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Quarterly Report
3rd Quarter, Year 3

HOMOPOLAR PIPELINE WELDING RESEARCH PROGRAM

Presented to:

JOINT INDUSTRY SPONSORS

AMOCO Corporation
BP Exploration
Exxon Production Research
Mobil Research and Development Corporation
Shell Development Company
Texaco, Inc.
CRC-Evans Automatic Welding (in-kind)
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Presented by:

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HOMOPOLAR PIPELINE WELDING RESEARCH PROGRAM

INTRODUCTION

This report is the third quarterly report of the third year to the sponsors of the Homopolar Offshore Pipeline Welding Research Program. The Joint Industry Program, which began in February 1993, was initially supported by a team of six oil companies and one welding contractor. The five-year program's ultimate goal is to produce a prototype system suitable for installation on a J-Lay barge. This is to be achieved by building and demonstrating operation of a full scale vertical HPW system capable of producing industry acceptable homopolar pulse welds in 12 inch schedule 60 (0.562 inch wall) carbon steel pipe. The research effort is being performed by the Center for Electromechanics at the University of Texas at Austin.

The current list of sponsors are:

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Quarterly review meetings brief sponsor representatives on program status and solicit sponsor input. These meeting locations alternate between Austin and Houston.

The preliminary work necessary to initiate this program was supported by the National Science Foundation through the Offshore Technology and Research Center (OTRC).

Quarterly Report
2nd Quarter, Year 3

HOMOPOLAR PIPELINE WELDING RESEARCH PROGRAM

1. SUMMARY

1.1 BACKGROUND

Typically, offshore pipelines are constructed using the S-lay method, which permits the pipe to be welded and inspected in the horizontal position. Multiple welding and inspection stations are possible with this method, being limited only by the deck length of the welding barge. Due to increased buckling stresses, deep water pipelines require the steeper angle of entry into the water presented by the J-lay method. The vertical or near-vertical welding position inherent in J-lay necessitates a single welding station, presenting great economic incentive to minimize pipe handling and welding cycle times.

Homopolar pulse welding (HPW) is a one-shot resistance welding process being investigated as a method to join API 5L carbon steel linepipe. Homopolar pulse welding utilizes the high current, low voltage electrical pulse produced by a homopolar generator to rapidly resistance heat the interface between abutting pipe ends, producing a full circumference resistance forge weld in under three seconds.

A five year joint industry program is sponsoring HPW research with the goal of developing the process for deep water offshore pipeline construction utilizing the J-lay method. The first 2 years of the program concentrated on weld parameter optimization by producing, testing and evaluating welds in various grades, wall thicknesses, types and compositions of three inch nominal (3.5 inch OD) diameter API 5L carbon steel pipe. Mechanical properties of the welds and parent metal were evaluated by tensile testing, impact testing and hardness traverse testing according to guidelines and criteria established by the industrial sponsors.

Homopolar pulse welding has demonstrated the capability to produce industrially acceptable full circumference welds in carbon steel linepipe via a rapid, one-shot process. Future work will concentrate on developing the process for commercial field installation, with the program's goal being the demonstration of a prototype system for producing HPW welds in twelve inch diameter pipe in a J-lay configuration.

1.2 Quarterly Summary

During the past quarter, 17 welds were performed, mechanical testing continued, the NDE effort acquired in-house automatic ultrasonic testing capabilities, and research continued in preparation for design of the 12 inch fixture.

The 17 welds performed consisted of 5 confirmation welds in B and D material, one weld each in the A and C materials using optimized B and D weld parameters, one D material weld using increase field current, and an eight weld series in D. All of the confirmation welds and A and C material welds used the D7.2 parameters, which produces a smooth weld bulge on both OD (outer diameter) and ID (inner diameter), lacking cracks where the extruded step forms a fin. All welds produced with D7.2 weld parameters have similar process parameters, including peak current, peak temperature, and displacement.

Welds performed using A and C material had low impact toughness test results, with a maximum 8 ft-lbs. Hardness test results revealed weldzone hardening similar to other A and C welds. Tensile testing is underway.

Six of the confirmation welds in B and D using D7.2 weld parameters will not receive standard mechanical testing. One each from B and D has been set aside for display, while the remaining four, 2 each from B and D, have been sent out for CTOD testing, arranged by CRC-Evans. Mechanical test results for confirmation welds in B and D material using D 7.2 weld parameters indicate that impact toughness, and yield and tensile strengths are not affected by rounding the bevel shoulder.

The three parameter, two level eight weld series in the D material varied all end geometry parameters: step length and width, and bevel angle. Generator parameters were 2,100 rpm discharge speed and 360 amp field current, using a 60 kip constant load. Impact toughness test results followed trends observed in series D3 and D6, with excessive heating drastically reducing impact toughness. Six of the eight welds had an overall mean impact toughness of 91 ft-lbs, with the remaining two having mean values of less than 1 ft-lb, due to possible overheating.

Mechanical testing of previous welds included tensile testing of 17 welds, with all meeting sponsor acceptance criteria. Pores observed on the fracture surface of tensile specimens of B and D material initiated a study of both materials, revealing the presence of grain sized pores randomly distributed through the parent material. Pore distribution and shape was not observed to be affected by the welding process. Review of CVN notch revealed that notch depth was shallow by 0.005 in., and that the notch placement was out of specification on 4 of 25 specimens, with the maximum error of 0.0135 inch. Corrective measures have been taken.

Lateral deformation at the weldline has been significantly reduced following modifications to the welding fixture and the set up procedure. Guide blocks were installed between the moving lower platen and the fixture corner posts (2 in. diameter), which limited lateral deflection of the lower platen. The procedural modification removed a source of random variation in the fixture.

With the need-to-do increased nondestructive testing, and the recent availability of a low-priced automatic ultrasonic testing system, the JIP has ordered the AUT system. The system should save the program money on AUT since the cost of the system is less than the cost of three contractor performed tests. The system will allow complete testing and correlation of NDT results with mechanical test results. The scanning head can be adapted to 12 in. diameter pipe.

2. MATERIALS

The pipe materials investigated to date are presented in Table 1. All materials are three inch nominal (3.5 in. OD) API 5L carbon steel pipe grades. Welds from these materials are identified by an alphabetical weld prefix code, with the first material investigated being assigned the code A, the second B, etc. Mill test reports for these steels are reproduced as Figures 1 through 4. Material D is a quenched and tempered grade X-65 pipe delivered in late November from Nippon. This pipe was made specifically for us in 3.5 in. diameter from a single bloom, therefore, chemical composition is available but mill mechanical test results are not.

Pipe for welding in the 12 in. fixture has been received and parent metal studies are underway on a short section of the pipe. The pipe had the following marking on the coated exterior:

SHELL P-8640 Auger 2
12 3/4 x 0.562 x 73.15 N.K.K. X-52
P.O. PX-88G736 - NAT 8-19-92
Bayou Pipe Coating 2 N.G. 2501

NKK 2639
41.2

NKK TEST - JT
Near/ White Blast
9-8-92

3. HPW PROCESS DESCRIPTION

Homopolar pulse welding is properly classified as a resistance-forge welding process. The primary components of a HPW system are the homopolar generator and the hydraulic welding fixture. The homopolar generator stores energy kinetically in a rotating flywheel and converts it to electrical energy in a discharge circuit via electromechanical energy conversion.

The HPW process begins by accelerating the homopolar generator's rotor to a predetermined discharge speed. Then the generator is energized by exciting the field and engaging the sliding electric contacts, or brushes, onto the slip ring of the spinning rotor. Discharge is initiated by closing switches in the circuit near the generator terminals. The resultant current pulse is directed through the pipes, where weld joint electrical resistance produces extensive localized heating. After a preset time delay, upset pressure is applied to the pipes, displacing metal at the original interface and creating a full circumferential butt weld.

Postweld cooling rate is determined by the pipe and electrode physical dimensions, with the copper electrodes acting as a heat sink during cooling. Increasing the distance between the electrodes heats a larger bulk of the pipe on either side of the weld joint and increases the thermal conduction path from the weld zone, slowing the cooling rate. In combination with electrode location, generator discharge speed and field current, pipe end preparation, upset pressure, time between generator discharge and application of upset pressure, and duration of the upset pressure are all controllable process parameters affecting weld quality.

The method is similar to other resistance welding methods, with the exception that the energy is delivered in the form of a single high current DC pulse. The process is therefore fast, and does not produce the localized skin heating effects present in AC resistance welding methods. Flash Butt Welding can be used on the same pipe diameters that are being targeted for J-lay, but flash butt welding takes from one to two minutes per joint, and produces extensive melting and a large heat affected zone (HAZ). Homopolar pulse welding requires only a few seconds and is considered a solid state welding process.

The same generator and fixturing used to produce a homopolar pulse weld may be utilized to heat treat the weld and HAZ. After the weld zone has cooled below the transformation temperature, an additional HPG pulse may be used to reheat the weld zone. Electrode location and generator parameters can be preselected to control the amount of heating, width of heated zone, and the subsequent cooling rate.

3.2 Process Parameters

Measured data from each weld is recorded on data logging digitizers and stored. Parameters measured during each weld include: current, voltage, displacement, and temperature near the weld interface along with generator speed, voltage and current data. In addition, each weld is recorded visually on videotape for later reference and analysis. The following listing provides more complete descriptions of the process parameters:

1. Total Current (TOTC): The total current, which is measured using a Rogowski coil, is the total current that flows through all the busswork and weld interface. The trace of the current is shown in Figure 5, with the measured values: peak current and time to peak.
2. Interface Voltage (INTV): The interface voltage, which is measured by spotwelding voltage probes to the OD surface 0.25 in. on either side of the interface, is the voltage drop between the voltage probes, which includes the weld interface. The trace of the interface voltage is shown in Figure 5 with the measured values: peak voltage and time to peak.
3. Weld Temperature (TCIF): The weld temperature, which is measured using a Type K infrared thermocouple having a 0.50 in. diameter minimum sensing area centered on the weld interface, is the temperature of the weld zone. The measured values are regarded as relative measures of weld zone temperature. Spotwelded thermocouples, previously used, provided highly variable temperature readings due to the transient nature of the HPW thermal cycle. The trace of the weld temperature is shown in Figure 6, with the measured values: peak temperature and time to peak.
4. Displacement (DISP): The weld or upset displacement, which is measured using a rotary displacement transducer, measures the movement of the hydraulic ram relative to ground. After the interface is brought to load, further deformation is due to softening and forging of the weld interface and adjacent material, while the weld is performed. With the use of the stepped and beveled end geometry and the high initial load, the displacement trace has a characteristic shape as shown in Figures 6. The initial sharp rise is attributed to heating and collapse of the step. The rate of softening exceeds the hydraulic ram velocity, resulting in a temporary reduction of applied load. The first shoulder occurs when the ram "catches up", returning to setpoint value, as shown in Figure 7. The first recorded value, DISP1, refers to the displacement at the time when ram peaks following softening. Subsequent displacement occurs at a reduced rate as remaining step material, the bevel and the wall heat, soften and forge under the applied load. The second recorded value, DISP2, which is recorded at the

time when the temperature peaks, is the displacement when the rate of deformation levels off, as shown in Figure 6.

Process data is included in this report for all recent welds.

4. EXPERIMENTAL PROCEDURE AND RESULTS

4.1 Mechanical Test Procedure

Impact test specimens are full size (10 mm x 10 mm x 55 mm) for welds in which the pipe is schedule 160 (0.438 in.) wall, half size (5 mm x 10 mm x 55 mm) for schedule 80 (0.300 in.) wall pipe welds. In other words, full size specimens are tested for material A and C welds, half size specimens are tested for material B and D welds. Specimens are cut to length with the weld line centered in the specimen, and standard Charpy V-notches are cut in the specimens at the weld line on a specimen side corresponding to the through wall thickness of the weld joint (for example, the 5 mm wide face is notched on the half size specimens). Testing is performed at 0°C by immersion of test specimens in an ice water bath at least five minutes prior to testing. The test values reported are actual test values, no adjustments are made for non-standard specimen sizes.

Tensile tests are performed on strip specimens with 0.50 in. specimen width in the two inch gage length, with the weld line centered in the gage section. Specimen thickness can vary from full thickness specimens (no machining on ID and OD) to less than 0.200 in. for flat specimens from welds requiring extensive cleanup due to non-symmetrical weld line deformation. Typically, flat specimens are nominally 0.25 inch in thickness. Cross sectional area of the specimens is obtained by measuring the width and thickness of each specimen to the nearest 0.005 inch.

Tensile testing is performed on an Instron Model 1125 test frame with a 100 kN load cell at a constant crosshead speed of 2 mm/minute. The load-displacement curve is plotted on chart paper during testing, this plot is then used to determine peak load and yield point load in cases where a yield point phenomena is observed. After testing to failure, the specimen halves are placed together and the final gage length, along with width and thickness at necked location, is measured and recorded. These values are used to calculate percent elongation after failure and percent reduction in area after testing.

Hardness traverses are performed using a Vickers macrohardness tester with a load of 10 kg. applied for 15 sec. A typical traverse covers 50 mm, 25 mm on each side of weld line, with indentations spaced 1 mm apart.

4.2 Evaluation of CVN Test Specifications and Corrective Measures

In response to an unexplained difference in impact toughness test results between the Welding Institute of Canada and CEM on the D4 welds, the impact toughness test was reviewed to determine whether it was within the ASTM specifications. The evaluation consisted of two parts: the notching of the specimens and the testing. The testing was found to be within specifications, which mostly consisted of assuring that the specimen was properly positioned in the fixture, and that test temperature was maintained at the notch prior to impact.

Evaluation of the notch included correct notch geometry and correct notch placement. Using a 20:1 optical comparator, the notch was found to have the correct angle (45°) and notch tip radius (0.010±0.001 in.) but was shallow by approximately 0.005 inch. Corrective measures, which included cleaning the broach, adjusting cut depth and changing cutting fluid, brought the notch depth within specification (0.079±0.002 in.).

Based on 25 CVN specimens from the D7 Weld Series, the prescribed specimen center was found to be out of specification on four of the specimens, with the maximum error less than 0.014 in. (0.36 mm). No variation in impact toughness was observed in specimens with notch placement errors.

Based on the lack of measurable difference in impact toughness test results between those performed before and after corrective measures, the CEM research team concluded that the difference in impact toughness test results between WIC and CEM should not be attributed to variations in the CVN test.

4.3 D Series Welds

Welds performed in the D material starting with the D3 series have used stepped and beveled end geometry with an high, constant load. Three 8 weld series, D3, D6, and D8, have been completed where three parameters were varied at two levels, permitting evaluation of individual input parameter effects and the effect of interaction between input parameters. Response tables are used to evaluate the effect of the variable input parameters on specific responses for three parameter two level weld series, specifically D3, D6, and D8 series. Test specimens for mechanical testing includes three or five CVN, two tensile, two metallurgical, and one hardness.

4.3.1 Series D3

Series D3 consisted of eight welds in the D material with parameters variations selected to investigate interface geometry and energy input, and their effect on mechanical properties.

Specific parameters varied include bevel angle, step length, and discharge RPM as presented in Table 2.

Updated tensile test results are presented in Table 3 for six of the eight welds as D3.4 and D3.7 failed to yield tensile specimens due to excessive lateral deformation. Tensile strengths ranged from 81.6 to 84.6 ksi while yield strengths ranged from 69 to 74.6 ksi. Impact toughness test results, presented in Table 4, indicate that doubling the step length decreases the impact toughness. Table 5 presents a response table for the mean impact toughness results, demonstrating that the step length had the greatest influence on impact toughness, and that the interaction of the step length and RPM had the second greatest influence on impact toughness. Hardness traverse results are presented in Figures 8 and 9. Test results indicate that increasing the step length increases WZ peak hardness while increasing discharge RPM increases HAZ width. No trends observed with changing the bevel angle.

Tables 6 summarize series D3 weld parameters, process parameters, and mechanical test results. Table 7 presents the weld parameter matrix with process parameters and CVN results.

4.3.2 Series D5: Confirmation Series

Series D5 consisted of six welds in the D material produced using identical weld parameters. Parameter selection was based on the high impact toughness test results of weld D3.2, as presented in Table 2, the Series D3 Weld Parameters. Hardness test results are presented in Figure 10 and 11. Tables 8 summarize series D5 weld parameters, process parameters, and mechanical test results. Impact toughness test results, presented in Table 10, show minimum impact toughness of 61 ft-lbs with an overall mean of 99.5 ft-lbs. Tensile test results for three welds, D5.2, D5.3, and D5.6 presented in Table 9, meet the Hammond Criteria for yield and tensile strength. The mechanical test results for the D5 series demonstrate that acceptable D material HPW welds are possible.

4.3.3 Series D6

Series D6 consisted of eight welds in the D material with parameter variations selected for continuing investigation of interface geometry and energy generation on mechanical properties. Specific parameters varied included contact width, load, and generator field current as presented in Table 11. Table 12 summarize series D6 weld parameters, process parameters, and mechanical test results. Table 13 presents the weld parameter matrix with process parameters and CVN results.

Impact toughness test results are presented in Table 14. The analysis, from the response table, Table 15, indicates that contact width has greatest affect on impact toughness, with the narrower contact width setting, 0.10 in., producing higher CVN values, with an average increase of 33 ft-lbs. Higher initial loads and higher field current settings increased impact toughness by 10-14 ft-lbs. The interaction of contact width and field current produced averaged 21 ft-lbs higher when both are set high or low. These settings do not tend to produce highest or lowest heating of the workpiece, reinforcing D3 series results that excessive heating degrades impact toughness as does insufficient heating.

Tensile test results, which are presented in Table 16, show that the tensile strength ranges from 81.0 to 83.6 ksi and the yield strength ranges from 71.7 to 73.8 ksi. These results are comparable with parent metal values, exceeding the Hammond Criteria.

Hardness test results are presented in Figures 12 and 13. The minimum hardness ranged from 167 to 172 kg/mm^2, with peak values from 193 to 206 kg/mm^2. Higher peak hardness, measured in welds with lower load settings, indicate that higher interface resistance produces higher temperatures at the interface. Higher peak temperatures are associated with increased hardness.

4.3.4 Series D7

Series D7 consisted of nine welds in the D material with parameter variations selected to investigate improving the weld bulge profile. Specific parameter variations focused on end geometry variations of Weld D3.2 and the D5 weld series., as presented in Table 17. Weld D7.1 had an additional bevel at a steeper angle and D7.2 had the bevel shoulder rounded into the OD and ID surfaces. D7.7 differed from D7.2 by using a lower discharge speed (2,100 rpm) combined with a higher field (360 A), while weld D7.3 used increased bevel angle and contact width to improve the as welded profile. Welds D7.4, D7.5, D7.6, D7.8, and D7.9 were confirmation welds using D7.2 weld parameters.

Figures 14 through 17 present macrographs of D5.4, the baseline profile, D7.1, D7.2, and D7.3, D7.1 and D7.3 did not improve the profile while D7.2 produced a smooth weld bulge, extending 0.075 in. beyond the OD and ID surfaces. No cracks were observed at the intersection where the fin projects perpendicularly from the weld bulge. Similar deformations were observed in the five confirmation welds. D7.7, which had less deformation due to the reduced discharge speed, still had an acceptable, though lower profile, weld bulge.

Tables 18 summarize series D7 weld parameters, process parameters, and mechanical test results. Weld D7.6 will not undergo mechanical testing as it has been saved for display, while welds D7.8 and D7.9 have been sent out for CTOD testing.

Tensile testing is completed on Welds D7.1-3 as presented in Table 19, with results similar to those of D3, D5, and D6 series welds: yield strength of 73 ksi and tensile strength of 82 ksi.

Impact toughness test results are presented in Table 20. With the exception of D3, all impact toughness specimens displayed 100% shear fracture with minimum value of 83 ft-lbs and a mean of 95 ft-lbs. For weld D3, two of the five specimens had partial shear fracture with minimum impact toughness of 65 ft-lbs. The remaining three specimens had an average impact toughness of 107 ft-lbs, higher than any other weld of the series. This variability might be attributed to increased interface heating, from lower initial interface pressure, and decreased deformation, from reduced load.

Hardness test results are presented in Figures 18 and 19 for welds D7.1-5. Peak hardness values range from 185 to 199 kg/mm^2, with minimum values of 161 to 166 kg/mm^2. The HAZ width is 10 to 14 mm wide. Compared to D5 hardness traverses, these D7.2, D7.4, and D7.5 have similar peak and minimum HV_{10} values, but the HAZ is slightly wider with the beveled shoulder.

4.3.5 Series D8

Series D8 consisted of eight welds in the D material with parameter variations selected to investigate weld bulge profile improvement with reduced energy input and the effect on mechanical properties. Specific parameters varied were limited to the end geometry, which includes step length, contact width, and bevel-angle, as presented in Table 21. All welds had rounded bevel shoulders, similar to D7.2. Table 22 summarizes series D8 weld parameters, process parameters, and mechanical test results. Weld D7.7 replaces D8.1 in the weld parameter test matrix, as D8.1 was welded using a higher field current, 390 amps, than the remaining welds in the series. Table 23 presents the weld parameter matrix with process parameters and CVN results.

The process parameters are generally consistent with the expected response due to end geometry changes, with increased step length, increased bevel angle or decreased contact width increasing the workpiece resistance. The total current (TOTC) for D8.3 should be higher than D7.7, as the wider contact width reduces workpiece resistance, raising peak current. The deformation response (DISP1, DISP2) is consistent with the parameter variations with increased step length, or increased bevel angle increasing displacement and increased contact width decreasing displacement.

Impact toughness test results are presented in Table 24. Except for welds D8.5 and D8.6, the impact toughness ranged from 36 to 120 ft-lbs with an mean value of 91 ft-lbs. D8.5 and D8.6, which had low values, all less than 2 ft-lbs, used similar weld parameters to D3.6 and D3.8, which had low impact toughness, mean CVN of 14.8 and 26.8 ft-lbs. respectively. These results confirm that long, thin step geometry produces low impact toughness, as this geometry supplies excessive heat to the weld zone. In contrast, impact toughness results for D8.7 and D8.8

were the best for the weld series. This geometry limits the heating by increasing the cross-sectional area of the step which reduces the current density in the step. These test results for the D8 series are similar to those of D6 series as the parameters that produce maximum and minimum heating result in lower impact toughness. For the D6 series, the interaction between the contact width and the field current produce better CV results when both parameters were increased or reduced, i.e. reduced contact width and reduced field. For the D8 series, the interaction of step length and contact width had the greatest influence on mean impact toughness values, as shown in Table 25.

Tensile and hardness testing is in progress.

4.4 B Series Welds

4.4.1 B18 Series: Confirmation Series

Series B18 consisted of four welds in the B material produced to evaluate the response of B material to D5 parameters. Weld parameters are presented in Table 26. Based on comparisons between B and D welds performed with identical settings, with B welds experiencing greater heating, B18.1 was welded using a lower discharge rpm, 2000 rpm, similar to D3.1. Heating and deformation of B18.1 was similar to D3.1, which had insufficient upset, indicating that with D5 parameters, B material response is similar to D. The remainder of the series was welded at 2200 rpm, with responses similar to D5 welds.

Impact toughness test results, found in Table 27, show mean impact toughness for series of 71.8 ft-lbs, ranging from 53 to 86 ft-lbs. These results demonstrate that D5 parameters produce acceptable impact toughness in B material.

Hardness test results are presented in Figure 20. The minimum hardness for the series is 162 kg/mm^2, with no weld line hardening and average HAZ width of 10 mm. Tensile tests are planned to evaluate the effect of HAZ softening.

Tensile test results for B18.1 and B18.2 are presented in Table 28c. Both specimens fractured at the weld line, which is consistent with lack of weldline hardening in the hardness tests. Tensile test results met the Hammond Criteria.

Table 28 summarize series B18 weld parameters, process parameters, and mechanical test results.

4.4.2 B19 Series: NDT Series

Series B19 consisted of four welds in the B material designed to simulate four possible HPW flaws for automatic ultrasonic inspection. The welds were produced with identical weld parameters as shown in Table 29. B19.1a had eight flat bottomed holes, with variations in depth and diameter, equally spaced around the circumference to simulate inclusion. B19.2 had 12 μm tungsten placed at four locations to simulate micro-inclusions, while B19.3 had 50 μm tungsten foil pieces place at four location to simulate a cold weld. B19.4 had oil wiped on the interface to simulate surface contamination that might occur in industry.

Weld B19.1 was repeated following welding fixture improvements, since excessive lateral deflection made the weld unsuitable for AUT. Following ultrasonic inspection, these welds will be mechanically tested. Table 30 summarizes series B19 weld parameters and process parameters.

4.4.3 B20 Series: Confirmation Series

Series B20 consisted of four welds in the B material produced to evaluate the response of B material to D7.2 weld parameters, as presented in Table 31. Table 32 summarizes series B20 weld parameters, process parameters, and mechanical test results. B20.1 is the only weld in the series undergoing mechanical testing, as B20.2 is saved for display along with D7.6. B20.3 and B20.4 have been sent out for CTOD testing with D7.8 and D7.9, as arranged by CRC-Evans.

Tensile test results for B20.1 were similar to B18 welds, with a slight reduction in ultimate tensile strength. Fracture occurred near the weld line. Impact toughness results, appended to Table 32c, had parent metal values, similar to B18 series results. Hardness testing in progress.

These mechanical test results indicate that modifying the end geometry by rounding the bevel shoulder has a minimal effect on mechanical properties of the resulting weld, similar to the response observed in the D material. As with the D material, rounding the bevel shoulder produces a smooth weld bulge with a thin fin extending from the center on both OD and ID surfaces, similar to that shown in Figure 12.

4.5 M1 Series

Series M1 consists of two welds, one each from A and C materials, using D7.2 weld parameters. The pipe was machined from schedule 160 (0.438 in. wall thickness) to schedule 80 (0.30 in. wall), by boring the ID. The purpose of this series was to determine if the apparent heat-limiting characteristics of the step and bevel with high constant load parameters would improve the mechanical properties of A or C welds. The weld parameters are presented in Table 31, along with the B20 parameters. Table 33 summarizes series M1 weld parameters, process parameters, and mechanical test results.

Impact toughness test results, appended to Table 33c, indicate that the D7.2 weld parameters do not improve the mechanical properties, as all specimens had low CVN values (less than 8 ft-lbs). Hardness test results are presented for the each material weld with those from the PP2 weld series in Figure 21. For the A material, the D7.2 parameters widened the hardened region around the weld line, with similar peak hardness values. For the C material, the effect was similar, with possible reduction of peak hardness. The impact toughness of the PP2 welds, A5.1 and C4.1, was slightly higher with mean CVN values around 9 ft-lbs for both material.

Tensile testing is underway.

4.6 Miscellaneous Work

Miscellaneous work undertaken during this quarter includes a study of pores observed in the B and D materials and evaluation and modification of the welding fixture and procedure.

4.6.1 Pores in B and D Material

Jui-Fa Kuo, the material science graduate student working on the mechanical testing, observed grain sized pores in the B and D material (Figure 22). A study was undertaken to characterize the pores, which included a study parent metal microstructures and microstructural variation through the weld zone. A similar study has been recommended by Dr. David Olson to better understand the effect of the thermal cycle on the microstructure. Kuo's study included optical microscopy and SEM to characterize the pores. The current findings indicate that the pores are randomly distributed throughout the parent metal and the HAZ, with little change in shape or density. Pores were observed on the fracture surfaces of both CVN and tensile specimens. From an SEM micrograph of a CVN fracture specimen containing shear and brittle fracture, the site of brittle fracture initiation had a pore at its base (Figure 23). This is a continuing study.

4.6.2 Welding Fixture Improvements

The welding fixture and the procedure for setting up a weld was examined to determine possible causes for the lateral deformation during welding, which produced unacceptable welds. Lateral deformation refers to the relative movement between the upper and lower pipes during a weld, which began with the use of beveled end geometry. The direction and magnitude of the lateral deformation was random with no apparent cause. It was observed that the lower, moving platen could deflect under side loading, so a pair of guide blocks were installed to limit this motion. This measure reduced the lateral deflection.

The weld set up procedure was evaluated to determine if it could be a source of variability. With the flat end geometry and the light initial load, precise alignment of the pipe ends was accomplished by adjusting the position of the upper platen. For each weld, the upper platen had been adjusted. Such precise alignment may not be required when using the increased initial load, as required with the reduced contact area. To evaluate this theory, the upper platen was set parallel to the lower platen, and its position measured. At the same time, the electrodes were positioned so that the centerline of pipes was centered between the four 2 in. posts connecting the upper platen with the lower platen. With the pipe-electrode assembly, the stack-up, in the fixture, the initial interface gap from a light load was less than 5 mils, often no gap was observed. Bringing the stack-up to successively higher loads removed or significantly reduced the gap when returned to the light initial load (1.7 kips). Welds performed using these procedures had minimal lateral deformation, typically less than 0.010 inch.

Procedure and fixture evaluation will continue to insure useful results from the misalignment weld series. Research is underway to implement gridmarking of the weld zone to monitor the forging of the weld metal.

4.6.3 Fatigue Testing for CTES

Several weeks ago we were approached by a company, CTES, which was involved in a study for the Gas Institute about the fatigue toughness of welds in coiled tubing. They said the figures they were getting for current methods of joining were disappointing, somewhere around twenty percent of parent metal values, and they wondered about the fatigue strength of homopolar welds. We told them about the testing done by Global in Houma some months ago, but they were looking for something more solid. So Bob Carnes and Terrell Cooksey spent an afternoon bending welding samples with the results found in Table X. This is as empirical as a test can be, but we think it bodes well for the acceptance of homopolar welding in a lot of areas.

5. NDE

5.1 Automatic Ultrasonic Testing of JIPB Welds

A round robin test series of HPW welds using automatic ultrasonic testing (AUT) has been in progress. Three AUT contractors agreed to test HPW welds using techniques suitable for detecting possible HPW defects, specifically cold welds and micro-inclusions. All contractors have tested the same set of welds. The welds are sectioned and will be examined for correlation with AUT results. The companies involved are:

SubSea International, formerly ABB AMDATA Inc. , Corpus Christi, Texas
WesDyne International, Concord, California
Guardian-Hyalog, Canada.

SubSea, formerly ABB AMDATA, completed testing of the welds in October, 1994 and reported the results using C scans. They used paired 10 MHz transducers in a through transmission mode, measuring the amplitude attenuation. The transducers were mounted in a one-piece Lucite wedge, using built-in water columns for coupling.

WesDyne completed testing in May, 1995, and reported their results using a combination of A and B scans. They used a UT technique designed to detect small targets that are aligned with the weld interface and located in the weld zone. A pair of 10 MHz transducers were used in a tandem transducer configuration, with both transducers located on the same side of the weld. Water columns built into the one-piece wedge provided coupling. Scanning was done manually with data collected using the Ultrasonic Data Recording and Processing System. They report that they see "structural differences due to scattering in the weld versus the base material," but the exact position is not known. They recommend testing with the weld bulge removed.

Shaw Pipeline Services, a subsidiary of Guardian Hyalog, completed testing of the welds and returned them. They manually scanned the welds using pulse echo techniques with a single 7 MHz, 12.5 mm focused transducer to interrogate the weld zone, with a scan angle set at 72°. One defective region was found in each of the welds, all 0.75 in. or less in circumferential length.

Reported indications were plotted circumferentially for each of the contractors, as illustrated in Figure 24. Arrows indicate discrete indications and shading indicates regions. Five or six sectors from each weld were identified for sectioning and evaluation, including one section with no indications. Mounted specimens will be successively ground along the circumferential direction, in approximately 100 μm intervals, to investigate microstructural changes through the regions with indications. At each layer, specimens will be ground, polished, and etched, then examined.

5.2 HPW Welds with Known Defects for NDT Technique Evaluation

Series B19, described in section 4.4.2, has been produced with four simulated defects: inclusions, micro-inclusions, cold welds, and surface contamination. Defect type, size, and location was recorded. Different materials were used to mimic each defect type. For the cold weld, tungsten foil was selected based on its density, and melting temperature. For micro-inclusions, 12 μm tungsten powder was placed in the interface. Holes of varying diameter and depth were used to mimic inclusions. Medium weigh oil was used to simulate typical surface contamination.

The welds will be tested in-house using a compact automatic ultrasonic system manufactured by WesDyne International. In-house testing will include testing with and without weld bulge removal. WesDyne will supervise testing and review test results. Mechanical evaluation of the NDT results will include sectioning and metallographic inspection of all sites with installed defects, any with defect indication from the NDT, and sites with no defects or defect indications. These results will be correlated with the NDT results.

Testing will begin upon receipt of the AUT system.

5.3 Fall ASNT Conference

Bob Carnes and Bobby Hudson attended the ASNT Fall Conference and Quality Testing Show in Dallas, Texas during the week of October 16-20, 1995. The short course on ultrasonic techniques emphasized manual techniques for locating and sizing flaws. On Friday, October 20, Frank Dodd, with WesDyne International, and Garth Prentice, with Shaw Pipeline Industries, visited CEM and discussed automatic ultrasonic testing. Frank Dodd demonstrated the compact automatic ultrasonic testing system which used a laptop computer to receive and display UT scans. The manually advanced scanning head provides position information for each pulse. Garth Prentice presented a simulation of girth weld inspection using their latest technology.

5.4 Automatic Ultrasonic Testing

Two years ago, ultrasonic testing (UT) was determined to be the best method for inspecting homopolar welds, and automatic ultrasonic testing (AUT) was determined to be the best implementation of UT, as it is capable of improved sensitivity and providing a permanent record of the inspection. The cost of suitable system was in the neighborhood of 50-100K. A cost estimate by WesDyne to inspect the four B19 welds was $7,500. Demonstration that the AUT system had acceptable sensitivity and repeatability for qualifying the test method would require extensive testing, possibly up to 100% testing as the process prepared for meeting acceptance criteria.

Based on the performance of WesDyne's compact AUT system, it was determined that purchasing such a device would meet the AUT needs of the research project, and at a total system cost under 20K would ultimately save the project money after three in-house tests. Having the system at CEM would permit the research staff to develop expertise in AUT in preparation for welding 12 in. pipe. The scanning head can be adapted to 12 in. pipe.

Frank Dodd suggested that data files could be transferred between CEM and WesDyne using the Internet, allowing WesDyne to supervise AUT performed at CEM. This relationship would shorten the learning curve on use of the AUT system and enable CEM to benefit form WesDyne's breadth of experience, while saving travel and lodging expenses.

6. 12 inch PIPE WELDING FIXTURE

Bob Carnes, Bobby Hudson and Ben Rech went to Houston Tuesday, the 28th of November to confer with Brian Laing, Paul Tewes, and other members of the CRC-Evans design team. That team has done considerable work on the design of a fieldable homopolar welding fixture, and CEM wanted to be sure that any good ideas that were generated could be, and would be incorporated in the twelve-inch lab fixture. Brian had also indicated that CRC stood ready to help in the areas of design, drafting and documentation, and they hoped to set up a protocol for making use of those services.

Plans are being generated that have the fabrication of the fixture underway in the February-March time frame, and making the first weld in November.

7. PLANNED 4th QUARTER ACTIVITIES

During the fourth quarter, planned activities include performing a misalignment series, performing some sensitivity studies on several weld parameters, and optimizing the weld parameters. AUT should begin this quarter upon receipt of the WesDyne System, permitting testing of the B19 series. Mechanical testing underway should be completed and the Round Robin NDE series metallurgical study should be completed.

The misalignment series will be designed to provide information about process sensitivity to misalignment. This series will provide tolerancing information for design of the 12 inch fixture. Types of misalignments include radial of transverse, axial angular, and contact uniformity. Contact surface waviness and roughness will also be investigated as they relate to contact uniformity.

Weld parameters under investigation this quarter may include bevel shoulder radius, field current, and radial position of step between OD and ID surfaces. This last parameter will investigate the effect of step location on ID weld bulge.

8. FINANCIAL STATEMENT

8.1 Financial

The balance sheet through the end of October is attached as Table 34. We have been spending at minimum levels since mid-summer in an attempt to conserve our resources. During November, we encumbered the consultation fee of Dr. Olson at $75 per hr, twelve hours per week, and we have authorized expenditure of approximately $20,000 for the ultra-sonic equipment from WesDyne. According to Dr. Charles Smith, the funds from the MMS will not be forthcoming until January. They will be used for the twelve-inch fixture in any case, but the situation makes it imperative that we get the next year's funding in on time to maintain even the current low level of basic investigation.

Outside Funds:

As revealed in earlier letters, the good news is that the MMS and the DOT have decided to help us with some funding for the design and construction of the twelve-inch fixture. There is currently authorization for $150,000 of the $200,000 requested, but there is a possibility that, that can be plussed up. Dr. Smith of the MMS will be in attendance at our December 1 meeting.

Our bid for DeepStar money was unsuccessful, as was our proposal to the ATP. I have heard various opinions about why that was so. We did not have enough votes to get our DeepStar proposal out of the committee responsible for recommending it, and possibly we were asking for a higher level of funding than they were able to commit. There is never any reason advanced for why one does not get the state's research funds, as nobody seems to be sure how the decisions are made. They did say that we ranked high enough to qualify for the funding, however.

Steve Nichols and Bob Carnes attended the recent Deep Offshore Technology Conference in Rio de Janeiro and made contact with representatives of Conoco, Chevron, and Petrobras. One of the subjects Bob Carnes will cover at the December meeting will be the handling of the penalty and late joining fees of any companies seeking to join.

TABLE 1. MILL TEST REPORT DATA

3 inch nominal (3.5 in. OD) API 5L Carbon Steel Linepipe

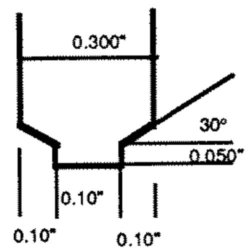
WELD PREFIX CODE	A	B	C	D
SUPPLIER	**Dixie Pipe**	**Prudential**	**Lone Star**	**Nippon**
API 5L GRADE	**X52**	**X60**	**X52**	**X65**
WALL THICKNESS	**0.438**	**0.300**	**0.438**	**0.315**
TYPE	**seamless**	**ERW**	**ERW**	**seamless**
HEAT TREATMENT (not on mill test report)	**Hot rolled**	**controlled rolled**	**normalized**	**quenched and tempered**
LADLE CHEMISTRY				
C	0.23	0.13	0.11	0.08
Mn	1.04	0.65	1.13	1.29
P	0.010	0.005	0.014	0.011
S	0.009	0.004	0.005	0.002
Si		0.22	0.28	0.19
Al		0.042	0.037	
Cr		0.03	0.073	
Mo		0.01	0.028	0.22
Ni		0.01	0.07	
Cu		0.02	0.13	
Cb		0.18	0.034	0.032
Ca		0.0048		0.0026
Ti			0.008	
V	0.08		0.040	
B			0.0003	
				0.035 Ti-Al
IIW C_{eq}	0.42	0.23	0.34	0.34
Yield Strength (ksi)	**66.0**	**79.5**	**59.5**	**71.6 ***
Tensile Strength (ksi)	**94.4**	**86.1**	**79.5**	**80.7 ***
% elong in 2 in.	**30**	**22**	**37**	**26.6 ***
Vickers Hardness ($kg.mm^2$)	**193.2**	**181.9**	**171.0**	**185 ***

* In-house test results, not included with mill test report.

TABLE 2. SERIES D3 WELD PARAMETERS

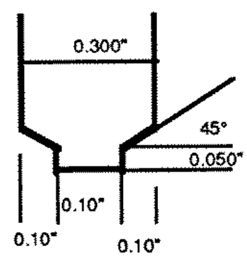
D3.1 - 2,000 rpm
D3.2 - 2,200 rpm

60 kip constant load
330 amp field



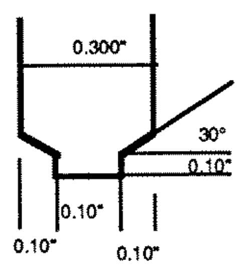
D3.3 - 2,000 rpm
D3.4 - 2,200 rpm

60 kip constant load
330 amp field



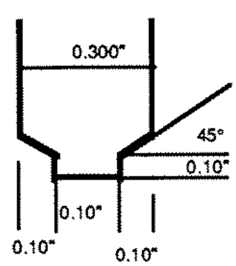
D3.5 - 2,000 rpm
D3.6 - 2,200 rpm

60 kip constant load
330 amp field



D3.7 - 2,000 rpm
D3.8 - 2,200 rpm

60 kip constant load
330 amp field



D3.2 Weld parameters used for D5 and B18 Confirmation Series parameters.

TABLE 3. SERIES D3 TENSILE TEST RESULTS

Specimen	YP (ksi)	UTS (ksi)	% elong	comments
D3.1 a	74.2	84.6	27.5	PM fracture
D3.1 b	63.8	83.7	26.0	PM fracture
D3.2 a	72.5	82.4	29.0	Fracture near gage marks
D3.2 b	74.6	83.1	25.0	HAZ fracture
D3.3 a	73.2	82.3	23.5	Fracture near gage marks
D3.5 a	72.7	82.9	23.8	PM fracture
D3.5 b	72.6	82.6	26	PM fracture
D3.6 a	73.5	82.8	27.5	HAZ fracture
D3.6 b	72.9	82.6	26.0	PM fracture
D3.8 a	73.3	82.8	27.5	HAZ fracture
D3.8 b	71.6	81.6	28.5	PM fracture

All specimens displayed ductile fracture surface.

TABLE 4. SERIES D3 CVN RESULTS

Test Temperature 0°C
Reported values for half size specimens.

WELD #	CVN #	ft-lbs	% shear		WELD #	CVN #	ft-lbs	% shear
D3.1	1	85	100%		D3.5	1	86	100%
	2	64	70%			2	76	100%
	3	65	60%			3	82	100%
	4	59	50%			4	91	100%
	5	60	60%			6	59	50%
	min.	59				min.	59	
	mean	66.6				mean	78.8	
	max.	85				max.	91	
D3.2	1	95	100%		D3.6	1	64	50%
	2	88	100%			2	2	0%
	3	108	100%			3	2	0%
	4	73	60%			4	2.5	0%
	5	90	100%			5	3.5	0%
	min.	73				min.	2	
	mean	90.8				mean	14.8	
	max.	108				max.	64	
D3.3	1	79	100%		D3.7	1	15	0%
	2	93	100%			2	5	0%
	3	56	60%			3	3	0%
	4	83	100%			4	2.5	0%
	6	93	100%			5	92	100%
	min.	56				min.	2.5	
	mean	80.8				mean	23.5	
	max.	93				max.	92	
D3.4	1	79	100%		D3.8	1	2.5	0%
	2	87	100%			2	5.5	0%
	3	82	100%			3	54	30%
	4	89	100%			4	42	20%
	5					6	30	10%
	min.	79				min.	2.5	
	mean	84.3				mean	26.8	
	max.	89				max.	54	

TABLE 5. SERIES D3 CVN RESPONSE TABLE

D3 SERIES																
Response		Input 1		Input 2		Input3		Interactions								
CVN MEAN (ft-lbs)		Step Length (inch)		Bevel Angle (°)		RPM										
Trial	Y	X1		X2		X3		X12		X13		X23		X123		
	ENTRY	L	H	L	H	L	H	L	H	L	H	L	H	L	H	
	Setting	0.05	0.1	30	45	2000	2200									
1	66.6	66.6		66.6		66.6			66.6		66.6		66.6	66.6		
2	90.8	90.8		90.8			90.8		90.8	90.8		90.8			90.8	
3	80.8	80.8			80.8	80.8		80.8			80.8	80.8			80.8	
4	84.3	84.3			84.3		84.3	84.3		84.3			84.3	84.3		
5	78.8		78.8	78.8		78.8		78.8		78.8			78.8		78.8	
6	14.8		14.8	14.8			14.8	14.8			14.8	14.8		14.8		
7	23.5		23.5		23.5	23.5			23.5	23.5		23.5		23.5		
8	26.8		26.8		26.8		26.8		26.8		26.8		26.8		26.8	
Total	466.4	322.5	143.9	251	215.4	249.7	216.7	258.7	207.7	277.4	189	209.9	256.5	189.2	277.2	
Average	58.3	80.63	35.98	62.75	53.85	62.43	54.18	64.68	51.93	69.35	47.25	52.48	64.13	47.3	69.3	
Effect	58.3	-44.65		-8.9		-8.25		-12.75		-22.1		11.65		22		
NORMALIZED EFFECT	100.0	-76.587		-15.266		-14.151		-21.870		-37.907		19.983		37.736		

TABLE 6. D3 SUMMARIES

a. **D3 Series Weld Parameters**

Weld No	Step Length (inch)	Contact width (inch)	Bevel Angle (°)	Special Geometry	RPM	Field (amp)	Load1 (kip)	Load2 (kip)
D3.1	0.05	0.1	30	none	2000	330	60	60
D3.2	0.05	0.1	30	none	2200	330	60	60
D3.3	0.05	0.1	45	none	2000	330	60	60
D3.4	0.05	0.1	45	none	2200	330	60	60
D3.5	0.1	0.1	30	none	2000	330	60	60
D3.6	0.1	0.1	30	none	2200	330	60	60
D3.7	0.1	0.1	45	none	2000	330	60	60
D3.8	0.1	0.1	45	none	2200	330	60	60

b. **D3 Series Process Parameters**

Weld No	TOTC (kA)	Time [totc] (sec)	INTV (v)	Time [intv] (sec)	TCIF (°C)	Time [tcif] (sec)	Disp1 (mil)	time [disp1] (sec)	Disp2 (mil)	time [disp2] (sec)
D3.1	189.5	0.102	1.008	0.118	607.9	2.5	71.5	0.345	97.5	3
D3.2	207.9	0.102	1.087	0.11	803	3.03	83.5	0.5	155	3
D3.3	185.9	0.11	1.012	0.125	593	3			161	3
D3.4	201.6	0.102	1.135	0.11	722	2.72	121.4	0.44	257	3.5
D3.5	178	0.102	1.397	0.133	630	2.5	180	0.5	205	3
D3.6	195.8	0.086	1.57	0.118	844	3.1	192	0.5	270	3
D3.7	186.4	0.094	1.485	0.118	656	2.7	217	0.53	253.7	3
D3.8	194.8	0.094	1.565	0.118	802	3.1	228	0.5	320.7	3

c, **D3 Series Mechanical Test Results**

Weld No	Act. Disp (inch)	CVN mean (ft-lbs)	CVN min. (ft-lbs)	YS (ksi)	TS (ksi)	%EL	HV 10 HAZ min. (kg/mm2)	HAZ width (mm)
D3.1	0.124	66.6	59	69	84.15	26.75	175	8
D3.2	0.2	90.8	73	73.55	82.75	27	165	12
D3.3	0.177	80.8	56	73.2	82.3	23.5	172	6
D3.4	0.293	84.3	79				166	12
D3.5	0.234	78.8	59	72.6	82.75	24.9	172	6
D3.6	0.312	14.8	2	73.2	82.7	26.75	165	12
D3.7	0.287	23.5	2.5				170	7
D3.8	0.358	26.8	2.5	72.45	81.9	28	165	10

TABLE 7. JIPD3 SERIES RESULTS

	STEP LENGTH / BEVEL ANGLE	0.05"		0.1"		RPM
WELD NO.	30°	D3.1		D3.5		2000
TOTC (kA)/TIME (sec)		189.5	0.094	178	0.102	
INTV (V)/TIME (sec)		1.008	0.118	1.397	0.133	
TCIF (°C)/TIME (sec)		607.9	2.5	630	2.5	
DISP1 (mil)/TIME (sec)		71.5	0.345	180	0.5	
DISP2 (mil)/TIME (sec)		97.5	3	205	3	
ACT. DISP (inch)		0.124		0.234		
CVN MIN (ft-lbs)		59		59		
CVN MEAN (ft-lbs)		66.6		78.8		
CVN MAX (ft-lbs)		85		91		
WELD NO.		D3.2		D3.6		2200
TOTC (kA)/TIME (sec)		207.9	0.102	195.8	0.086	
INTV (V)/TIME (sec)		1.087	0.11	1.57	0.118	
TCIF (°C)/TIME (sec)		803	3.03	844	3.1	
DISP1 (mil)/TIME (sec)		83.5	0.5	192	0.5	
DISP2 (mil)/TIME (sec)		155	3	270	3	
ACT. DISP (inch)		0.2		0.312		
CVN MIN (ft-lbs)		73		2		
CVN MEAN (ft-lbs)		90.8		14.8		
CVN MAX (ft-lbs)		108		64		
WELD NO.	45°	D3.3		D3.7		2000
TOTC (kA)/TIME (sec)		185.9	0.11	186.4	0.094	
INTV (V)/TIME (sec)		1.012	0.125	1.485	0.118	
TCIF (°C)/TIME (sec)		593	3	656	2.7	
DISP1 (mil)/TIME (sec)		115	0.48	217	0.53	
DISP2 (mil)/TIME (sec)		161	3	253.7	3	
ACT. DISP (inch)		0.177		0.287		
CVN MIN (ft-lbs)		56		2.5		
CVN MEAN (ft-lbs)		80.8		23.5		
CVN MAX (ft-lbs)		93		92		
WELD NO.		D3.4		D3.8		2200
TOTC (kA)/TIME (sec)		201.6	0.102	194.8	0.094	
INTV (V)/TIME (sec)		1.135	0.11	1.565	0.118	
TCIF (°C)/TIME (sec)		722	2.72	802	3.1	
DISP1 (mil)/TIME (sec)		121.4	0.44	228	0.5	
DISP2 (mil)/TIME (sec)		257	3.5	320.7	3	
ACT. DISP (inch)		0.293		0.358		
CVN MIN (ft-lbs)		79		2.5		
CVN MEAN (ft-lbs)		84.3		26.8		
CVN MAX (ft-lbs)		89		54		

TABLE 8. D5 SUMMARIES

a. D5 Series Weld Parameters

Weld No	Step Length (inch)	Contact width (inch)	Bevel Angle (°)	Special Geometry	RPM	Field (amp)	Load1 (kip)	Load2 (kip)
D5.1	0.05	0.1	30	none	2200	330	60	60
D5.2	0.05	0.1	30	none	2200	330	60	60
D5.3	0.05	0.1	30	none	2200	330	60	60
D5.4	0.05	0.1	30	none	2200	330	60	60
D5.5	0.05	0.1	30	none	2200	330	60	60
D5.6	0.05	0.1	30	none	2200	330	60	60

b. D5 Series Process Parameters

Weld No	TOTC (kA)	Time [totc] (sec)	INTV (v)	Time [intv] (sec)	TCIF (°C)	Time [tcif] (sec)	Disp1 (mil)	time [disp1] (sec)	Disp2 (mil)	time [disp2] (sec)
D5.1	196.35	0.11	1.077	0.11	765	2.94	89	0.44	155	4.065
D5.2	209	0.102	1.095	0.102	768	2.565	92	0.5	158	3.31
D5.3	201.05	0.102	1.082	0.11	765	2.94	86.74	0.44	168.1	4.44
D5.4	201.6	0.11	1.105	0.117	768	2.75	92.16	0.535	159.38	2.94
D5.5	202.65	0.102	1.08	0.11	772	2.875	86.74	0.47	152.8	3.125
D5.6	201.6	0.125	1.067	0.11	758	2.905	87.82	0.405	151.79	3.345

c. D5 Series Mechanical Test Results

Weld No	Act. Disp (inch)	CVN mean (ft-lbs)	CVN min. (ft-lbs)	YS (ksi)	TS (ksi)	%EL	HV 10 HAZ min. (kg/mm2)	HAZ width (mm)
D5.1	0.188	108.2	99				165	15
D5.2	0.194	106.2	70	72.73	81.65	29	160	12
D5.3	0.206	106.6	93	67.16	76.58	25	163	11
D5.4	0.2	85.9	72.5				165	11
D5.5	0.195	86.6	61				160	12
D5.6	0.187	103.6	94	72.59	81.88	25.5	160	11

TABLE 9. SERIES D5 TENSILE TEST RESULTS

Specimen	YP (ksi)	UTS (ksi)	% elong	comments
D5.2	72.73	81.65	29	PM fracture
D5.3	67.16	76.58	25	PM fracture
D5.6	72.59	81.88	25.5	PM fracture

All specimens displayed ductile fracture surface.

TABLE 10. SERIES D5 CVN RESULTS

Test Temperature 0°C
Reported values for half size specimens.

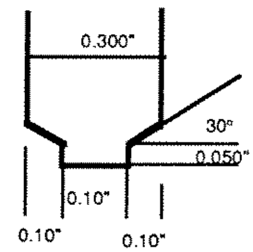
WELD #	CVN	ft-lbs	%shear		WELD #	CVN	ft-lbs	%shear
D5.1	**1**	104	100		**D5.4**	**1**	80	100
	2	110	100			**2**	72.5	80
	3	99	100			**3**	86	100
	4	106	100			**4**	89	100
	5	122	100			**5**	102	100
	min.	99				**min.**	72.5	
	mean	108.2				**mean**	85.9	
	max.	122				**max.**	102	
D5.2	**1**	70	60		**D5.5**	**1**	95	100
	2	115	100			**2**	100	100
	3	122	100			**3**	90	100
	4	124	100			**4**	61	50
	5	100	100			**5**	87	100
	min.	70				**min.**	61	
	mean	106.2				**mean**	86.6	
	max.	124				**max.**	100	
D5.3	**1**	96	100		**D5.6**	**1**	106	100
	2	118	100			**2**	94	100
	3	102	100			**3**	116	100
	4	93	100			**4**	94	100
	5	124	100			**5**	108	100
	min.	93				**min.**	94	
	mean	106.6				**mean**	103.6	
	max.	124				**max.**	116	
Series D5	**min.**	**61**						
	mean	**99.51667**						
	max.	**124**						

TABLE 11. SERIES D6 WELD PARAMETERS

D6.1 - 300 Amp Field
D6.2 - 360 Amp Field

60 kip constant load

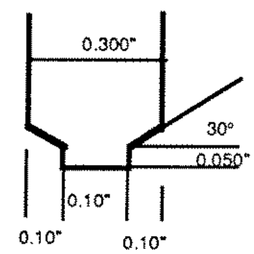
2,200 rpm



D6.3 - 300 Amp Field
D6.4 - 360 Amp Field

45 kip constant load

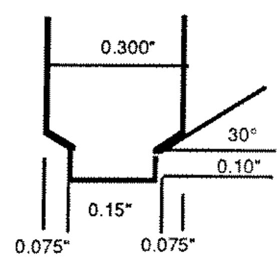
2,200 rpm



D6.5 - 300 Amp Field
D6.6 - 360 Amp Field

60 kip constant load

2,200 rpm



D6.7 - 300 Amp Field
D6.8 - 360 Amp Field

45 kip constant load

2,200 rpm

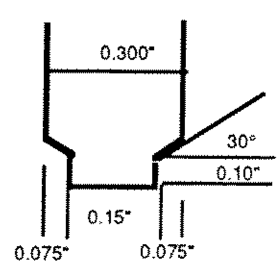


TABLE 12. D6 SUMMARIES

a. D6 Series Weld Parameters

Weld No	Step Length (inch)	Contact width (inch)	Bevel Angle (°)	Special Geometry	RPM	Field (amp)	Load 1 (kip)	Load 2 (kip)
D6.1	0.05	0.1	30	none	2200	300	60	60
D6.2	0.05	0.15	30	none	2200	360	60	60
D6.3	0.05	0.1	30	none	2200	300	45	45
D6.4	0.05	0.15	30	none	2200	360	45	45
D6.5	0.05	0.1	30	none	2200	300	60	60
D6.6	0.05	0.15	30	none	2200	360	60	60
D6.7	0.05	0.1	30	none	2200	300	45	45
D6.8	0.05	0.15	30	none	2200	360	45	45

b. D6 Series Process Parameters

Weld No	TOTC (kA)	Time [totc] (sec)	INTV (v)	Time [intv] (sec)	TCIF (°C)	Time [tcif] (sec)	Disp1 (mil)	time [disp1] (sec)	Disp2 (mil)	time [disp2] (sec)
D6.1	192.65	0.118	1.035	0.118	747	3.065	88.9	0.595	148.5	4.03
D6.2	216.3	0.094	1.187	0.102	779	2.655	98.66	0.125	174.5	4.03
D6.3	194.25	0.109	1.115	0.125	795	2.94	87.2	0.5	124.7	3.31
D6.4	214.7	0.094	1.222	0.102	765	2.97	88.8	0.28	129	2.845
D6.5	197.4	0.11	0.885	0.211	697	3.53	52	0.595	95.4	3.28
D6.6	224.15	0.11	1.022	0.172	729	2.845	56.13	0.405	116.01	2.655
D6.7	197.4	0.11	0.9025	0.219	705	3.125	48.79	0.5	71.56	2.875
D6.8	220.5	0.11	1.032	0.188	753	2.845	47.7	0.28	82.4	2.625

c. D6 Series Mechanical Test Results

Weld No	Act. Disp (inch)	CVN mean (ft-lbs)	CVN min. (ft-lbs)	YS (ksi)	TS (ksi)	%EL	HV 10 HAZ min. (kg/mm2)	HAZ width (mm)
D6.1	0.182	104.6	86	71.73	81	24.5	170	9
D6.2	0.209	102.4	92	72.95	81.88	23.5	167	11
D6.3	0.15	110.75	97	72.84	81.71	27.5	167	10
D6.4	0.166	91	60	72.59	81.88	29	167	11
D6.5	0.126	64.4	58	73.83	83.57	25	171	9
D6.6	0.155	99	90	72.75	81.75	24	172	10
D6.7	0.102	41.8	7	73.58	82.69	25.5	171	10
D6.8	0.177	70.8	48	73.61	82.01	25.5	168	10

TABLE 13. D6 SERIES RESULTS

	Contact Width / LOAD	0.100"		0.150"		FIELD
WELD NO.	60 KIP	D6.1		D6.5		300
TOTC (kA)/TIME (sec)		192.65	0.118	197.4	0.11	
INTV (V)/TIME (sec)		1.035	0.118	0.885	0.211	
TCIF (°C)/TIME (sec)		747	3.065	697	3.53	
DISP1 (mil)/TIME (sec)		88.9	0.595	52	0.595	
DISP2 (mil)/TIME (sec)		148.5	4.03	95.4	3.28	
ACT. DISP (inch)		0.182		0.126		
CVN MIN (ft-lbs)		86		58		
CVN MEAN (ft-lbs)		104.6		64.4		
CVN MAX (ft-lbs)		120		71		
WELD NO.		D6.2		D6.6		360
TOTC (kA)/TIME (sec)		216.3	0.094	224.15	0.11	
INTV (V)/TIME (sec)		1.187	0.102	1.022	0.172	
TCIF (°C)/TIME (sec)		779	2.655	729	2.845	
DISP1 (mil)/TIME (sec)		98.66	0.125	56.13	0.405	
DISP2 (mil)/TIME (sec)		174.5	4.03	116.01	2.655	
ACT. DISP (inch)		0.209		0.155		
CVN MIN (ft-lbs)		92		90		
CVN MEAN (ft-lbs)		102.4		99		
CVN MAX (ft-lbs)		110		109		
WELD NO.	45 KIP	D6.3		D6.7		300
TOTC (kA)/TIME (sec)		194.25	0.109	197.4	0.11	
INTV (V)/TIME (sec)		1.115	0.125	0.9025	0.219	
TCIF (°C)/TIME (sec)		795	2.94	705	3.125	
DISP1 (mil)/TIME (sec)		87.2	0.5	48.79	0.5	
DISP2 (mil)/TIME (sec)		124.7	3.31	71.56	2.875	
ACT. DISP (inch)		0.15		0.102		
CVN MIN (ft-lbs)		97		7		
CVN MEAN (ft-lbs)		110.75		41.8		
CVN MAX (ft-lbs)		120		67		
WELD NO.		D6.4		D6.8		360
TOTC (kA)/TIME (sec)		214.7	0.094	220.5	0.11	
INTV (V)/TIME (sec)		1.222	0.102	1.032	0.188	
TCIF (°C)/TIME (sec)		765	2.97	753	2.845	
DISP1 (mil)/TIME (sec)		88.9	0.28	47.7	0.28	
DISP2 (mil)/TIME (sec)		129	2.845	82.4	2.625	
ACT. DISP (inch)		0.166		0.177		
CVN MIN (ft-lbs)		60		48		
CVN MEAN (ft-lbs)		91		70.8		
CVN MAX (ft-lbs)		107		100		

TABLE 14. SERIES D6 CVN RESULTS

Test Temperature 0°C
Reported values for half size specimens.

WELD #	CVN #	ft-lbs	% shear		WELD #	CVN #	ft-lbs	% shear
D6.1	1	115	100		D6.5	1	65	60
	2	94	100			2	71	70
	3	86	100			3	66	60
	4	108	100			4	62	60
	5	120	100			6	58	50
	min.	86				min.	58	
	mean	104.6				mean	64.4	
	max.	120				max.	71	
D6.2	1	100	100		D6.6	1	109	100
	2	106	100			2	90	100
	3	92	100			3	98	100
	4	110	100			4	96	100
	5	104	100			5	102	100
	min.	92				min.	90	
	mean	102.4				mean	99.0	
	max.	110				max.	109	
D6.3	1	97	100		D6.7	1	34	20
	2		60			2	67	60
	3	120	100			3	54	50
	4	112	100			4	47	35
	6	114	100			5	7	0
	min.	97				min.	7	
	mean	110.75				mean	41.8	
	max.	120				max.	67	
D6.4	1	107	100		D6.8	1	48	40
	2	90	100			2	52	30
	3	96	100			3	94	100
	4	60	40			4	100	100
	5	102	100			6	60	50
	min.	60				min.	48	
	mean	91				mean	70.8	
	max.	107				max.	100	
D6 Series	min.	7						
	mean	85.6						
	max.	120						

TABLE 15. SERIES D6 CVN RESPONSE TABLE

D6 SERIES																	
Response		Input 1		Input 2		Input3		Interactions									
CVN Mean (ft-lbs)		CONTACT WIDTH (inch)		LOAD (KIP)		FIELD (amp)											
Trial	Y	X1		X2		X3		X12		X13		X23		X123			
	ENTRY	L	H	L	H	L	H	L	H	L	H	L	H	L	H		
	Setting	0.1	0.15	60	45	300	360										
1	**104.6**	104.6		104.6		104.6			104.6		104.6		104.6	104.6			
2	**102.4**	102.4		102.4			102.4		102.4	102.4		102.4			102.4		
3	**110.75**	110.8			110.8	110.8		110.8			110.8	110.8			110.8		
4	**91**	91			91		91	91		91			91	91			
5	**64.4**		64.4	64.4		64.4		64.4		64.4			64.4		64.4		
6	**99**		99	99			99	99			99	99		99			
7	**41.8**		41.8		41.8	41.8			41.8	41.8		41.8		41.8			
8	**70.8**		70.8		70.8		70.8		70.8		70.8		70.8		70.8		
Total	684.75	408.8	276	370.4	314.4	321.6	363.2	365.2	319.6	299.6	385.2	354	330.8	336.4	348.4		
Average	85.594	102.2	69	92.6	78.59	80.39	90.8	91.29	79.9	74.9	96.29	88.49	82.7	84.1	87.09		
Effect	85.594	-33.1875		-14.0125		10.4125		-11.3875		21.3875		-5.7875		2.9875			
NORMALIZED EFFECT	100.0	-38.773		-16.371		12.165		-13.304		24.987		-6.762		3.490			

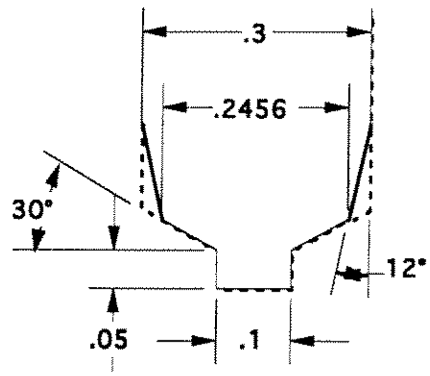
TABLE 16. SERIES D6 TENSILE TEST RESULTS

Specimen	YP (ksi)	UTS (ksi)	% elong	comments
D6.1	71.73	81	24.5	PM fracture
D6.2	72.95	81.88	23.5	PM fracture
D6.3	72.84	81.71	27.5	PM fracture
D6.4	72.59	81.88	29	PM fracture
D6.5	73.83	83.57	25	PM fracture
D6.6	72.75	81.75	24	PM fracture
D6.7	73.58	82.69	25.5	PM fracture
D6.8	73.61	82.01	25.5	PM fracture

TABLE 17. SERIES D7 WELD PARAMETERS

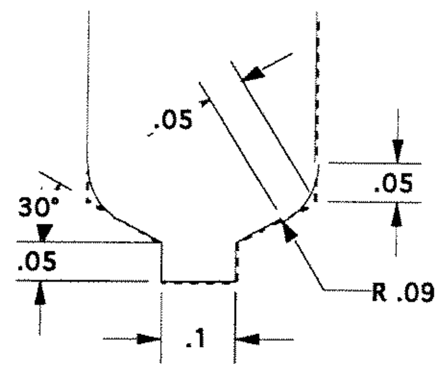
D7.1

2,200 rpm
60 kip constant load
330 amp field



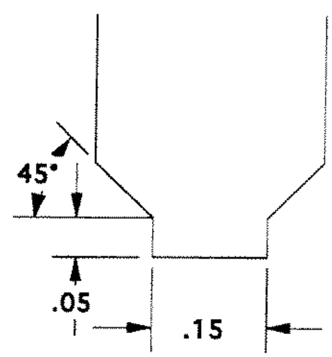
D7.2, D7.4, D7.5,
D7.6, D7.8, D7.9

2,200 rpm
60 kip constant load
330 amp field



D7.3

2,200 rpm
45 kip constant load
330 amp field



D7.7

2,100 rpm
60 kips constant load
360 amp field

Same Geometry as D7.2

This weld used as first weld in D8 weld series.

TABLE 18. D7 SUMMARIES

a. D7 Series Weld Parameters

Weld No	Step Length (inch)	Contact width (inch)	Bevel Angle (°)	Special Geometry	RPM	Field (amp)	Load 1 (kip)	Load 2 (kip)
D7.1	0.05	0.1	30	2nd bevel	2200	330	60	60
D7.2	0.05	0.1	30	.09R shld'r	2200	330	60	60
D7.3	0.05	0.15	45	none	2200	330	45	45
D7.4	0.05	0.1	30	.09R shld'r	2200	330	60	60
D7.5	0.05	0.1	30	.09R shld'r	2200	330	60	60
D7.6	0.05	0.1	30	.09R shld'r	2200	330	60	60
D7.7	0.05	0.1	30	.09R shld'r	2100	360	60	60
D7.8	0.05	0.1	30	.09R shld'r	2200	330	60	60
D7.9	0.05	0.1	30	.09R shld'r	2200	330	60	60

b. D7 Series Process Parameters

Weld No	TOTC (kA)	Time [totc] (sec)	INTV (v)	Time [intv] (sec)	TCIF (°C)	Time [tcif] (sec)	Disp1 (mil)	time [disp1] (sec)	Disp2 (mil)	time [disp2] (sec)
D7.1	197.4	0.094	1.092	0.11	735	2.97	94.33	0.405	199.5	2.845
D7.2	209.45	0.094	1.157	0.102	811	2.78	96.498	0.405	211.43	2.655
D7.3	204.75	0.11	0.9625	0.203	816	3.065	60.7	0.405	106.26	2.815
D7.4	209	0.094	1.142	0.102	790	2.815	96.498	0.315	202	2.69
D7.5	208.95	0.125	1.195	0.102	821	2.815	101.9	0.315	196.2	2.69
D7.6	210.5	0.102	1.14	0.102	781	2.815	93.24	0.375	182	2.69
D7.7	215.75	0.086	1.167	0.102	691	2.53	96.49	0.345	159.4	2.405
D7.8	210.5	0.102	1.127	0.11	763	2.905	87.8	0.375	162.6	2.78
D7.9	na	na	-	-	-	-	-	-	-	-

c. D7 Series Mechanical Test Results

Weld No	Act. Disp (inch)	CVN mean (ft-lbs)	CVN min. (ft-lbs)	YS (ksi)	TS (ksi)	%EL	HV 10 HAZ min. (kg/mm2)	HAZ width (mm)
D7.1	0.24	93	86	72.92	81.46	27.5		
D7.2	0.259	90.6	83	73.67	82.15	22.5		
D7.3	0.14	91.6	65	72.9	82.92	23		
D7.4	0.248	101.6	90					
D7.5	0.241	91.8	87					
D7.6	0.23							
D7.7	0.196							
D7.8	0.205							
D7.9	0.217							

TABLE 19. SERIES D7 TENSILE TEST RESULTS

Specimen	YP (ksi)	UTS (ksi)	% elong	comments
D7.1	72.92	81.46	27.5	PM fracture
D7.2	73.67	82.15	22.5	PM fracture
D7.3	72.9	82.92	23.0	PM fracture
All specimens displayed ductile fracture surface.				

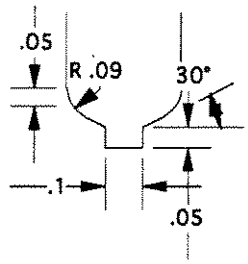
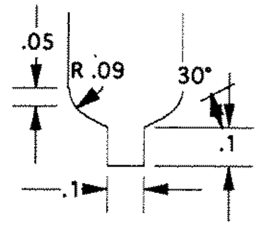
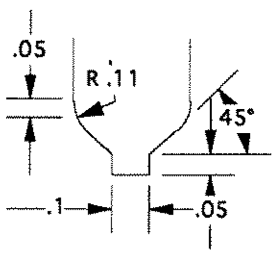
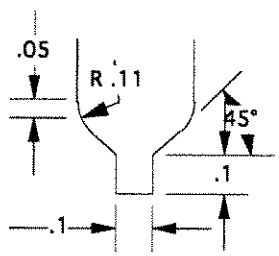
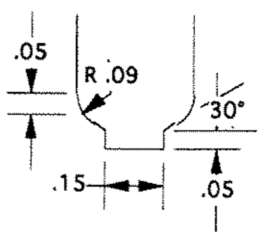
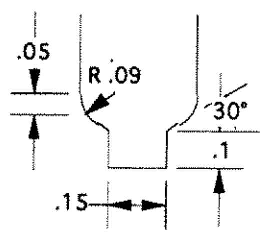
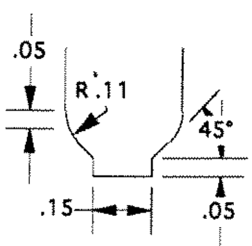
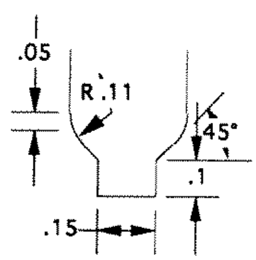
TABLE 20. SERIES D7 CVN RESULTS

Test Temperature 0°C Reported values for half size specimens.

WELD #	CVN	ft-lbs	%shear		WELD #	CVN	ft-lbs	%shear
D7.1	**1**	104	100		**D7.4**	**1**	106	100
	2	86	100			**2**	101	100
	3	101	100			**3**	90	100
	4	104	100			**4**	100	100
	5	88	100			**5**	111	100
	min.	86				**min.**	90	
	mean	93				**mean**	101.6	
	max.	104				**max.**	111	
D7.2	**1**	84	100		**D7.5**	**1**	96	100
	2	83	100			**2**	94	100
	3	90	100			**3**	92	100
	4	104	100			**4**	87	100
	5	92	100			**5**	90	100
	min.	83				**min.**	87	
	mean	90.6				**mean**	91.8	
	max.	104				**max.**	96	
D7.3	**1**	72	40		**D7.7**	**1**	117	100
	2	114	100			**3**	87	100
	3	113	100			**5**	95	100
	4	94	100					
	5	65	40					
	min.	65				**min.**	87	
	mean	91.6				**mean**	99.7	
	max.	114				**max.**	117	
Series D7	**min.**	**65**						
	mean	**94.4**						
	max.	**117**						

TABLE 21. SERIES D8 WELD PARAMETERS

Discharge Speed	**2,100 rpm**		
Field	**360 amps**	**Electrode Gap**	**2 inch**
Load	**60 kips constant**	**Wall Thickness**	**0.30 in.**

D7.7 	**D8.5** 
D8.2 	**D8.6** 
D8.3 	**D8.7** 
D8.4 	**D8.8** 

Note: Weld D8.1 was welded with field current of 390 amps, which is the only difference from other welds in series. D7.7 used in place

TABLE 22. D8 SUMMARIES

a. D8 Series Weld Parameters

Weld No	Step Length (inch)	Contact width (inch)	Bevel Angle (°)	Special Geometry	RPM	Field (amp)	Load 1 (kip)	Load 2 (kip)
D8.1	0.05	0.1	30	.09R shld'r	2100	360	60	60
D7.7	0.05	0.1	30	.09R shld'r	2100	360	60	60
D8.2	0.05	0.1	45	.11R shld'r	2100	360	60	60
D8.3	0.05	0.15	30	.09R shld'r	2100	360	60	60
D8.4	0.05	0.15	45	.11R shld'r	2100	360	60	60
D8.5	0.1	0.1	30	.09R shld'r	2100	360	60	60
D8.6	0.1	0.1	45	.11R shld'r	2100	360	60	60
D8.7	0.1	0.15	30	.09R shld'r	2100	360	60	60
D8.8	0.1	0.15	45	.11R shld'rr	2100	360	60	60

b. D8 Series Process Parameters

Weld No	TOTC (kA)	Time [totc] (sec)	INTV (v)	Time [intv] (sec)	TCIF (°C)	Time [tcif] (sec)	Disp1 (mil)	time [disp1] (sec)	Disp2 (mil)	time [disp2] (sec)
D8.1	215.75	0.086	1.167	0.102	691	2.53	96.5	0.345	159.4	2.405
D7.7	215.75	0.086	1.167	0.102	691	2.53	96.49	0.345	159.4	2.405
D8.2	215.7	0.094	1.21	0.102	641	2.5	136.6	0.5	191.9	2.375
D8.3	212	0.11	0.915	0.196	629	2.405	55.3	0.435	97.6	2.185
D8.4	219.95	0.11	0.9725	0.18	645	2.44	73.72	0.435	119.3	2.22
D8.5	203.7	0.094	1.577	0.118	676	2.875	202.7	0.44	256.9	2.75
D8.6	201	0.094	1.597	0.118	713	3.2	233.1	0.47	297.1	3.155
D8.7	216.3	0.11	1.165	0.18	681	2.595	150	0.53	192.99	2.405
D8.8	212.1	0.102	1.185	0.188	675	2.565	177.8	0.78	212.5	2.375

c. D8 Series Mechanical Test Results

Weld No	Act. Disp (inch)	CVN mean (ft-lbs)	CVN min. (ft-lbs)	YS (ksi)	TS (ksi)	%EL	HV 10 HAZ min. (kg/mm2)	HAZ width (mm)
D8.1	0.196							
D7.7	0.196							
D8.2	0.234							
D8.3	0.132							
D8.4	0.155							
D8.5	0.288							
D8.6	0.333							
D8.7	0.229							
D8.8	0.248							

TABLE 23. JIPD8 SERIES RESULTS

Weld Parameters			
	RPM	2100	
	Field	360	Amp
	Load	60	kip
	Electrode Gap	2	inch

	STEP LENGTH / CONTACT WIDTH	0.05"		0.1"		BEVEL ANGLE
WELD NO.	0.1	D7.7		D8.5		30°
TOTC (kA)/TIME (sec)		215.75	0.086	203.7	0.094	
INTV (V)/TIME (sec)		1.167	0.102	1.577	0.118	
TCIF (°C)/TIME (sec)		691	2.53	676	2.875	
DISP1 (mil)/TIME (sec)		96.5	0.345	202.7	0.44	
DISP2 (mil)/TIME (sec)		159.4	2.405	256.9	2.75	
ACT. DISP (inch)		0.196		0.288		
CVN MIN (ft-lbs)		87		0		
CVN MEAN (ft-lbs)		999.7		0.83		
CVN MAX (ft-lbs)		117		2		
WELD NO.		D8.2		D8.6		45°
TOTC (kA)/TIME (sec)		215.7	0.094	201	0.094	
INTV (V)/TIME (sec)		1.21	0.102	1.597	0.118	
TCIF (°C)/TIME (sec)		641	2.5	713	3.2	
DISP1 (mil)/TIME (sec)		136.6	0.5	233.1	0.47	
DISP2 (mil)/TIME (sec)		191.9	2.375	297.1	3.155.	
ACT. DISP (inch)		0.234		0.333		
CVN MIN (ft-lbs)		36		0		
CVN MEAN (ft-lbs)		70		0		
CVN MAX (ft-lbs)		89		0		
WELD NO.	0.15	D8.3		D8.7		30°
TOTC (kA)/TIME (sec)		212	0.11	216.3	0.11	
INTV (V)/TIME (sec)		0.915	0.196	1.165	0.18	
TCIF (°C)/TIME (sec)		629	2.405	681	2.595	
DISP1 (mil)/TIME (sec)		55.3	0.435	150	0.53	
DISP2 (mil)/TIME (sec)		97.6	2.185	192.99	2.405	
ACT. DISP (inch)		0.132		0.229		
CVN MIN (ft-lbs)		64		85		
CVN MEAN (ft-lbs)		90.3		98.7		
CVN MAX (ft-lbs)		105		120		
WELD NO.		D8.4		D8.8		45°
TOTC (kA)/TIME (sec)		219.95	0.11	212.1	0.102	
INTV (V)/TIME (sec)		0.9725	0.18	1.185	0.188	
TCIF (°C)/TIME (sec)		645	2.44	675	2.565	
DISP1 (mil)/TIME (sec)		73.72	0.435	177.8	0.78	
DISP2 (mil)/TIME (sec)		119.3	2.22	212.5	2.375	
ACT. DISP (inch)		0.155		0.248		
CVN MIN (ft-lbs)		61		97		
CVN MEAN (ft-lbs)		75.7		108		
CVN MAX (ft-lbs)		93		115		

TABLE 24. SERIES D8 CVN RESULTS

Test Temperature 0°C
Reported values for half size specimens.

WELD #	CVN #	ft-lbs	% shear		WELD #	CVN #	ft-lbs	% shear
D8.1	1	120	100		D8.5	1	2	0
	3	86	100			3	2.5	0
	5	105	100			6	0	0
	min.	86				min.	0	
	mean	103.7				mean	.83	
	max.	120				max.	2	
D8.2	1	36	30		D8.6	1	0	0
	3	85	100			3	0	0
	5	89	100			5	0	0
	min.	36				min.	0	
	mean	70				mean	0	
	max.	89				max.	0	
D8.3	1	64	60		D8.7	1	91	100
	3	102	100			3	85	100
	6	105	100			5	120	100
	min.	64				min.		
	mean	90.3				mean		
	max.	105				max.		
D8.4	1	73	75%		D8.8	1	115	100
	3	61	60%			3	112	100
	5	93	100%			6	97	100
	min.	61				min.	97	
	mean	75.6				mean	108	
	max.	93				max.	115	
D8 Series	min.	0						
	mean	68.4						
	max.	120						

TABLE 25. SERIES D8 CVN RESPONSE TABLE

D8 SERIES															
	Response	Input 1		Input 2		Input3		Interactions							
CVN MEAN (ft-lbs)		Step Length (inch)		Contact Width (inch)		Bevel Angle (°)									
Trial	Y	X1		X2		X3		X12		X13		X23		X123	
	ENTRY	L	H	L	H	L	H	L	H	L	H	L	H	L	H
	Setting	0.05	0.1	30	45	2000	2200								
1	**99.7**	99.7		99.7		99.7			99.7		99.7		99.7	99.7	
2	**70**	70		70			70		70	70		70			70
3	**90.3**	90.3			90.3	90.3		90.3			90.3	90.3			90.3
4	**75.7**	75.7			75.7		75.7	75.7		75.7			75.7	75.7	
5	**0.083**		0.083	0.083		0.083		0.083		0.083			0.083		0.083
6	**0**		0	0			0	0			0	0		0	
7	**98.7**		98.7		98.7	98.7			98.7	98.7		98.7		98.7	
8	**108**		108		108		108		108		108		108		108
Total	542.48	335.7	206.8	169.8	372.7	288.8	253.7	166.1	376.4	244.5	298	259	283.5	274.1	268.4
Average	67.81	83.93	51.7	42.45	93.18	72.2	63.43	41.52	94.1	61.12	74.5	64.75	70.87	68.53	67.1
Effect	67.81	-32.22925		50.72925		-8.77075		52.57925		13.37925		6.12075		-1.42925	
NORMALIZED EFFECT	100.0	-47.528		74.810		-12.934		77.539		19.730		9.026		-2.108	

TABLE 26. SERIES B18 WELD PARAMETERS

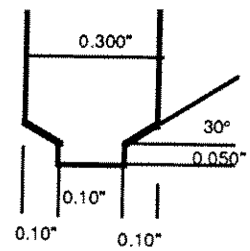
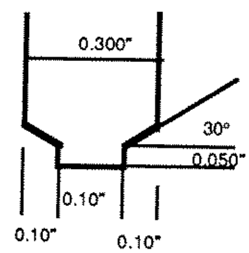
B18.1 - 2,000 rpm 60 kip constant load 330 amp field	
B18.2, B18.3, B18.4 - 2,200 rpm 60 kip constant load 330 amp field	

TABLE 27. SERIES B18 CVN RESULTS

Test Temperature 0°C
Reported values for half size specimens.

WELD	CVN #	ft-lbs	% shear	comments
B18.1	1	68	100	
	2	79	100	
	3	86	100	
	4	71	100	
	5	73	100	
	min.	68		
	mean	75.4		
	max.	86		
B18.2	1	76	100	
	2	72	100	
	3	65	100	
	4	73	100	
	5	62	100	
	min.	62		
	mean	69.9		
	max.	76		
B18.3.1	1	75	100	
	2	78	100	
	3	63	100	
	4	53	100	
	5	61	100	
	E	64	100	Extra Specimen, CVN value not included in mean calculation
	min.	53		
	mean	66.0		
	max.	78		
B18.4	1	80	100	
	2	75	100	
	3	83	100	
	4	66	100	
	5	77	100	
	min.	66		
	mean	76.2		
	max.	83		

B18 Series mean 71.8 ft lbs, range 53 - 86 ft lbs.

TABLE 28. B18 SUMMARIES

a. **B18 Series Weld Parameters**

Weld No	Step Length (inch)	Contact width (inch)	Bevel Angle (°)	Special Geometry	RPM	Field (amp)	Load 1 (kip)	Load 2 (kip)
B18.1	0.05	0.1	30	none	2000	330	60	60
B18.2	0.05	0.1	30	none	2200	330	60	60
B18.3	0.05	0.1	30	none	2200	330	60	60
B18.4	0.05	0.1	30	none	2200	330	60	60

b. **B18 Series Process Parameters**

Weld No	TOTC (kA)	Time [totc] (sec)	INTV (v)	Time [intv] (sec)	TCIF (°C)	Time [tcif] (sec)	Disp1 (mil)	time [disp1] (sec)	Disp2 (mil)	time [disp2] (sec)
B18.1	182.7	0.102	0.905	0.133	549	2.655	75.9	0.5	95	2.53
B18.2	200.6	0.11	0.975	0.118	701	3.47	93.25	0.595	164.8	3.44
B18.3	202.1	0.109	0.985	0.125	705	3.44	92.16	0.56	177.8	3.375
B18.4	203.7	0.11	0.983	0.11	744	3.405	88.91	0.47	167	3.28

c. **B18 Series Mechanical Test Results**

Weld No	Act. Disp (inch)	CVN mean (ft-lbs)	CVN min. (ft-lbs)	YS (ksi)	TS (ksi)	%EL	HV 10 HAZ min. (kg/mm2)	HAZ width (mm)
B18.1	0.124	75.4	68	67.21	80.57	14		
B18.2	0.207	69.9	62	66.27	78.32	15		
B18.3	0.223	66.0	53					
B18.4	0.215	76.2	66					

TABLE 29. SERIES B19 WELD PARAMETERS

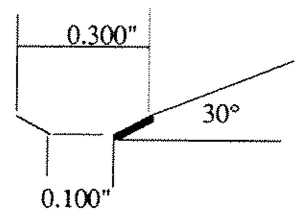
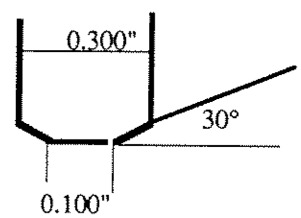
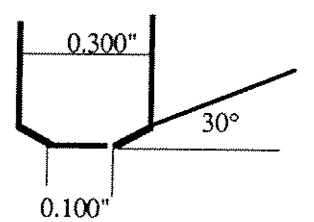
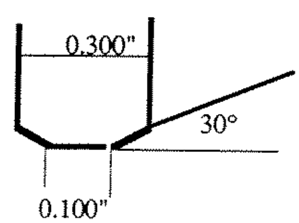
B19.1 2,400 rpm 30 kip constant load 330 amp field 8 flat bottomed holes: dia. = 0.03125 in., 0.0625 in. depth range = 0.040 - 0.140 in.	
B19.2 24,00 rpm 30 kip constant load 330 amp field 12µ tungsten powder 1 x 1 mm @ 0° & 180° 1 x 2 mm @ 90° & 270°	
B19.3 2,400 rpm 30 kip constant load 330 amp field 50µ tungsten foil 1 x 1 mm @ 0° & 180° 1 x 2 mm @ 90° & 270°	
B19 2,400 rpm 30 kip constant load 330 amp field thin oil film on lower pipe	

TABLE 30. B19 SUMMARIES

a. B19 Series Weld Parameters

Weld No	Step Length (inch)	Contact width (inch)	Bevel Angle (°)	Special Geometry	RPM	Field (amp)	Load 1 (kip)	Load 2 (kip)
B19.1	0	0.1	30	holes	2400	330	30 (.05)	60 (1)
B19.2	0	0.1	30	W powder	2400	330	30	30
B19.3	0	0.1	30	W foil	2400	330	30	30
B19.4	0	0.1	30	oil	2400	330	30	30
B19.1a	0	0.1	30	holes	2400	330	30	30

b. B19 Series Process Parameters

Weld No	TOTC (kA)	Time [totc] (sec)	INTV (v)	Time [intv] (sec)	TCIF (°C)	Time [tcif] (sec)	Disp1 (mil)	time [disp1] (sec)	Disp2 (mil)	time [disp2] (sec)
B19.1	240.5	0.11	0.998	0.125	1090	2.78	8.67	0.125	204.9	1.31
B19.2	240.5	0.094	1.012	0.118	1191	3.345	0	0	139.9	3.19
B19.3	243.1	0.11	0.985	0.133	1184	3.345	0	0	137.7	3.345
B19.4	242.6	0.102	1.002	0.125	1178	3.655	0	0	156.1	3.465
B19.1a	228.4	0.118	0.917	0.133	1074	3.19	7.58	0.22	116	3.19

c. B19 Series Mechanical Test Results

Weld No	Act. Disp (inch)	CVN mean (ft-lbs)	CVN min. (ft-lbs)	YS (ksi)	TS (ksi)	%EL	HV 10 HAZ min. (kg/mm2)	HAZ width (mm)
B19.1	0.241							
B19.2	0.191							
B19.3	0.185							
B19.4	0.202							
B19.1 a	0.163							

TABLE 31. SERIES B20 and M1 WELD PARAMETERS

B20.1-4
MA.1, MC.1

2,200 rpm
60 kip constant load
330 amp field

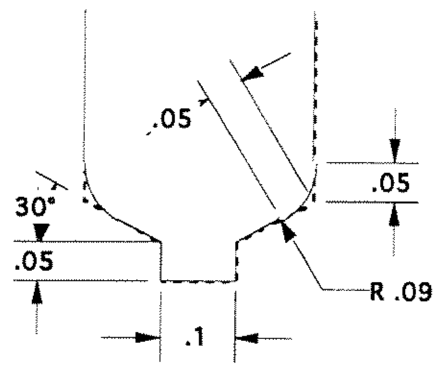


TABLE 32. B20 SUMMARIES

a. B20 Series Weld Parameters

Weld No	Step Length (inch)	Contact width (inch)	Bevel Angle (°)	Special Geometry	RPM	Field (amp)	Load 1 (kip)	Load 2 (kip)
B20.1	0.05	0.1	30	.09R shld'r	2200	330	60	60
B20.2	0.05	0.1	30	.09R shld'r	2200	330	60	60
B20.3	0.05	0.1	30	.09R shld'r	2200	330	60	60
B20.4	0.05	0.1	30	.09R shld'r	2200	330	60	60

b. B20 Series Process Parameters

Weld No	TOTC (kA)	Time [totc] (sec)	INTV (v)	Time [intv] (sec)	TCIF (°C)	Time [tcif] (sec)	Disp1 (mil)	time [disp1] (sec)	Disp2 (mil)	time [disp2] (sec)
B20.1	214.7	0.102	1.072	0.102	782	3	101.9	0.345	208.2	2.875
B20.2	214.2	0.101	1.105	0.109	778	2.655	104.1	0.47	195.2	2.56
B20.3	215.75	0.102	1.067	0.11	761	2.905	93.24	0.125	190.8	2.87
B20.4	213.65	0.11	1.037	0.11	768	3.095	89.99	0.405	183.2	2.97

c. B20 Series Mechanical Test Results

Weld No	Act. Disp (inch)	CVN mean (ft-lbs)	CVN min. (ft-lbs)	YS (ksi)	TS (ksi)	%EL	HV 10 HAZ min. (kg/mm2)	HAZ width (mm)
B20.1	0.262	65.66	63	65.93	77.7	15		
B20.2	0.25	saved for display						
B20.3	0.243	sent out for CTOD testing						
B20.4	0.239	sent out for CTOD testing						
B20.1-1		69						
B20.1-3		63						
B20.1-5		65						

TABLE 33. M1 SUMMARIES

a — M1 Series Weld Parameters

Weld No	Step Length (inch)	Contact width (inch)	Bevel Angle (°)	Special Geometry	RPM	Field (amp)	Load 1 (kip)	Load 2 (kip)
MA.1	0.05	0.1	30	.09R shld'r	2200	330	60	60
MC.1	0.05	0.1	30	.09R shld'r	2200	330	60	60

b — M1 Series Process Parameters

Weld No	TOTC (kA)	Time [totc] (sec)	INTV (v)	Time [intv] (sec)	TCIF (°C)	Time [tcif] (sec)	Disp1 (mil)	time [disp1] (sec)	Disp2 (mil)	time [disp2] (sec)
MA.1	210	0.094	1.177	0.102	708	2.97	103	0.375	171	2.845
MC.1	210.5	0.094	1.135	0.102	763	3	99.75	0.405	183.23	2.875

c — M1 Series Mechanical Test Results

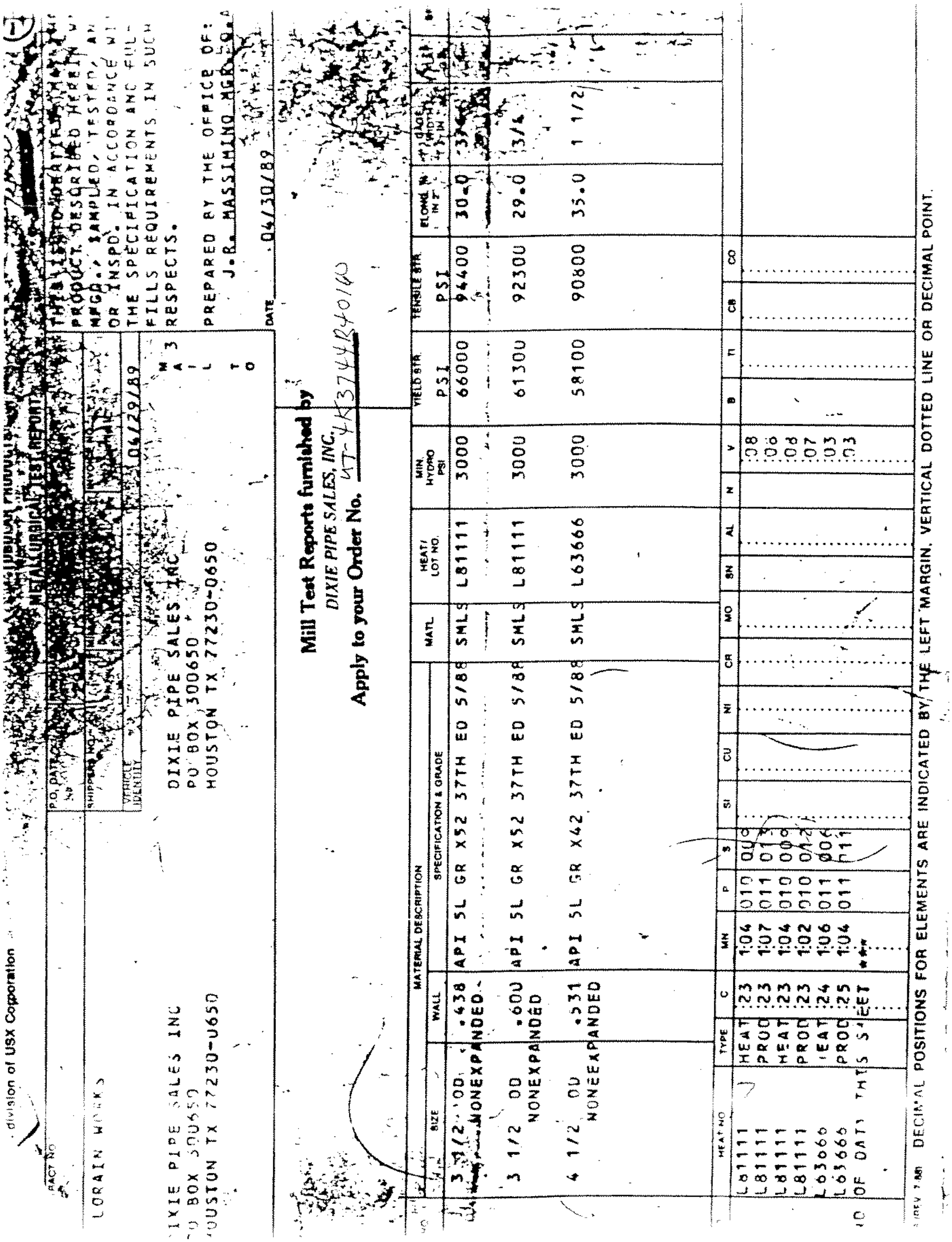
Weld No	Act. Disp (inch)	CVN mean (ft-lbs)	CVN min. (ft-lbs)	YS (ksi)	TS (ksi)	%EL	HV 10 HAZ min. (kg/mm2)	HAZ width (mm)
MA.1	0.208	3.2	2.5					
[1]		3.5						
[3]		3.5						
[5]		2.5						
MC.1	0.24	5.8	4.5					
[1]		8						
[3]		4.5						
[5]		5						

TABLE 34. FINANCIAL STATEMENT

CONTRACT JIP A/C 29-9010-02XX	BUDGET INC./TRANS.	YEAR 1 2/93-1/94	YEAR 2 2/94-1/95	February 1995	March 1995	April 1995	May 1995	June 1995	July 1995	August 1995	September 1995	October 1995	November 1995	December 1995	January 1995	February 1995	FREE BALANCE Y-T-D
SALARIES & WAGES	$317,377.00	$80,648.82	$118,862.46	$12,789.84	$13,874.68	$13,129.57	$11,638.88	$10,071.48	$7,905.43	$7,809.46	$7,011.77	$8,051.37	$0.00	$0.00	$0.00	$0.00	$25,585.26
FRINGE BENEFITS	$83,780.00	$20,968.31	$31,803.88	$3,850.32	$3,815.19	$3,327.12	$2,956.29	$2,717.08	$1,855.97	$1,806.24	$1,712.44	$2,081.59	$0.00	$0.00	$0.00	$0.00	$8,844.59
OTHER EXPENSE	$27,684.00	$7,396.38	$8,889.75	$2,824.41	$882.74	$1,033.18	$882.21	$1,138.68	$368.73	$1,613.92	$669.31	$261.41	$0.00	$0.00	$0.00	$0.00	$1,962.30
COMPUTATION (67)	$499.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$499.00
TRAVEL	$21,083.00	$1,890.14	$5,386.35	$653.86	$622.88	$1,510.85	$1,879.79	$0.00	$0.00	$0.00	$755.43	$544.68	$0.00	$0.00	$0.00	$0.00	$7,838.87
MTDC	$450,303.00	$110,922.65	$164,942.44	$20,018.22	$19,165.47	$19,000.72	$17,057.17	$13,927.18	$10,131.13	$11,229.62	$10,146.86	$10,938.33	$0.00	$0.00	$0.00	$0.00	$42,820.12
OVERHEAD	$223,787.00	$54,350.62	$82,340.62	$10,009.11	$9,682.74	$9,500.38	$8,528.59	$6,963.59	$5,065.57	$5,614.81	$5,074.48	$5,469.66	$0.00	$0.00	$0.00	$0.00	$21,296.87
TUITION	$2,200.00	$1,066.40	$924.89	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$208.71
EQUIP./FAB. (83680)	$43,700.00	$34,016.43	$6,020.81	$0.00	$0.00	$0.00	$5,400.95	$0.00	$12.90	$64.57	$38.40	$0.00	$0.00	$0.00	$0.00	$0.00	($1,854.16)
TOTAL	$720,000.00	$200,358.10	$254,228.88	$30,027.33	$28,748.21	$28,501.08	$30,986.71	$20,890.77	$15,209.60	$16,909.00	$15,281.83	$16,408.99	$0.00	$0.00	$0.00	$0.00	$62,471.54

REMARKS:

FUNDED Y-T-D: $640,000 EXPIRATION: 2/28/95



Size	Wall	Specification & Grade	Matl.	Heat/Lot No.	Min. Hydro PSI	Yield Str. PSI	Tensile Str. PSI	Elong. in 2"	Gage
3 1/2 OD NONEXPANDED	.438	API 5L GR X52 37TH ED 5/88	SMLS	L81111	3000	66000	94400	30.0	3/4
3 1/2 OD NONEXPANDED	.600	API 5L GR X52 37TH ED 5/88	SMLS	L81111	3000	61300	92300	29.0	3/4
4 1/2 OD NONEXPANDED	.531	API 5L GR X42 37TH ED 5/88	SMLS	L63666	3000	58100	90800	35.0	1 1/2

Heat No.	Type	C	Mn	P	S	V
L81111	HEAT	.23	1.04	.010	[illegible]	.08
L81111	PROD	.23	1.07	.011	[illegible]	.06
L81111	HEAT	.23	1.04	.010	[illegible]	.08
L81111	PROD	.23	1.02	.010	[illegible]	.07
L63666	HEAT	.24	1.06	.011	[illegible]	.03
L63666	PROD	.25	1.04	.011	.011	.03

END OF DATA THIS SHEET

FIGURE 1. PIPE A MILL TEST REPORT

AGE OF

PRUDENTIAL STEEL LTD.

P.O. BOX 1510, CALGARY, ALBERTA, CANADA T2P 2L6

SALES OFFICE
1800, 140 4th AVE S.W.
(403) 267-0300
FAX 261-0936

MILL LOCATION
8919 BARLOW TRAIL S.E.
(403) 279-4401
FAX: 236-2249

QUALITY CONTROL DOCUMENT #36 (MILL TEST CERTIFICATE)

CUSTOMER

U OF T ELECTROMECHANICS
BRC MAIL CODE 77000
AUSTIN, TEXAS.
ATTN: BOB CARNES

PRODUCT SIZE & GAUGE: 3½ x 0.300
HYDROSTATIC PRESSURE: 4930 psi
HYDROSTATIC TIME: 5 SEC
CONFORMING TO: A.P.I. 5L X60

SHIPPED VIA: WESTFREIGHT
CUSTOMER P.O.: 4K2808R40101
MILL ORDER: 121465

DATE: Sept.23/93
ITEM NO: 01

SEAM INDUCTION:
NORMALIZING TEMP:
MILL SPEED:
METERS SHIPPED: 120.11 FT.
SECTIONS SHIPPED: 4

HEAT NO.	COIL CODE	YIELD	TENSILE	% ELONG IN 50 mm	YIELD / TENSILE	CHEMICAL ANALYSIS	C	Mn	P	S	Si	Al	Cr	Mo	Ni	Cu	Cb	Ca	Ti	V	B	CARBON EQUIV.	HARDNESS TYPE	LOW	HIGH	AVERAGE
73512	FL75	79,460	86,130	22	.92	LADLE	.13	.65	.005	.004	.22	.042	.03	.01	.01	.02	.018	.0048				.23	HRB	89	95	91.8
						CHECK	.12	.63	.003	.005	.22	.047	.03	.006	.005	.015	.017	.0040					HV	194	205	200.7
						LADLE																	HRB			
						CHECK																	HV			
						LADLE																	HRB			
						CHECK																	HV			
						LADLE																	HRB			
						CHECK																	HV			
						LADLE																	HRB			
						CHECK																	HV			
						LADLE																	HRB			
						CHECK																	HV			
						LADLE																	HRB			
						CHECK																	HV			
						LADLE																	HRB			
						CHECK																	HV			
						LADLE																	HRB			
						CHECK																	HV			

CHARPY V NOTCH IMPACT TESTS

TRANSVERSE
LONGITUDINAL
PIPE BODY
TEMPERATURE
JOULES
FOOT POUNDS

HEAT NO. SAMPLE POS.	ENERGY	% SHEAR	ENERGY	% SHEAR	ENERGY	% SHEAR	ENERGY	% SHEAR	ENERGY	% SHEAR
#1										
#2										
#3										

HEAT NO. SAMPLE POS.	ENERGY	% SHEAR	ENERGY	% SHEAR	ENERGY	% SHEAR	ENERGY	% SHEAR	ENERGY	% SHEAR
#1										
#2										
#3										

GENERAL COMMENTS

WE CERTIFY THAT THE PRODUCT DESCRIBED ABOVE PASSED ALL OF THE TESTS REQUIRED BY THE SPECIFICATION

COMPANY REPRESENTATIVE

CUSTOMER REPRESENTATIVE

FIGURE 2. PIPE B MILL TEST REPORT

714R
15:58

L O N E   S T A R   S T E E L   C O M P A N Y
MATERIAL TEST REPORT
CASING, LINE PIPE & TUBING

Page: 1
12/13/93

LSO: 0011091 Item: 001 Customer Order No.: VERBAL Specimen Size: 1.0

Heat: 79638 Lot: 02 Diameter: 3.500 Wall: .438

Description: PE-BEV RG 3(42'+/-3") BR , LSS SPEC 001 ERW , 30 DEGREE BEVEL BOTH ENDS

Specification: LSS GR X52, ERW, MFG IN USA.(Not an API size for grade but meets requirements for API 5L)

.... Sold to ....

UNIVERSITY OF TEX-AUSTIN
BOX 123

AUSTIN
TX 70033

.... Ship to ....

UNIVERSITY OF TEX-AUSTIN
C/O T & N WHSE
BOND

TX

Copies to Sold to: 3

Copies to Ship to:

C H E M I C A L   A N A L Y S I S

	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Sn	Al	V	Cb	Ti	B
at:	.110	1.13	.014	.005	.28	.13	.07	.073	.028	.018	.037	.0400	.034	.008	.0003
eck:	.110	1.16	.012	.005	.28	.13	.07	.075	.026	.015	.035	.0420	.036	.012	.0002
eck:	.110	1.18	.012	.006	.29	.14	.07	.076	.027	.015	.037	.0420	.037	.011	.0004

M E C H A N I C A L   P R O P E R T I E S

	Yield Strgth (KSI) Long	Yield Strgth (KSI) Tran		Tensile Strgth (KSI) Long	Tensile Strgth (KSI) Tran	Elong. % in 2" Long	Elong. % in 2" Tran	Elong. % in 2" Frac
dy:	59.5		Body:	79.5		37.0		
ld:			Weld:					

Hardness: O.D. I.D. M.W. BODY WELD HAZ SURF

pact Properties: Direction Location Temp F/C Size Energy % Shear Lat Exp

Collapse	Hydrotest	Flattening
	3000	OK

Quality Assurance

This is to certify that the product described herein was manufactured, sampled, tested, and inspected in accordance with the specification and the order, and fulfills requirements in such respects.

FIGURE 3. PIPE C MILL TEST REPORT

MITSUI TUBULAR PRODUCTS, INC.

1000 LOUISIANA ST, SUITE 5700, HOUSTON TEXAS 77002

*** FACSIMILE COVER SHEET ***

TO : UNIVERSITY OF TEXAS (AUSTIN) FAX: (512) 471-0781

ATTN : MR. BOB CARNES

FROM : JUN MURATA [MANAGER OF LINEPIPE]
TEL : (713) 236-6183 FAX : (713) 236-6134
DATE : 5-26-94 TOTAL PAGE /

****

SUB: STEEL PIPE SAMPLE BY NIPPON STEEL CORPORATION

We understand you had communication with Nippon Steel Mr. Suzuki on the supply of steel pipe sample for your HOMOPOLAR PROJECT. In this regard, Nippon has some stock of bloom in Japan, from which they can provide the following sample pipes.

OUT DIAMETER (OD) : 3-1/2''
WALL THICKNESS (WT) : BETWEEN 0.315'' TO 0.433''
Please nominate required wall thickness
LENGTH :40FT
QUANTITY : 5 PIECES
GRADE : API 5L X-65
PROCESS : SEAMLESS PIPE
HEAT TREATMENT : QUENCHING AND TEMPARING
CHEMICAL COMPOSITION (LADLE ANALYSIS):
C/0.08, Si/0.19, Mn/1.29, P/0.011, S/0.002,
Mo/0.22, Nb/0.032, T-Al/0.035, Ca/0.0026
PRICE : $350.- PER PIECE AT PORT OF HOUSTON
SHIPMENT : IN 3 MONTHS AFTER ORDER EX JAPAN.
THEN, ABOUT 1.5 MONTHS FOR VESSEL
SAILING TO HOUSTON.

Please contact us if you need those sample pipes.
MITSUI TUBULAR PRODUCTS INC
HOUSTON, TEXAS,
LINEPIPE MANAGER JUN MURATA
TEL: (713) 236-6183
FAX: (713) 236-6134

Yours faithfully,

JUN MURATA
MITSUI TUBULAR PRODUCTS INC

FIGURE 4. PIPE D CHEMICAL COMPOSITION

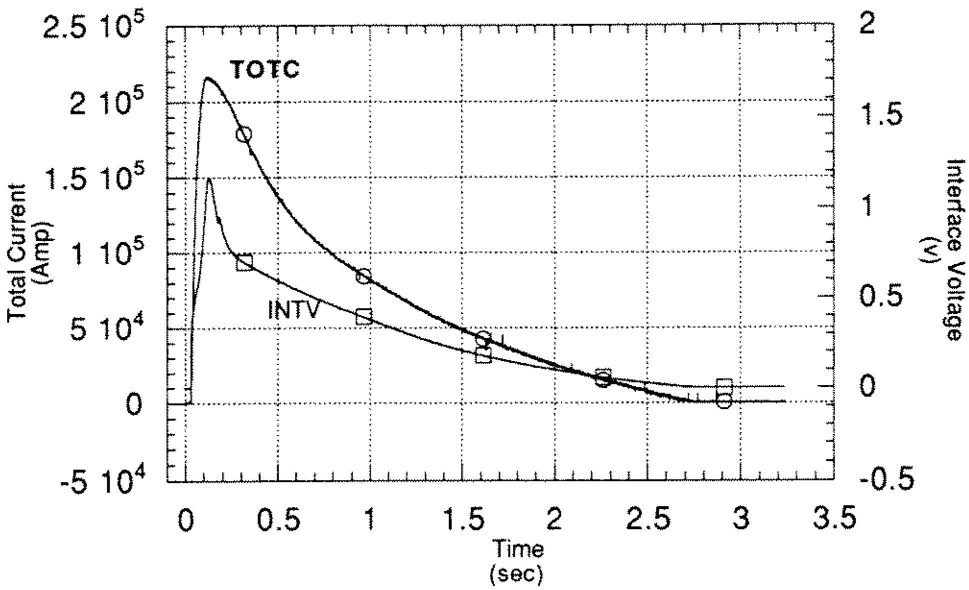


FIGURE 5. Plot of process parameters: total current and interface voltage

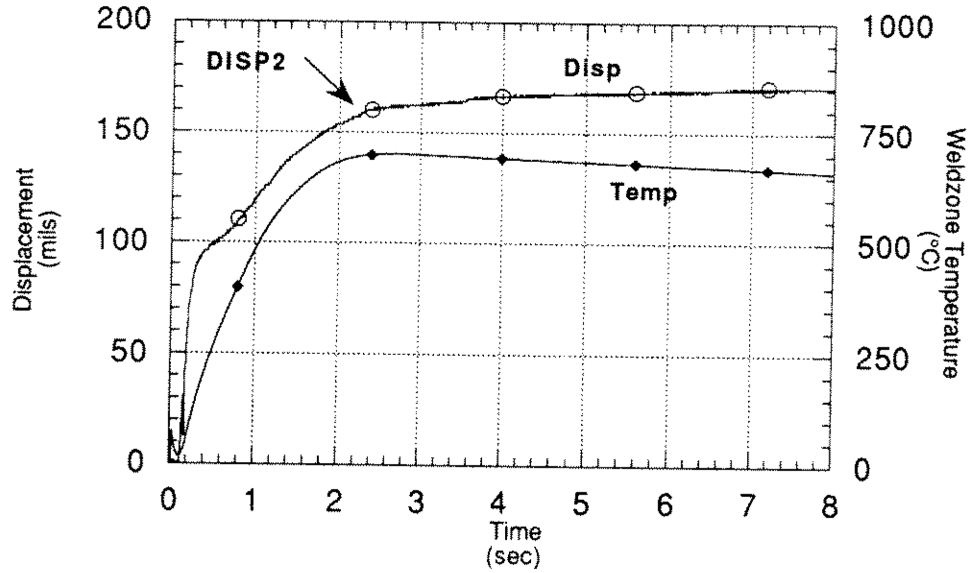


FIGURE 6. Plot of process parameters: displacement and temperature

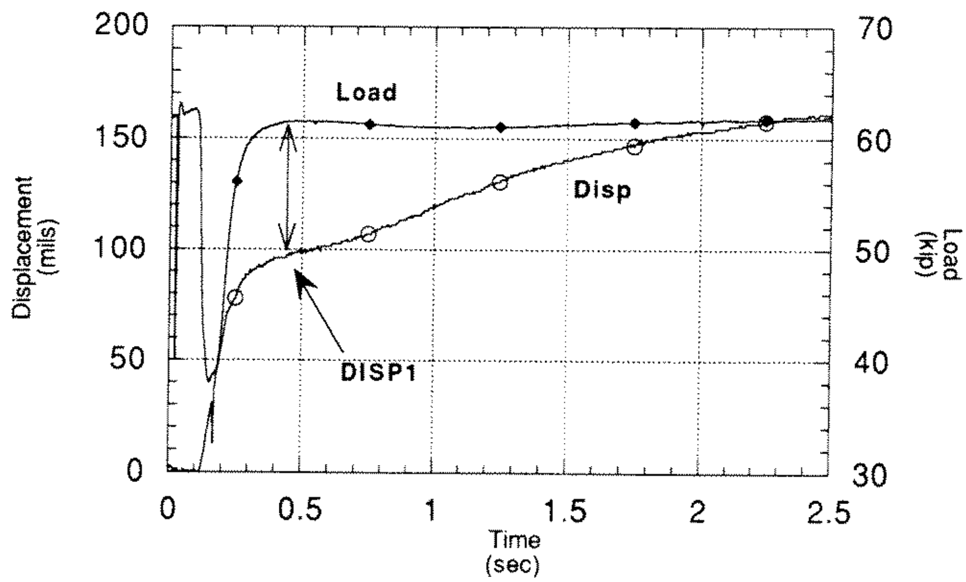


FIGURE 7. Plot of process parameters: displacement and load

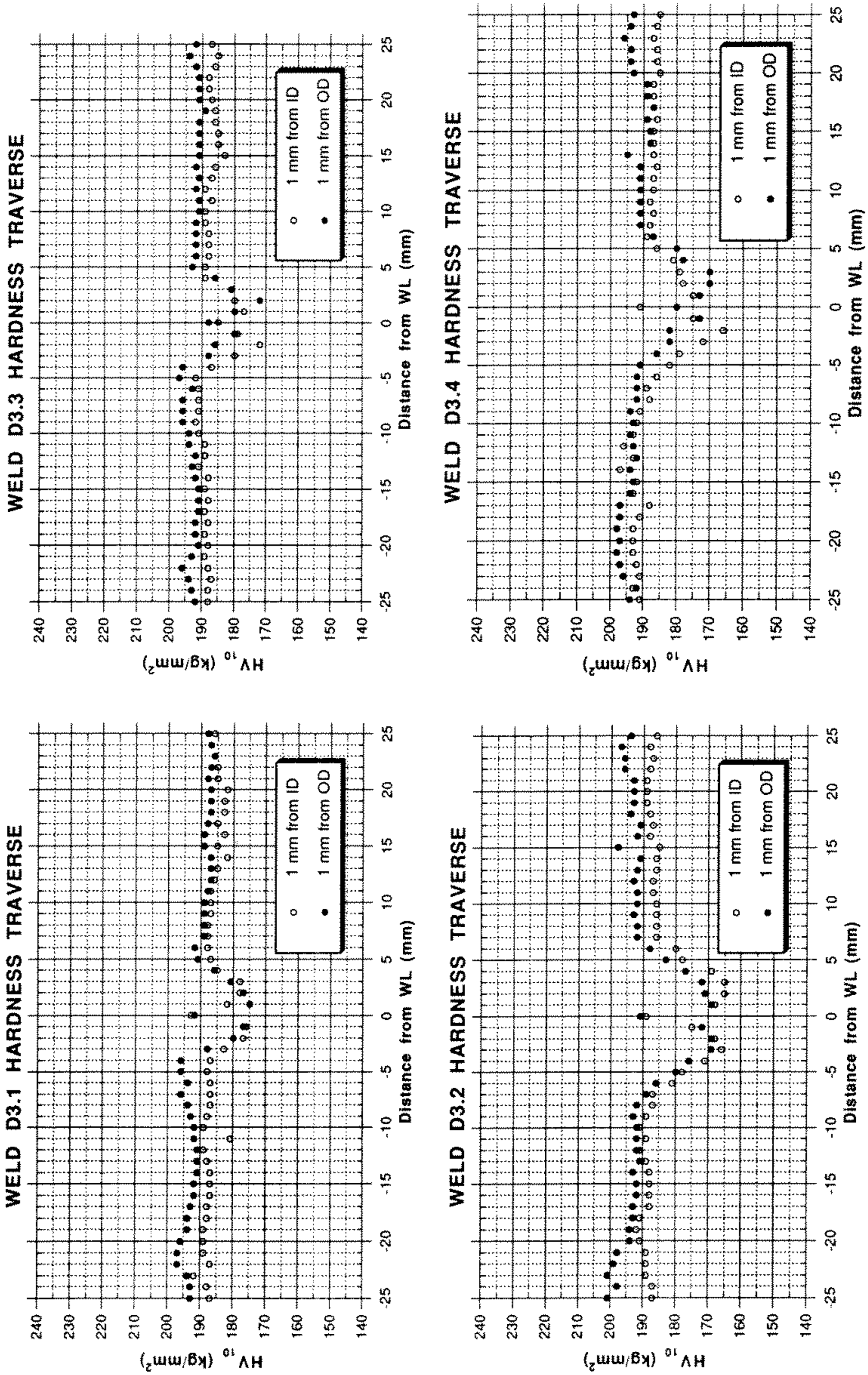


FIGURE 8. Hardness Test Results D3.1-4

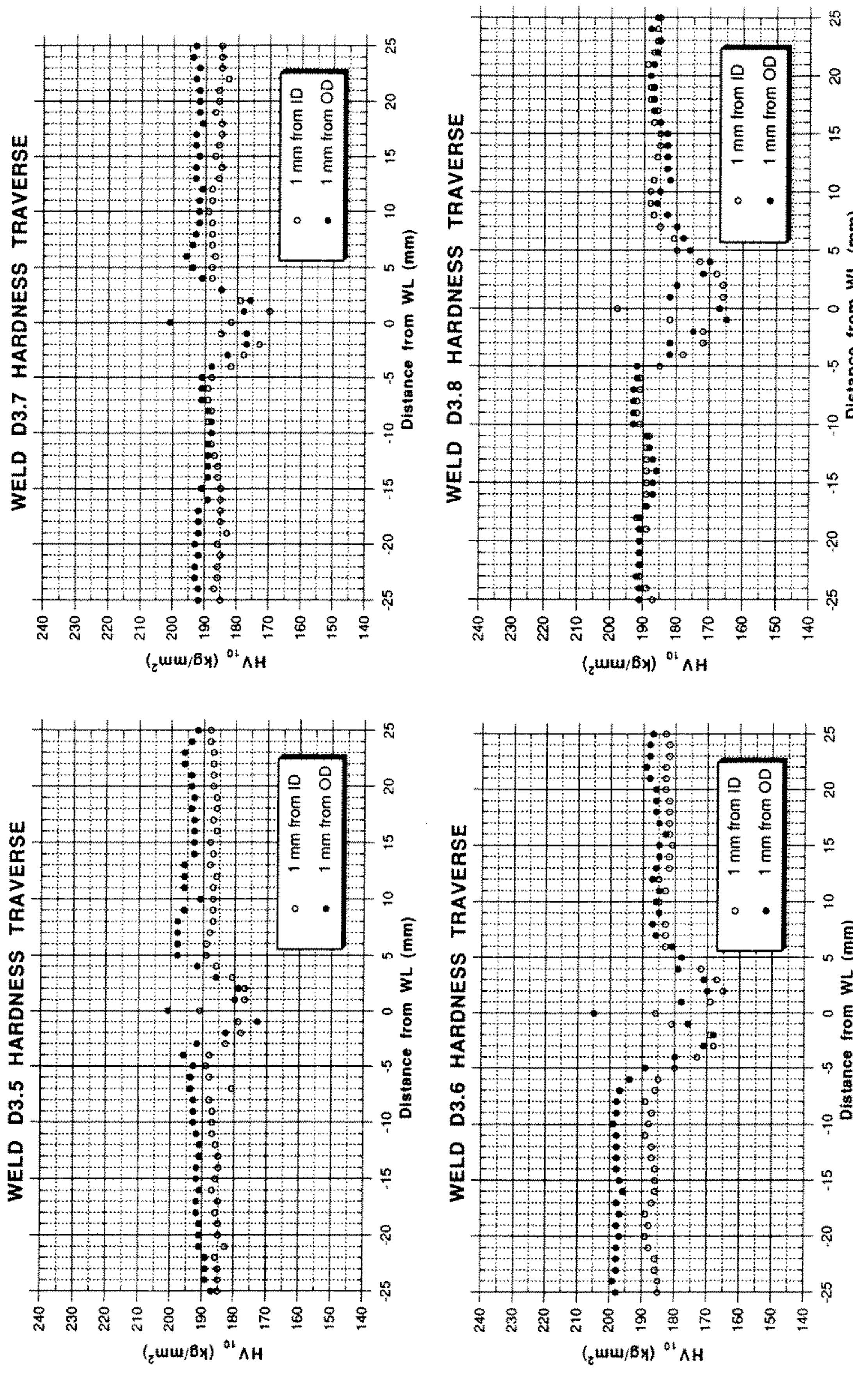


FIGURE 9. Hardness Test Results D3.5-8

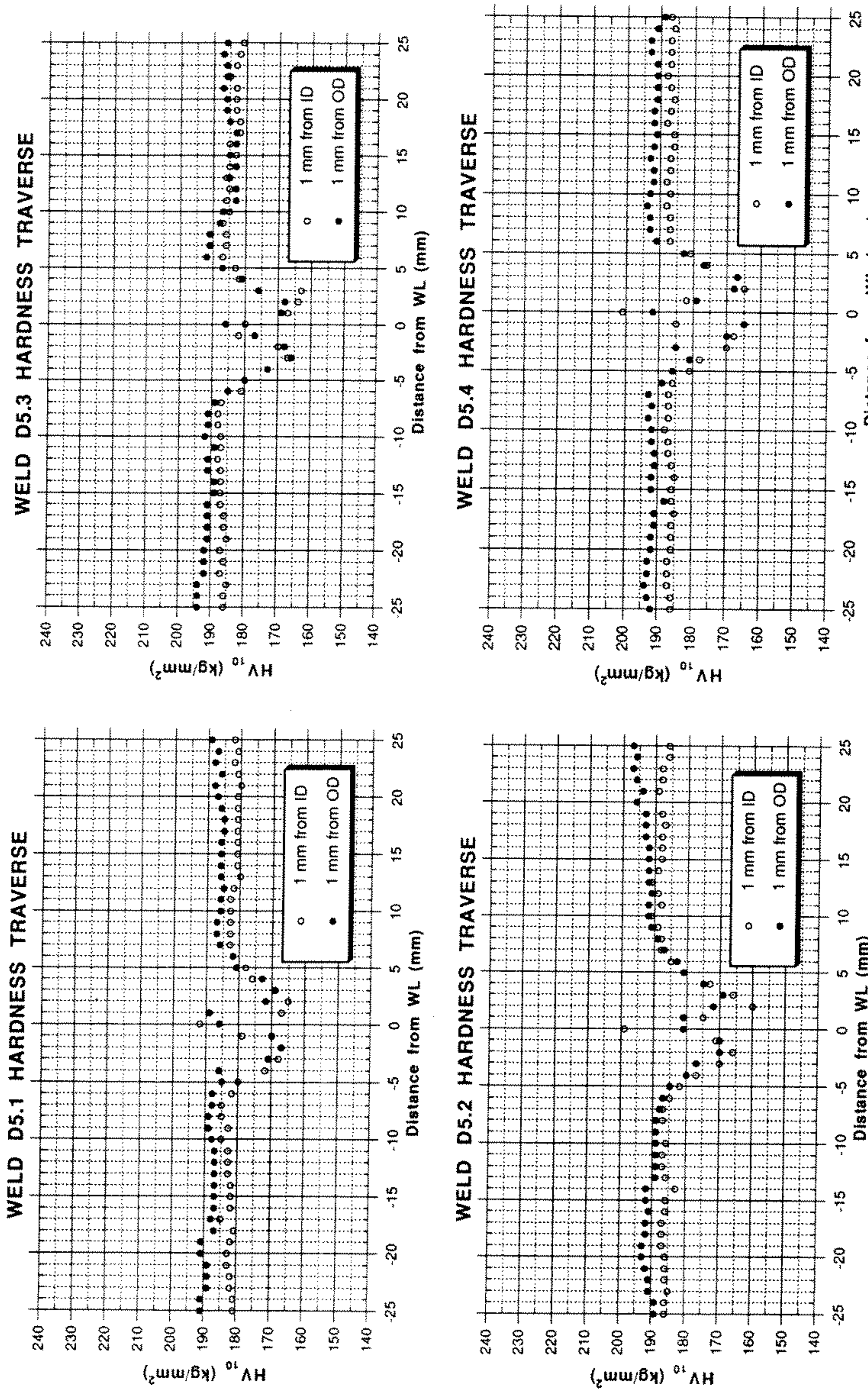
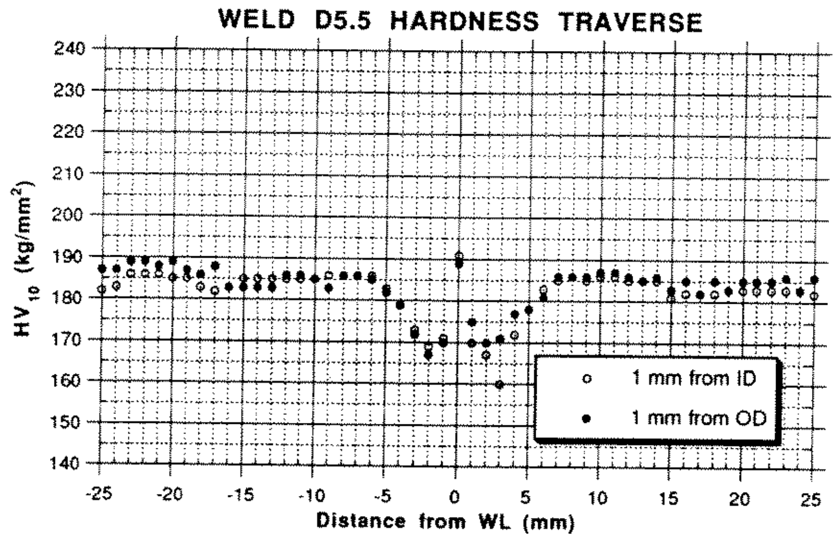


FIGURE 10. Hardness Test Results D5.1-4



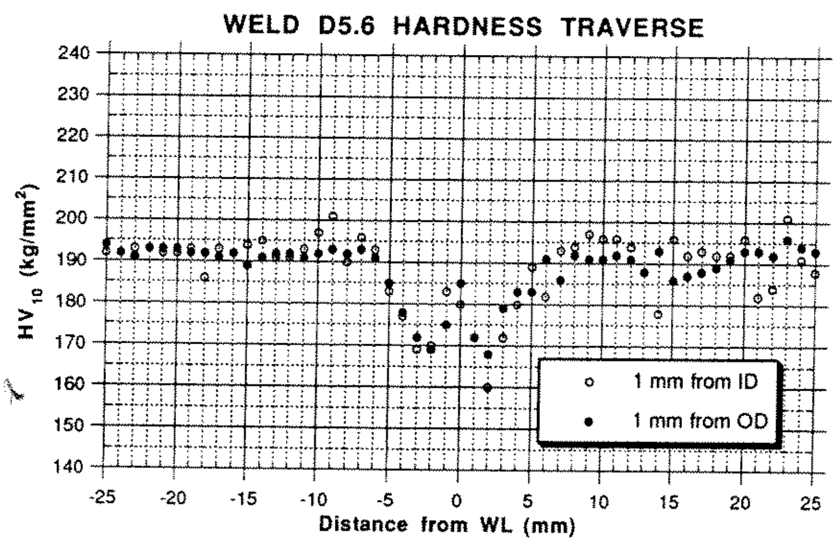


FIGURE 11. Hardness Test Results D5.5

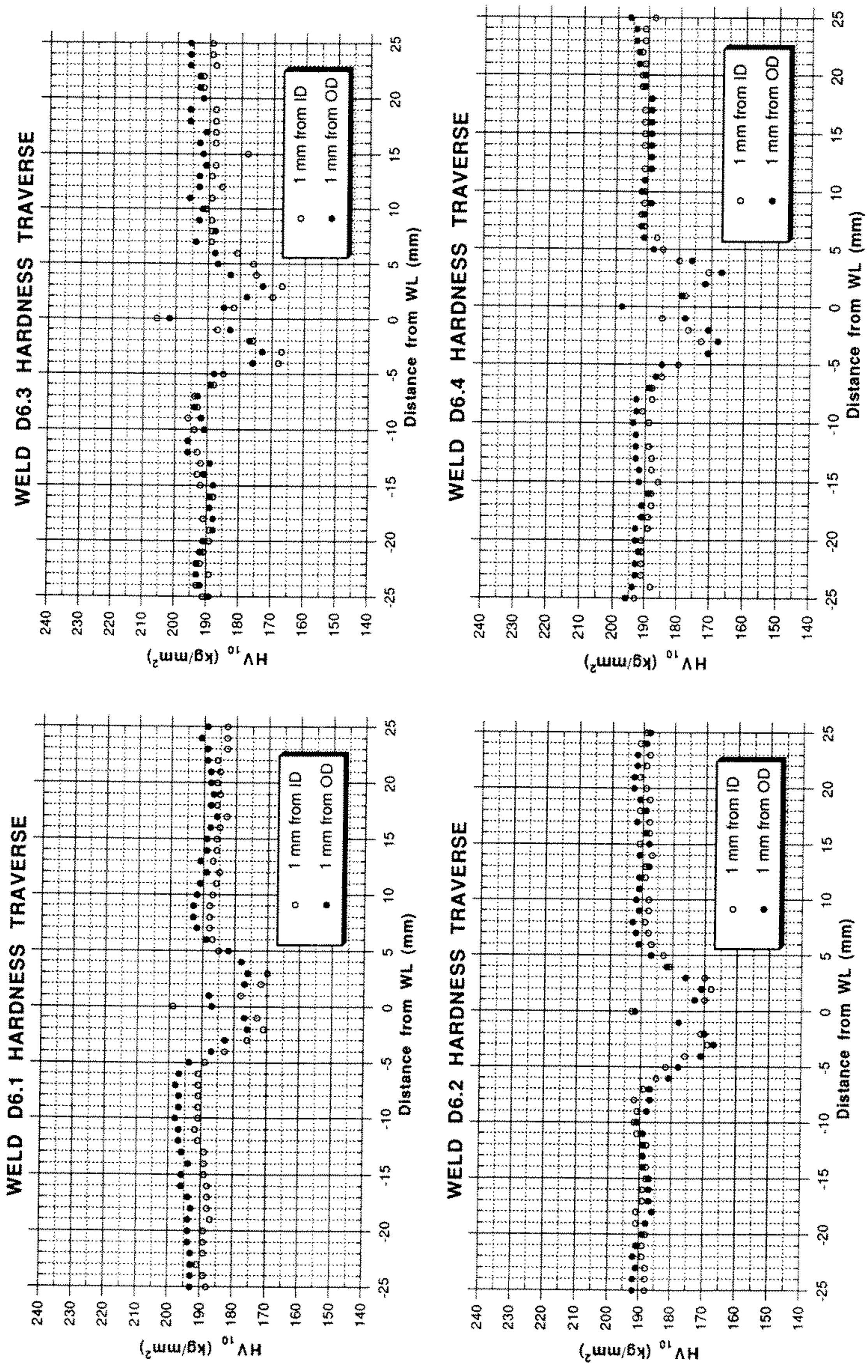
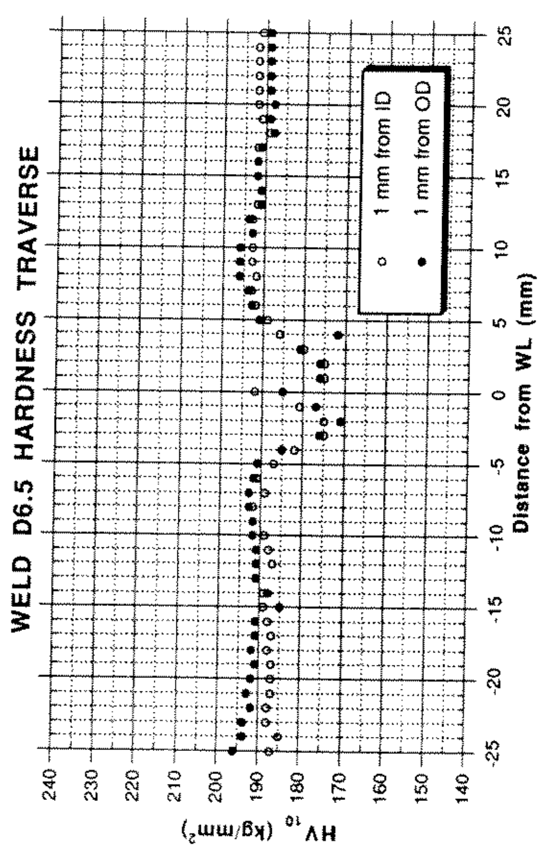
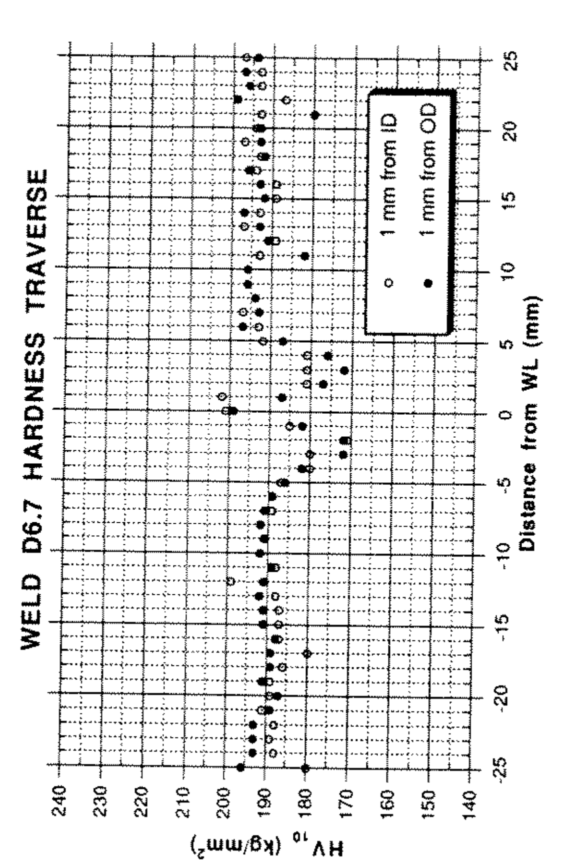
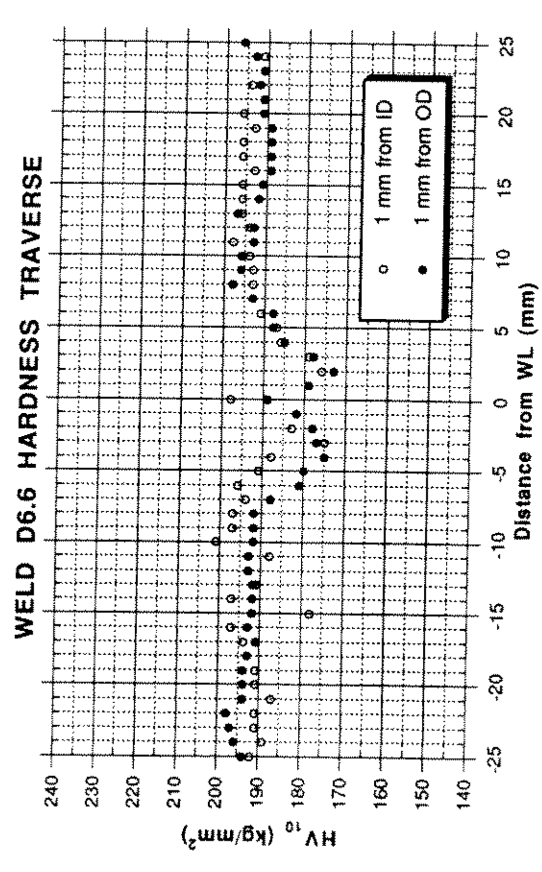


FIGURE 12. Hardness Test Results D6.1-4







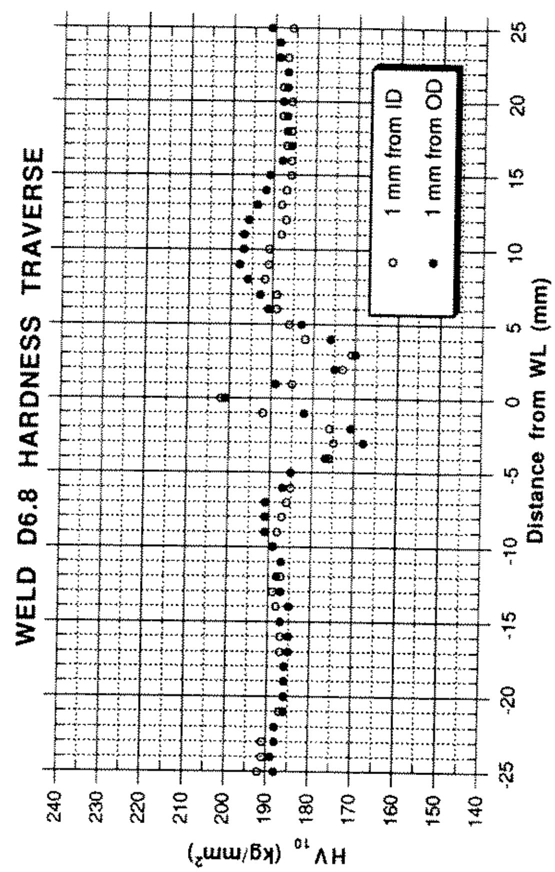
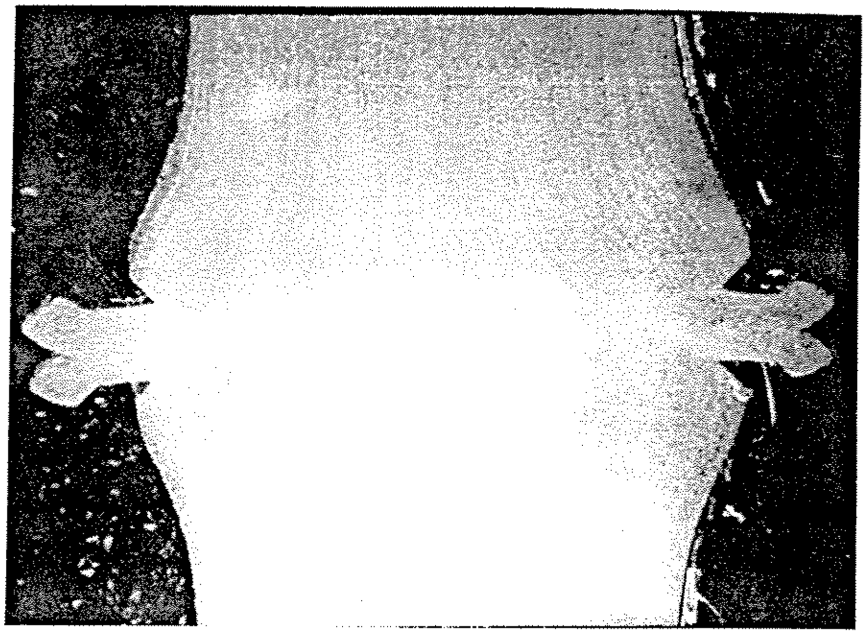
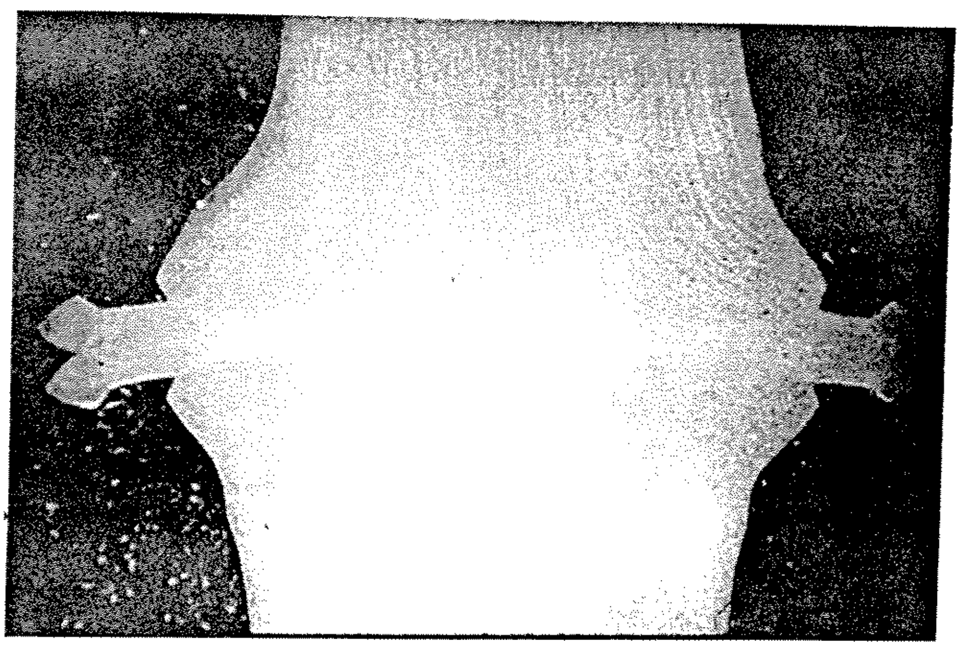


FIGURE 13. Hardness Test Results D6.5-8



S 620

FIGURE 14. Macrograph of D5.4 Weld Profile, Mag. 6X



S 6201.00

FIGURE 15. Macrograph of D7.1 Weld Profile, Mag. 6X

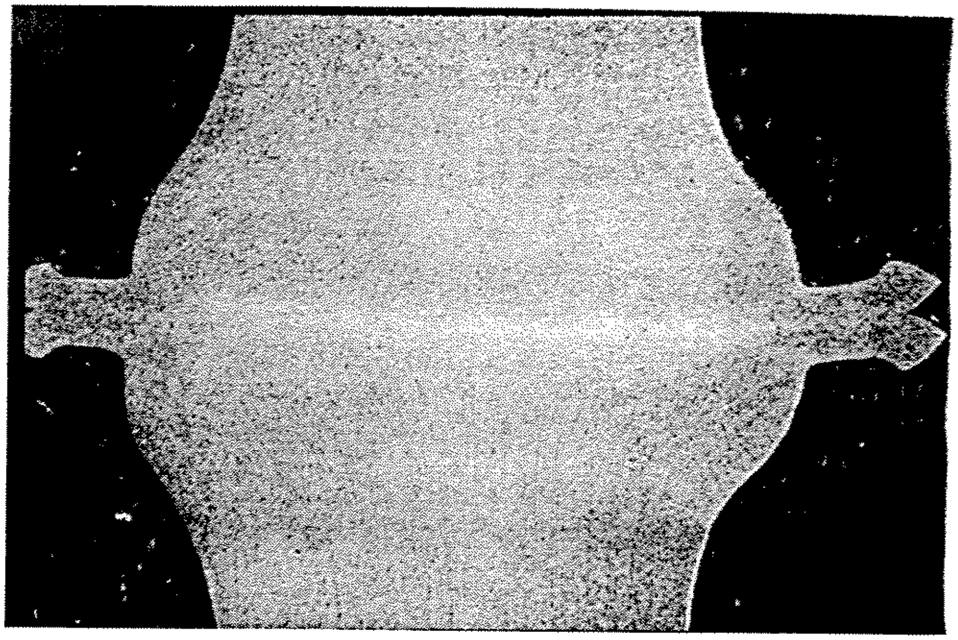


FIGURE 16. Macrograph of D7.2 Weld Profile, Mag. 6X

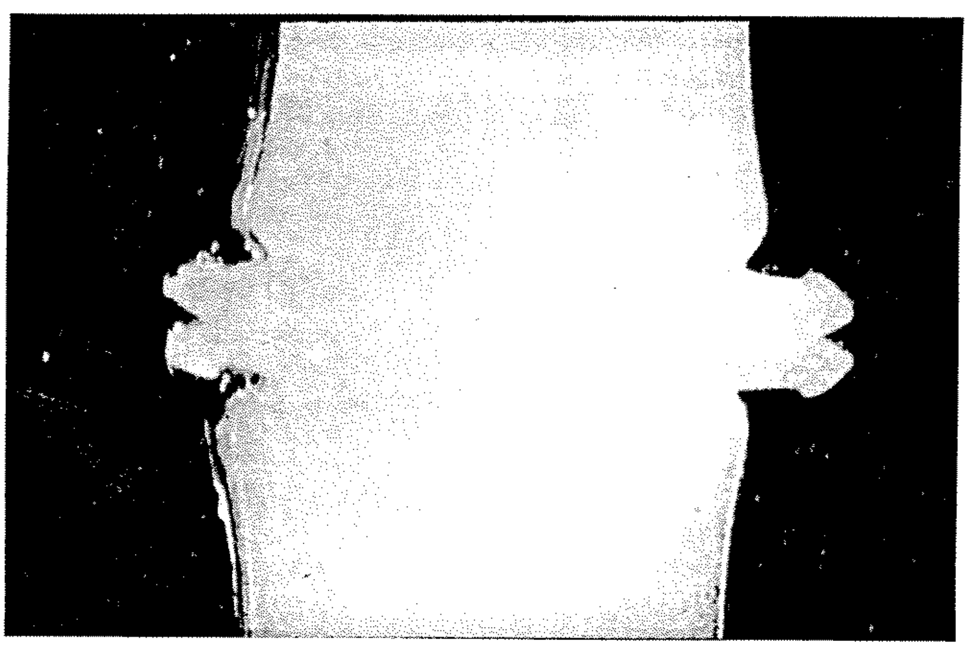


FIGURE 17. Macrograph of D7.3 Weld Profile, Mag. 6X

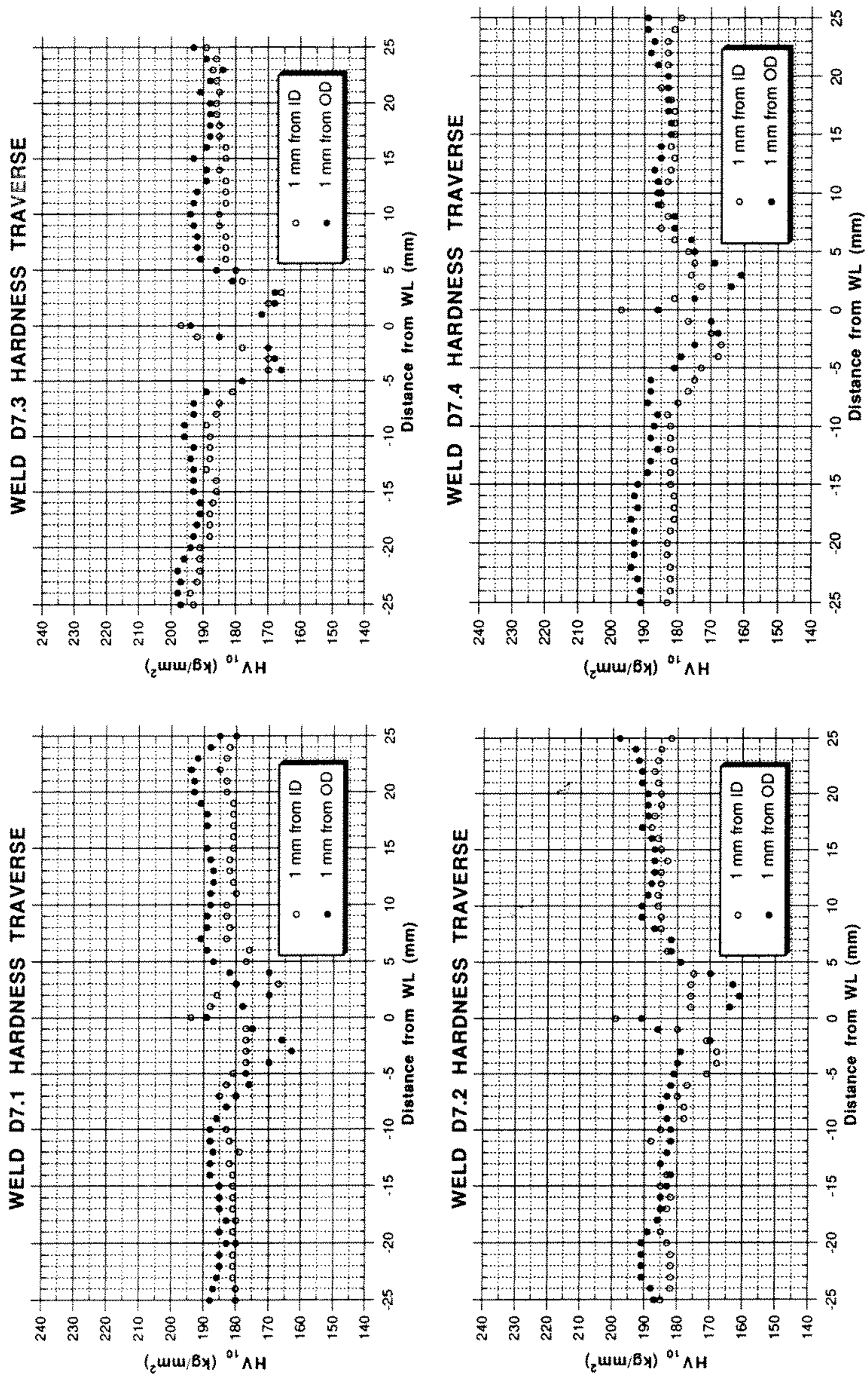


FIGURE 18. Hardness Test Results D7.1-4

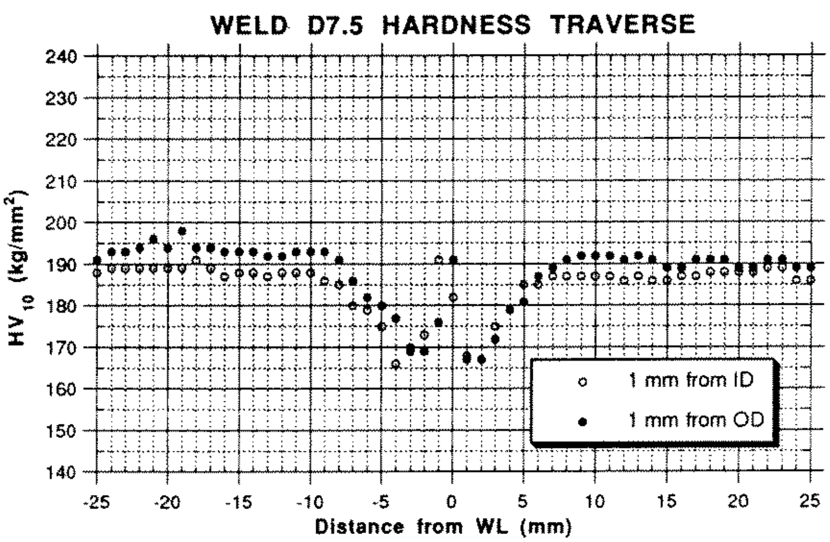


FIGURE 19. Hardness Test Results D7.5

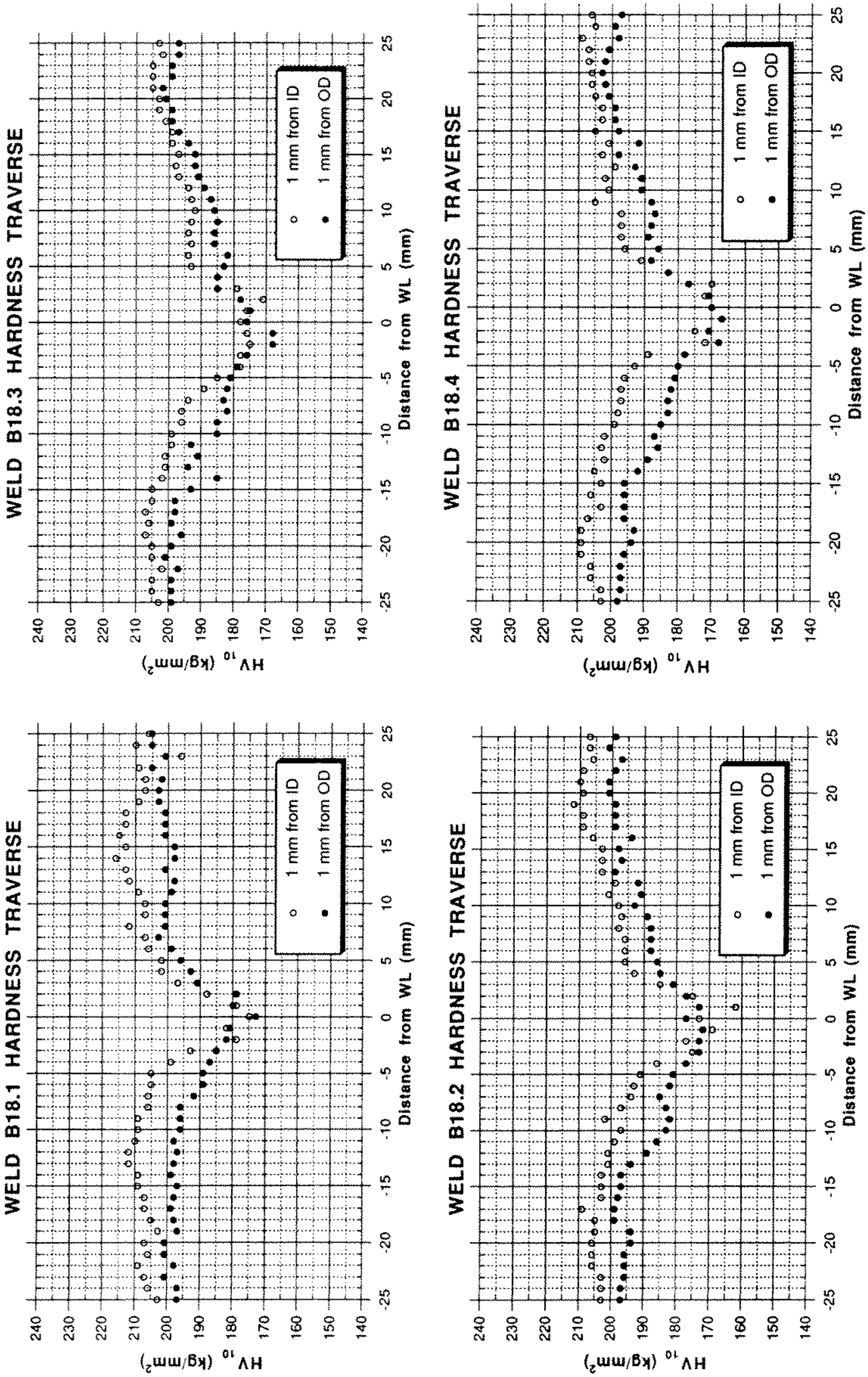


FIGURE 20. Hardness Test Results B18.1-4

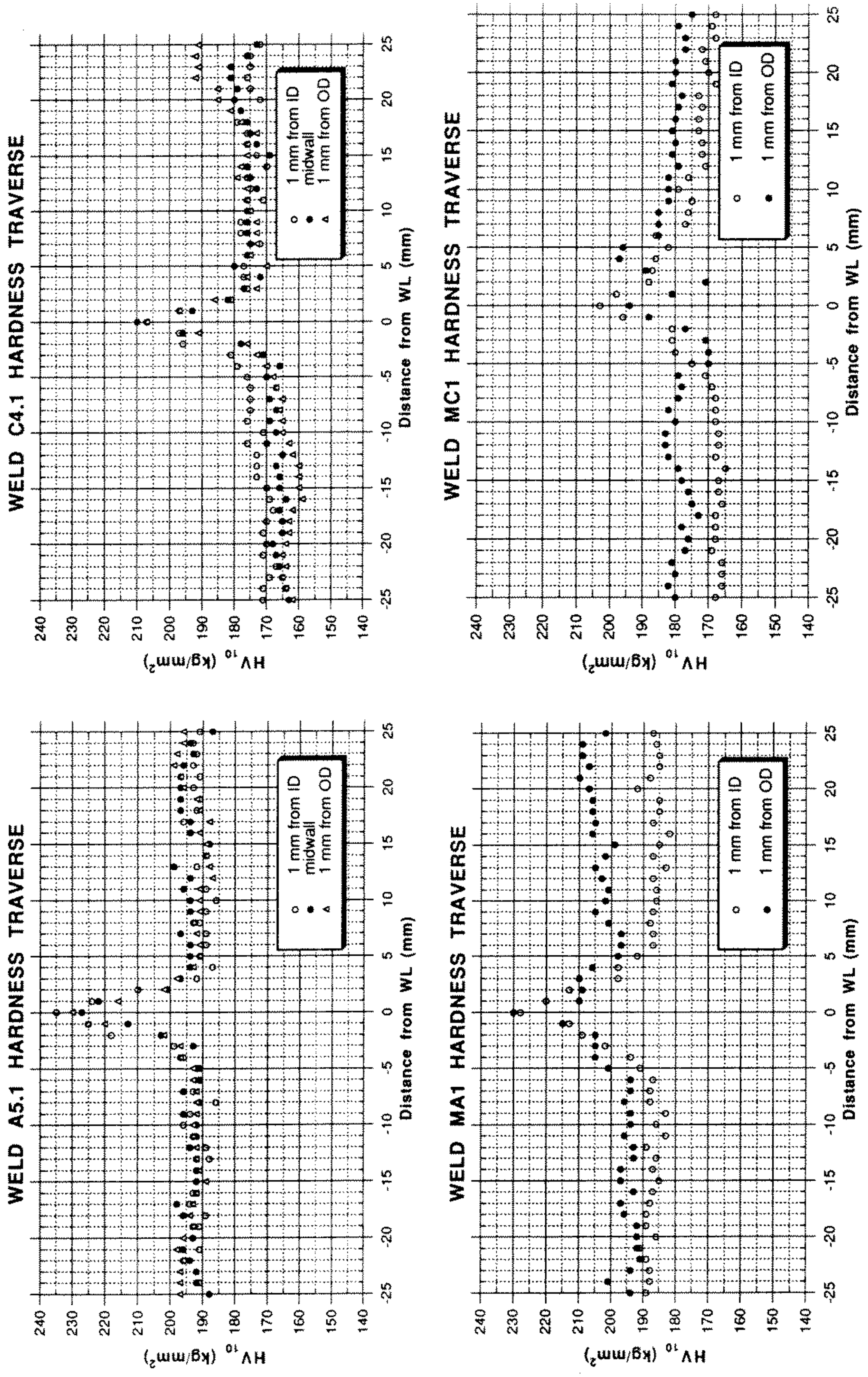


FIGURE 21. Hardness Test Results A5.1, MA1, C4.1, and MC1

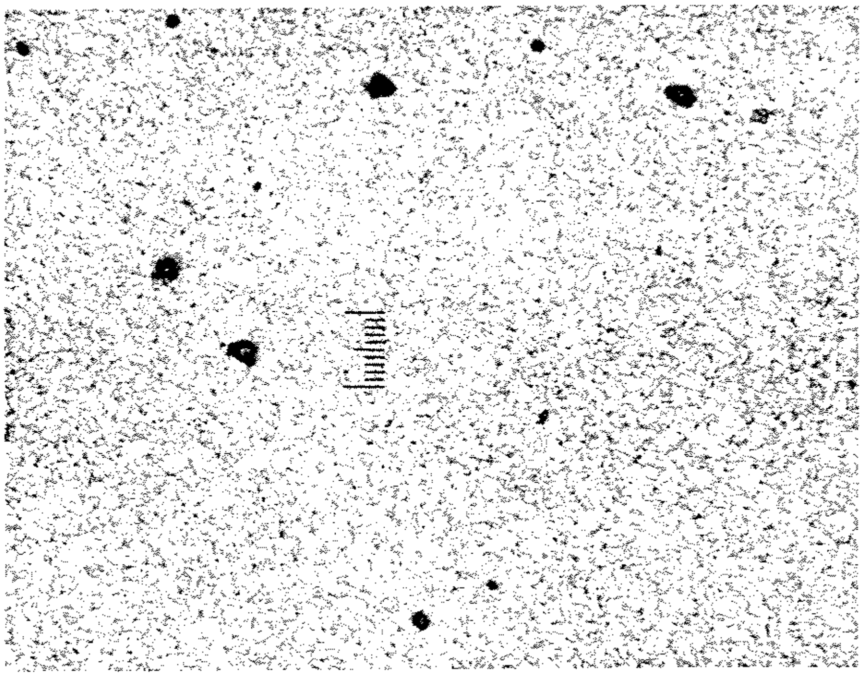


FIGURE 22. Optical micrograph of D material. Pores and parent metal grains are shown.The pore size varies from 5 to 20μm

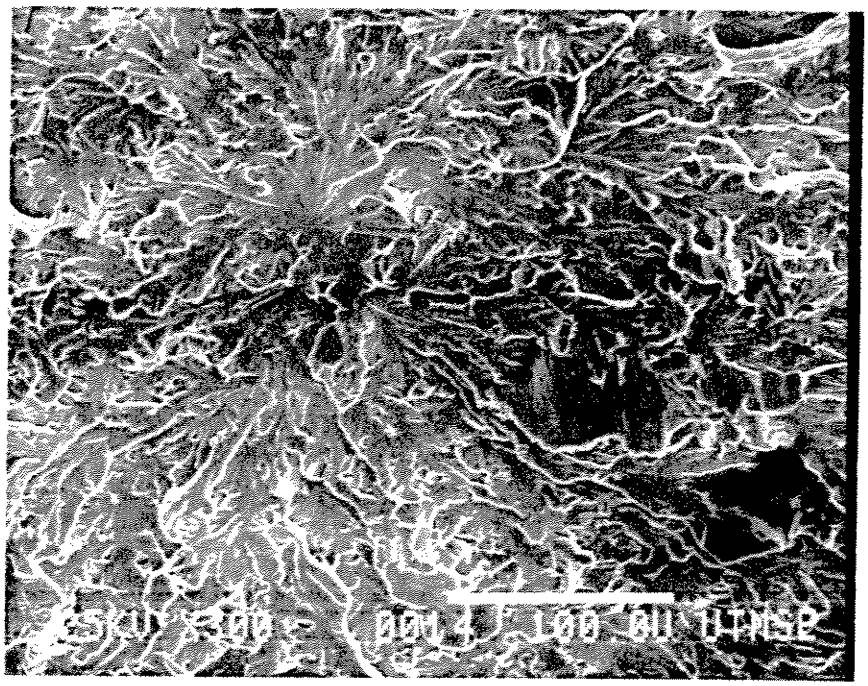


FIGURE 23. SEM micrograph of brittle fracture initiation stie on a D material CVN specimen. A pore was observed at the initiation center

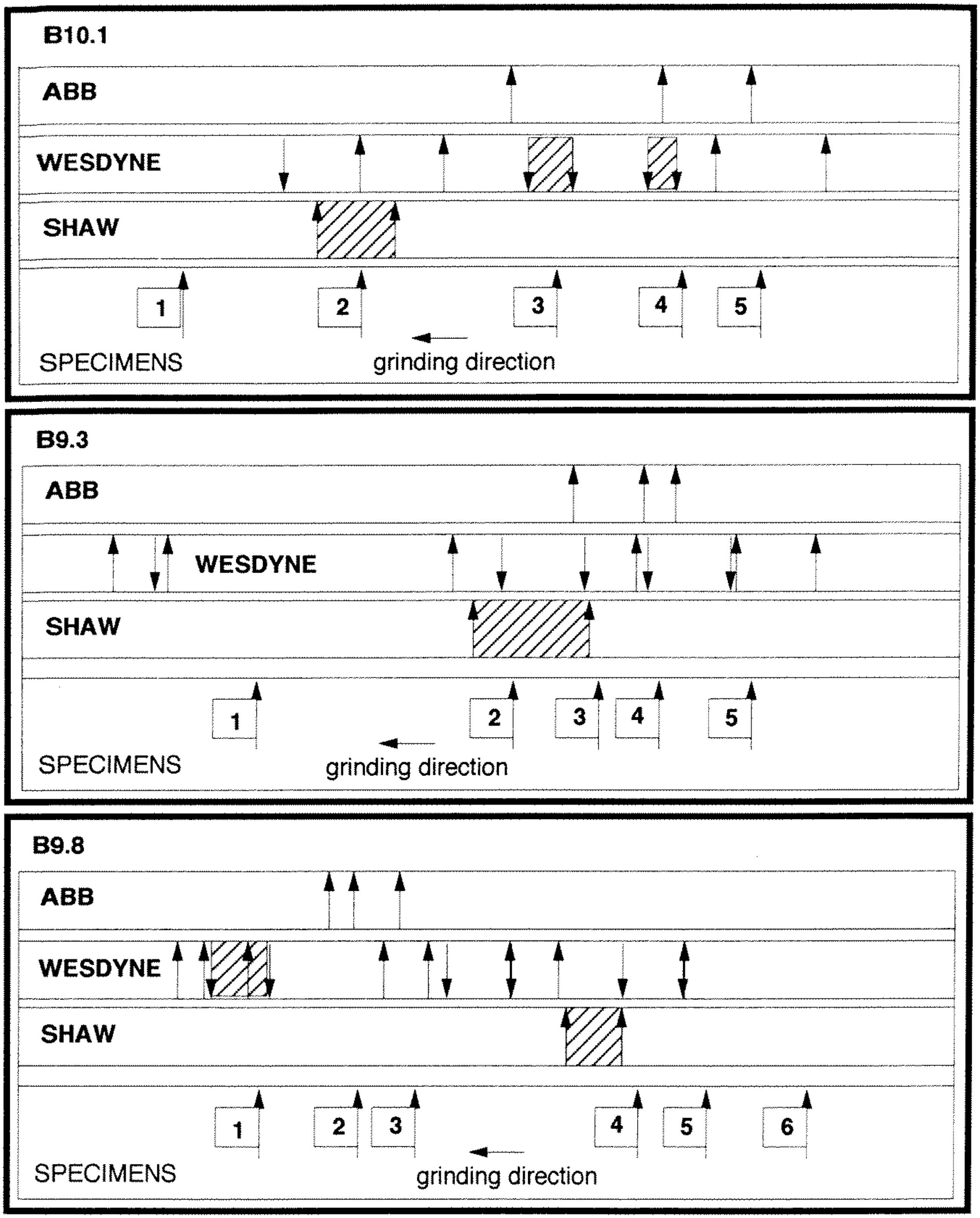


FIGURE 24. Developed plots of flaw indications from Round Robin NDT test series, with DT specimens