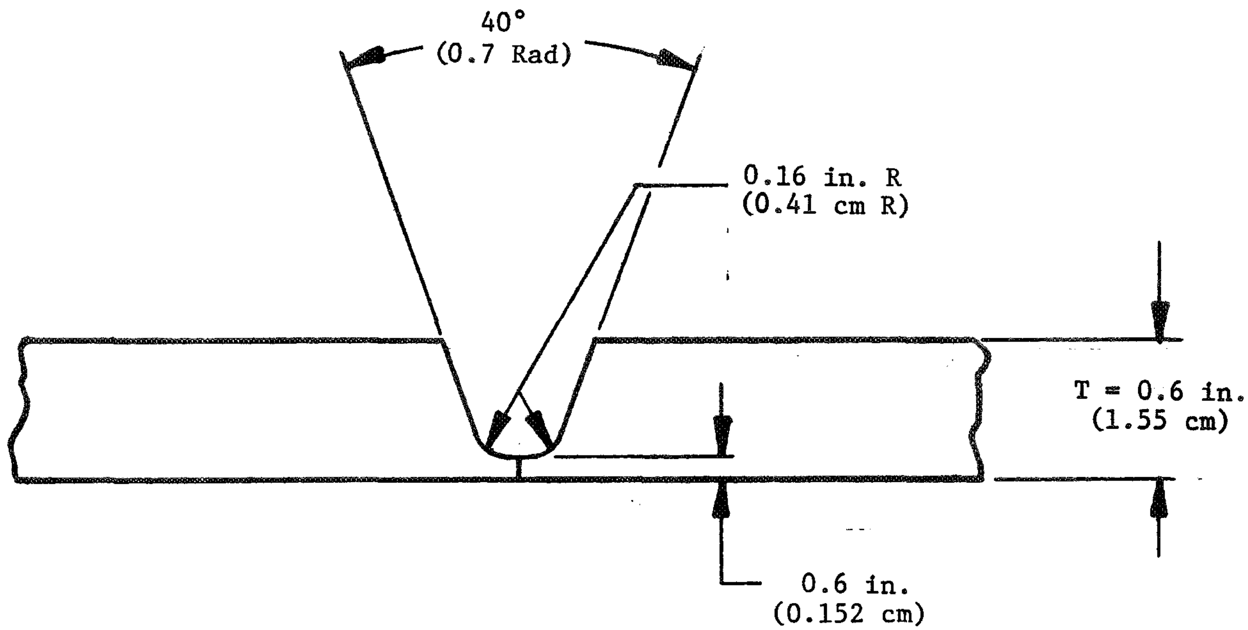
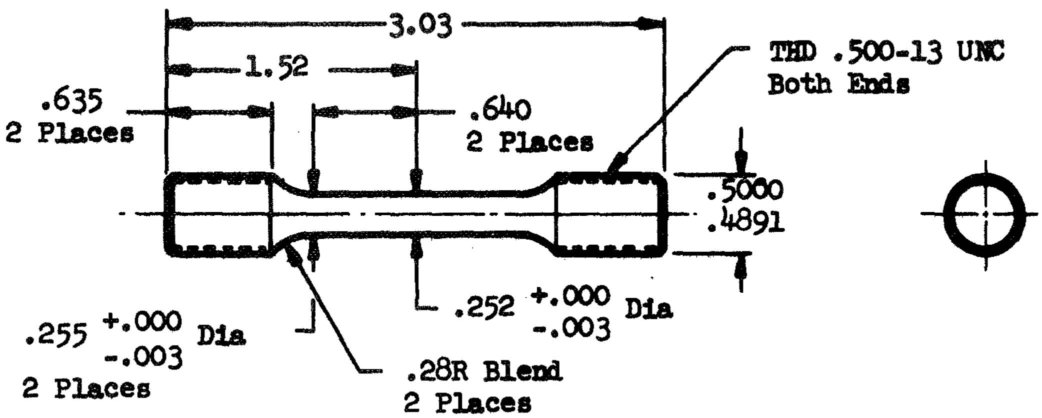
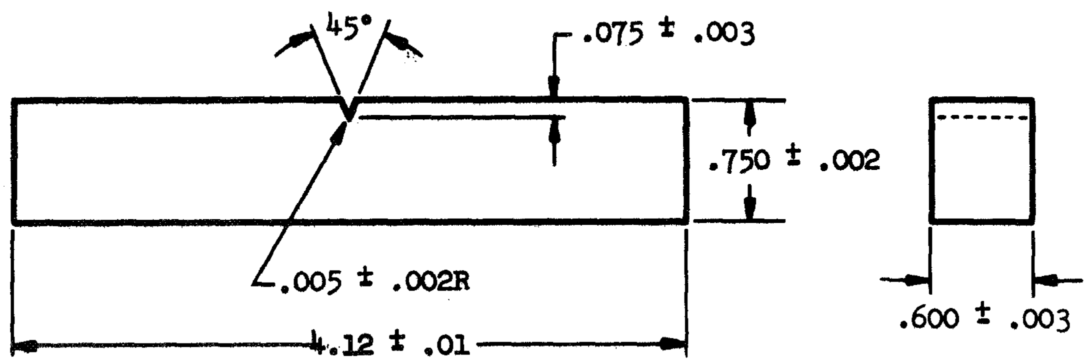


Figure 1

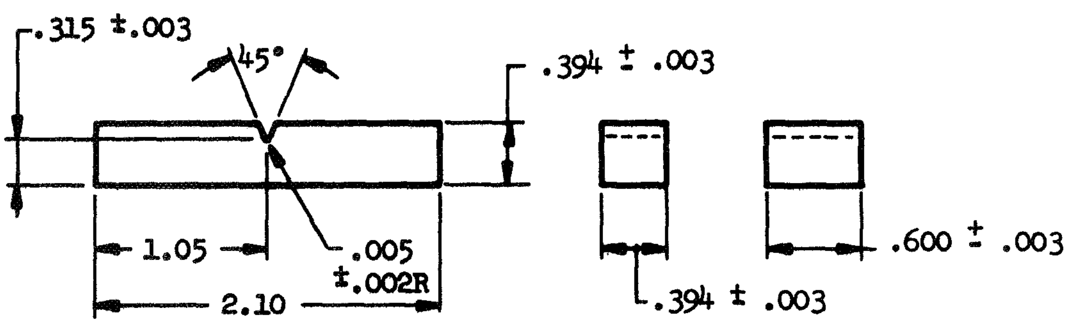
Typical Weld Edge Preparation



Tensile Specimen



Slow-Notch-Bend Specimen

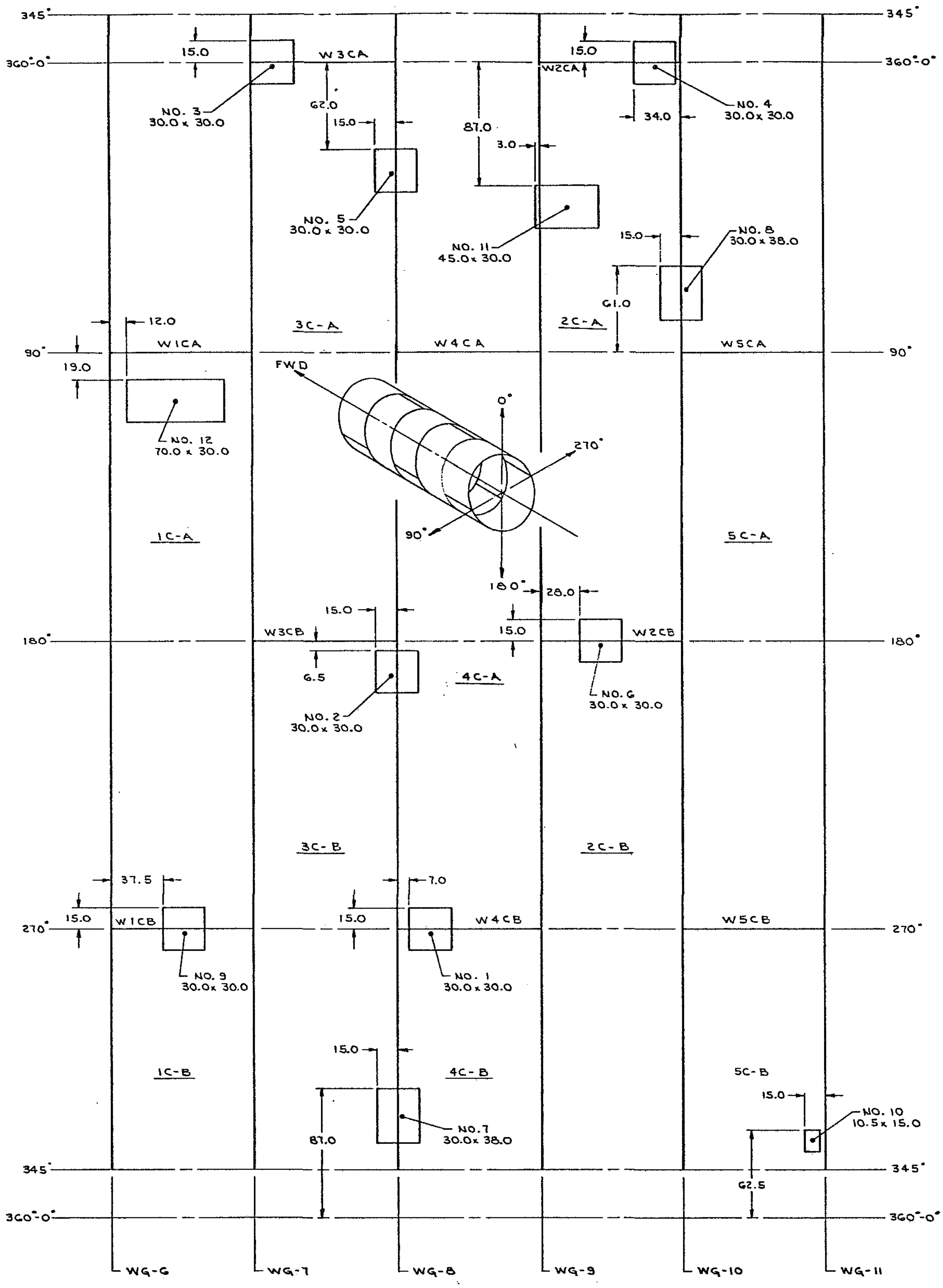


Precracked Charpy Impact Specimen

Note: Dimensions in inches.

Specimen Configurations

Figure 2

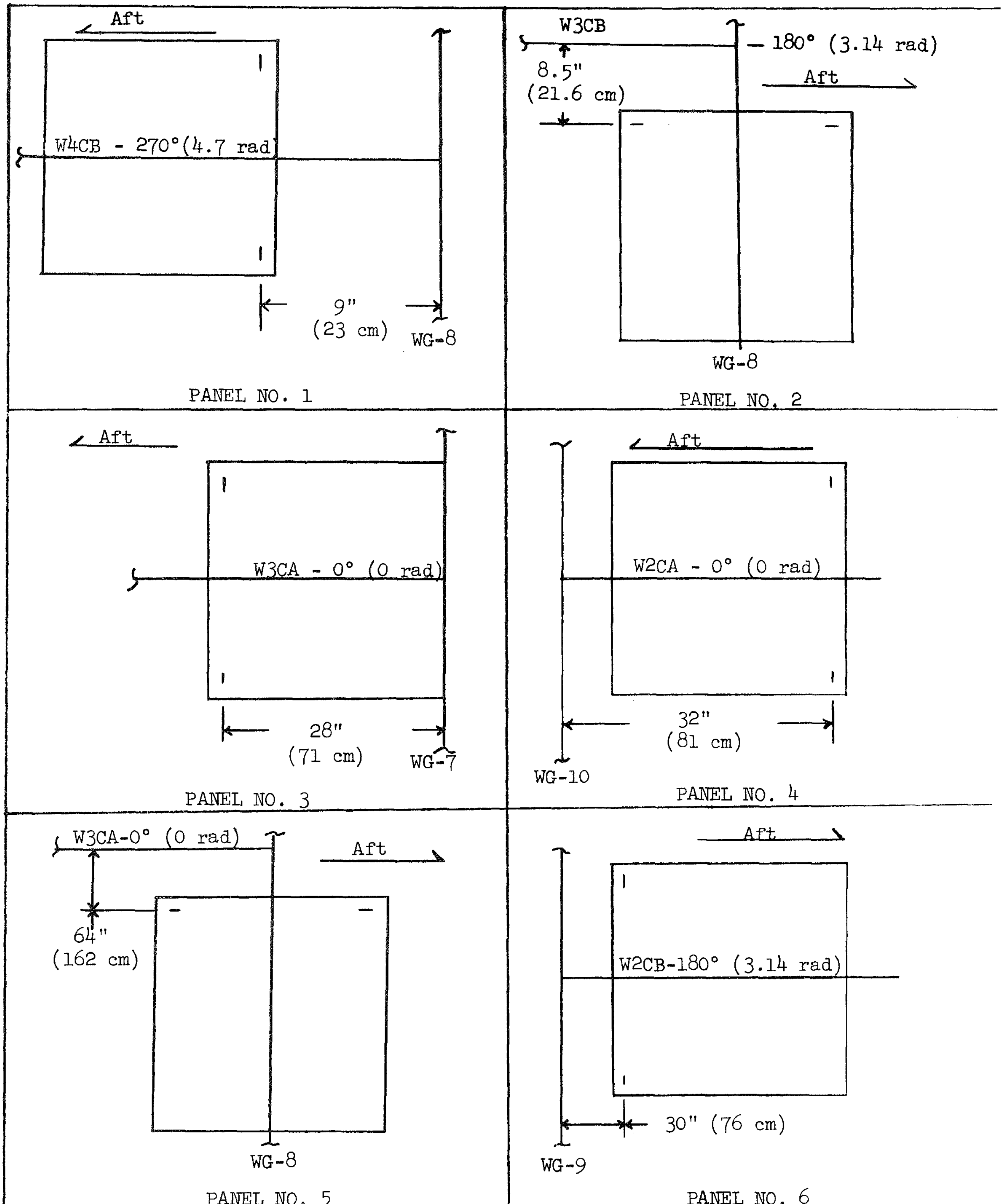


FWD

NOTE: Dimension in inches

Test Panel Locations

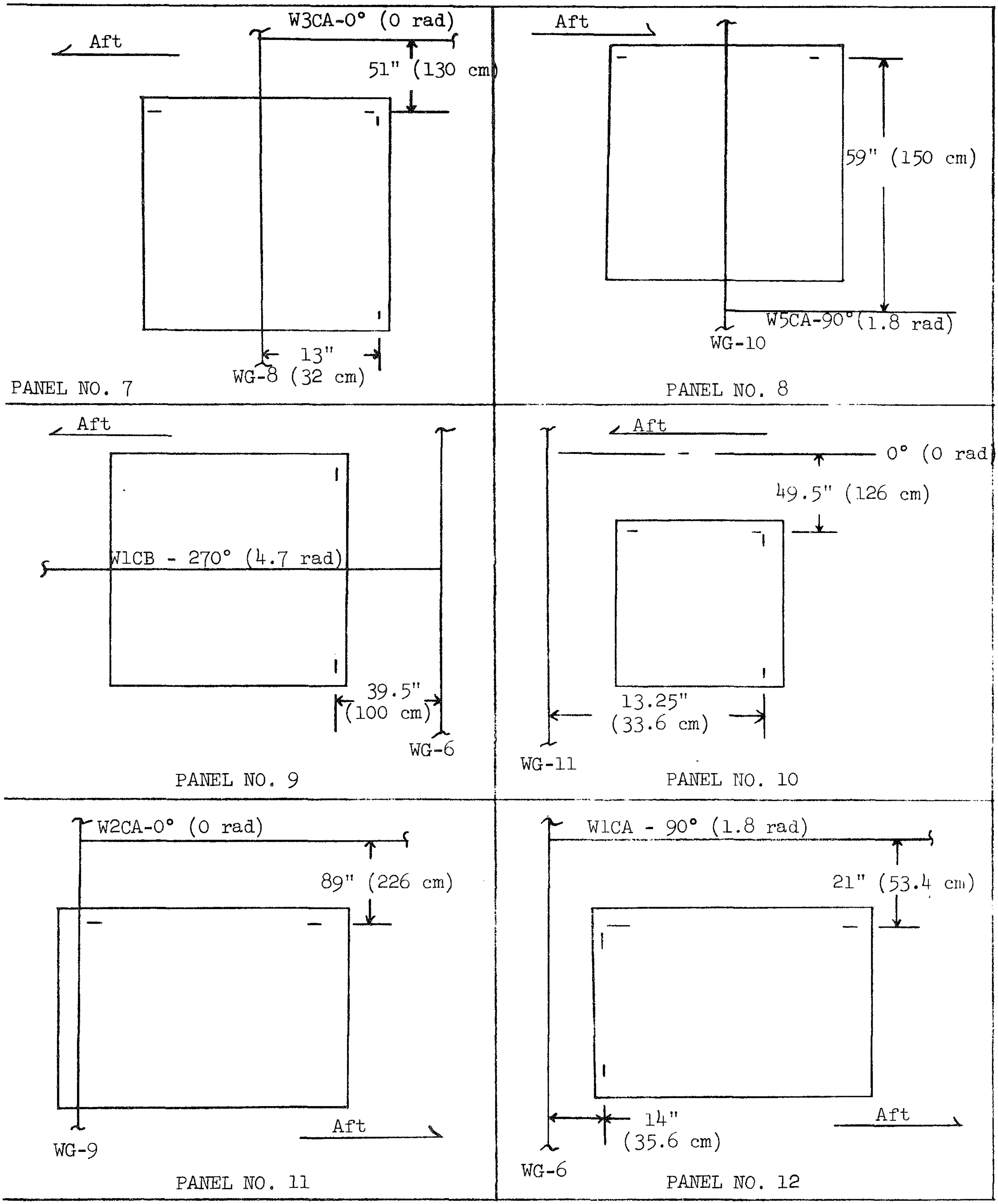
Figure 3



Note: Dimensions in inches.

Test Panel Orientation - Looking at Exterior Surface

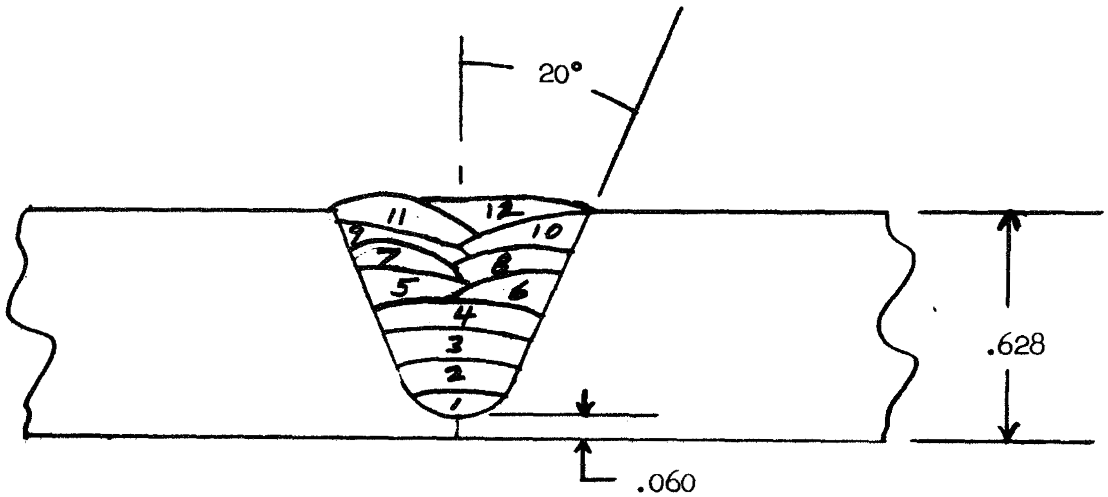
Figure 4
Sheet 1 of 2



Note: Dimensions in inches.

Test Panel Orientation - Looking at Exterior Surface

Figure 4
Sheet 2 of 2

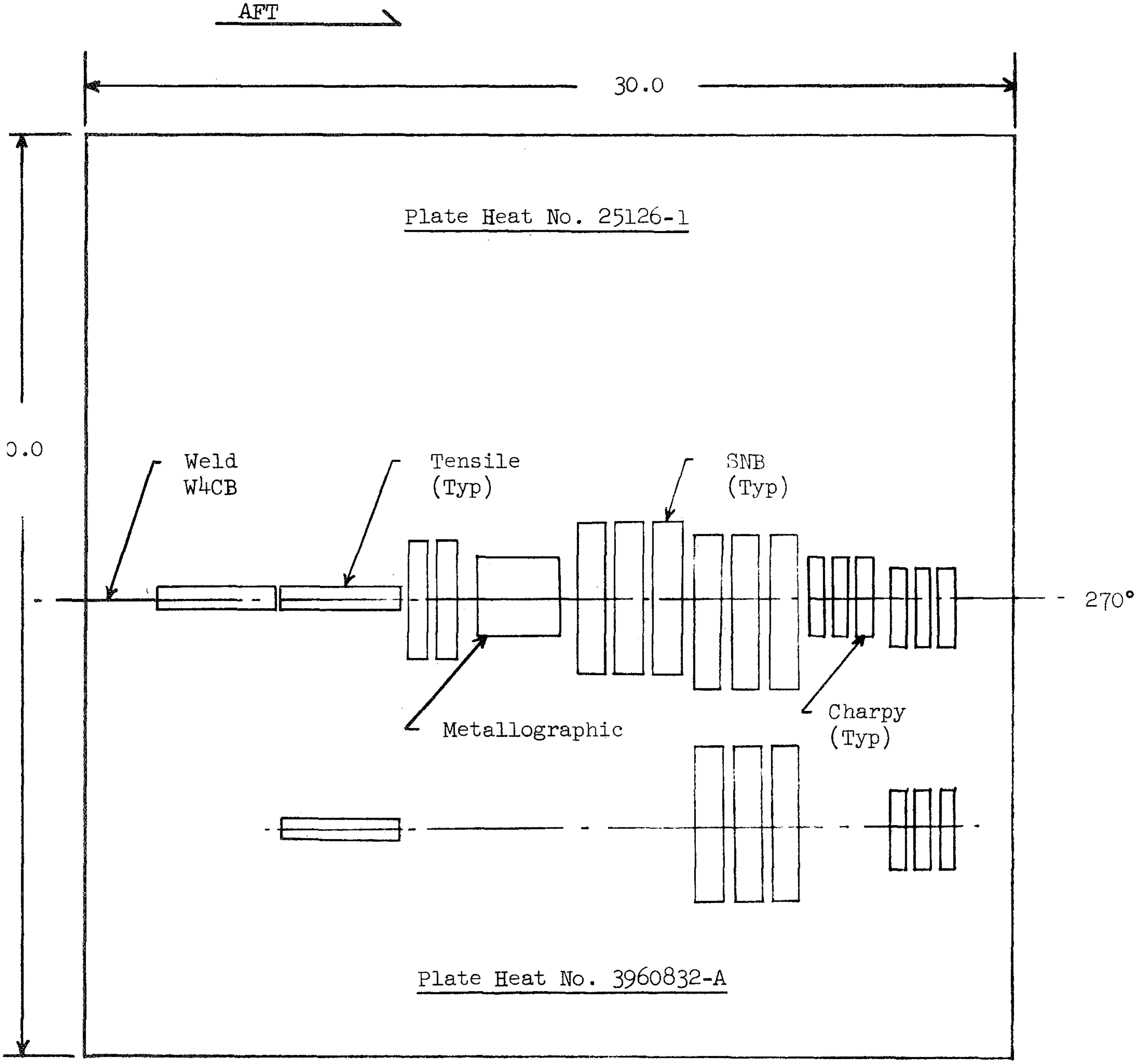


WELD PROCESS RECORD

Pass No.	Amperage	Voltage	Travel (ipm)	Travel (cm/min)	Wire-Feed (ipm)	Wire-Feed (cm/min)
1	330	10.5	5	(12.7)	60	(152)
2	370	11	8	(20.3)	60	(152)
3	371	11	8	(20.3)	60	(152)
4	No Record					
5	371	11.1	8	(20.3)	60	(152)
6	372	11.1	8	(20.3)	60	(152)
7	371	11.1	8	(20.3)	60	(152)
8	371	11.1	8	(20.3)	60	(152)
9	371	11.1	8	(20.3)	60	(152)
10	372	11.1	8	(20.3)	60	(152)
11	371	11	8	(20.3)	60	(152)
12	371	10.9	8	(20.3)	60	(152)

W4CB Weld Deposit Configuration

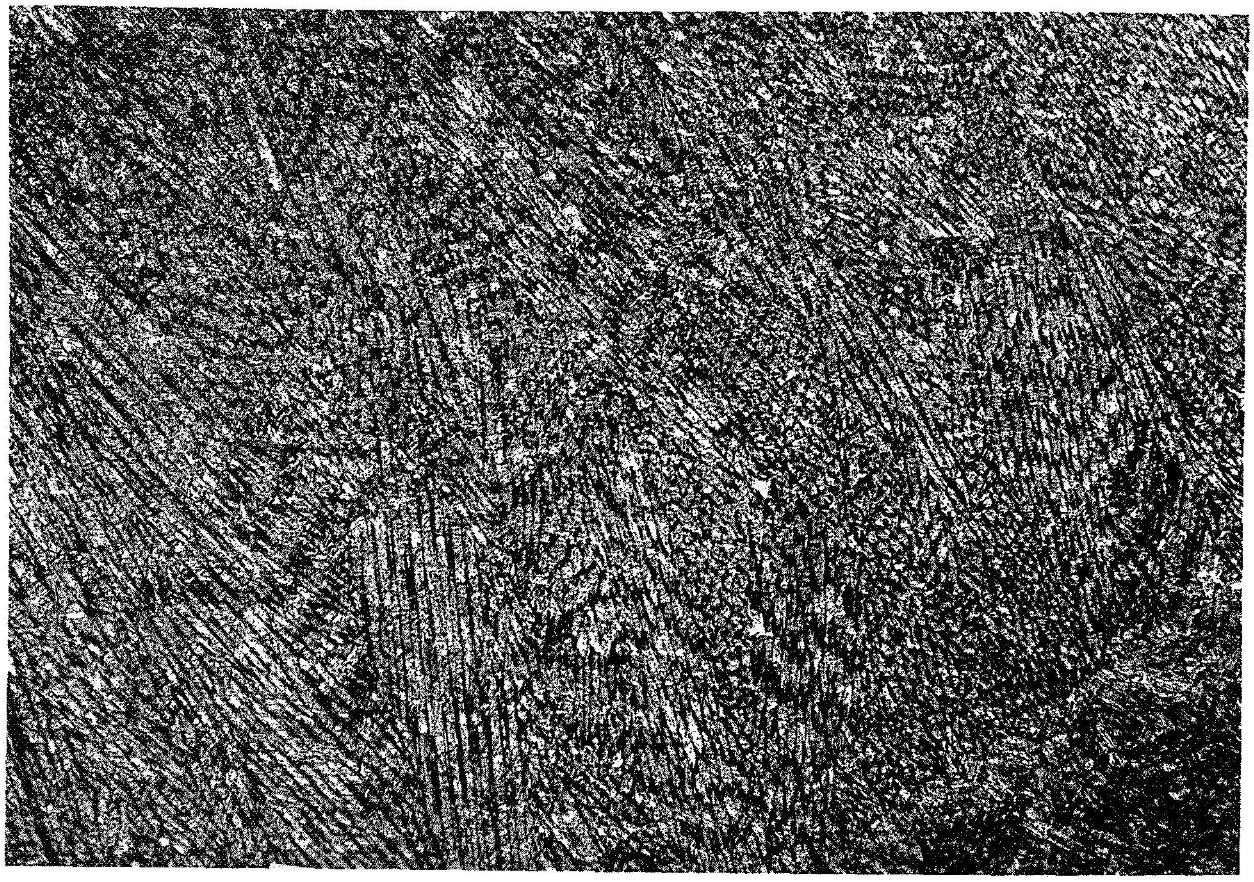
Figure 5



Note: Dimensions in inches.

Task III Test Specimen Layout

Figure 6

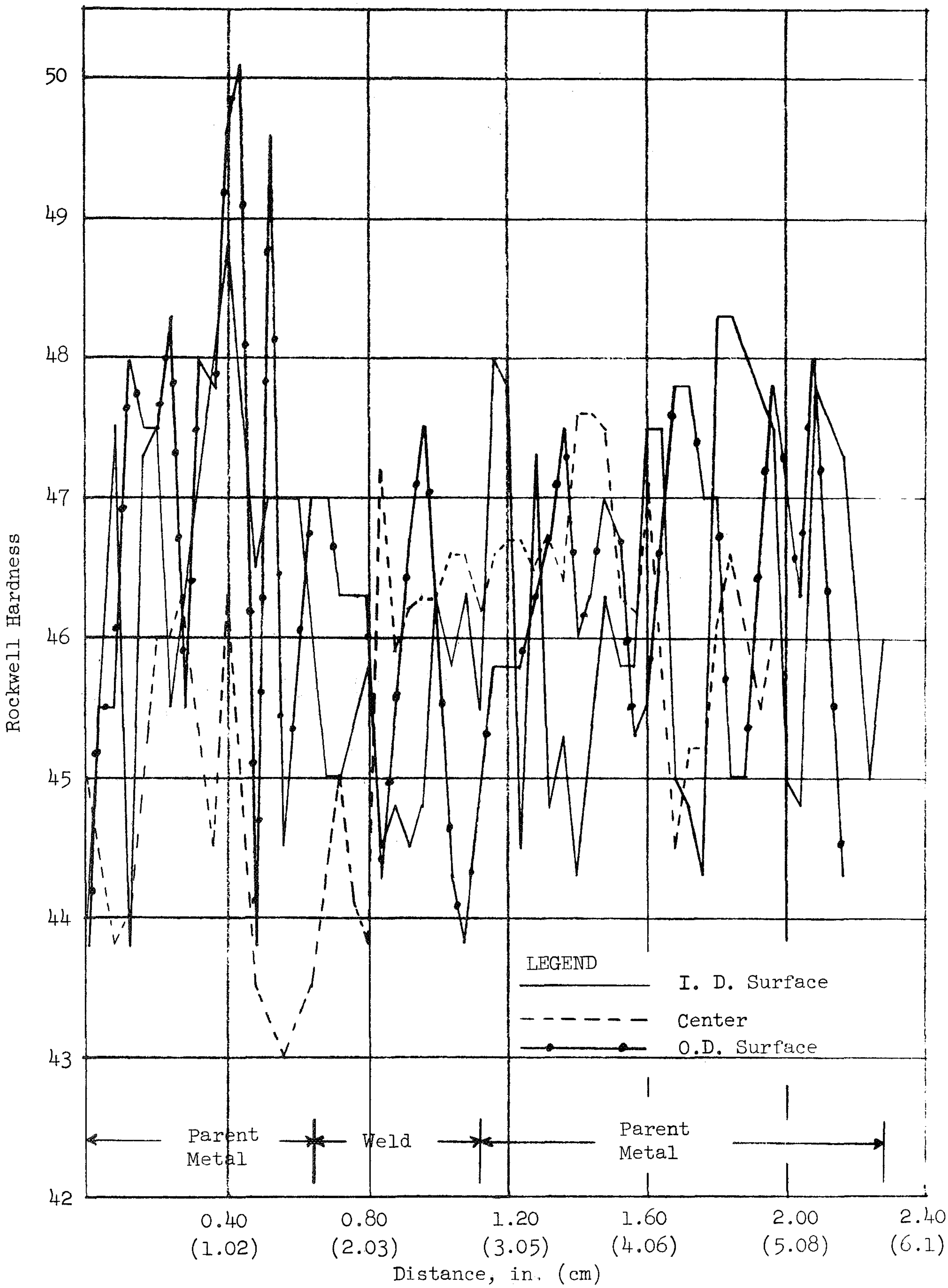


MAGNIFICATION: 100X

ETCHANT: MARBLES

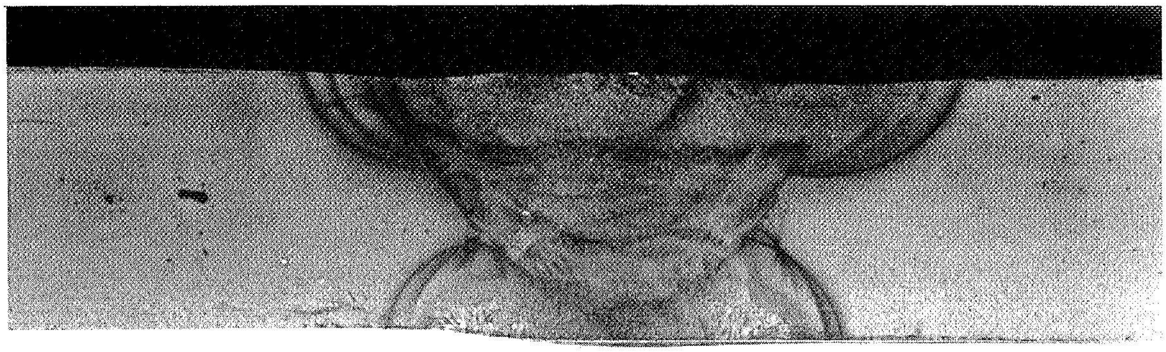
Microstructure of Standard Production
Automatic Weld - Test Panel No. 1

Figure 7

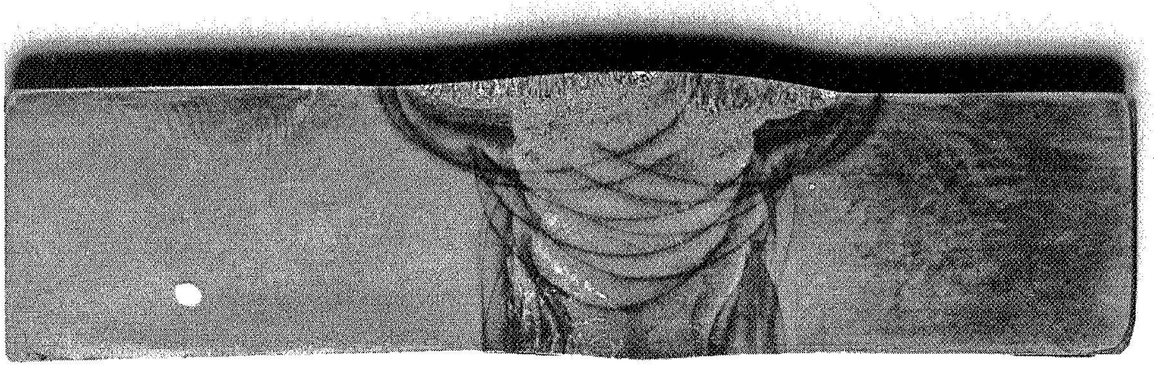


Test Panel No. 1 Hardness Traverse

Figure 8



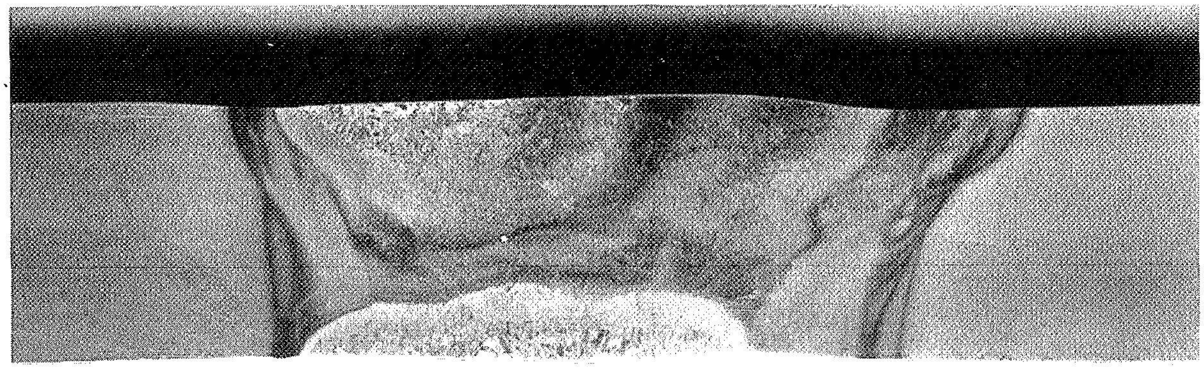
Panel 2 section transverse to WG8 weld. Section is through region of weld burnthrough occurring when cylinder rotation stopped during welding. 2X; marbles etch; O. D. surface at top



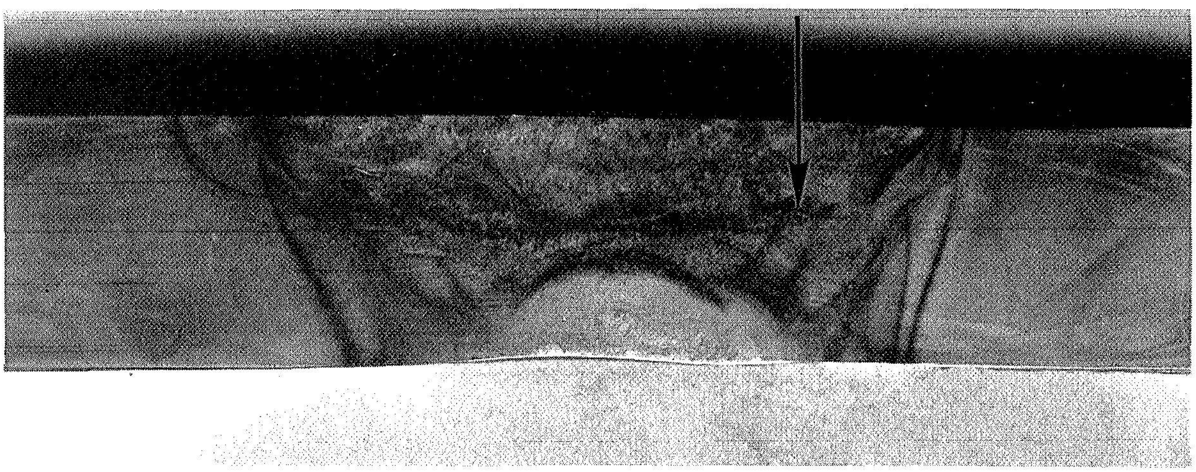
Panel 3 section transverse to W3CA weld. Section is through region of four overlapping weld repairs. 2X; marbles etch; O. D. surface at top

TYPICAL WELDS - TEST PANELS 2 THROUGH 5

Figure 9, Sheet 1 of 2



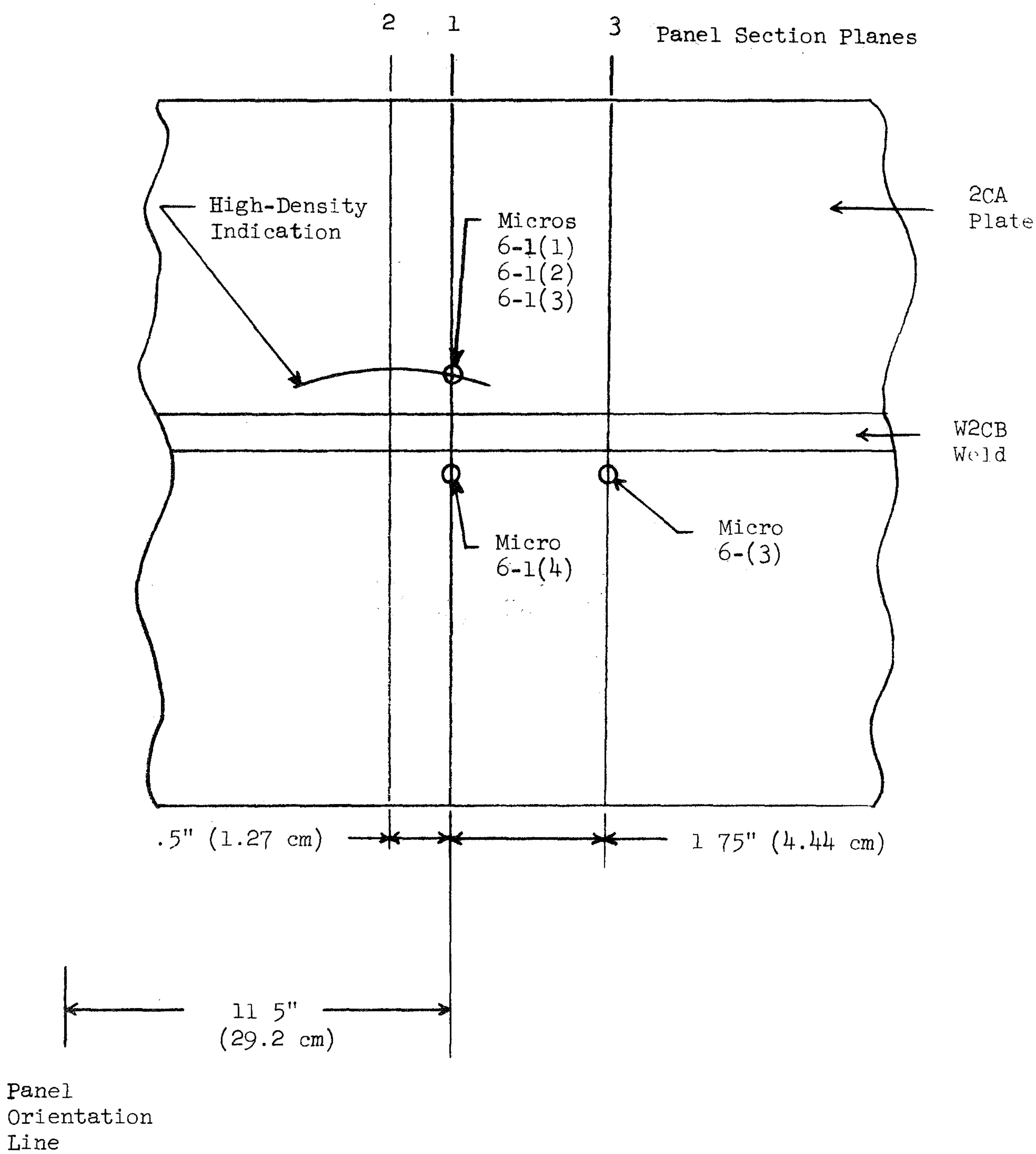
Panel 4 section transverse to W2CA weld. Section is through region of seven multiple repairs. 2X; marbles etch; O. D. surface at top



Panel 5 section transverse to WG8 weld. Typical section is through region of multiple scattered porosity, arrow, and several weld repairs. 2X; marbles etch; O. D. surface at top

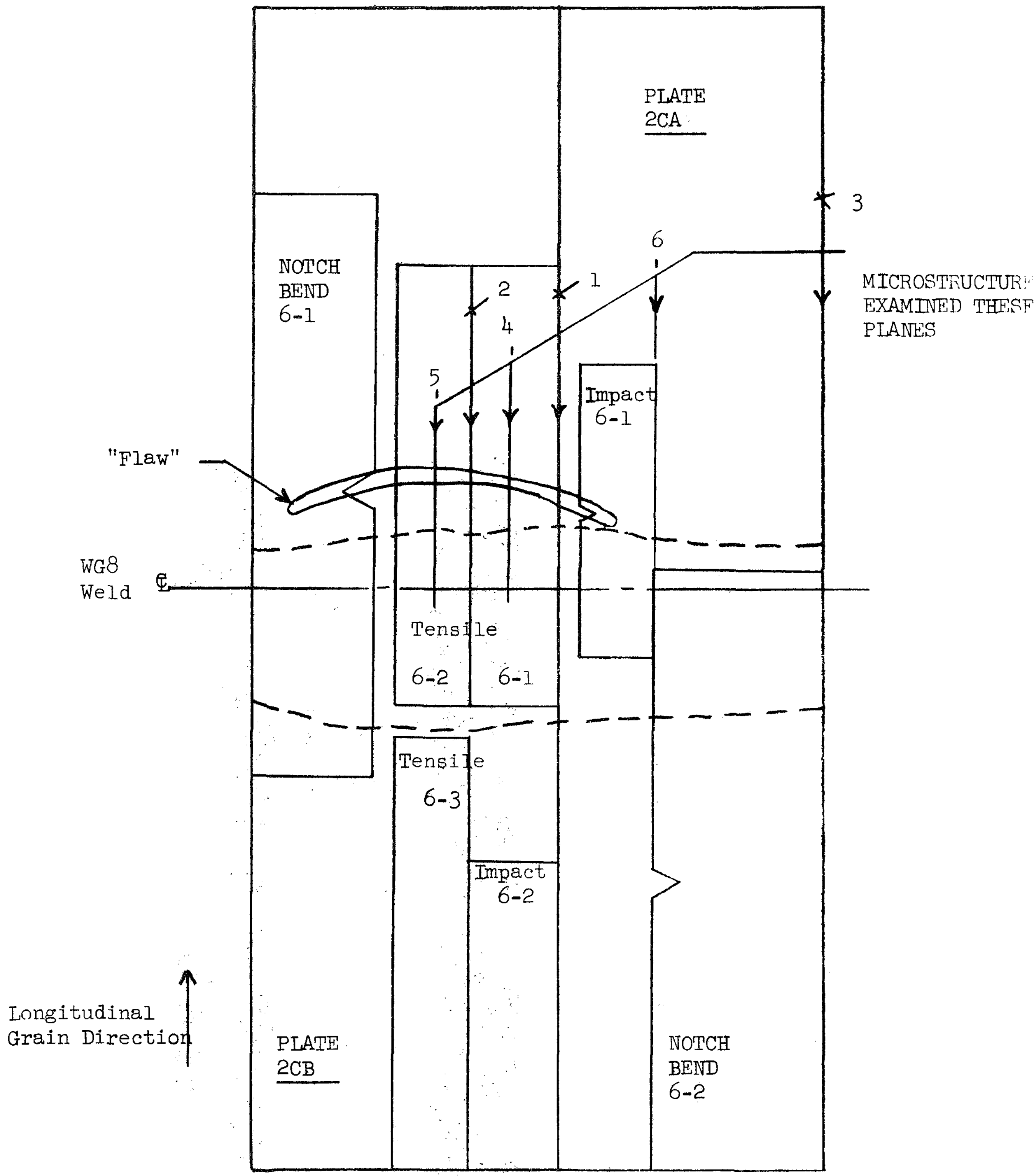
TYPICAL WELDS - TEST PANELS 2 THROUGH 5

Figure 9, Sheet 2 of 2



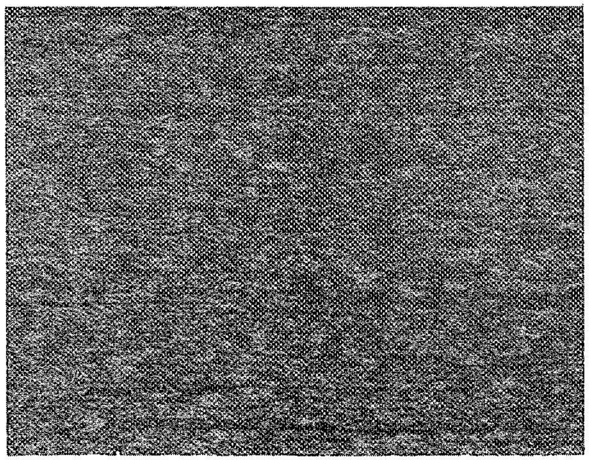
Initial Panel 6 Evaluation Planes

Figure 10

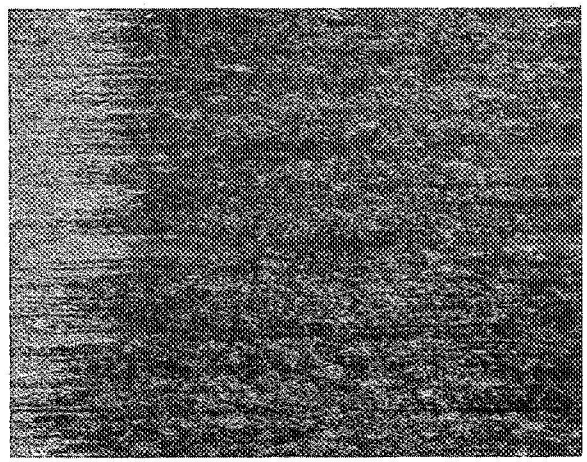


Specimen Layout in Panel No. 6 in Vicinity of Radiographically Detected "Flaw"

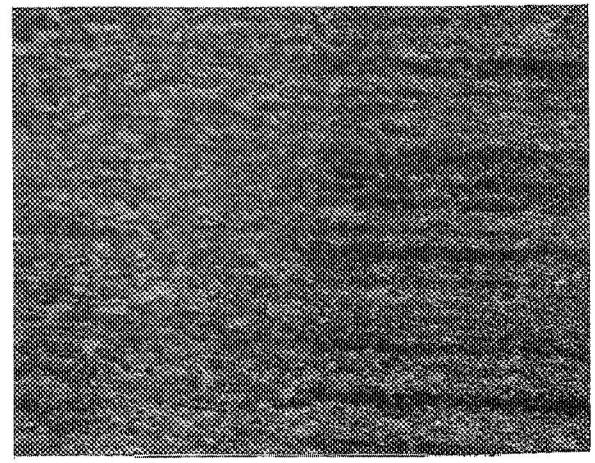
Figure 11



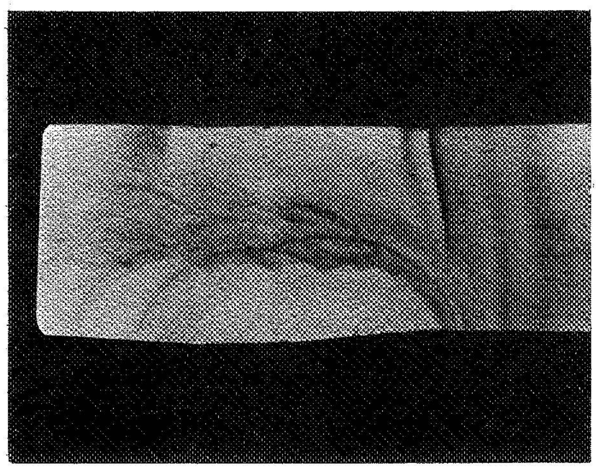
6-1(3)
100X



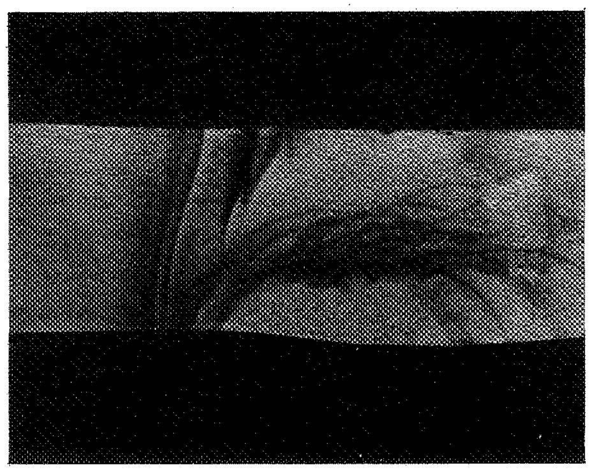
6-1(2)
100X



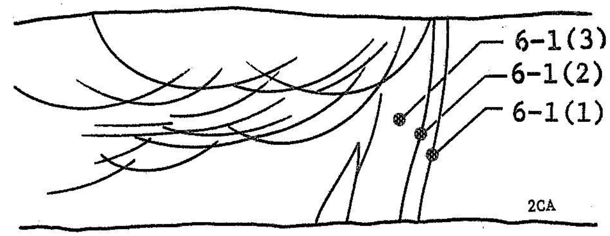
6-1(1)
100X



Plane 2 3X



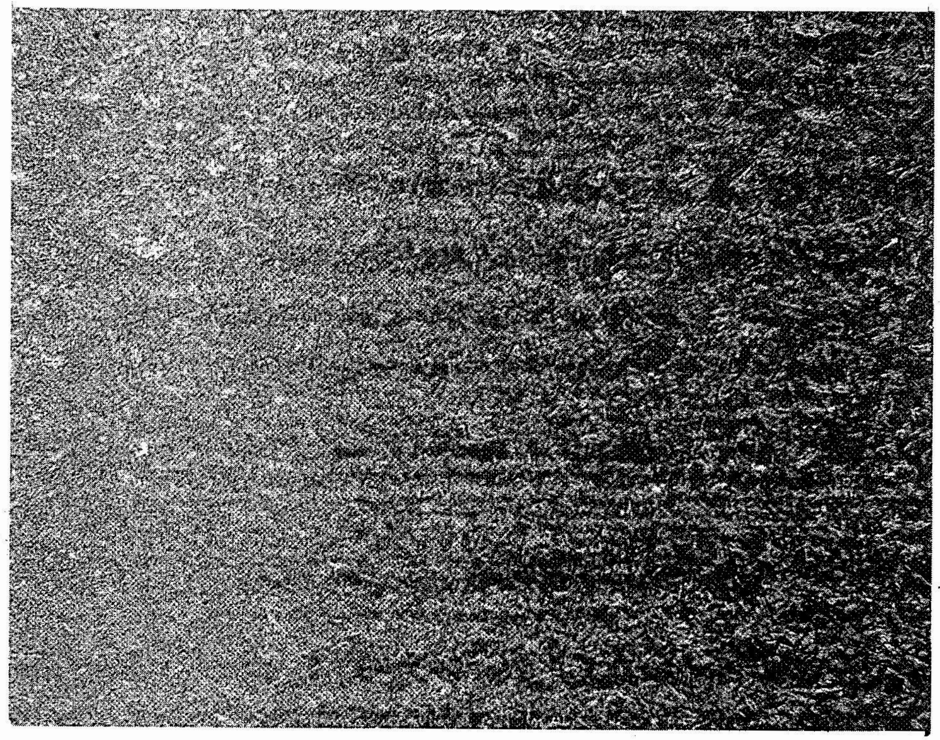
Plane 1 3X



Plane 1

Panel 6 Macro and Micro Examinations - Marble Etch

Figure 12



6-1(4)

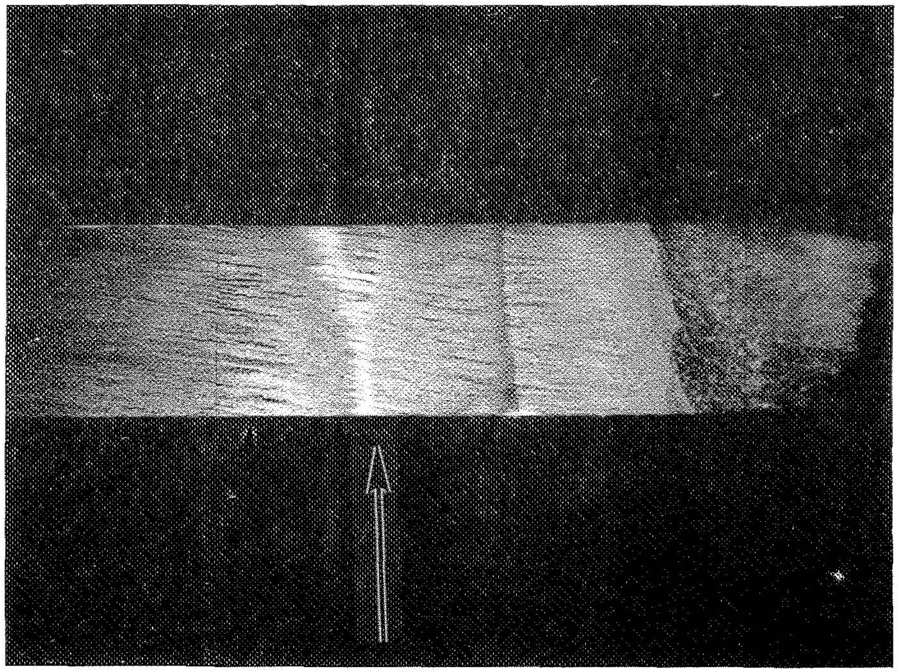
6-3

Heat affected zone microstructure in regions beyond indication in Panel No. 6, Plane 1 left, Plane 3 right. Width of structural changes seen in 6-3 right occurs in 6-1 indication (Figure 12) region over a band four times as wide.

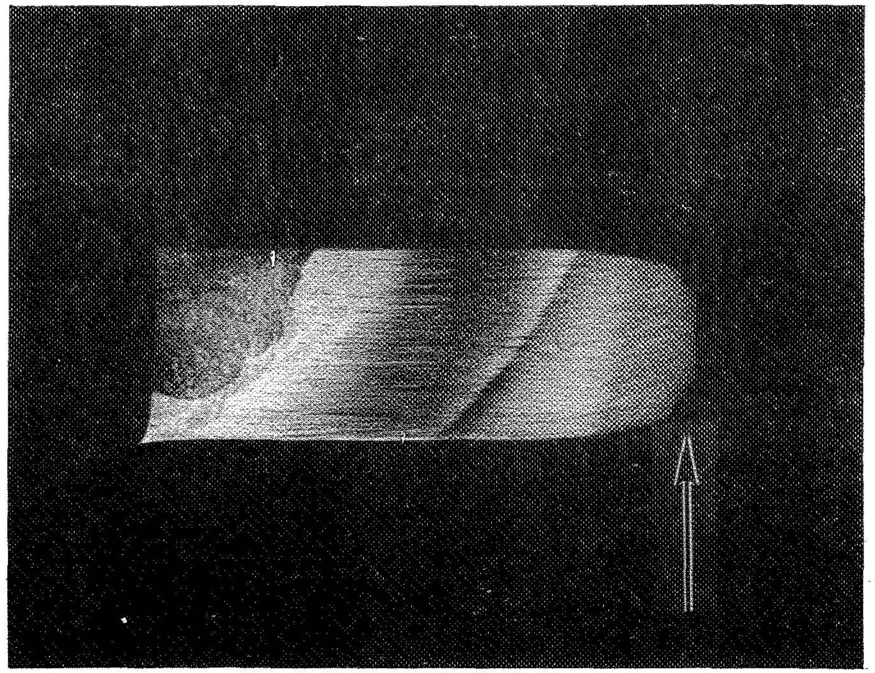
100X Marbles etch.

Panel 6 Microstructural Examinations

Figure 13



Plane 4

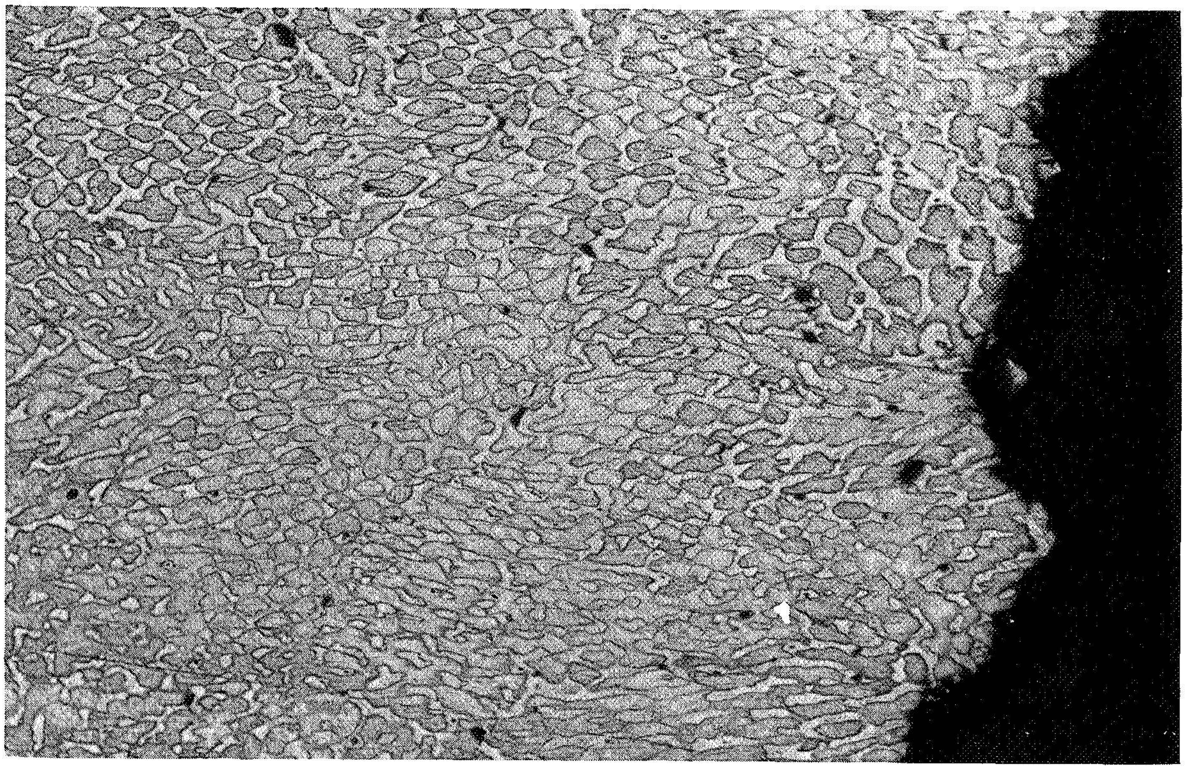


Plane 5

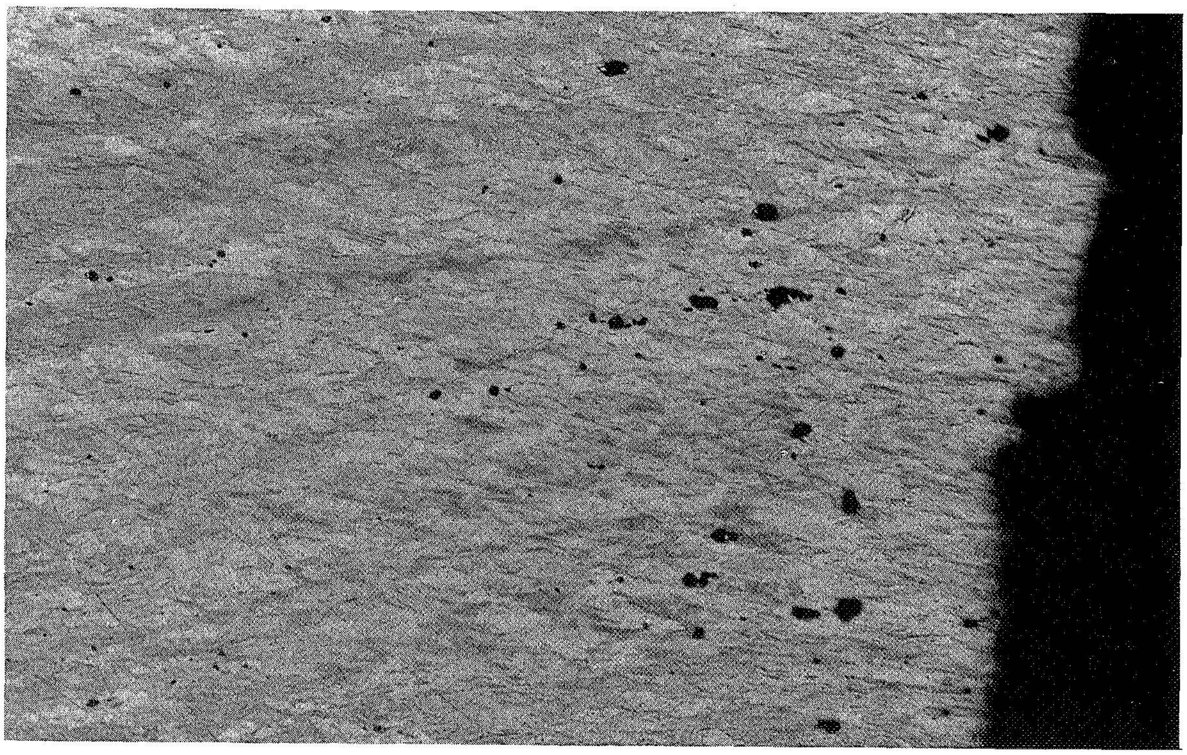
"Flaw" arrows in heat affected zone of plate 2CA in Panel No. 6 after tensile tests. Specimen (Plane 4), left, failed in weld; specimen (Plane 5), right, failed in "flaw". Magnification 4X. Marbles etchant.

Sections Through "Flaw" in Panel No. 6 Planes 4 and 5

Figure 14



Plane 4



Plane 5

Fracture regions of Panel No. 6 tensile specimens; Planes 4, above, showing weld microstructure, Plane 5, below, showing "flaw" microstructure. Dark voids due to pullout of Ti (C, N) compounds. Fracture surfaces to right. Magnification 100X. Marbles etchant

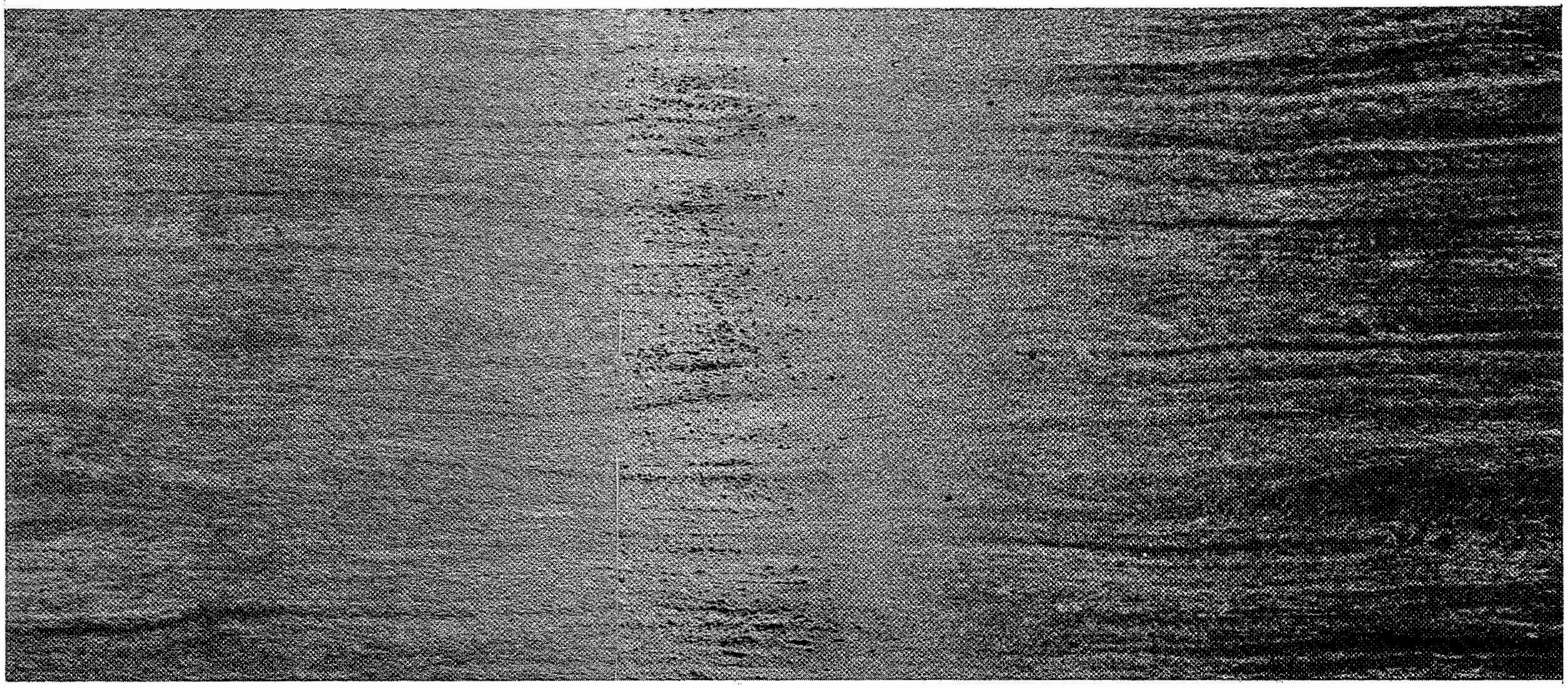
Fracture Regions of Panel No. 6 Tensile Specimens - Planes 4 and 5

Figure 15

Section through heat affected zone of plate 2CA in Panel No. 6 after impact test, specimen 6C1. View is of base of specimen. Through-the-thickness notch, oriented parallel to fracture, above right, was located in "flaw" but about 0.4 inch (1.02 cm) beyond plane of view. No evidence of abnormal microstructural features is observed, i.e., the view plane is beyond the flaw. Magnification 100X. Marbles etchant.

Fracture Region of Panel No. 6 Impact Specimen—Plane 6

Figure 16

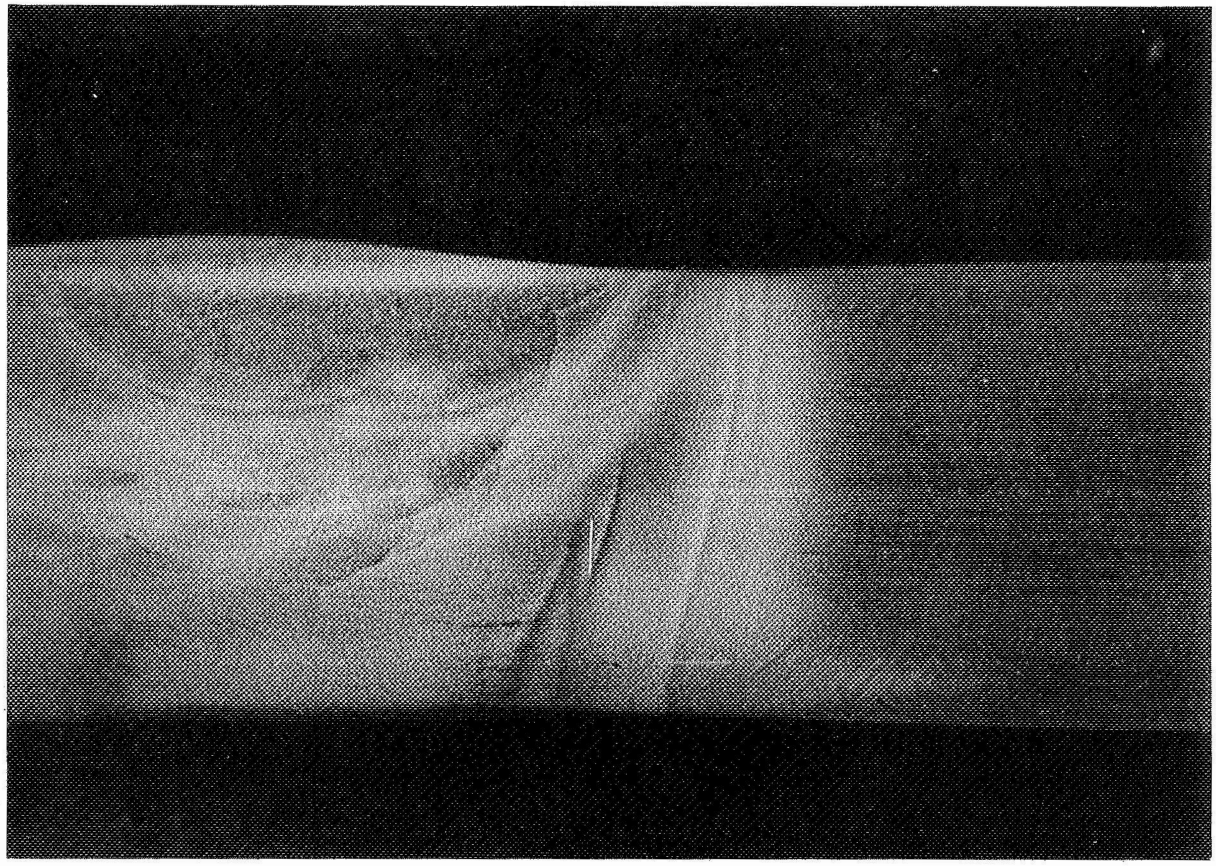


Transition microstructure in heat affected zone of Plate No. 8 (weld toward left). Compare to broad band of structure in Panel No. 6, Figure 12. Fine particles may be reverted austenite stabilized by alloy segregation occurring in barrels and by the thermal history of the HAZ.

100X Marbles etchant.

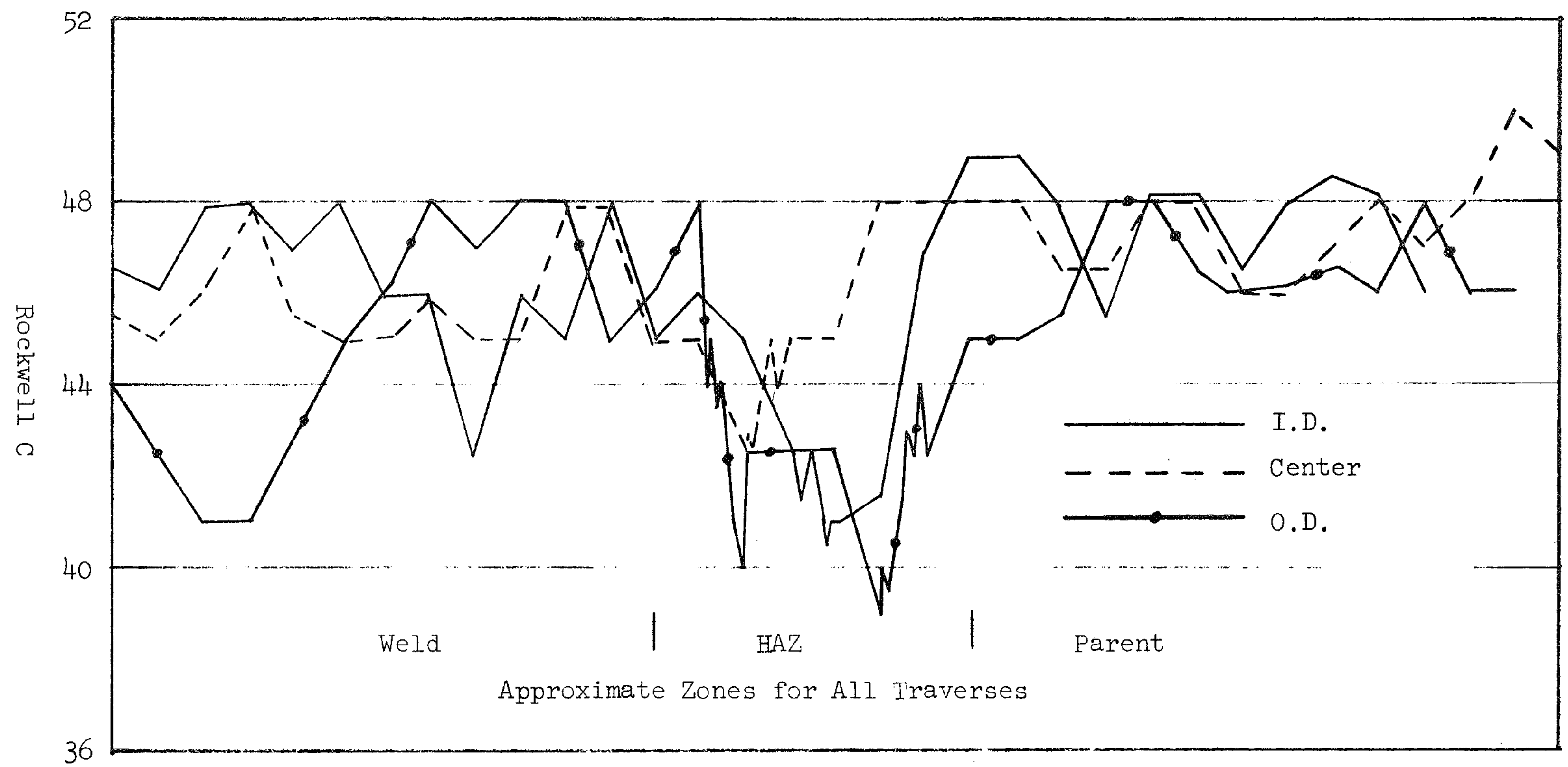
Panel No. 8 Microstructural Examination

Figure 17



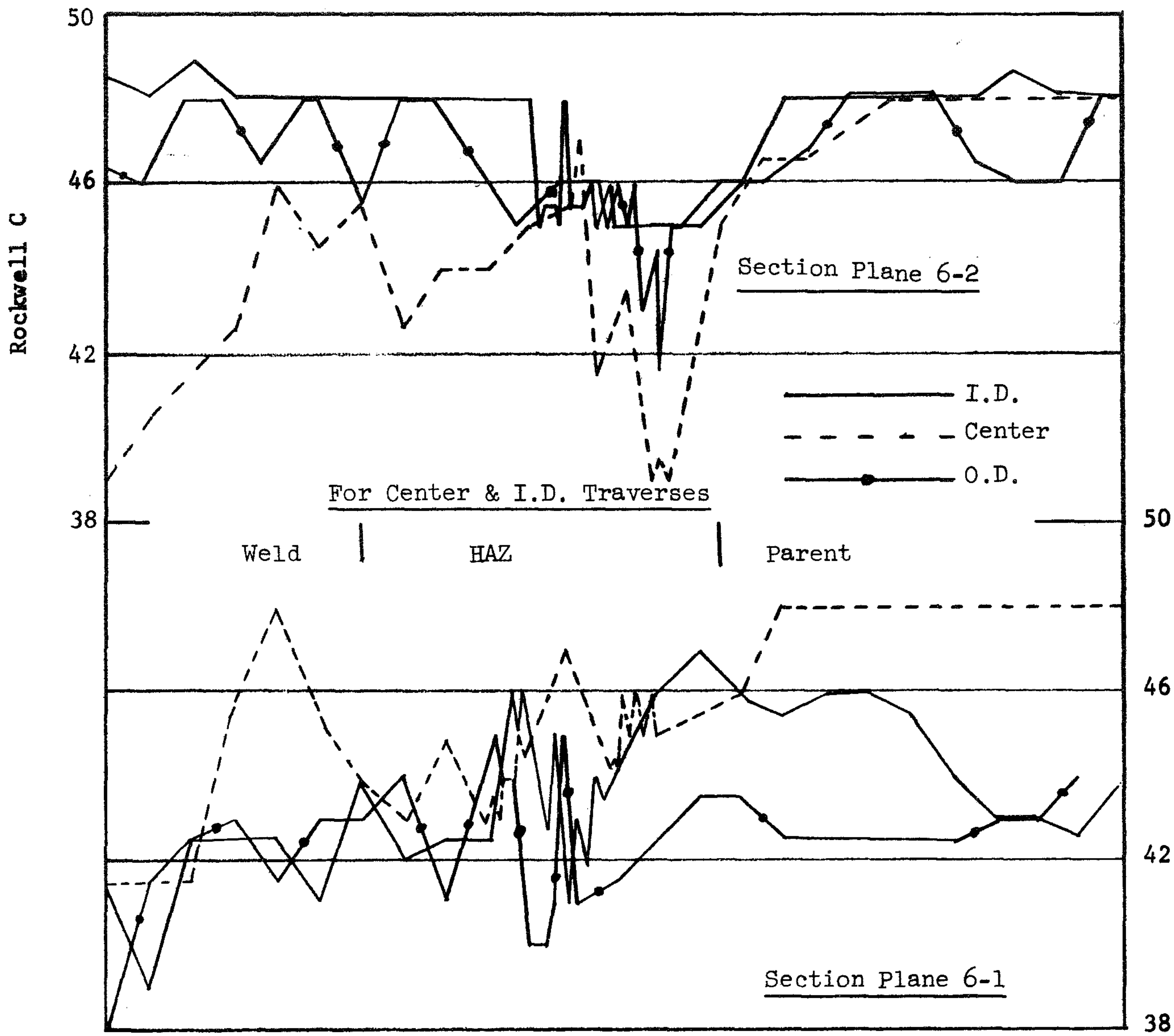
Microhardness Transverse Through Radiographic and Magnetic
Particle Indication Region of Plate No. 6, Plane 1

Figure 18



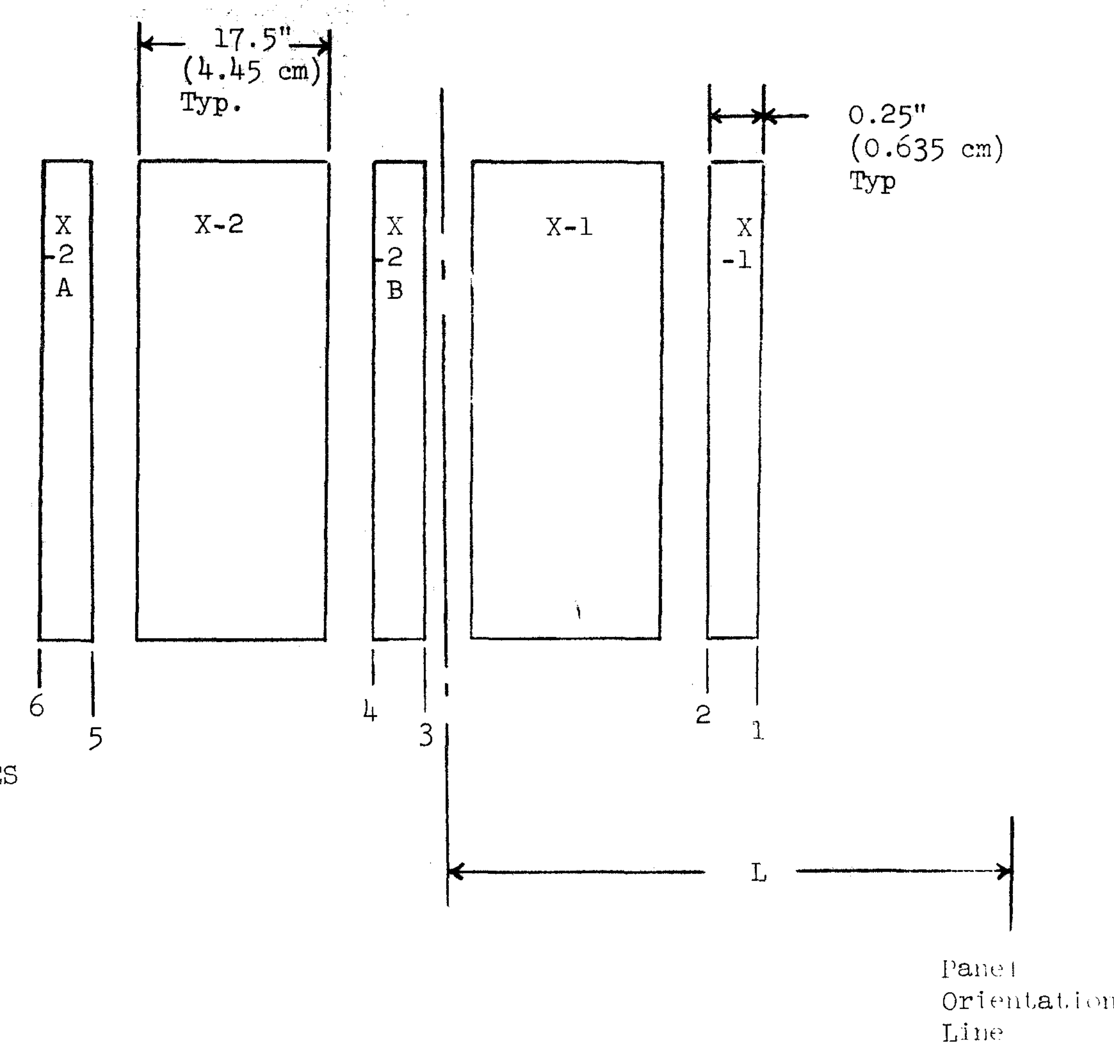
Weld-to-Parent Microhardness Traverses Plate 6,
Section through Radiographic Indication, Section Plane 6-1

Figure 19



Typical Microhardness Weld-to-Parent Traverses Plate 6. Section 6-1 Outside High-Density Indication and Section 6-2 Through High-Density Indication

Figure 20

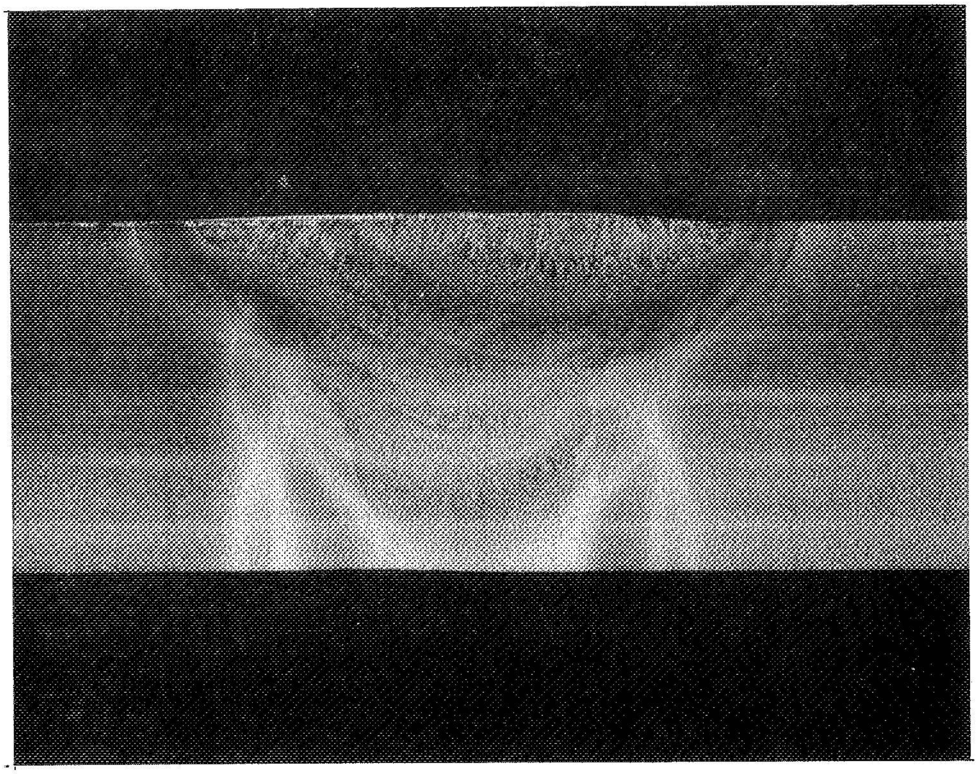


NOTE: X = Panel No., i.e., 7, 8, and 9

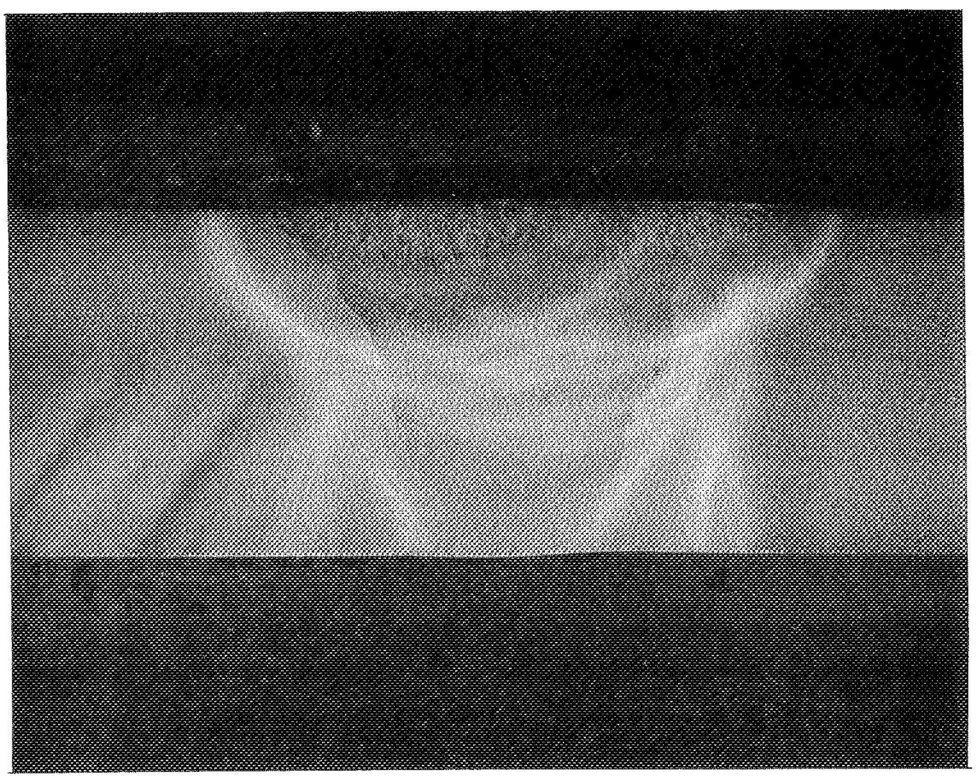
Plate No.	L-in (cm)
7	23.0 (58.5)
8	17.0 (43.2)
9	17.5 (44.5)

Panels 7, 8, and 9 Evaluation Section Planes

Figure 21



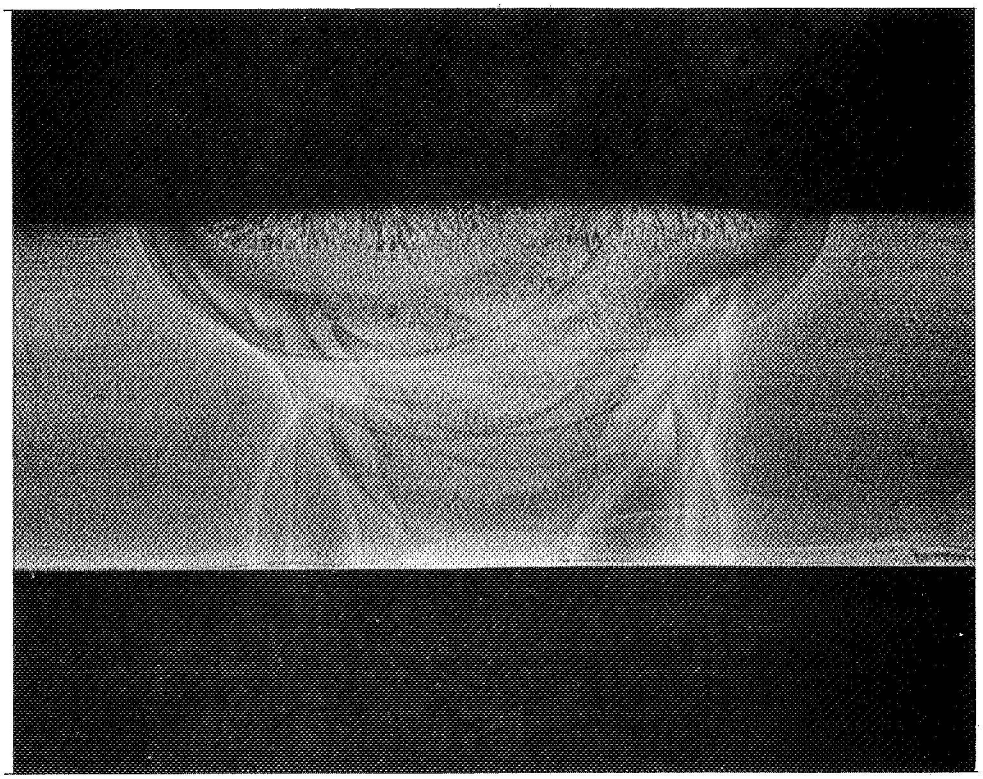
Section Plane 1



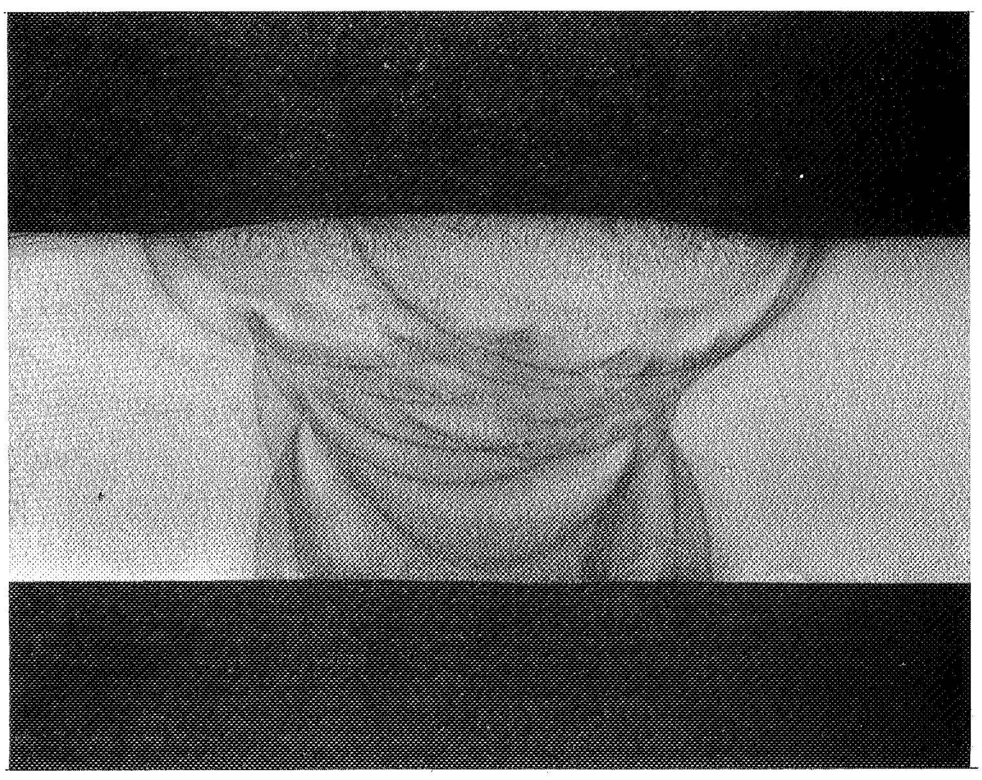
Section Plane 2

Plate 7 Sections Transverse to WG8 Weld. O.D. Surface at Top. Section Planes 1 and 2. Normal Microstructure. (Evidence of Abrasive Wheel Cut-Off Burn Lower Left of Bottom Photo.) 3X Marbles Etch.

Figure 22



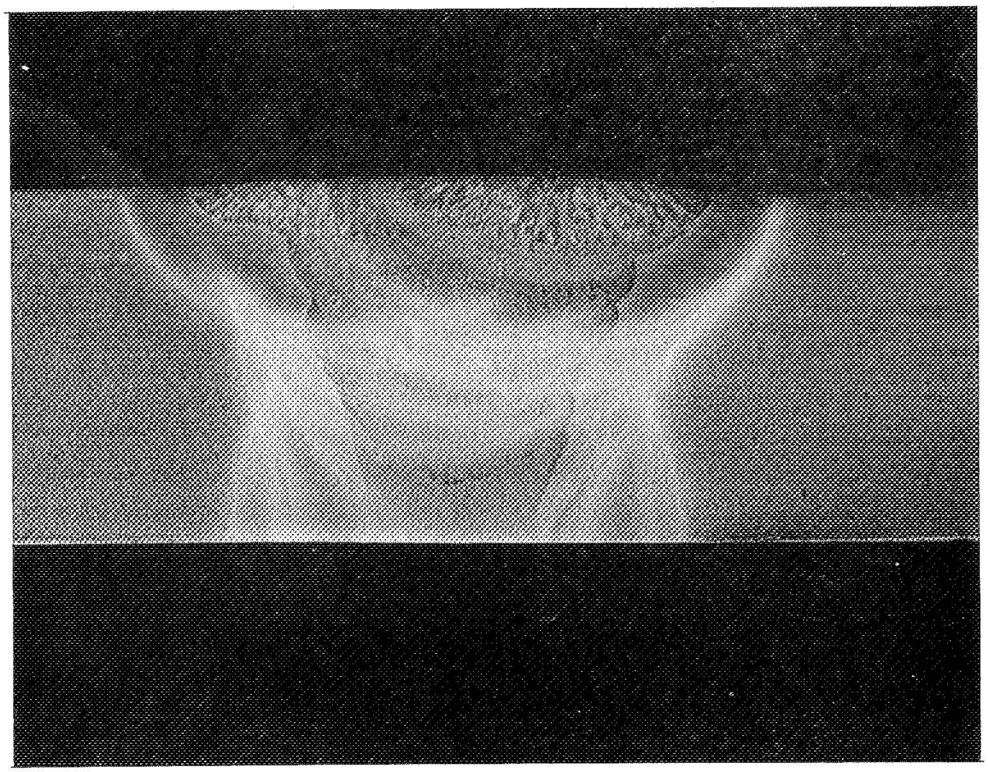
Section Plane 3



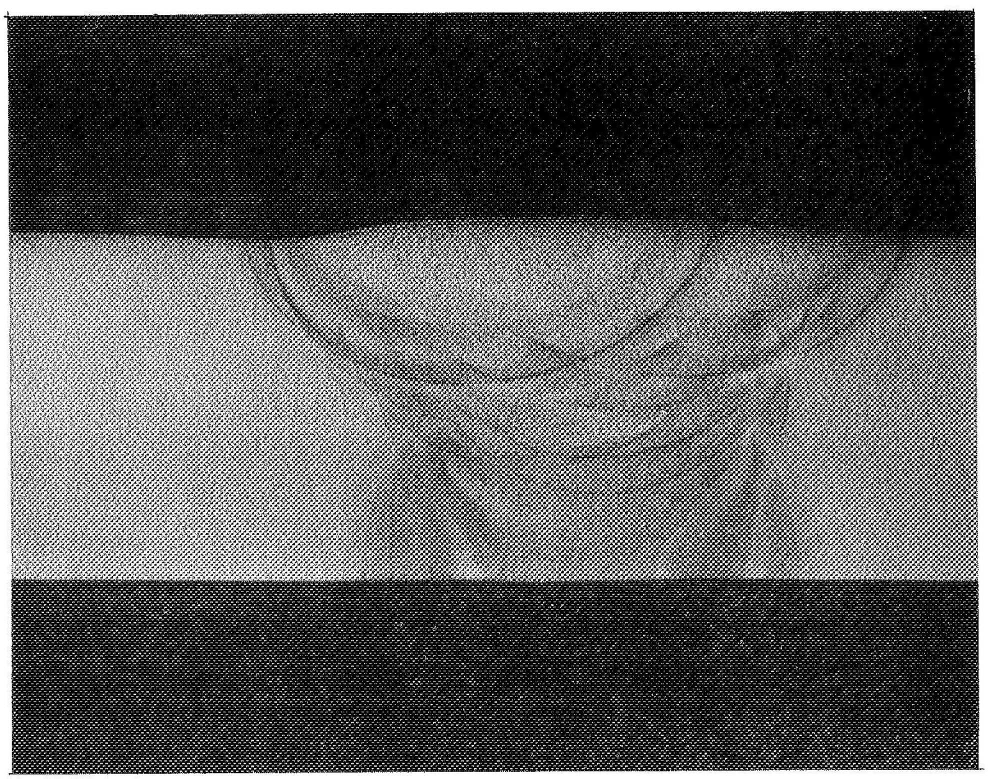
Section Plane 4

Plate 7 Sections Transverse to WG8 Weld. O.D. Surface at Top. Section Planes 3 and 4. Normal Microstructure. 3X Marbles Etch.

Figure 23

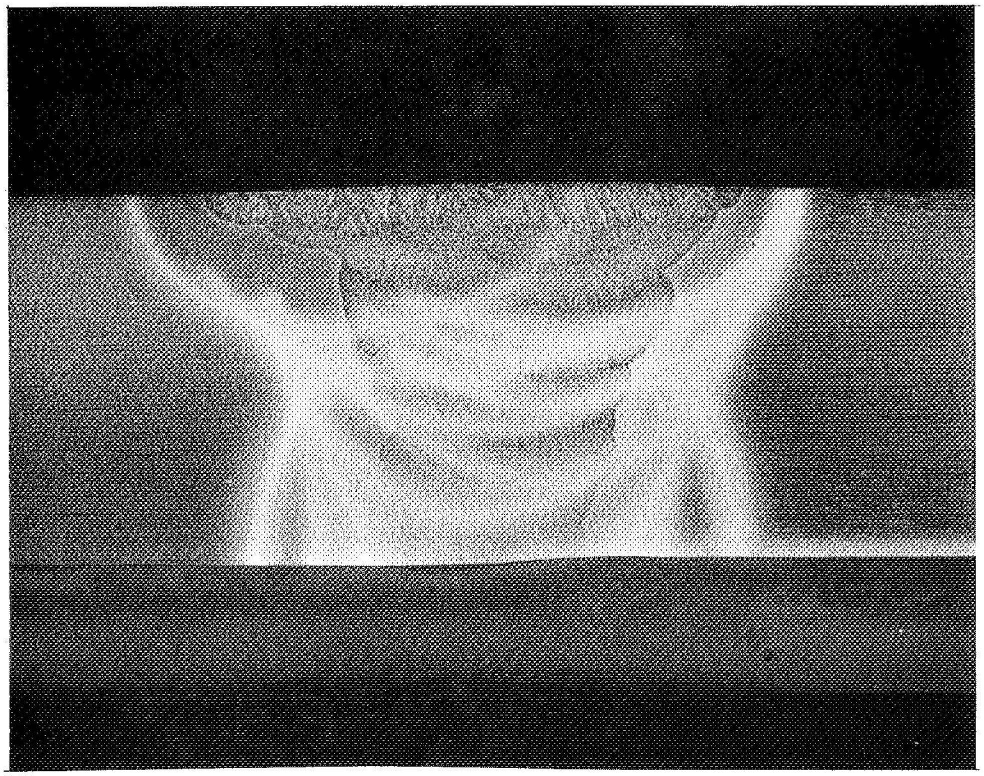


Section Plane 5

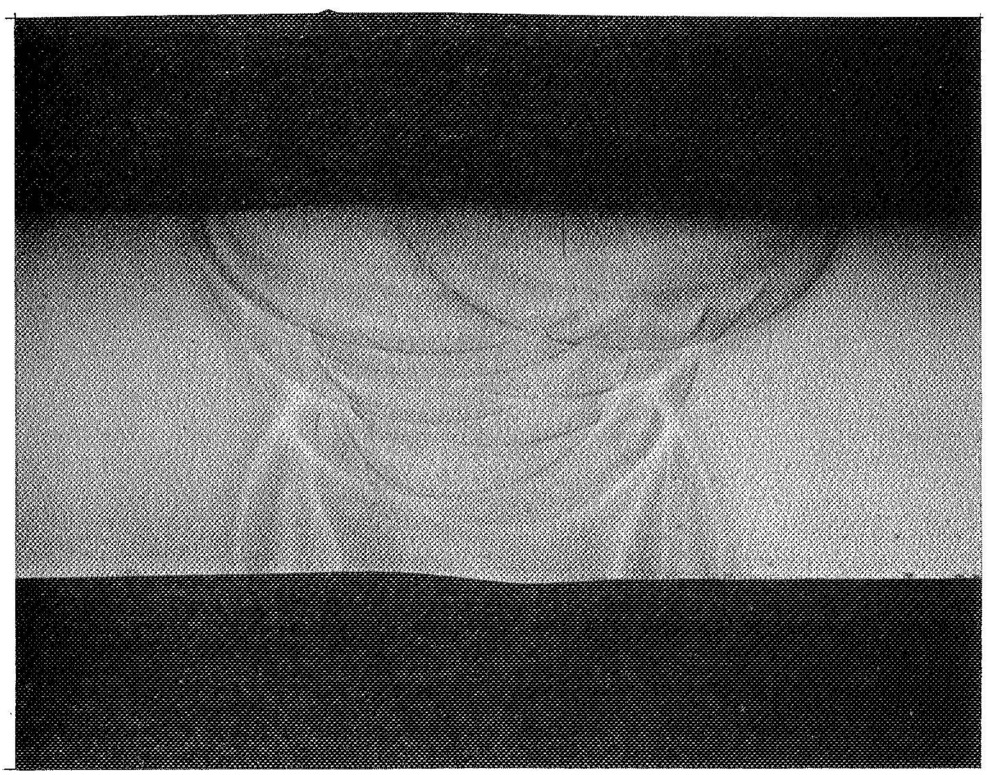


Section Plane 6

Plate 7 Sections Transverse to WG8 Weld. O.D. Surface at Top. Section Planes 5 and 6. Normal Microstructure. 3X Marbles Etch.



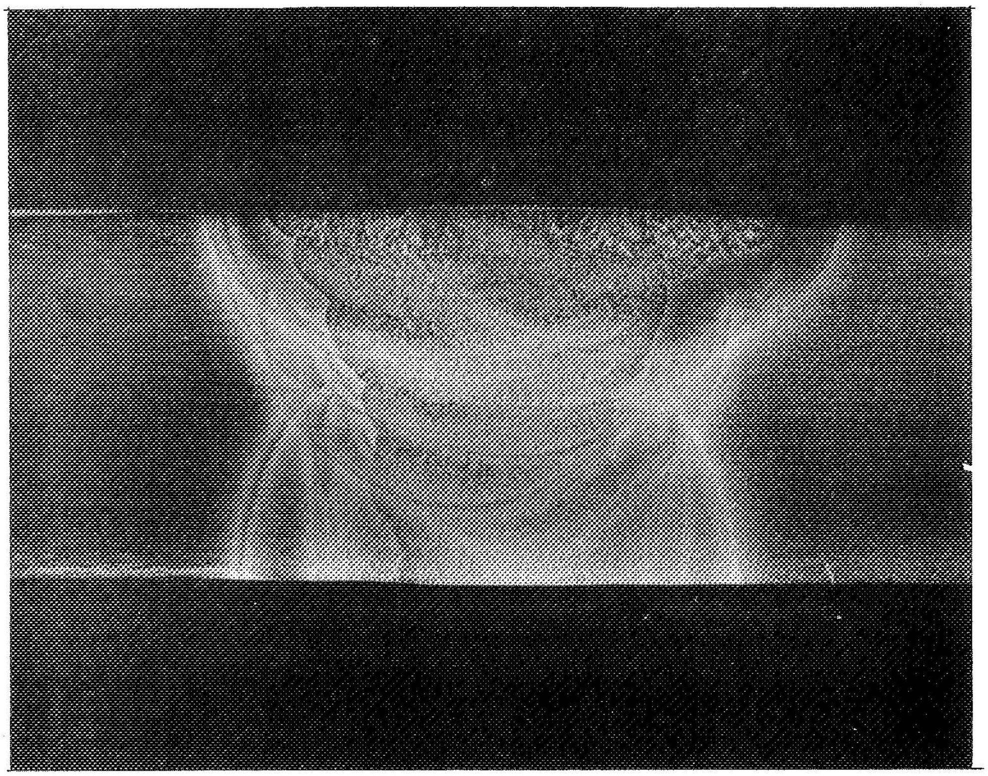
Section Plane 1



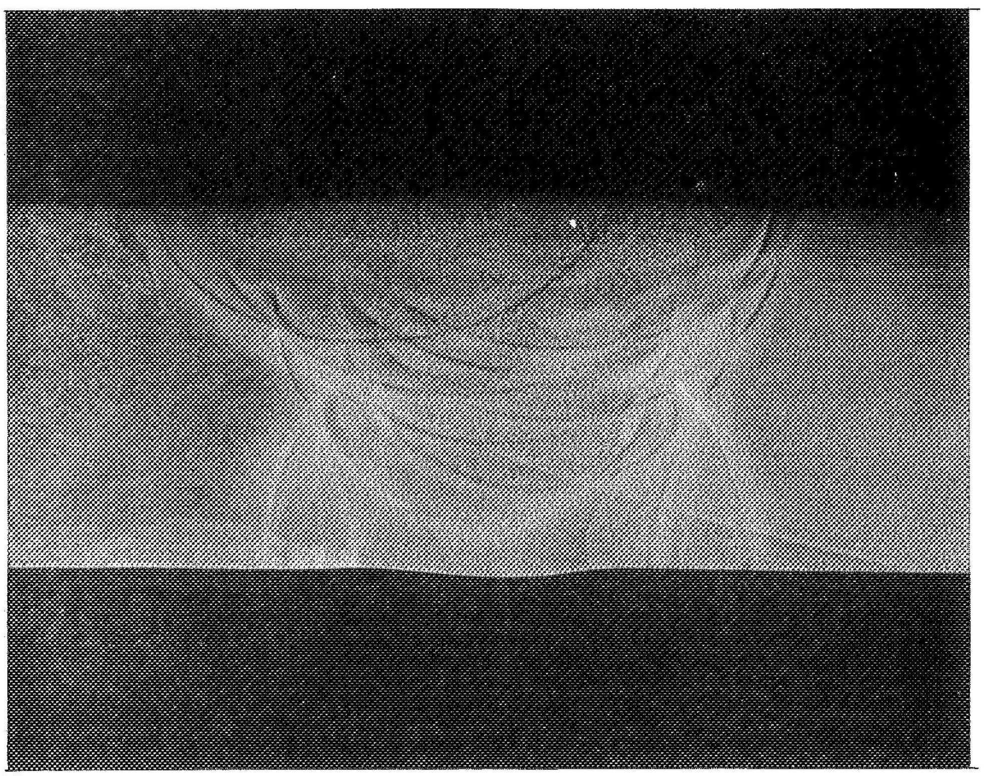
Section Plane 2

Plate 8 Sections Transverse to WG10 Weld. O.D. Surface at Top. Section Planes 1 and 2. Normal Microstructure. 3X Marbles Etch.

Figure 25



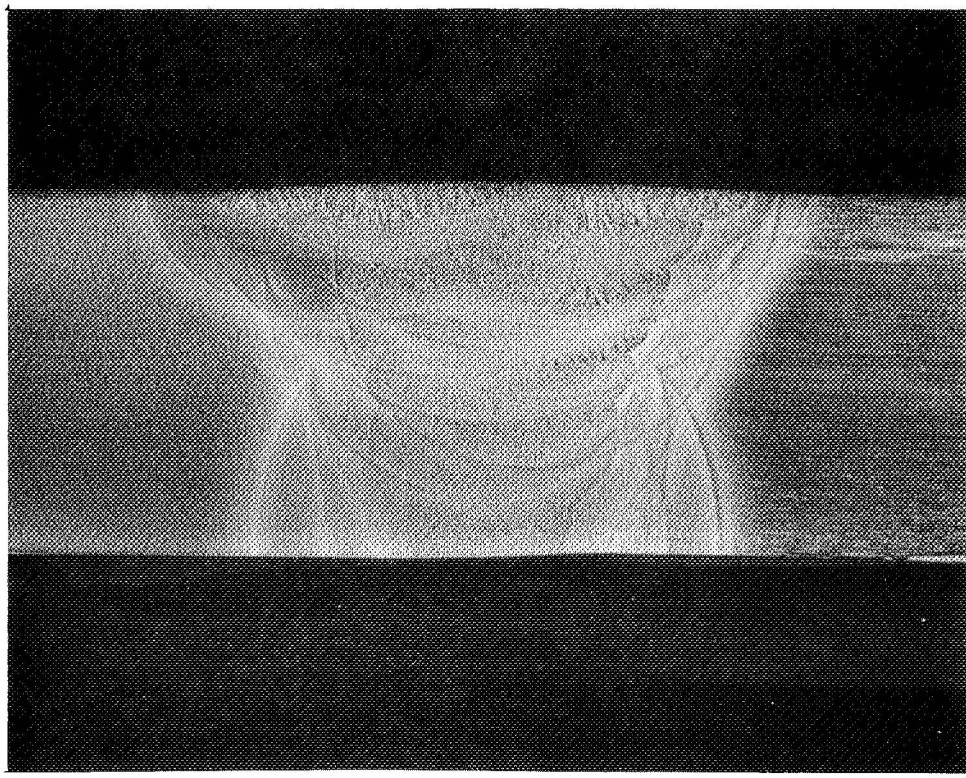
Section Plane 3



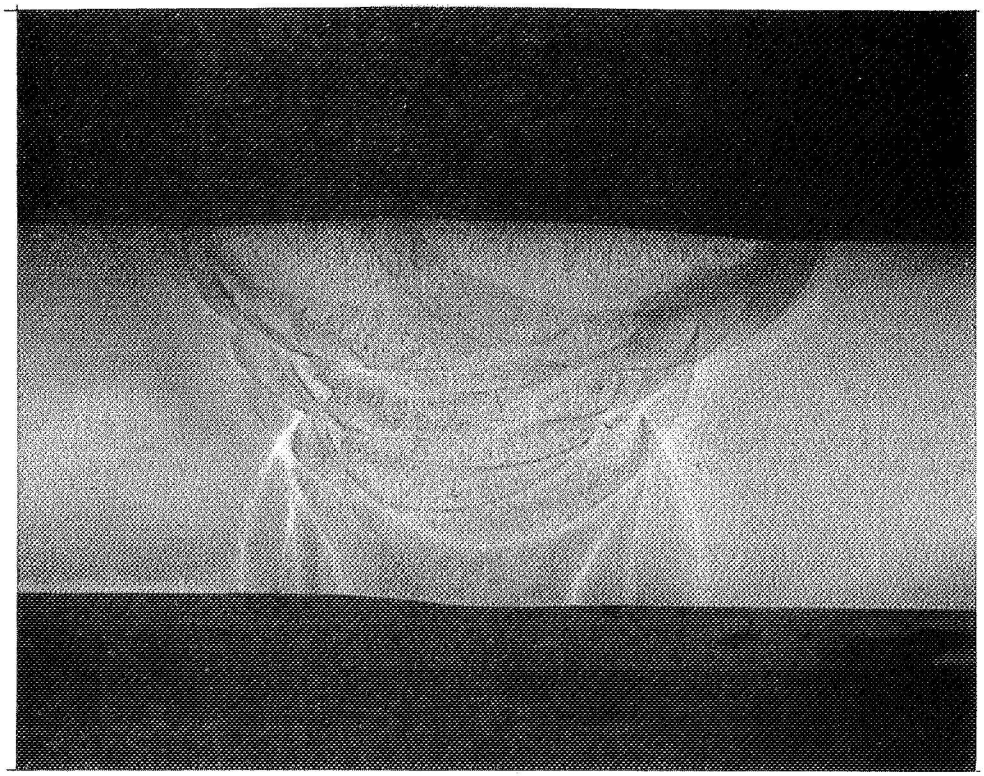
Section Plane 4

Plate 8 Sections Transverse to WG10 Weld. O.D. Surface at Top. Section Planes 3 and 4. Normal Microstructure. (Horizontal Streks are Etching Stains.)
3X Marbles Etch.

Figure 26



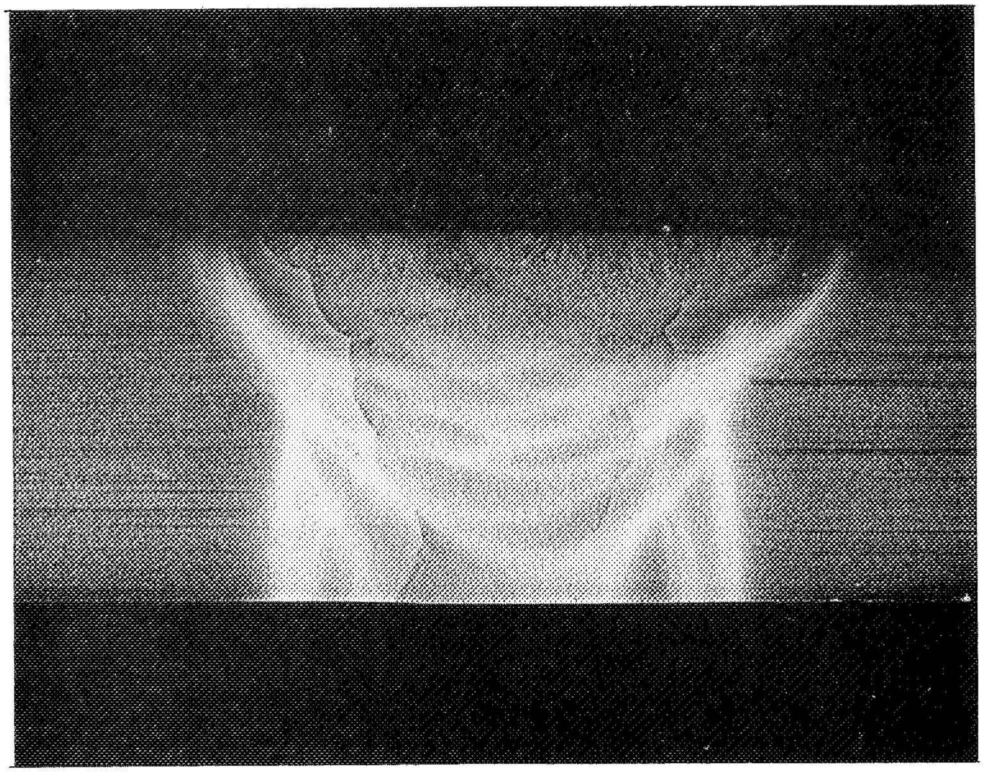
Section Plane 5



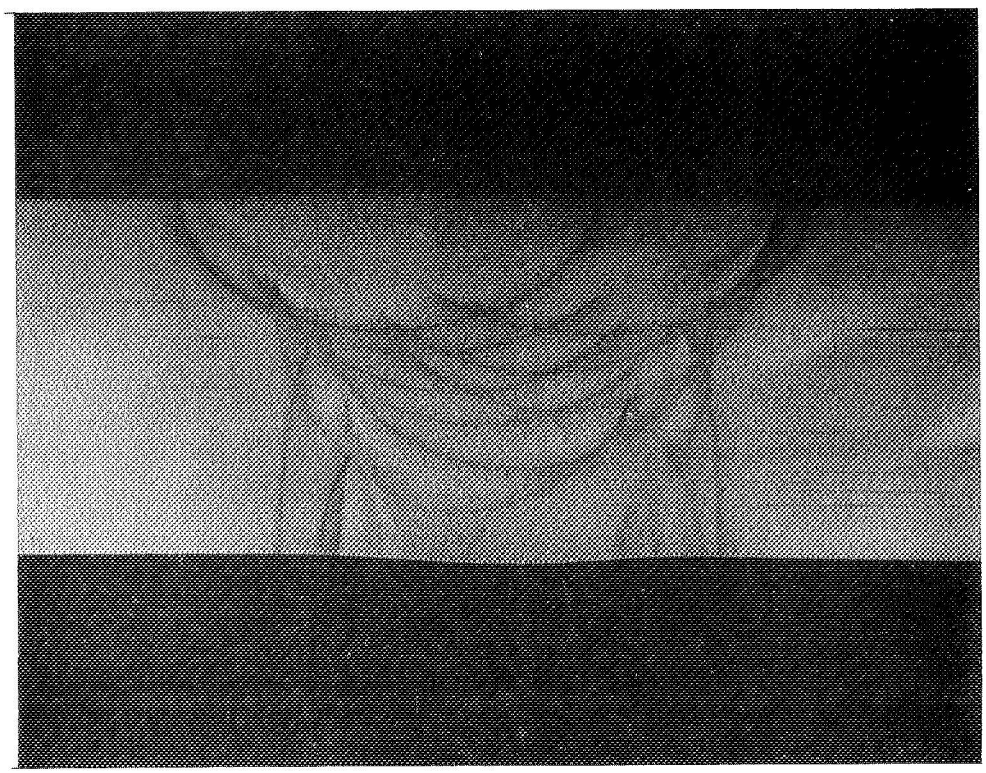
Section Plane 6

Plate 8 Sections Transverse to WG10 Weld. O.D. Surface at Top. Section Planes 5 and 6. Normal Microstructure. 3X Marbles Etch.

Figure 27



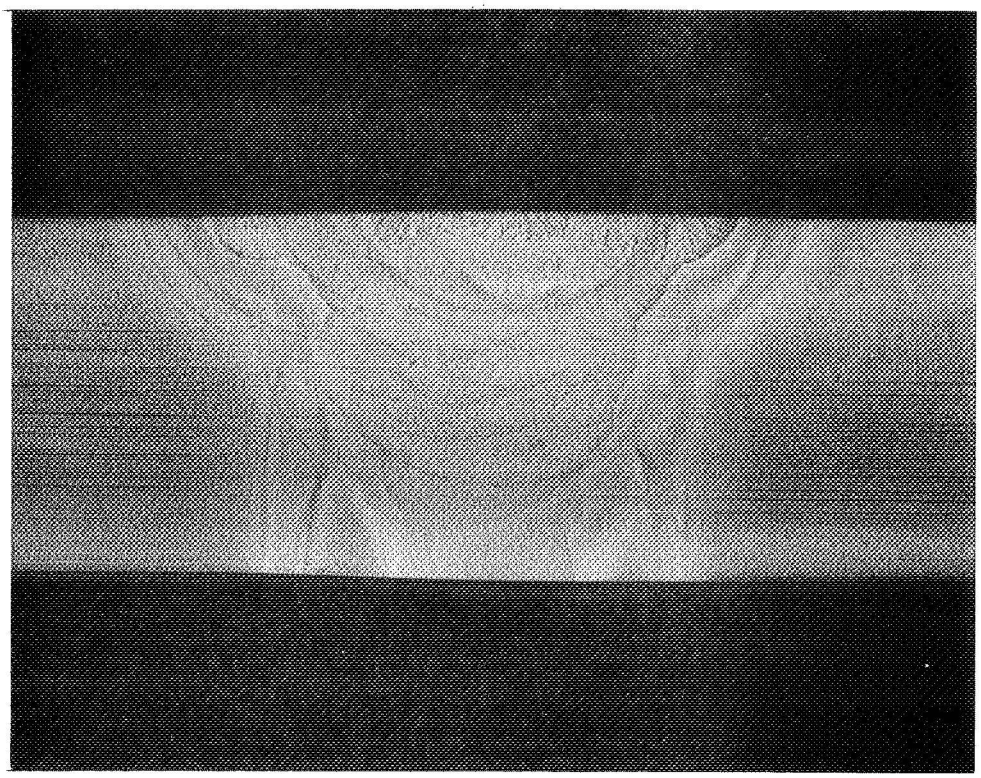
Section Plane 1



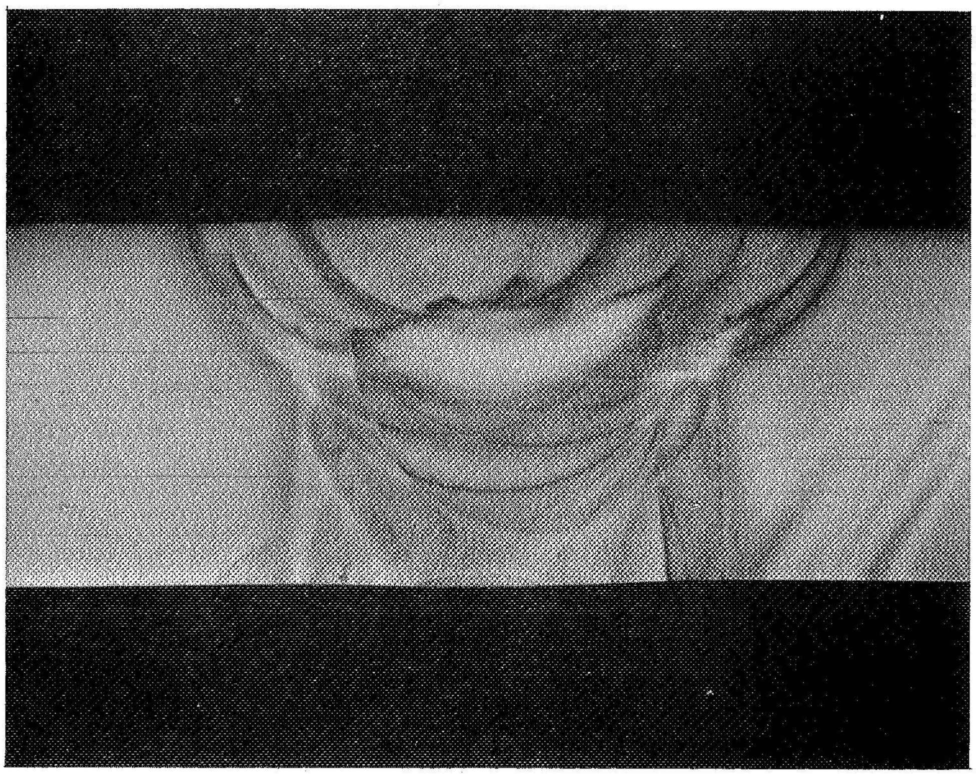
Section Plane 2

Plate 9 Section Transverse to W1CB Weld. O.D. Surface at Top. Section Planes 1 and 2. Normal Microstructure. 3X Marbles Etch.

Figure 28



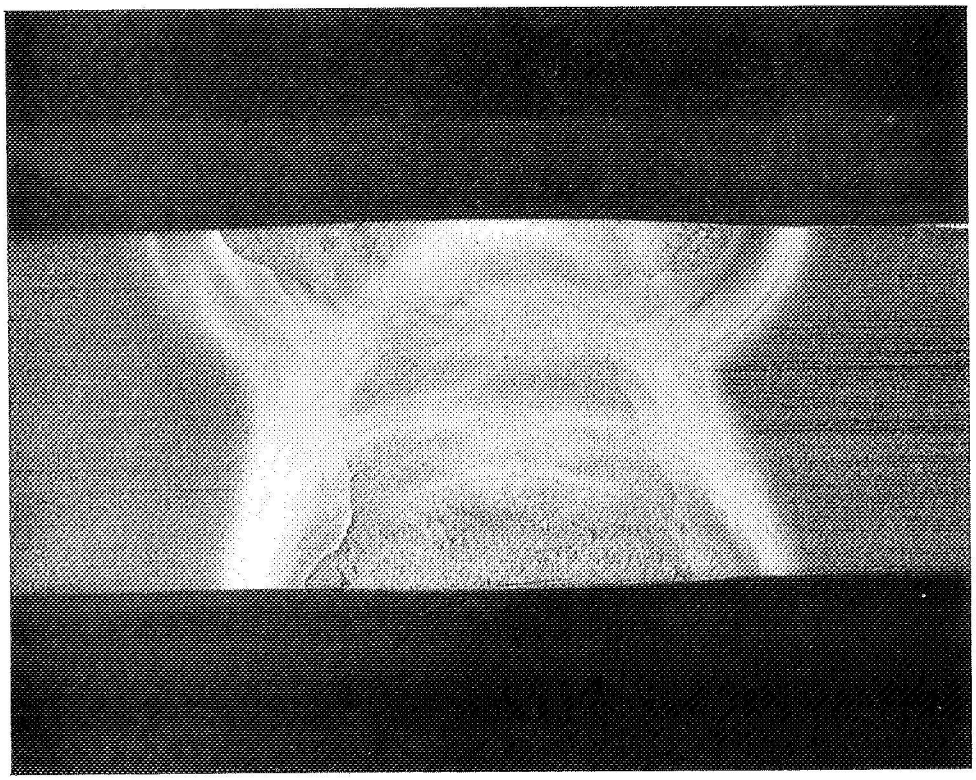
Section Plane 3



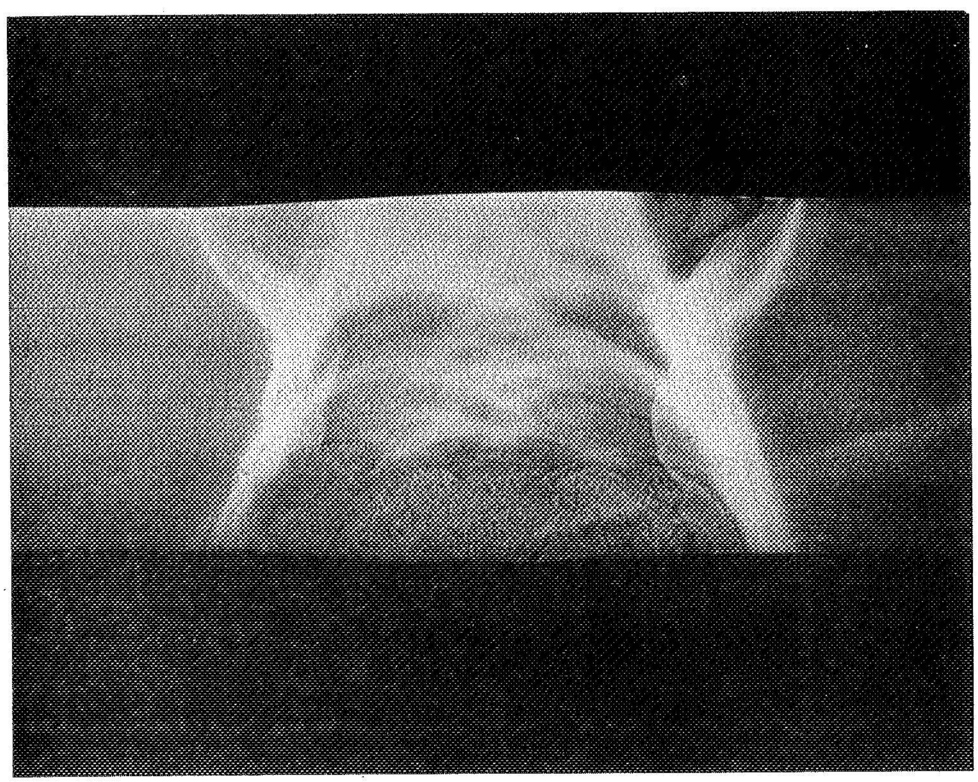
Section Plane 4

Plate 9 Section Transverse to W1CB Weld. O.D. Surface at Top. Section Planes 3 and 4. Normal Microstructre. (Evidence of Abrasive Wheel Cut-Off Burn in Lower Photo.) 3X Marbles Etch.

Figure 29



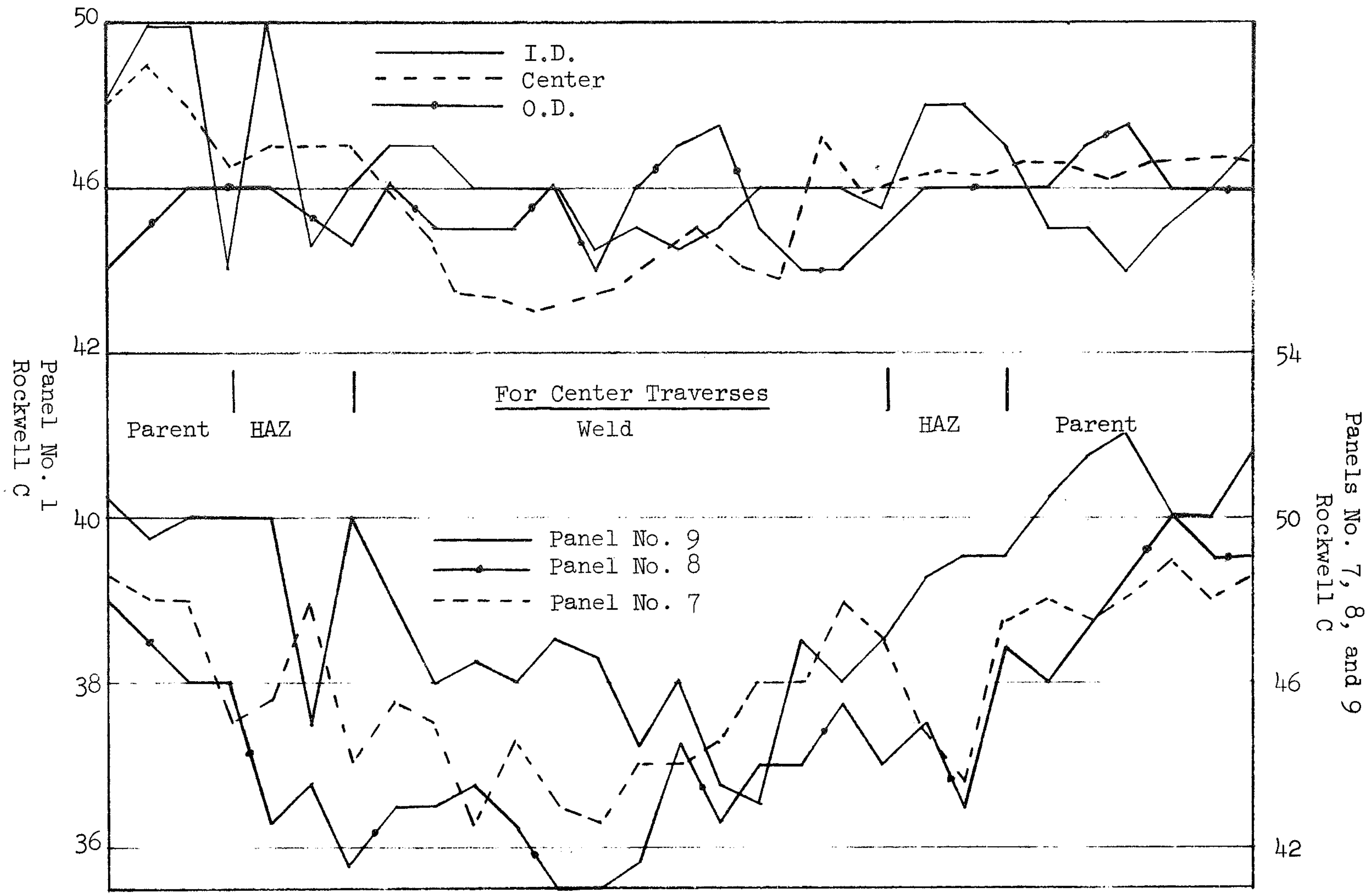
Section Plane 5



Section Plane 6

Plate 9 Sections Transverse to W1CB Weld. O.D. Surface at Top. Section Planes 5 and 6. Normal Microstructure. Weld Repair on I.D. Surface Evident. 3X Marbles Etch.

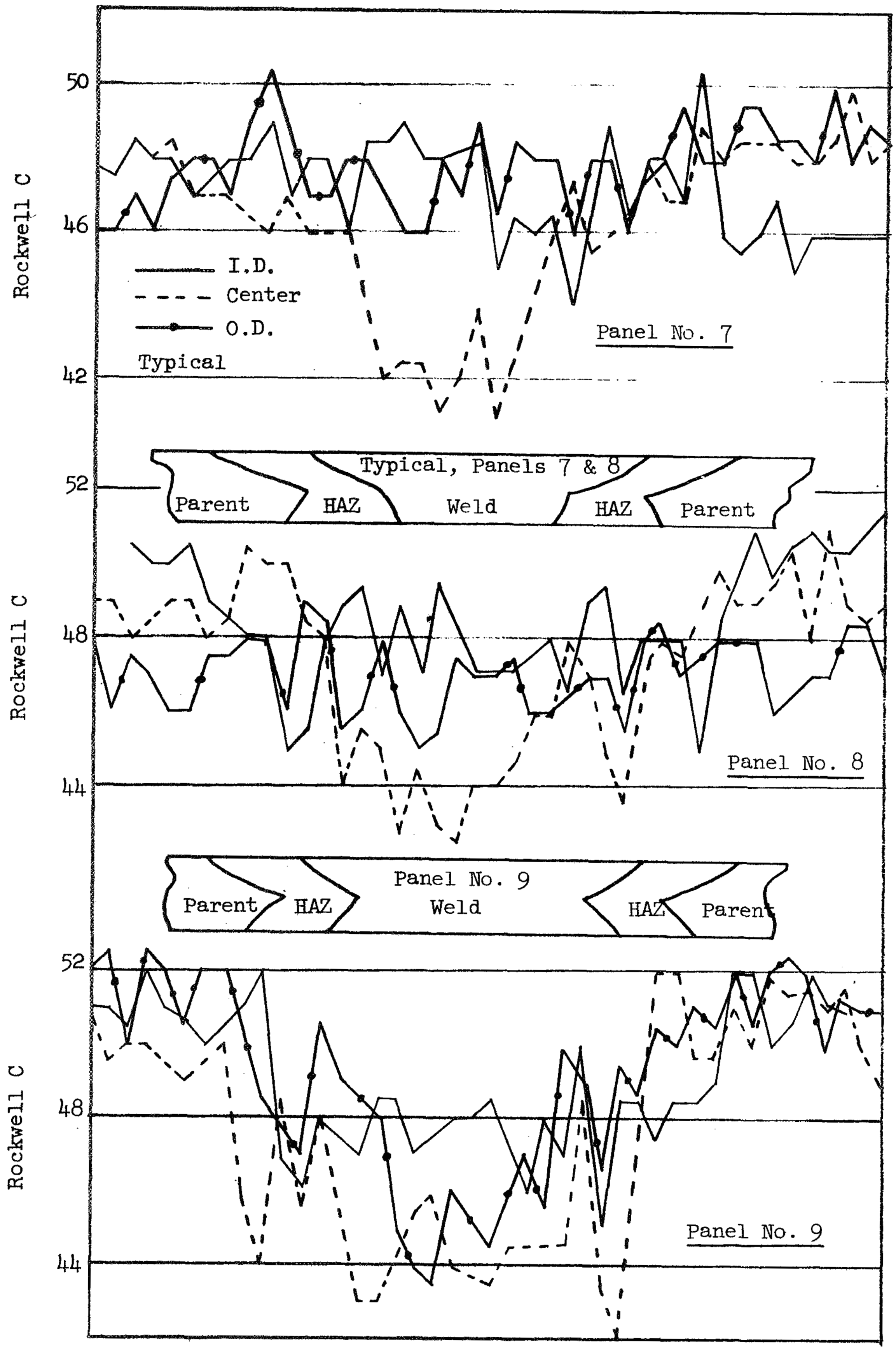
Figure 30



NASA CR 72676

Microhardness Traverses Through Typical Welds, Panel No. 1 Standard;
Panels No. 7, 8, 9 Typical Mid-Thickness Traverses

Figure 31

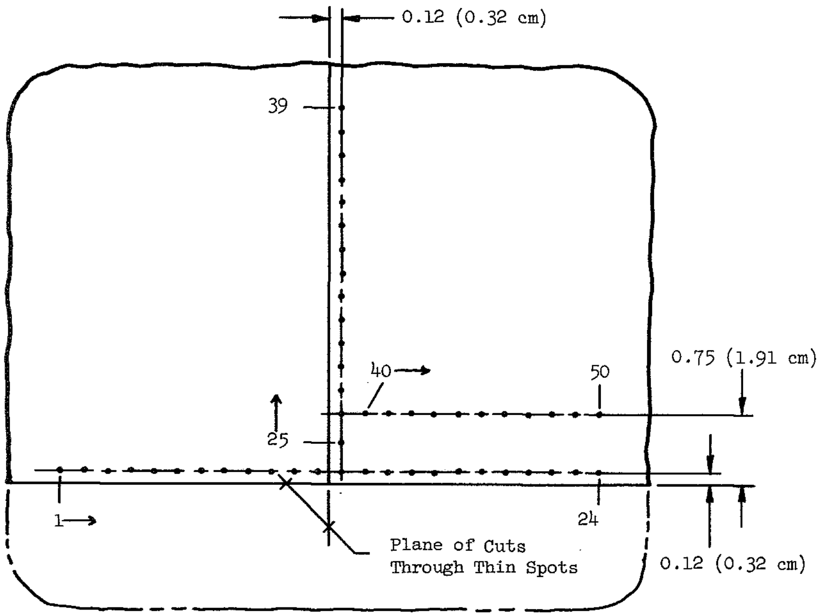


Typical I.D., O.D. and Center Microhardness Traverses, Panels No. 7, 8, and 9

Figure 32

Figure 33

a. Layout of Thickness Measurement Locations:



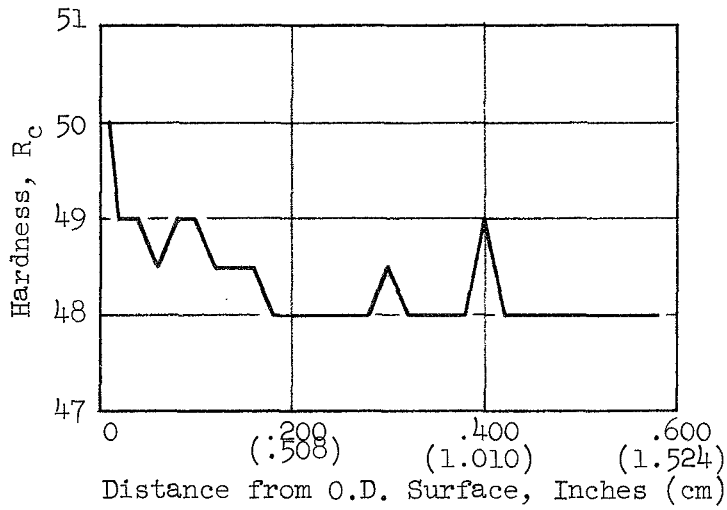
NOTE: Numbers represent thickness reading station locations.
Measurements spaced approximately 0.25 inch (0.64 cm) apart.

b. Table of Thickness Measurements

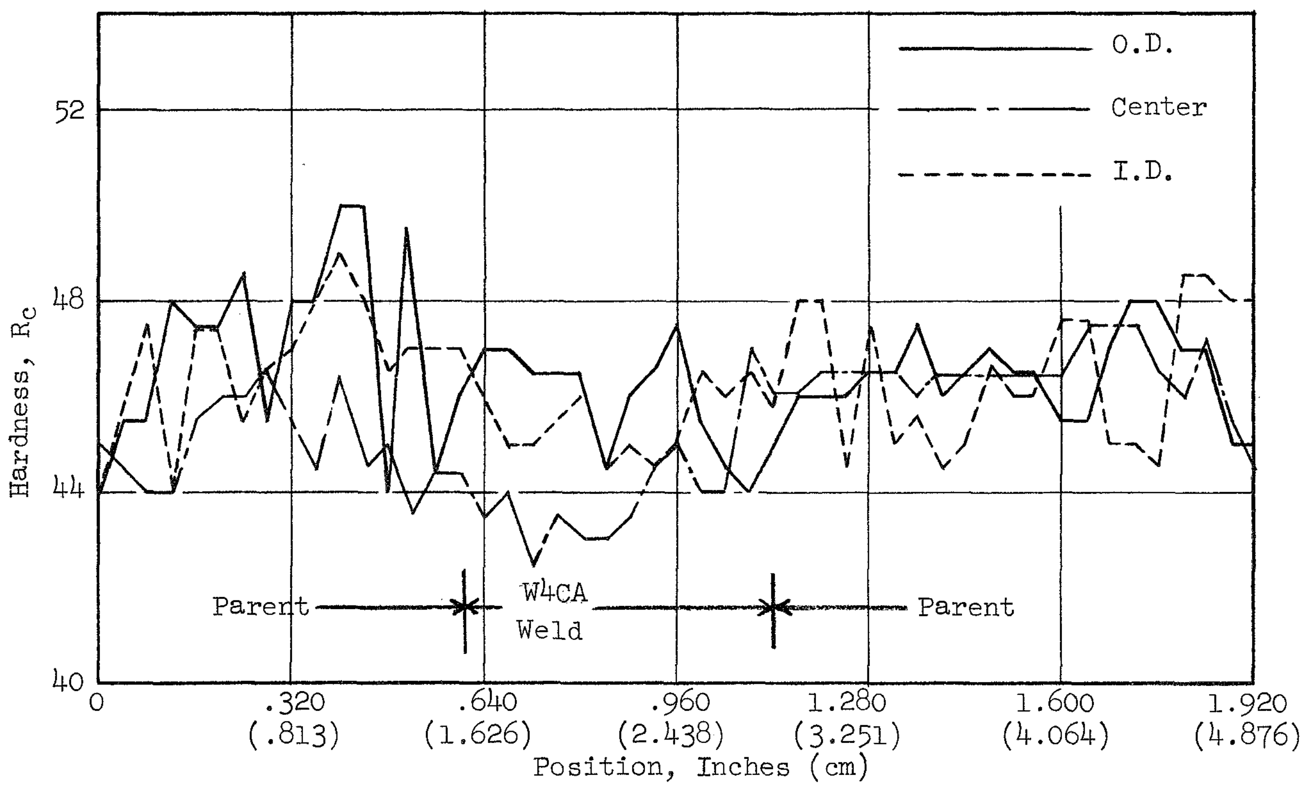
Station No.	Thickness Dim. Inch	(cm)	Station No.	Thickness Dim. Inch	(cm)
1	0.653	1.659	26	0.587	1.491
2	0.652	1.656	27	0.595	1.511
3	0.651	1.654	28	0.602	1.529
4	0.647	1.643	29	0.611	1.552
5	0.641	1.628	30	0.619	1.572
6	0.636	1.615	31	0.628	1.595
7	0.629	1.598	32	0.633	1.608
8	0.621	1.577	33	0.639	1.623
9	0.607	1.542	34	0.643	1.633
10	0.597	1.516	35	0.646	1.641
11	0.586	1.488	36	0.650	1.651
12	0.577	1.466	37	0.651	1.654
13	0.565	1.435	38	0.653	1.659
14	0.565	1.435	39	0.652	1.656
15	0.571	1.450	40	0.586	1.488
16	0.582	1.478	41	0.586	1.488
17	0.593	1.506	42	0.592	1.504
18	0.602	1.529	43	0.601	1.526
19	0.612	1.554	44	0.608	1.544
20	0.617	1.567	45	0.617	1.567
21	0.624	1.585	46	0.622	1.580
22	0.628	1.595	47	0.626	1.590
23	0.635	1.613	48	0.632	1.605
24	0.639	1.623	49	0.636	1.615
25	0.574	1.458	50	0.639	1.623

Panel No. 10 Micrometer Thickness Measurements

a. Through-the-Thickness Hardness Adjacent to Thin Spot in Panel No. 10

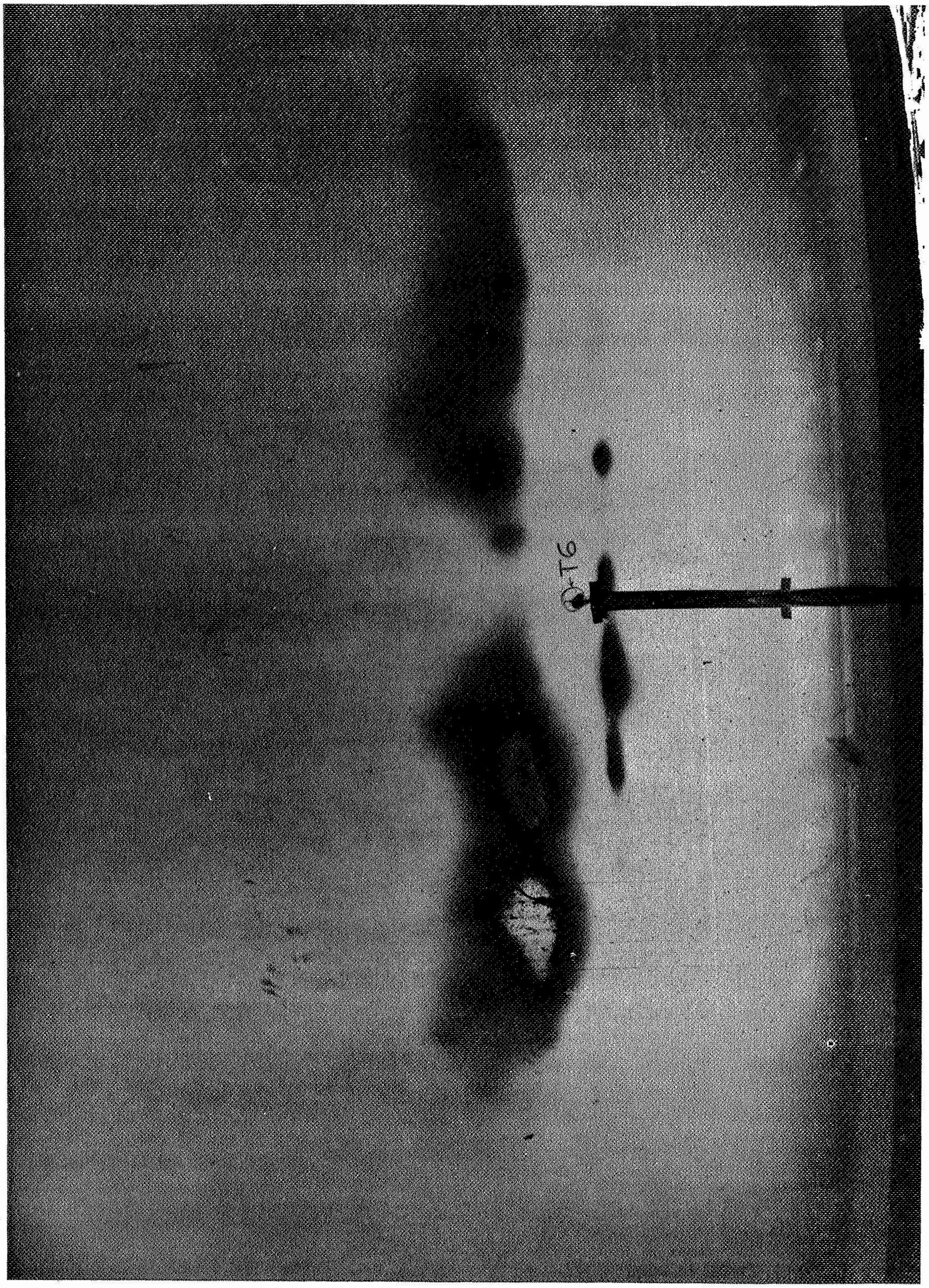


b. Hardness Traverse Through Standard Production Weld 260 Motor Case S/N SL-3.



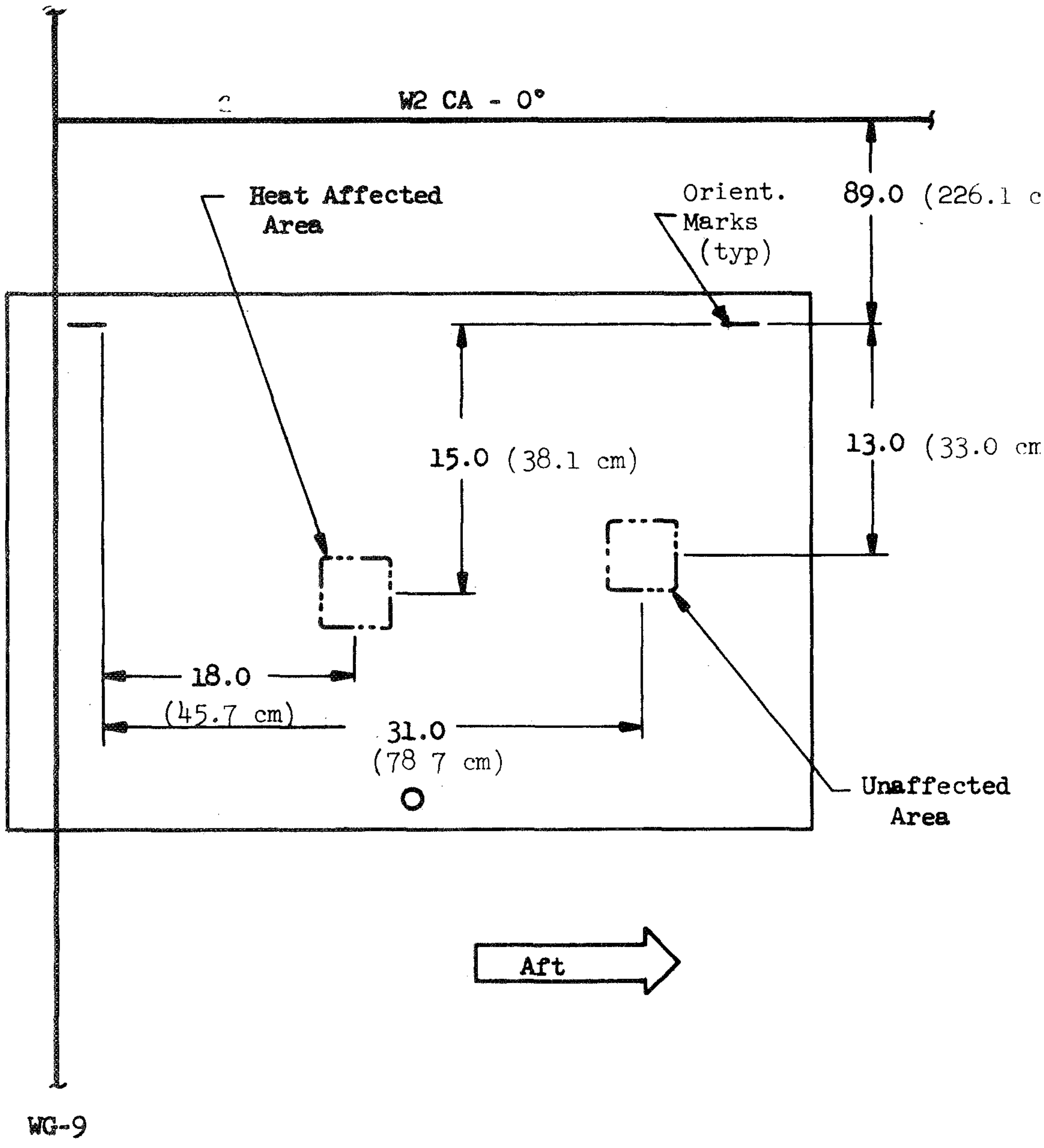
Panel No. 10 Thin Area Microhardness Compared to Standard Productions Weld

Figure 34



Typical Hot Spot on Motor 260-SL-3

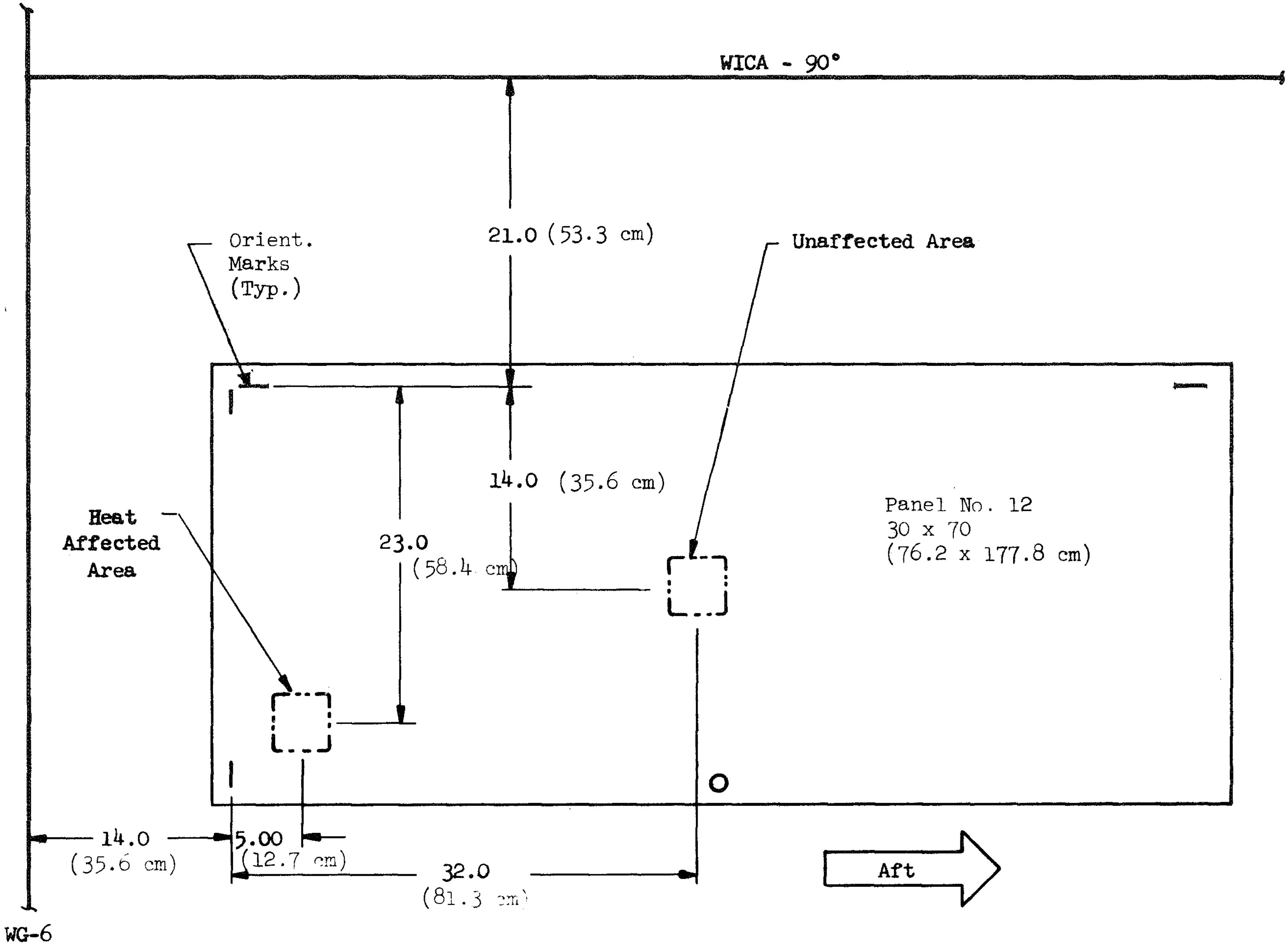
Figure 35



Note: Dimensions in inches.

Test Specimen Layout for Panel No. 11

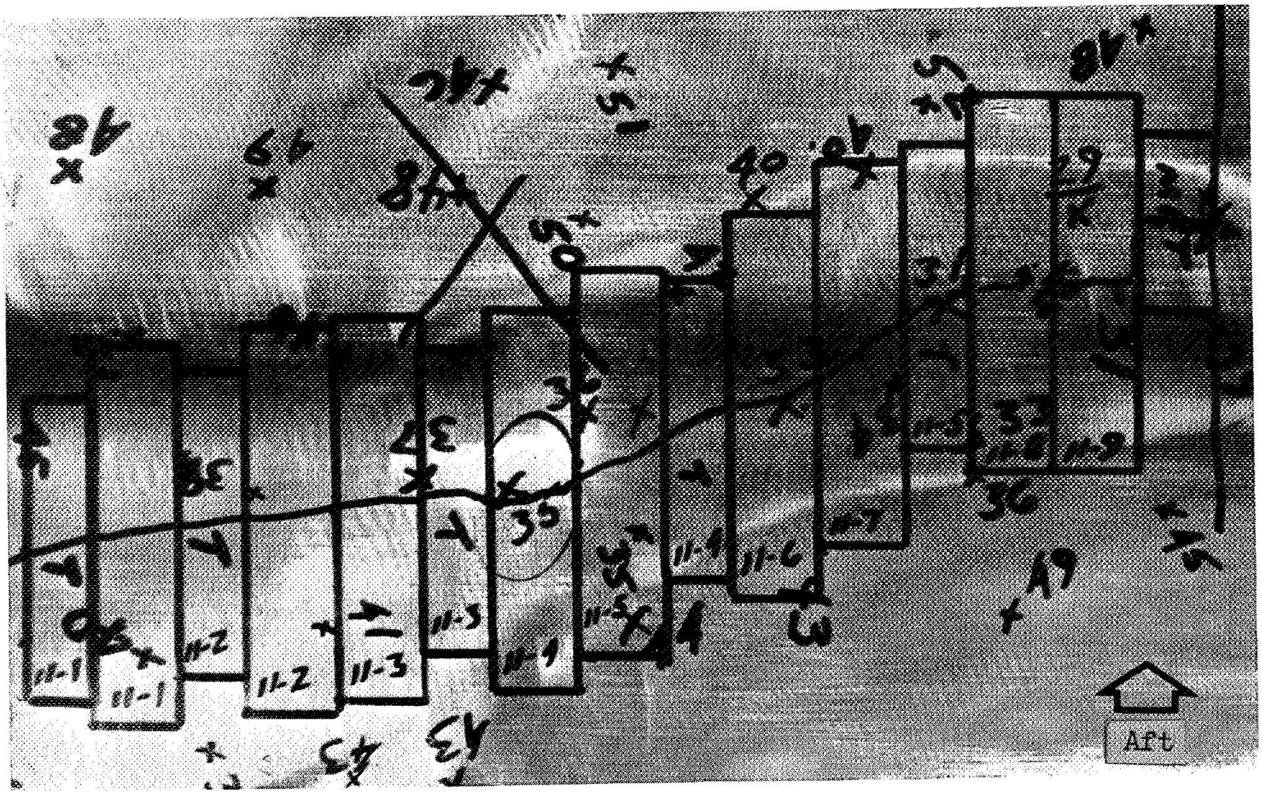
Figure 36



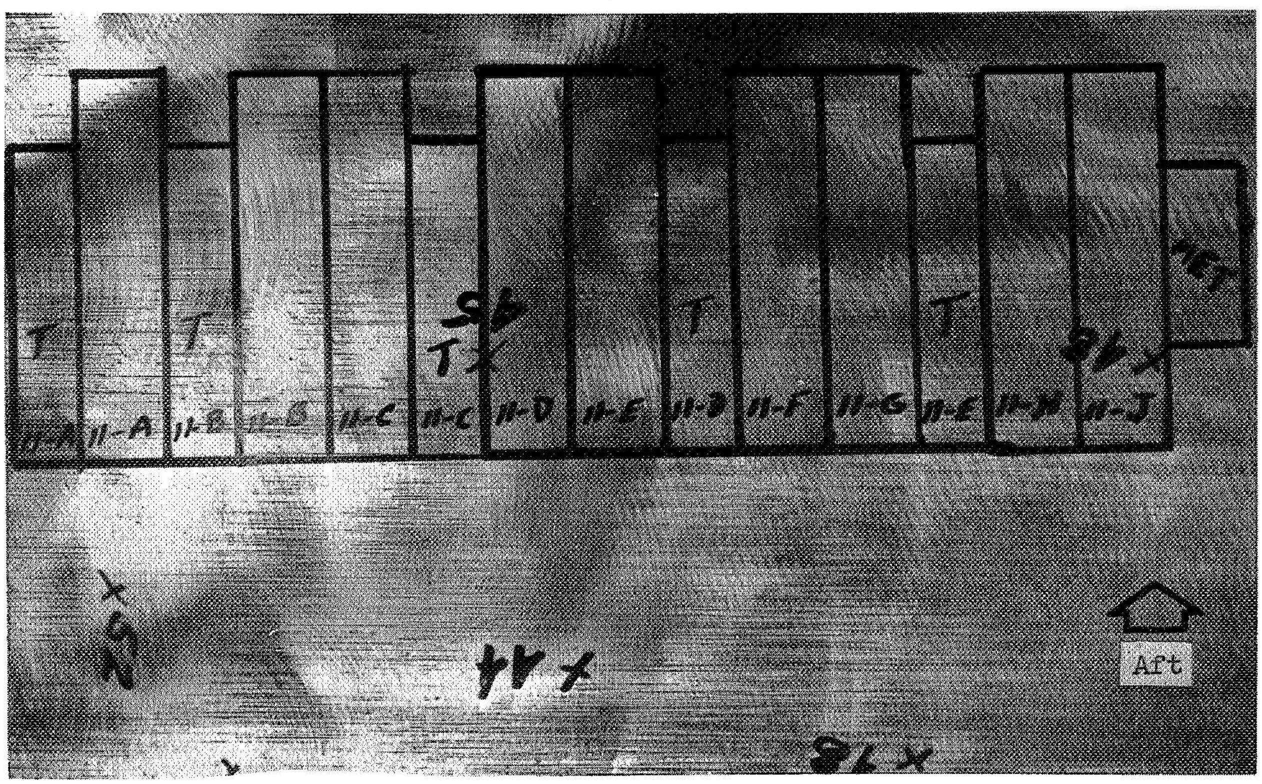
Note: Dimensions in inches.

Figure 37

Test Specimen Layout for Panel No. 12



(A)

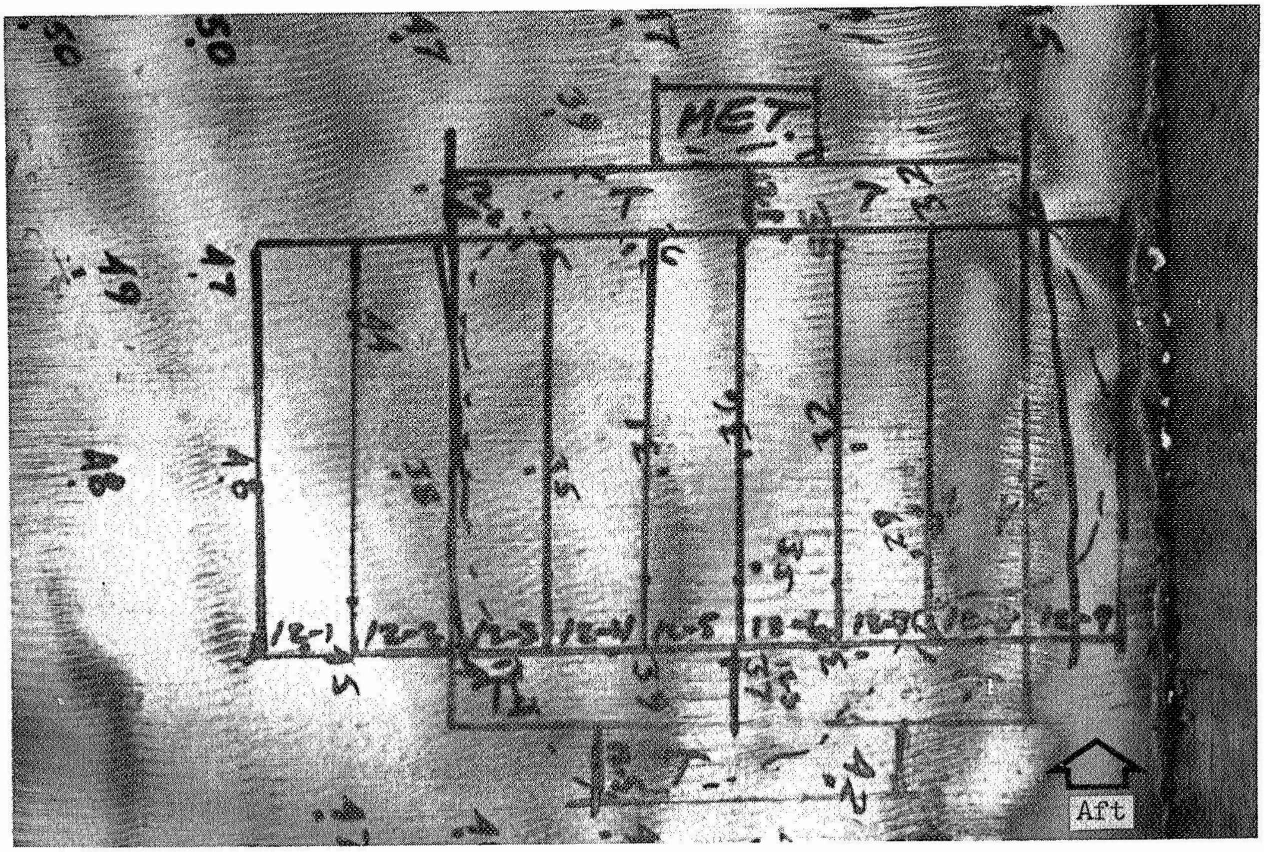


(B)

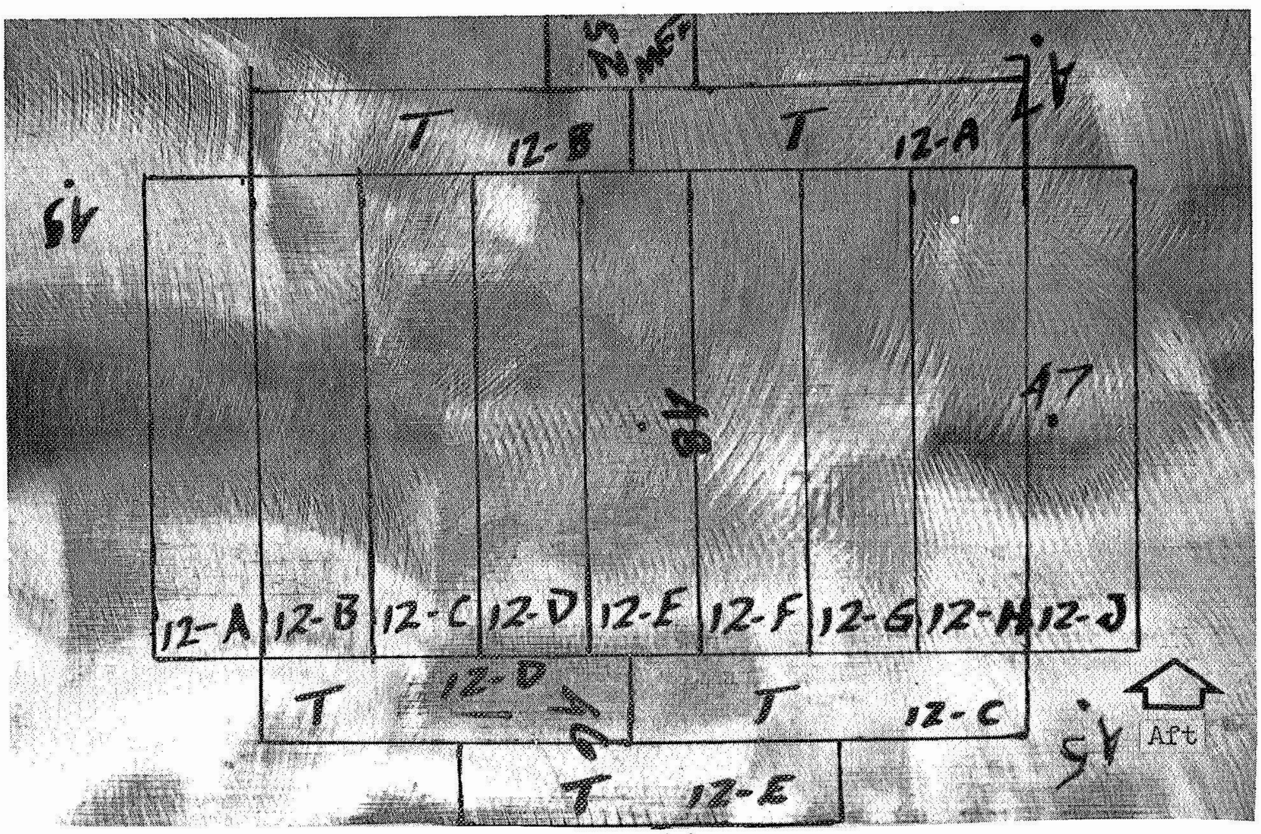
Numbers Indicate Surface Hardness Readings in R_c.
(A) Heat Affected Area; (B) Unaffected Area

Specimen Layout for Panel No. 11

Figure 38



(A)

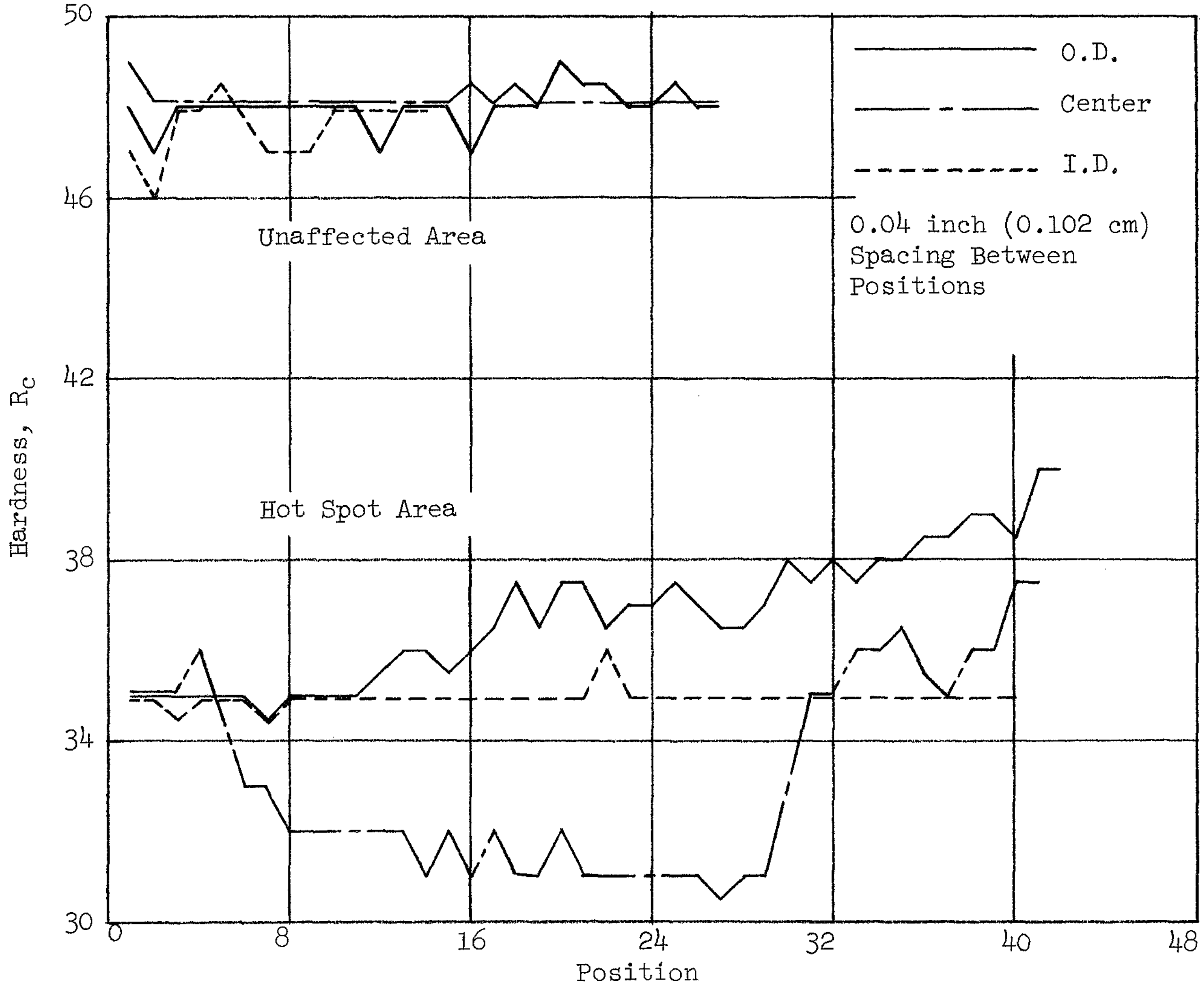


(B)

Numbers Indicate Surface Haraness Readings in R_c.
(A) Heat Affected Area; (B) Unaffected Area.

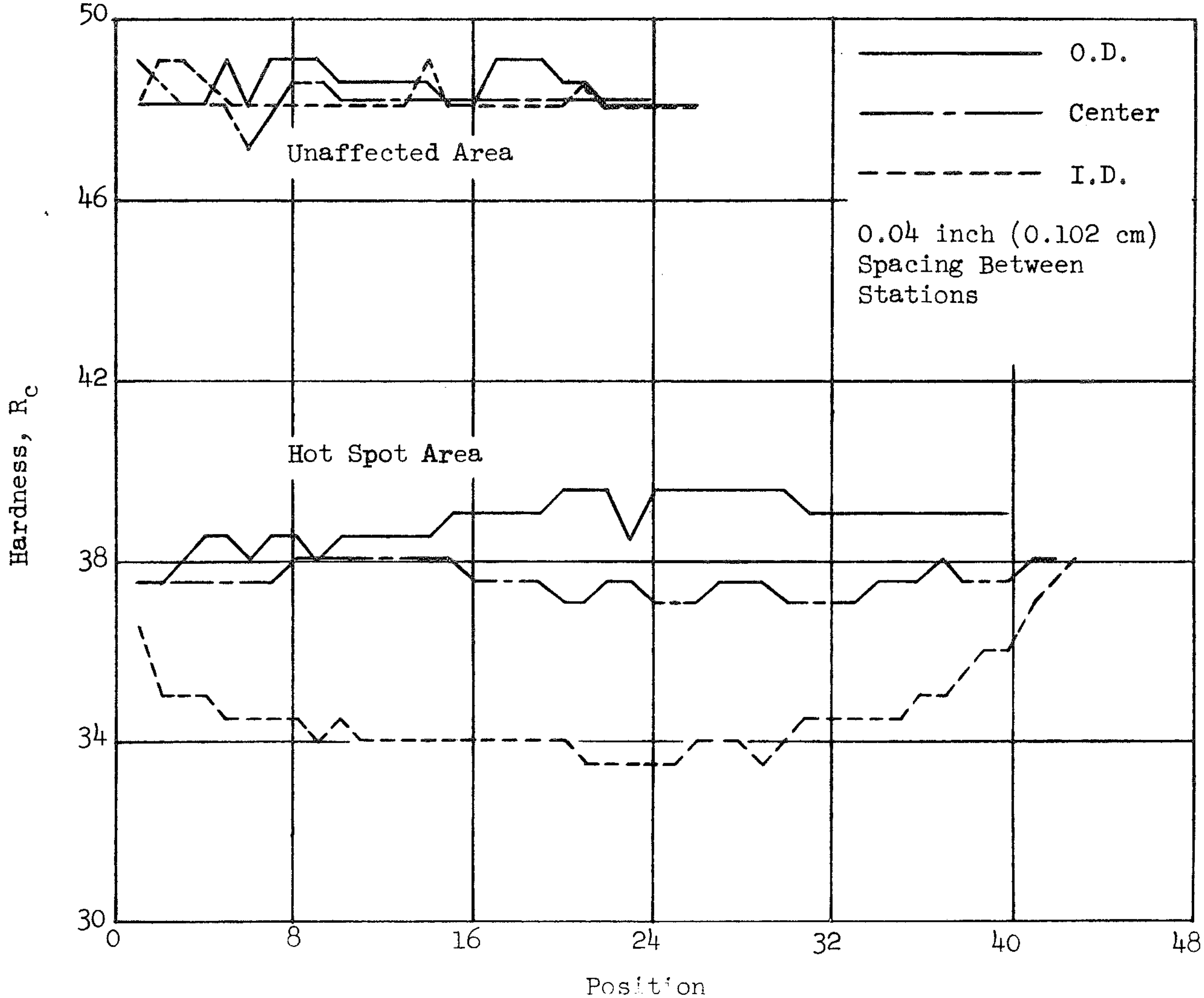
Specimen Layout for Panel No. 12

Figure 39



Microhardness Measurements, Panel No. 11

Figure 40

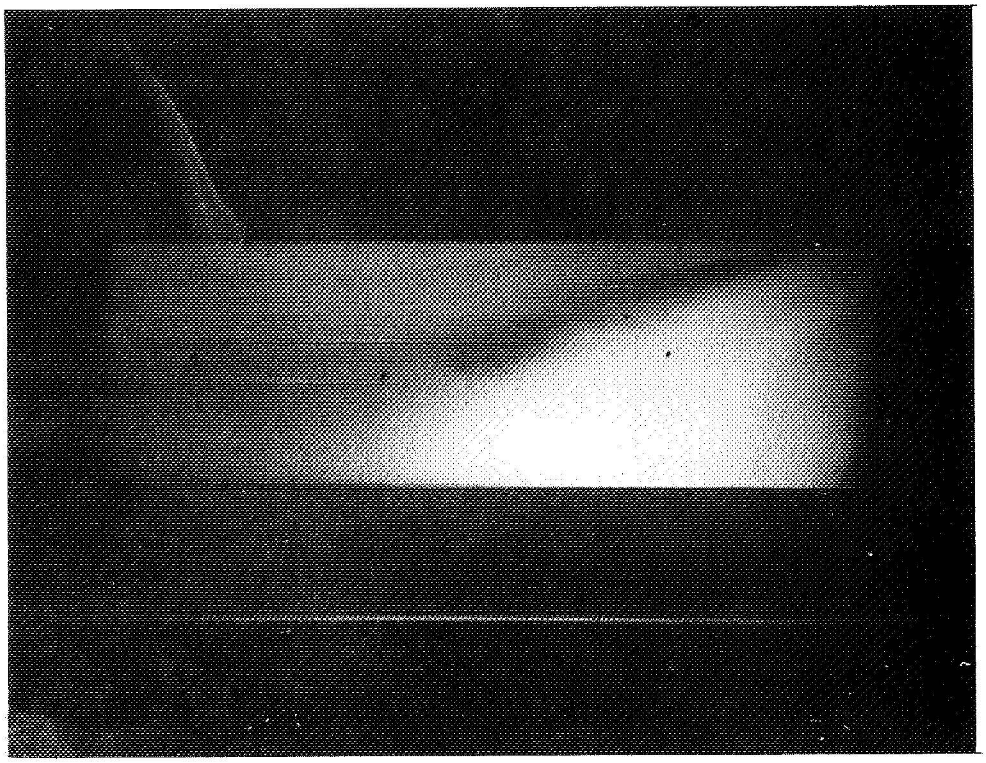


Microhardness Measurements, Panel No. 12

Figure 41

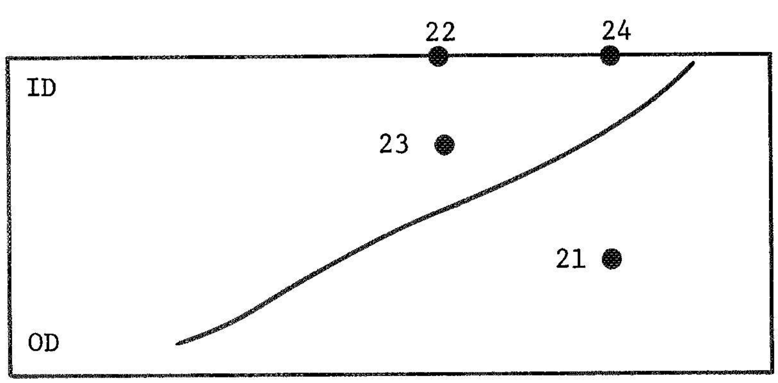
NASA CR 72676

I.D.



O.D.

Hot spot area, dark etching portion, of Panel 11. 2X. Marbles etch.



Microstructural examinations in areas shown

Hot Spot Microstructural Examination of Panel No. 11

Figure 42

Figure 43

Comparison of Panel 11 Microstructure Near ID Surface

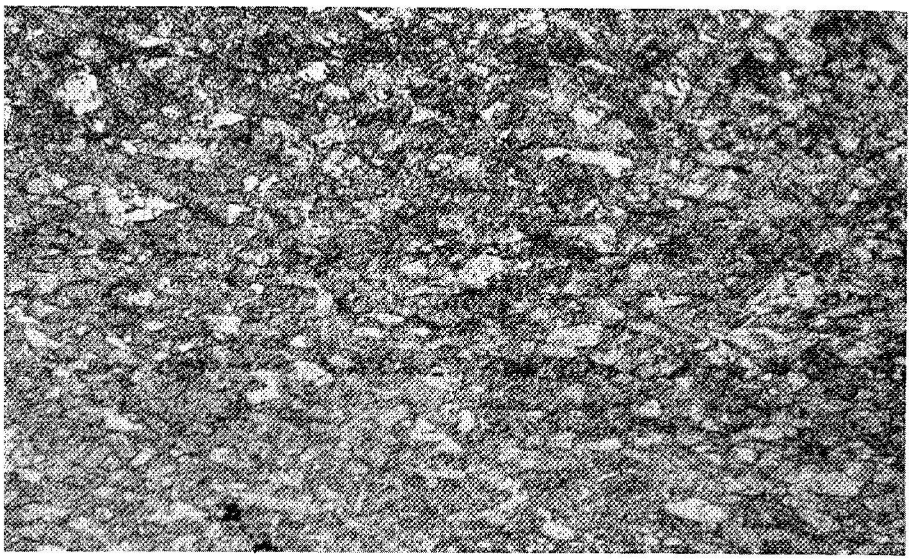
Comparison of microstructures of Plate 11 away from I.D. surface, in hot spot area 23, left; in hot spot area 21 center; outside hot spot area, right. No evidence of thermal effects in the area 23 or 21. Magnification 100X. Etchant 10% chromic acid electrolytic.

Comparison of Panel No. 11 Microstructures Away From I.D. Surface

Figure 44

Plate 12

a. Near I.D. surface in hot spot area. No thermal effects. 100X. 10% chromic acid electrolytic etch.

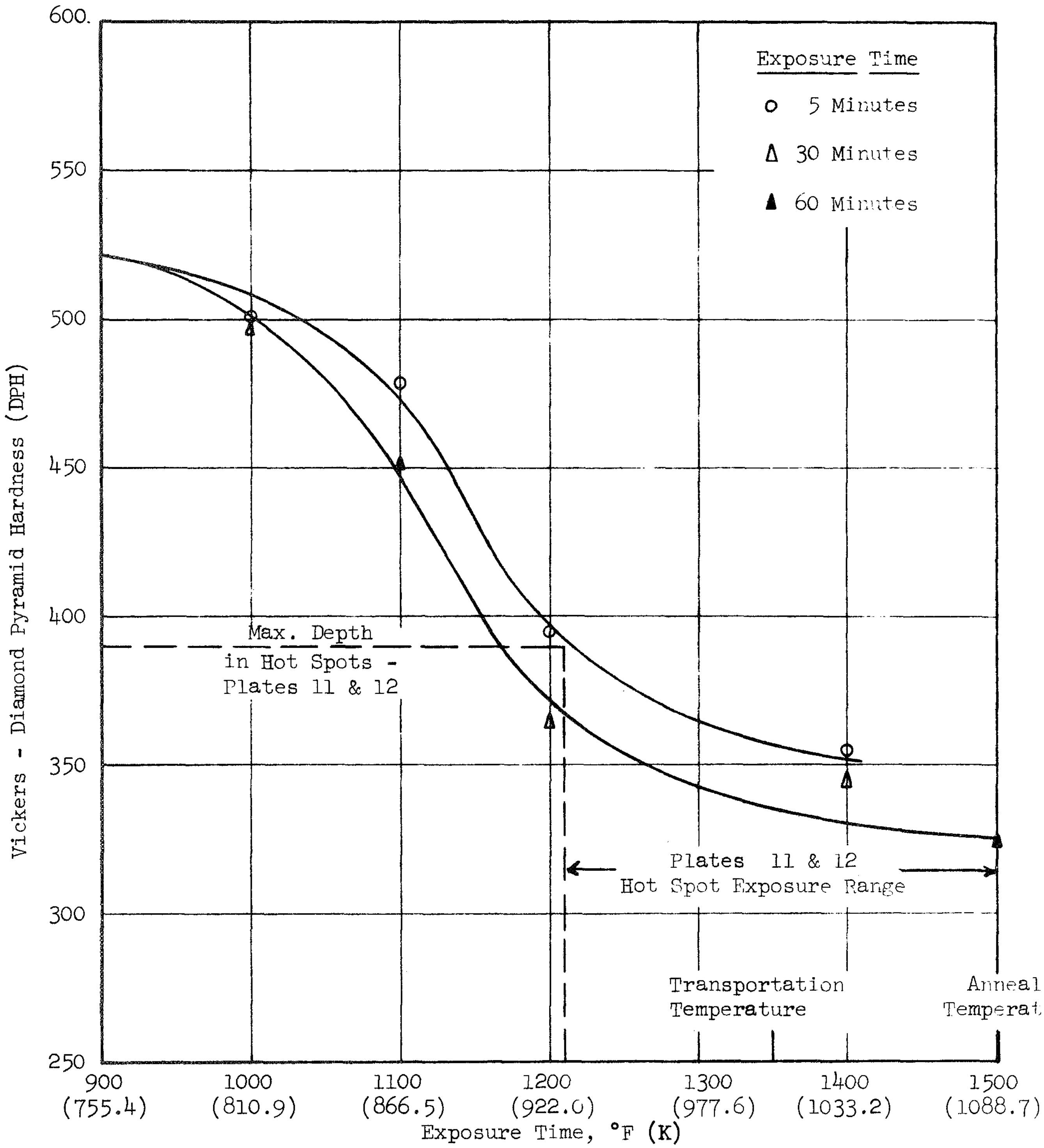


b. Near I.D. surface away from hot spot area. No thermal effects. 100X. 10% chromic acid electrolytic etch.

c. Same as b. except marbles etch.

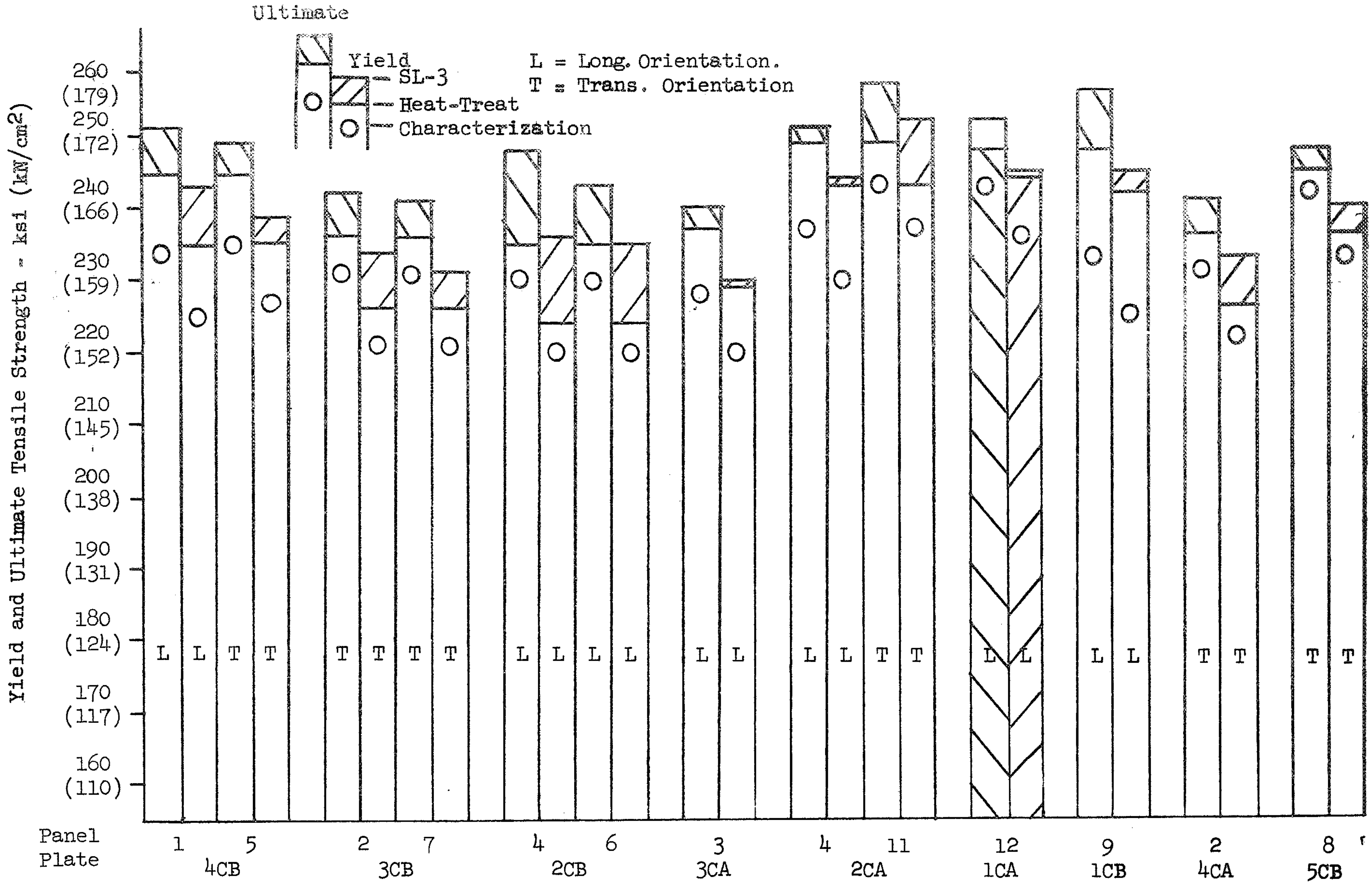
Microstructural Examination of Test Panel No. 12

Figure 45



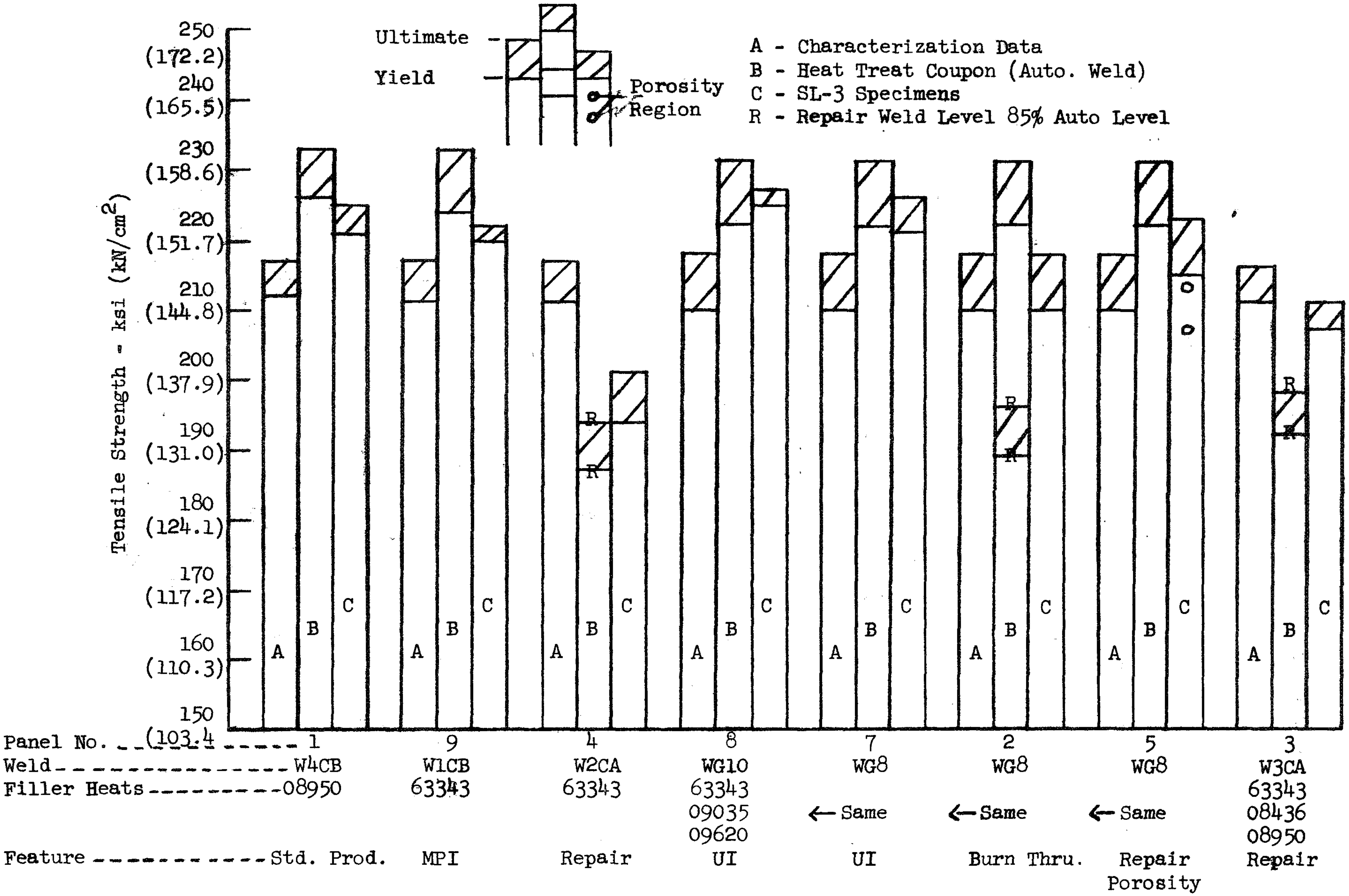
Effect of Overheating Aged 18% Ni Maraging Steel

Figure 46



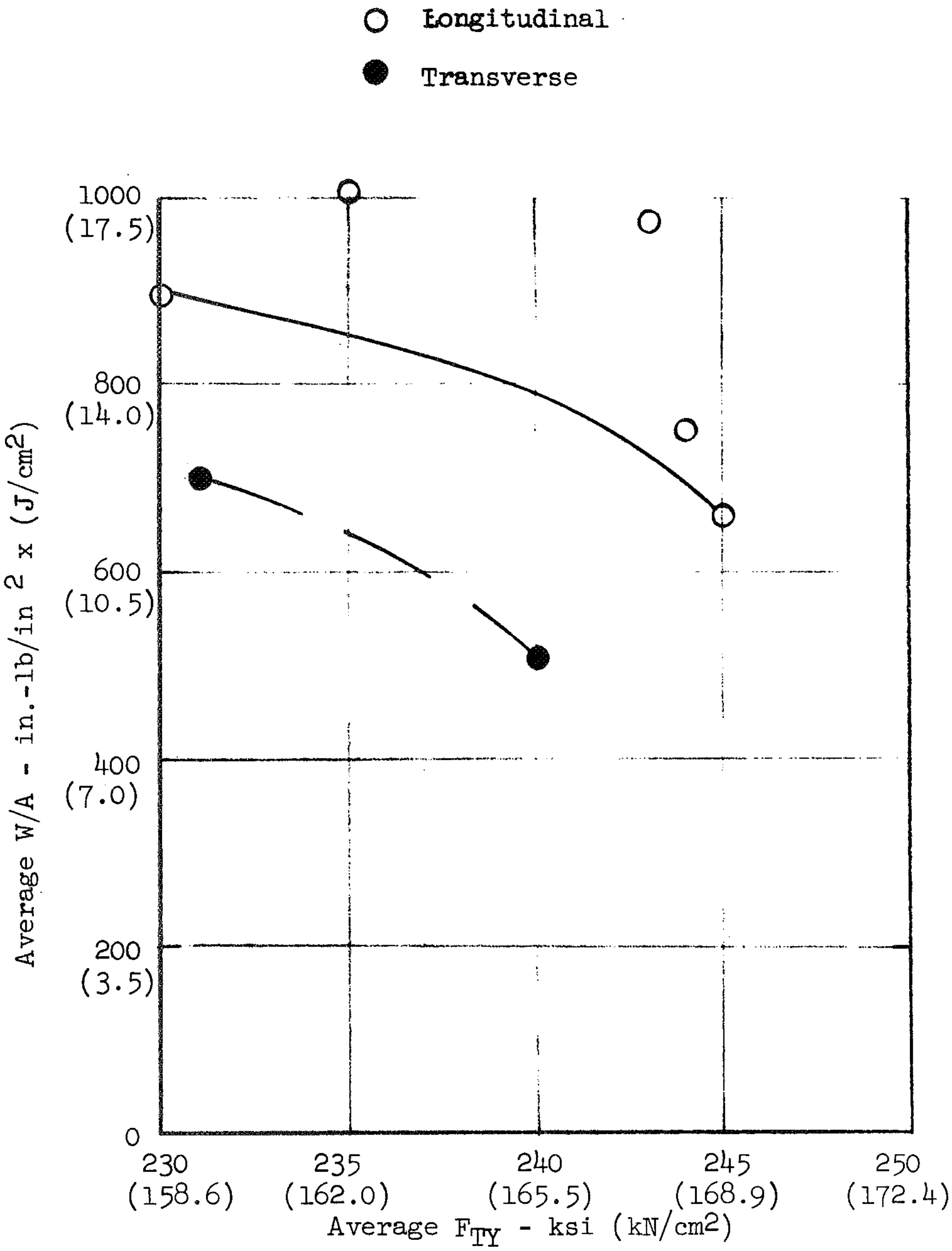
Tensile Properties of 18 Ni Marage Steel Plates

Figure 47



Tensile Properties of Weld Joints

NASA CR 72676



Average Precracked Charpy Impact vs
Average Tensile Yield Strength for
260 Motor Case SL-3 Parent Plates, +75°F (297°K)

Figure 49

NASA CR 72676

APPENDIX

AGC-34315 DEVELOPMENT SPECIFICATION STEEL PLATES, MARAGING 18 PERCENT NICKEL

and

AGC-34326 DEVELOPMENT SPECIFICATION WIRE FILLER; 18 PERCENT NICKEL MARAGING STEEL, FOR FUSION WELDING

AEROJET-GENERAL CORPORATION

CODE IDENT. NO. 13310

AGC-34315
Amendment 1
3 April 1964

STEEL PLATES, MARAGING, 18 PERCENT NICKEL

This amendment forms a part of Aerojet-General Corporation Specification AGC-34315.

Paragraph 3.3

Delete: "...solution treated after rolling at 1500 ± 25°F for..."

Substitute: "...solution treated after rolling at a nominal temperature in the range between 1650 and 1700°F for...

Authorized for Release:

J. H. Yetto, Manager
Specifications and Standards
Solid Rocket Plant
Sacramento

AEROJET-GENERAL CORPORATION
CODE IDENT. NO. 13310

AGC-34315
22 August 1963

DEVELOPMENT SPECIFICATION

STEEL PLATES, MARAGING, 18 PERCENT NICKEL

1. SCOPE

1.1 Scope. - This specification covers three classes of maraging 18 percent nickel steel plate, 200,000 pounds per square inch (psi) minimum yield strength.

1.2 Classification. - Maraging steel plates shall be classified in accordance with the melting practice used in manufacture as follows:

Grade	Melting Practice
A	Vacuum-arc remelted
B	Vacuum degassed
C	Air melted

2. APPLICABLE DOCUMENTS

2.1 Department of Defense documents. - Unless otherwise specified, the following documents, listed in the issue of the Department of Defense Index of Specifications and Standards in effect on the date of invitation for bids, shall form a part of this specification to the extent specified herein.

SPECIFICATION

Military

MIL-C-16173	Corrosion Preventive Compound, Solvent Cutback, Cold-Applications

STANDARDS

Federal

Fed. Test Method Std. No. 151	Metals: Test Methods
Fed. Std. No. 183	Continuous Identification Marking of Iron and Steel Products

(Copies of documents required by contractors in connection with specific procurement functions should be obtained as indicated in the Department of Defense Index of Specifications and Standards.)

2.2 Other documents. - Unless otherwise specified, the following documents, of the issue in effect on the date of invitation for bids, shall form a part of this specification to the extent specified herein.

SPECIFICATION

Society of Automotive Engineers

AMS-2252	Tolerances, Alloy Steel Sheet, Strip, and Plate

(Copies may be obtained from the Society of Automotive Engineers, Inc., 485 Lexington Avenue, New York 17, New York.)

PUBLICATION

American Society for Testing and Materials

ASTM E 45	Recommended Practice for Determining the Inclusion Content of Steel

(Copies may be obtained from American Society for Testing and Materials, 1916 Race Street, Philadelphia 3, Pennsylvania.)

2.3 Aerojet-General Corporation documents. - Unless otherwise specified, the following documents, of the latest issue in effect, shall form a part of this specification to the extent specified herein.

SPECIFICATIONS

AGC-32115	Ultrasonic Inspection of Maraging Steel
AGC-32116	Magnetic Particle Inspection of Ferro-Magnetic Materials

3. REQUIREMENTS

3.1 Chemical composition. - The steel shall contain the following elements within the limits as indicated:

	Element	Percent Min	Percent Max
(a)	Carbon	---	0.03
(b)	Manganese	---	0.10
(c)	Silicon	---	0.10

	Element	Percent Min	Percent Max
(d)	Phosphorus	----	0.025
(e)	Sulfur	----	0.01
(f)	Nickel	17.5	19.0
(g)	Titanium	0.05	0.25
(h)	Aluminum	0.05	0.15
(i)	Cobalt	7.0	8.0
(j)	Molybdenum	4.0	4.5

3.2 Melting practice. - The melting practice used in the manufacture of the steel shall be in accordance with the following:

Grade	Melting Practice
A	Vacuum-arc remelted
B	Vacuum degassed
C	Air melted

3.2.1 Additives. - The following materials shall be added to the steel during melting:

	Material	Amount, Percent
(a)	Boron	0.003
(b)	Zirconium	0.02
(c)	Calcium	0.06 in increments of 0.02

3.3 Solution treatment. - Steel plates shall be solution treated after rolling at 1500 ± 25°F for not less than one hour. Plates greater than one inch (in.) thick shall be held at temperature for time of one hour per inch of thickness.

3.4 Mechanical properties. - The steel plates shall have a yield strength of 200,000 to 235,000 psi at 0.20 percent offset after treatment in accordance with 4.4.3.

3.5 Grain size. - The steel plates shall have a grain size of five or finer; however, occasional grains as large as three shall be acceptable.

3.6 Inclusion rating. - The inclusion rating shall be determined by comparison of the worst area of inclusions found in the test specimens with Plate I of Publication ASTM E 45. The inclusion rating of each type of thin or heavy series of inclusions shall not exceed the following ASTM E 45 numerical designations:

Type Inclusion	Numerical Designation of Maximum Permissible Inclusion Rating	
	Thin Series	Heavy Series
A	2	1-1/2
B	2-1/2	1-1/2
C	2	1-1/2
D	2-1/2	2

(Titanium nitrides shall be rated as type B inclusions.)

3.7 Tolerances. - Tolerances shall be in accordance with Specification AMS-2252. Maximum rate of change for any variation from flatness (waviness, kinks, etc.) to be 0.25 in. per foot. Maximum variation from flatness (buckles, kinks, oil canning, etc.) shall be 2 in. in any 12 feet in any direction.

3.8 Identification. - Steel plates shall be marked in accordance with Standard Fed. Std. No. 183. Marking shall not be accomplished with sulfur or lead base inks, or with any other material capable of degrading the physical or mechanical properties of the steel. Each steel plate shall be identified with the following information:

(a) Number of this specification
(b) Supplier identification
(c) Supplier heat number
(d) Nominal thickness

3.9 Defects. - Steel plates shall conform to Specifications AGC-32115 and AGC-32116.

3.10 Workmanship. - Steel plates furnished under this specification shall be uniform in quality and contain no tears, cracks, seams, laps, internal ruptures, imbedded scale, or segregation. Material surface shall have a finish suitable for magnetic particle and ultrasonic inspection. Plates may be conditioned by the supplier for the removal of surface imperfections or depressions on either surface by grinding or other suitable methods, provided the area is well flared or blended and the grinding does not exceed the flatness variation or thickness tolerances. All conditioning shall be completed before magnetic particle and ultrasonic inspection.

4. QUALITY ASSURANCE PROVISIONS

4.1 Supplier responsibility.-

4.1.1 Inspection.- Unless otherwise specified, the supplier is responsible for the performance of all inspection requirements specified herein and may use any facilities acceptable to the Aerojet-General Corporation (AGC).

4.1.2 Processing changes.- The supplier shall make no changes in processing techniques or other factors affecting the quality of the product without prior approval of AGC.

4.1.3 Reports.- The supplier shall submit with each shipment four copies of test results verifying that the requirements of section 3 have been met. In addition, this report shall include:

- (a) Melting practice report
- (b) Additive report
- (c) Solution treatment report
- (d) Name of the supplier
- (e) Testing laboratory
- (f) Purchase order number
- (g) Number of this specification
- (h) Physical dimensions or referenced engineering document
- (i) Quantity from each heat

4.2 Lot size.- Each heat shall constitute a lot.

4.3 Sampling.- Preparation of samples shall be in accordance with Standard Fed. Test Method Std. No. 151. Selection of samples shall be as follows:

4.3.1 Chemical composition grain size and inclusion rating.- At least one sample shall be taken from the center and edge of both ends of each plate for the analysis of chemical composition, for determination of grain size and for determination of inclusion rating. Samples shall be selected from each as-rolled plate. An as-rolled plate is the product of one slab.

4.3.2 Mechanical properties.- At least three longitudinal test specimens and three transverse test specimens for determination of mechanical properties shall be prepared from samples obtained from each as-rolled plate.

4.3.3 Tolerances and workmanship. - The determination of tolerances, ultrasonic inspection, and magnetic particle inspection shall be performed on each finished and solution-treated plate.

4.4 Test methods. - The following test methods shall be used to determine compliance with requirements of section 3.

	Requirement	Test Method
(a)	Chemical composition	4.4.1
(b)	Melting practice	4.4.2
(c)	Additives	4.4.2
(d)	Solution treatment	4.4.2
(e)	Mechanical properties	4.4.3
(f)	Grain size	Fed. Test Method Std. No. 151, method 311
(g)	Inclusion rating	ASTM E 45
(h)	Tolerances	4.4.2
(i)	Identification	4.4.2
(j)	Defects	4.4.4
(k)	Workmanship	4.4.2

4.4.1 Chemical composition. - Chemical composition shall be determined as specified in Standard Fed. Test Method Std. No. 151, method 111 or 112, or other approved method. In the event of variation of composition, analysis shall be by method 111, except for carbon which shall be by the combustion method.

4.4.2 Visual examination. - Compliance with the requirements for melting practice, additives, and solution treatment, shall be verified by surveillance by the procuring activity and inspection of supplier certifications. Compliance with the requirements for tolerances, identification, workmanship, and the requirements of section 5 shall be verified by visual inspection of the steel plates presented for acceptance.

4.4.3 Mechanical properties. - Mechanical properties shall be determined as specified in Standard Fed. Test Method Std. No. 151, method 211. Test results shall be identified by item, serial number, heat number, etc. Test specimens shall be solution treated at 1500 ± 25°F for 30 minutes, air cooled to room temperature, and aged at 890 ± 10°F for four to eight hours.

4.4.4 Defects.- Steel plates shall be inspected for defects as specified in Specifications AGC-32115 and AGC-32116. Direct current magnetic particle wet-continuous inspection shall be used employing the yoke method. Sufficient current shall be used to reveal any detrimental discontinuities. Distance between poles shall be 18 in. or greater. The inspection media will be fluorescent particles. Any controversial indication that cannot be resolved will be investigated further by polishing and etching, and viewed employing magnification of 10X or higher. Demagnetization shall be accomplished employing alternating current to reduce the residual magnetic field to a level of intensity which will not be detrimental during subsequent machining, forming, and welding operations.

4.5 Retest.- Rejected parts shall not be resubmitted for inspection without furnishing full particulars concerning previous rejection, and measures taken to overcome the defects.

5. PREPARATION FOR DELIVERY

5.1 Preservation.- Unless otherwise specified, all material shall be prepared for storage by coating with corrosion preventive compound that conforms to the requirements of Specification MIL-C-16173, grade 2.

6. NOTES

6.1 Ordering data.- Procurement documents should specify the following:

(a) Number of this specification
(b) Place of inspection
(c) Lot size
(d) Place of delivery
(e) Marking location (if applicable)
(f) Forming process (if applicable)
(g) Tensile coupon specimen location (if applicable)

Authorized for Release:

J. H. Yetto, Manager
Standards and Specifications
Solid Rocket Plant
Sacramento

AEROJET-GENERAL CORPORATION

CODE IDENT. NO. 13310

AGC-34326
Amendment 2
19 March 1964
Superseding
Amendment 1
27 December 1963

DEVELOPMENT SPECIFICATION

WIRE FILLER; 18 PERCENT NICKEL MARAGING STEEL FOR FUSION WELDING

This amendment forms a part of Aerojet-General Corporation Specification AGC-34326.

Paragraph 3.1 Add:

"(k) Metallic calcium 0.05 (optional)"

Paragraph 3.1.1 (a) Delete and substitute:

"(a) Oxygen 30"

Paragraph 5.1.1 Delete and substitute:

"5.1.1 Containers.- Coils and rods shall be packaged in clean, hermetically sealed containers with a dry internal atmosphere. The material shall be packaged in such a manner as to insure freedom of the wire from deterioration, due to environmental conditions, for a minimum period of one year after sealing."

Authorized for Release:

J. H. Yetto, Manager
Specifications and Standards
Solid Rocket Plant
Sacramento

AEROJET GENERAL

AEROJET-GENERAL CORPORATION

CODE IDENT. NO. 13310

AGC-34326
4 October 1963

DEVELOPMENT SPECIFICATION

WIRE-FILLER; 18 PERCENT NICKEL MARAGING STEEL, FOR FUSION WELDING

1. SCOPE

1.1 This specification covers the requirements for one grade of vacuum arc remelted 18 percent nickel maraging steel filler wire.

2. APPLICABLE DOCUMENTS

2.1 Department of Defense documents. - Unless otherwise specified, the following documents, listed in the issue of the Department of Defense Index of Specifications and Standards in effect on the date of invitation for bids, shall form a part of this specification to the extent specified herein.

STANDARDS

Federal

Fed. Test Method Std. No. 151	Metals; Test Methods
Fed. Std. No. 102	Preservation, Packaging and Packing Levels

Military

MIL-STD-129	Marking for Shipment and Storage

(Copies of documents required by contractors in connection with specific procurement functions should be obtained as indicated in the Department of Defense Index of Specifications and Standards.)

3. REQUIREMENTS

3.1 Composition. - The filler wire shall be manufactured from vacuum-melted steels and shall have the following end-product chemical analysis:

	Element	Wt %
(a)	Carbon	0.03 max
(b)	Manganese	0.10 max
(c)	Silicon	0.01 max
(d)	Sulfur	0.01 max
(e)	Phosphorous	0.01 max
(f)	Aluminum	0.1 added
(g)	Nickel	17.5/18.5
(h)	Cobalt	7.5/8.0
(i)	Molybdenum	3.6/3.8
(j)	Titanium	0.26/0.30

3.1.1 Gas impurities. - Gas impurities in the material shall not exceed the following:

	Element	Parts per Million
(a)	Oxygen	20
(b)	Hydrogen	5
(c)	Nitrogen	35

3.2 Dimensions and weights. - Wire shall be wound on standard spools for use on automatic welding equipment, or furnished in packages of straight lengths. The wire shall have the following dimensions.

3.2.1 Spooled wire. - Spooled wire shall have a diameter from 0.020 to 0.093 inch (in.) with a tolerance of $\pm$ 0.001 in. The approximate coil weight shall be as follows:

(a) 0.062 in. diameter and larger: 25 pounds
(b) Less than 0.062 in. diameter: 10 pounds

3.2.2 Straight lengths.- Straight lengths shall be 36 ± 0.25 in. long and shall have a diameter from 0.062 to 0.093 in. with a tolerance of plus 0.002, minus 0.003. A package shall weigh two to five pounds.

3.3 Uniformity.- The wire shall meet the following requirements:

3.3.1 Spooled wire.- The wire on any single spool shall be one continuous length from one heat of material.

3.3.2 Straight wire.- The wire in a single package shall represent one heat of material.

3.4 Workmanship.- The wire surfaces shall be uniform in quality and shall show no pits, die marks, corrosion, scale, scrapes, splits, cracks, seams, or other defects and, in addition, the material shall contain no internal foreign material or gas pockets. The wire shall be manufactured so as not to be wavy or kinked, and shall melt and flow smoothly during a welding process.

4. QUALITY ASSURANCE PROVISIONS

4.1 Supplier responsibility.-

4.1.1 Inspection.- Unless otherwise specified, the supplier is responsible for the performance of all inspection requirements specified herein and may use any facilities acceptable to the Aerojet-General Corporation (AGC).

4.1.2 Processing changes.- The supplier shall make no changes in processing techniques or other factors affecting the quality of the product without prior approval of AGC.

4.2 Sampling.- A sample of filler wire shall be randomly selected from each heat of wire.

4.3 Acceptance tests.- Acceptance tests for individual heats shall be performed on each sample for all requirements in section 3.

4.4 Test methods. - Tests to determine compliance with the requirements of section 3 shall be in accordance with the following:

	Requirement	Test
(a)	Composition	Method 111, Fed. Test Method Std. No. 151
(b)	Gas impurities	Method 111, Fed. Test Method Std. No. 151
(c)	Dimensions and weights	4.4.1
(d)	Uniformity	4.4.1
(e)	Workmanship	4.4.1

4.4.1 Visual examination. - Each weld wire sample shall be examined to determine compliance with the requirement of section 3 for dimensions, weight, and workmanship. The supplier shall furnish certification that the material meets the requirements of section 3 for uniformity.

4.5 Test. - The material shall be chemically analyzed in accordance with method 111 of Standard Fed. Test Method Std. No. 151.

5. PREPARATION FOR DELIVERY

5.1 Preservation, packaging, and packing. - Except as specified herein, preservation, packaging, and packing methods shall conform to level C of Standard Fed. Std. No. 102.

5.1.1 Container. - Coils and rods shall be packaged in hermetically-sealed containers, insuring cleanliness and dryness.

5.1.2 Spools. - The materials and construction of the spools shall furnish protection for the wire against damage, and electrically insulate the wire from the welding machine spindle.

5.2 Layer winding. - Wire shall be closely wound in layers, but adjacent turns within a layer need not be touching. The winding shall not produce kinks, waves, or sharp bends. Unwinding of the coil shall be unrestricted, without overlapping or wedging. The terminal end of the coiled wire shall be marked and shall be readily accessible.

5.3 Marking. - Each spool package and shipping container shall be marked in conformance with Standard MIL-STD-129 and shall include, but not be limited to, the following information:

(a) Wire size
(b) Wire quantity
(c) Material heat number
(d) Purchase order number
(e) Manufacturer's identification
(f) Number of this specification
(g) Do not open for receiving inspection. Verify accountability only

6. NOTES

6.1 Intended use. - Material conforming to the requirements of this specification is intended for use on material that develops a yield strength of 200 to 235 ksi, in the following processes:

(a) Inert-gas, metal-arc, nonconsumable electrode
(b) Inert-gas, metal-arc, consumable electrode

Authorized for Release:

J. H. Yetto, Manager
Specifications and Standards
Solid Rocket Plant
Sacramento

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