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16th Quarterly Report

March 7,1997
Austin, Texas

HOMOPOLAR PIPELINE WELDING RESEARCH PROGRAM

Presented to:

JOINT INDUSTRY SPONSORS

AMOCO Corporation
BP Exploration
Exxon Production Research
Mobil Research and Development Corporation
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CRC-Evans Automatic Welding
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Department of Transportation

RF 162

Presented by:

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The University of Texas at Austin
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INTRODUCTION

This report is the sixteenth quarterly report 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 in. schedule 60 (0.562 in. 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).

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 3 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 two years of the program concentrated on weld parameter optimization by producing, testing and evaluating welds in various grades, wall thicknesses, types and compositions of 3 in. nominal (3.5 in. 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 12 in. diameter pipe in a J-lay configuration.

1.2 Quarterly Summary

During the past quarter, six welds were performed in the 3 inch material, mechanical testing was completed on the D14 series, and the 12-inch fixture was fabricated. Two of the welds performed this quarter were demonstration welds using the large end geometry on D material. The remaining four welds were made using B and D materials which were normalized prior to end preparation and welding. The purpose was to study the effect of modifying microstructure while holding chemistry constant. Normalized B and D materials should have the coarser grains present in the hot worked or normalized A and C materials. Mechanical testing is underway on these welds.

Mechanical test results of the D14 series showed that profiling or pulsing the applied welding upset load has little effect on mechanical properties for high initial loads. Impact toughness remained high. Placing a drop of saltwater on the interface immediately before welding reduced the impact toughness where the salt water spread. Two welds designed to investigate step width effects on mechanical properties demonstrated that the short step length (0.050 in.) is less sensitive to step width variation than the long step length (0.10 in.).

Fabrication of the 12-inch fixture was the main focus of the JIP team during this quarter. The fixture has many sub-assemblies including 24 hydraulic cylinders that provide the electrode force to the pipe OD and transfer any lateral forces during welding to the guided welding structure. A bussbar assembly from the three homopolar generators and a hexapolar cable assembly provide a low resistance path to carry the 1.5MA peak current pulse to the welding fixture. This assures more uniform current distribution. A separate hydraulic module allows rapid weld setup and breakdown and applies the upset load for welding. A DAS/Instrumentation system collects weld data for weld analysis and fixture data for fixture monitoring. Commissioning and welding are scheduled for March 1997.

2. MATERIALS

The pipe materials investigated to date are presented in Table 1, and mill test reports are presented in Figures 1-4 for the 3 inch material.

3. EXPERIMENTAL PROCEDURE AND RESULTS

3.1 Introductory Remarks

Mechanical testing performed on weld series include impact toughness (Charpy V-Notch), hardness (Vickers), and microscopic examination. Routine tensile testing was discontinued because the test results showed little variation between welds for a given material. Complete descriptions of mechanical test procedures are found in the 13th Quarterly Report of the HOPWRP §4.1.

Weld series results discussed in the remainder of this section include the D14 series and a four weld series performed using B and D material normalized prior to welding.

3.2 Series D14

Series D14 consists of six welds in the D material with weld parameters selected to investigate effects of modified loading schemes, step width variations and two additional confirmation welds based on D8.7 weld parameters. Tables A2 and A3, found in Appendix A contain the weld data summaries and the CVN test results, respectively. Hardness test results are presented in Figures A1-A3. Demonstrations welds D14.7 and 8 will not undergo mechanical testing.

Interrupted Load D14.1 & D14.2

The first pair of welds investigated the effects of terminating the upset load at the end of the current pulse on the process parameters and mechanical properties. The motivation for this study was reducing the degree of coldworking in the weld, possibly lowering residual stress, as suggested by Dr.

Olson. To implement these weld parameters with the existing control system, the baseline load was set to 10 kip, then pulsed immediately following discharge (0.020 s) to 60 kip and held for the duration of the current pulse, 2.5 s. The load was returned to and held at the baseline setting for an additional one to two minutes, typical of constant load welds.

Mechanical test results demonstrate that these parameters have little effect on impact toughness, hardness, or metallurgy. The hardness test results indicate slight weld line softening of 4 to 10 VHN.

Load Droop Compensation: D14.3 & D14.4

The second pair of welds investigated the effect of constant load deformation, similar to the expected performance of the 12 inch fixture with the load applied by accumulators only. This modification was implemented by pulsing the 60 kip baseline load at the instant the step collapses, lasting for the duration of the load droop.

On D14.3, a drop of saltwater, prepared from tap water and table salt, was placed on a portion of the lower pipe to investigate effects of a likely offshore contaminant. The saltwater drop spread to at least 1/3 of the interface surface. Additional metallurgical and CVN specimens are cut from the saltwater contaminated section of the weld.

Hardness test results show a 10 VHN reduction in peak weld line hardness for D14.3 while typical results for D14.4, as compared with the baseline welds, D7.7 and D8.7. Impact toughness test results were typical for D14.4, but for D14.3, the mean impact toughness was reduced to 44 ft-lb and the minimum to 17 ft-lb. The low impact CVN values are associated with the spread of the saltwater drop. The CVN specimen furthest from the saltwater drop had a more typical value (106 ft-lb.). Future studies of the effects of saltwater contamination on HPW will use a more controlled method to apply the saltwater to the interface and monitor the spread.

Step Width D14.6 & D14.6

The third pair of welds investigated the effect of step width on mechanical properties, process parameters, and weld profile. A decreased step width was used for both small and large end geometries. The motivation for these welds resulted from the step length studies, which showed that impact toughness had an optimum value at 0.050 in. step length for narrow step geometry welds, but showing little sensitivity to step length for the wide step geometry. These two welds should indicate whether similar trends exist for step width.

Mechanical test results for D14.5 and 6 were typical showing minimal effect on weld zone hardness, metallurgy and impact toughness. Table 1 presents the results from the step length and width studies. For step lengths of 0.050 in., impact toughness shows little variation for step widths from 0.075 in. to 0.150 in. For the longer step, 0.100 in., the impact toughness values decrease rapidly as step width decreases from 0.125 in to 0.10 in. These results indicate reduced sensitivity to step width for the short step length.

Table 1. Charpy Impact Toughness Results for Step Width and Length Studies

Mean (Minimum) Values in ft-lb

Width / Length	0.075″	0.10″	0.125″	0.150″
0″		8.7 (8)		
0.025″		37 (33)		
0.050″	101 (95)	99.7 (87)		90.3 (64)
0.075″		77.6 (56)		75 (68)
0.100″		0.83 (0.0)	108 (66)	98.7 (85)
0.125″				92 (80)
0.150″				108 (104)

3.3 Normalized B and D Material Weld Series

The normalized B and D material weld series consisted of four welds in the B and D materials using large and small end geometry preparation. The series was designed to investigate grain size and microstructural changes in the base material on weld properties holding chemical composition constant. Table A4 presents the weld data summaries and parameters. Normalizing B and D materials prior to welding will produce a microstructure similar to that of A and C materials, which have not met acceptable impact toughness with homopolar welding.

Weld parameters were based on D7.7 and D8.7. Since the normalizing process reduced the penetration hardness of the base metal to less than 130 VHN, the constant load was reduced to 50 kip for DN1.1 to avoid excessive deformation. This adjustment to the weld parameters proved unnecessary. The process parameters were typical of both materials, with slightly lower displacement than the baseline welds, but within the range observed with these parameters. Mechanical testing is underway.

4. 12-inch PIPE WELDING FIXTURE

Final assembly and commissioning of the 12-inch fixture are scheduled for completion in March 1997. Major sub-assemblies of the fixture include:

- Electrode hydraulics: 24 hydraulic cylinders, 12 pilot operated check valves, fittings, and tubing;
- Electrodes: 24 electrodes, flex cables, bussbars, and mounting plates;
- BHPG bussbars and welding cables: busswork from Balcones homopolar generators to transition plates (2 sets) and flexible welding cables (36 hexapolar cables) from transition plates to welding fixture;
- Platens and guide shafts to maintain weld alignment during weld: four platens, three guide shafts, and seven bearings with bearing housings;
- Hydraulic module: central tension rod, 250 ton capacity hydraulic cylinder assembly with accumulator supplied upset force, spherical bearings in housing and pipe anvils, and alignment and piloting guides;
- Instrumentation and DAS: 15 to 19 DAS channels capturing current, voltage, temperature and displacement of work piece, and additional voltage, temperature and hydraulic channels to monitor the process and the fixture.

Efforts on other areas of investigation were put aside to focus all available manpower and energy on completing the 12 inch fixture on schedule. Terrell Cooksey and Jim Wright with PKD have worked on the DAS/Instrumentation System. Mike Harville, also of PKD has helped fabricate the 36 hexapolar cables.

5. PLANNED ACTIVITIES

During the next quarter, the primary emphasis will be commissioning the 12-inch fixture and producing 12 in. welds. Work will resume on ultrasonic testing, including development of procedures for calibration and testing of 3.5 in. welds and adapting the tests to the 12 in. welds. Testing will resume on the B19 welds. Mechanical testing of the normalized B and D material welds will be completed.

6. ADMINISTRATIVE

9.1 Financial Statement

The balance sheet for the program is presented in Table 2.

Table 2. Financial Statement

CONTRACT: JIP A/C 26-6010-02XX	BUDGET INC./TRANS.	YEAR 1 2/93-1/94	YEAR 2 2/94-1/95	YEAR 3 2/95-1/96	AUGUST 1996	SEPTEMBER 1996	OCTOBER 1996	NOVEMBER 1996	NOVEMBER ADJ 1996	DECEMBER 1996	JANUARY 1997	FREE BALANCE Y-T-D
SALARIES & WAGES	$444,618.26	$80,646.82	$118,862.46	$122,534.57	$11,654.98	$16,569.12	$12,425.93	($2,273.97)	$9,268.03	$11,190.94	$12,418.44	($13,140.4
FRINGE BENEFITS	$109,347.13	$20,989.31	$31,803.88	$31,316.31	$2,280.74	$3,250.87	$3,028.88	($1,265.62)	$1,764.98	$2,228.76	$2,445.34	($2,097.0
OTHER EXPENSE	$50,146.00	$7,396.38	$8,889.75	$14,364.38	$1,786.63	$1,892.59	$1,815.14	$1,485.40	$0.00	$1,122.08	$0.00	$99.1
COMPUTATION (67)	$499.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$469.2
TRAVEL	$18,753.00	$1,890.14	$5,386.35	$6,643.61	$0.00	$301.65	$795.82	$0.00	$0.00	$0.00	$0.00	$1,788.0
MTDC	$623,363.39	$110,922.65	$164,942.44	$174,858.87	$15,722.35	$22,034.23	$18,065.77	($2,054.19)	$11,033.01	$14,541.78	$14,863.78	($12,881.0
OVERHEAD	$311,060.83	$54,350.62	$82,340.62	$87,429.43	$7,861.18	$11,017.12	$9,032.89	($1,027.10)	$5,516.51	$7,270.89	$7,431.89	($5,820.1
TUITION	$4,200.00	$1,066.40	$924.89	$1,198.97	$1,759.60	($879.80)	$0.00	$0.00	$0.00	$0.00	$0.00	$129.9
EQUIP /FAB (83&80)	$61,375.78	$34,016.43	$8,020.91	$24,145.47	$217.11	$10,042.83	$133.35	($3,818.95)	$0.00	$720.00	$5,697.51	$10.7
TOTAL	$1,000,000.00	$200,356.10	$254,228.86	$287,632.74	$25,560.24	$42,214.38	$27,232.01	($6,900.23)	$16,549.52	$22,532.67	$27,993.18	($18,560.5

REMARKS:

FUNDED Y-T-D: $1,000,000 EXPIRATION:

Appendix A Weld Data

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TABLE A1. MILL TEST REPORT DATA

3 in. nominal (3.5" OD) API 5L Carbon Steel Linepipe WELD PREFIX CODE	A	B	C	D	M
SUPPLIER	**Dixie Pipe**	**Prudential**	**Lone Star**	**Nippon**	**NKK**
API 5L GRADE	**X52**	**X60**	**X52**	**X65**	**X52**
WALL THICKNESS	**0.438**	**0.300**	**0.438**	**0.315**	**0.562**
TYPE	**seamless**	**ERW**	**ERW**	**seamless**	**seamless**
HEAT TREATMENT (not on mill test report)	**Hot rolled**	**controlled rolled**	**normalized**	**quenched and tempered**	**Hot Finished**
LADLE CHEMISTRY					
C	0.23	0.13	0.11	0.08	.08-.12
Mn	1.04	0.65	1.13	1.29	1.07-1.13
P	0.010	0.005	0.014	0.011	0.006-0.014
S	0.009	0.004	0.005	0.002	0.001
Si		0.22	0.28	0.19	0.21-0.29
Al		0.042	0.037		0.026-0.046
Cr		0.03	0.073		.0.04-0.07
Mo		0.01	0.028	0.22	Tr
Ni		0.01	0.07		0.02-0.03
Cu		0.02	0.13		0.01-0.02
Cb		0.18	0.034	0.032	Tr
Ca		0.0048		0.0026	0.0020-0.0028
Ti			0.008		0.002-0.005
V	0.08		0.040		.003-0.04
B			0.0003		Tr -0.0003
				0.035 Ti-Al	
IIW C_{eq}	0.42	0.23	0.34	0.34	0.28-0.33
Yield Strength (ksi)	**66.0**	**79.5**	**59.5**	**71.6 ***	**62.75=**
Tensile Strength (ksi)	**94.4**	**86.1**	**79.5**	**80.7 ***	**78.4=**
% elong in 2"	**30**	**22**	**37**	**26.6 ***	**31.37=**
Vickers Hardness ($kg.mm^2$)	**193.2**	**181.9**	**171.0**	**185 ***	**186-204=**

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

= In-house test results. Mill test not available.

TABLE A2 D14 SUMMARIES

a. **D14 Series Weld Parameters**

Weld No	Step Length (in.)	Contact width((in.)	Bevel Angle (°)	Shoulder Radius [in.]	Special Geometry	RPM	Field (amp)	Load1 (kip)	Load2 (kip)	Load2 Delay (sec)	Load2 Length (sec)
D14.1	0.05	0.10	30	0.11		2100	360	**10**	60	**0.020**	**2.50**
D14.2	0.10	0.15	30	0.11		2100	360	**10**	60	**0.020**	**2.50**
D14.3	0.05	0.10	30	0.11		2100	360	60	**85**	**0.100**	**0.30**
D14.4	0.10	0.15	30	0.11		2100	360	60	**75**	**0.180**	**0.44**
D14.5	0.05	**0.075**	30	0.11		2100	330	60	60	—	—
D14.6	0.10	**0.125**	30	0.11		2100	360	60	60	—	—
D14.7	0.10	0.150	30	0.11		2100	360	60	60	—	—
D14.8	0.10	0.15	30	0.15		2100	360	60	60	—	—

b. **D14 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)
D14.1	197.9	0.102	1.037	0.110	635	2.405	79	0.220	125	2.450
D14.2	203.1	0.110	1.105	0.196	665	2.500	131	0.360	175	2.355
D14.3	203.1	0.102	1.035	0.102	624	2.690	91	0.090	115	2.625
D14.4	205.2	0.110	1.080	0.180	593	2.530	144	0.440	165	2.340
D14.5	199.5	0.133	1.170	0.086	636	2.280	100	0.250	146	2.250
D14.6	216.8	0.102	1.397	0.141	661	2.655	164	0.375	214	2.500
D14.7	218.4	0.110	1.207	0.188	656	2.530	144.2	0.375	191.9	2.340
D14.8	209.5	0.110	1.157	0.188	586	2.440	145.3	0.470	181.1	2.220

c. **D14 Series Mechanical Test Results**

Weld No	Act. Disp (in.)	CVN mean (ft-lb)	CVN min (ft-lb)	YS (ksi)	TS (ksi)	%EL	HV10 HAZ min	HAZ width (mm)
D14.1	0.147	82.7	72					
D14.2	0.196	106.3	90					
D14.3	0.143	44	17					
D14.4	0.194	94.3	88					
D14.5	0.178	101	95					
D14.6	0.251	108	66					
D14.7								
D14.8								

Table A3 D14 Series CVN Results

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

WELD #	CVN	ft-lb	%shear		WELD #	CVN	ft-lb	%shear
D14.1	1	84	100		D14.4	1	101	100
	2	92	100			2	88	100
	3	72	70			3	94	100
	min	72				min	88	
	mean	82.7				mean	94.3	
	max	92				max	101	
D14.2	1	123	100(st)		D14.5	1	102	100
	2	90	100			2	106	100
	3	106	100			3	95	100
	min	90				min	95	
	mean	106.3				mean	101	
	max	123				max	106	
D14.3	1	106	100		D14.6	1	66	60
	2	25	5			2	108	100
	3	17	0			3	78	70
	5	28	5					
	min	17				min	66	
	mean	44				mean	84	
	max	106				max	108	
SERIES								
	min	17						
	mean	85.4						
	max	123						
	St.Dev	22.3						

Table A4 Normalized B and D Material Weld Summaries

a. **D14 Series Weld Parameters**

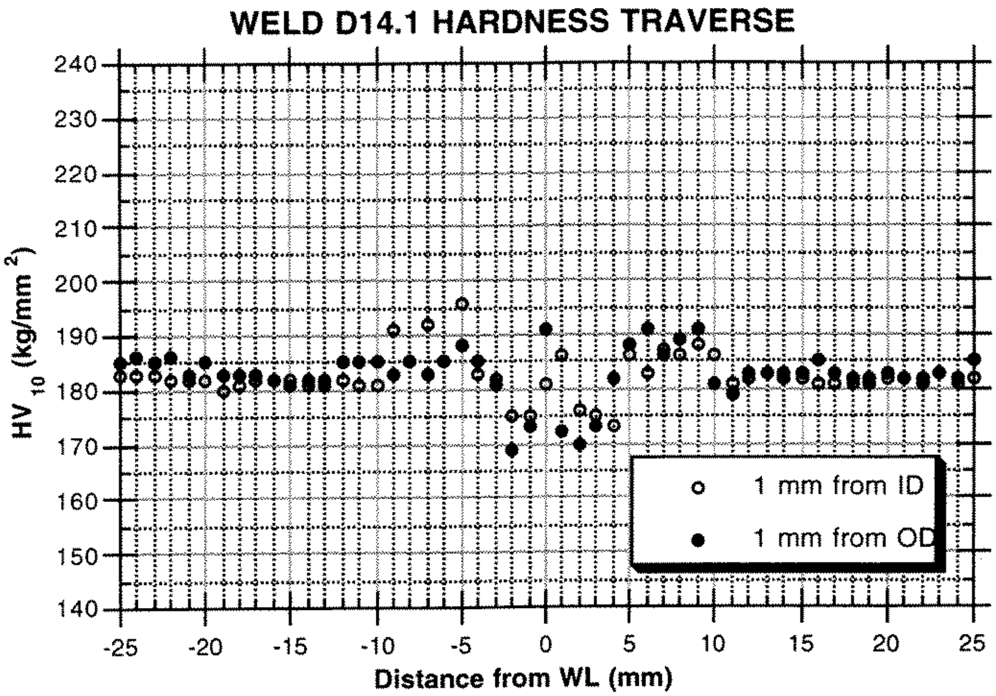
Weld No	Step Length (in.)	Contact width((in.)	Bevel Angle (°)	Shoulder Radius [in.]	Special Geometry	RPM	Field (amp)	Load1 (kip)	Load2 (kip)	Load2 Delay (sec)	Load2 Length (sec)
BN1.1	0.10	0.15	30	0.11	*Normalized*	2100	360	60	60	0	60
BN1.2	0.05	0.10	30	0.11	*Pipe*	2100	360	60	60	0	60
DN1.1	0.05	0.10	30	0.11	*Prior to*	2100	360	**50**	**50**	0	60
DN1.2	0.10	0.15	30	0.11	*Welding*	2100	360	60	60	0	60

b. **D14 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)
BN1.1	214.2	0.110	1.017	0.211	586	2.665	121.4	0.405	212.5	2.465
BN1.2	214.2	0.102	0.95	0.125	555	2.690	79.2	0.315	173.5	2.565
DN1.1	202.1	0.094	1.107	0.118	645	2.405	84.6	0.405	126.8	2.080
DN1.2	205.8	0.110	1.102	0.203	580	2.625	123.6	0.435	182.1	2.405

c. **D14 Series Mechanical Test Results**

Weld No	Act. Disp (in.)	CVN mean (ft-lb)	CVN min (ft-lb)	YS (ksi)	TS (ksi)	%EL	HV10 HAZ min	HAZ width (mm)
BN1.1								
BN1.2								
DN1.1								
DN1.2								



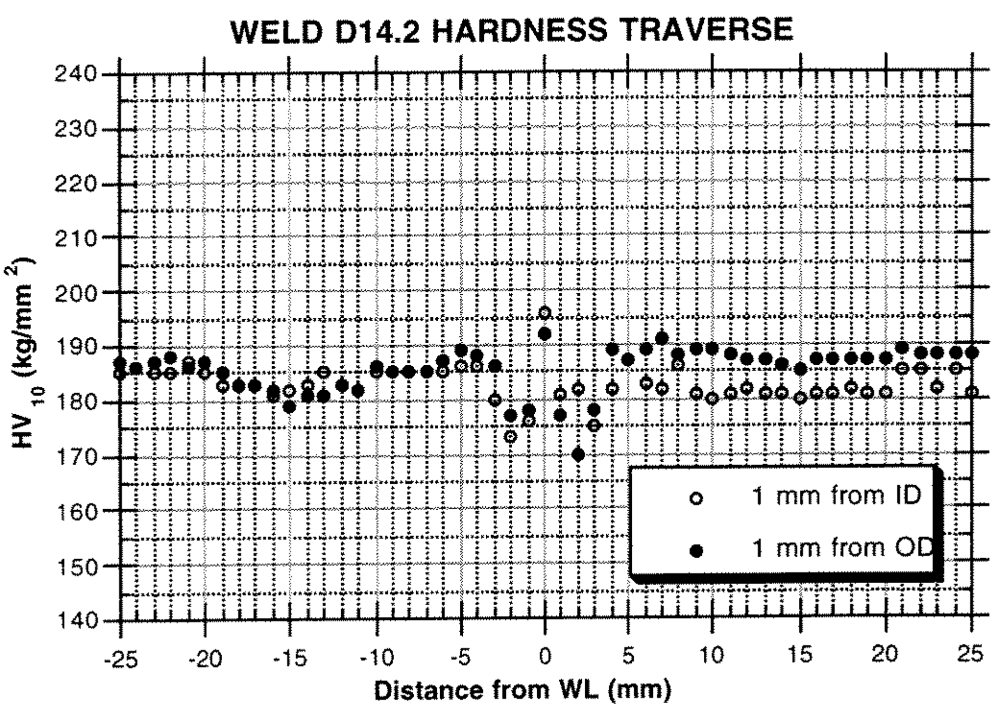
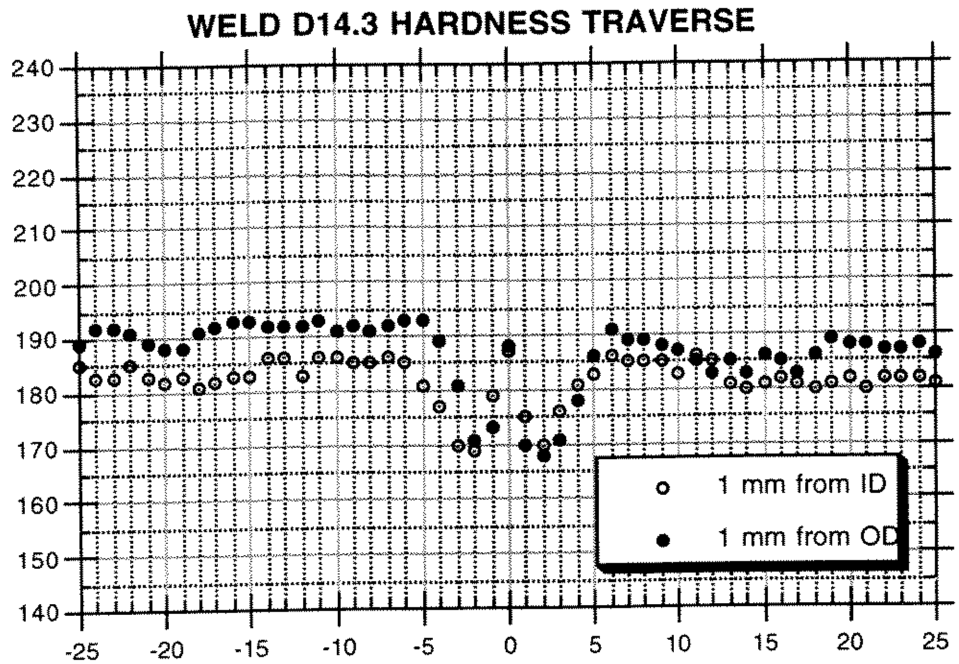


Figure A1. Hardness Test Results D14.1-2



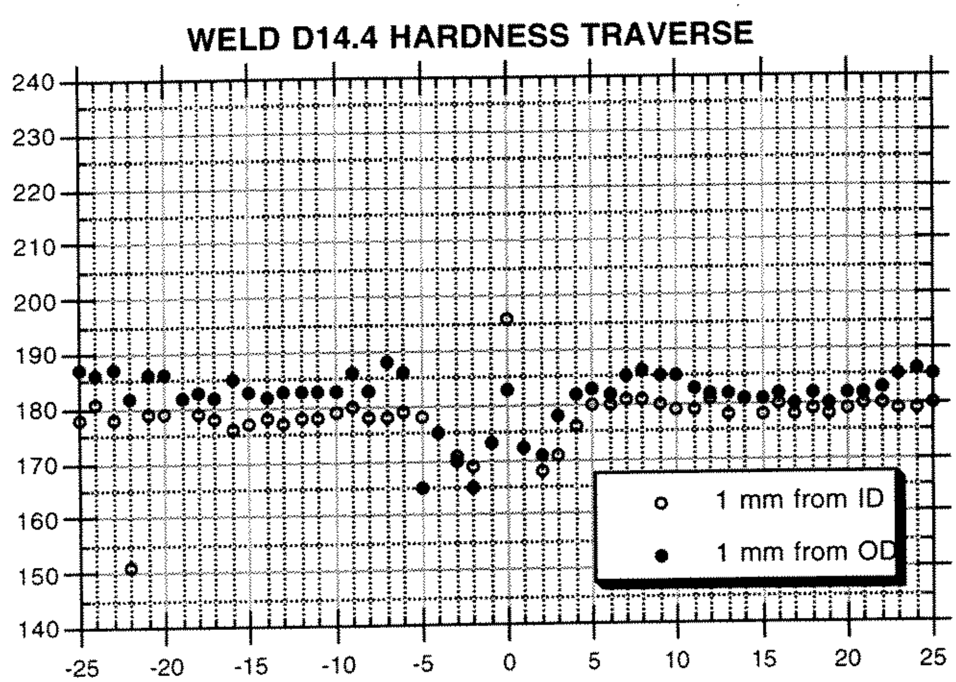
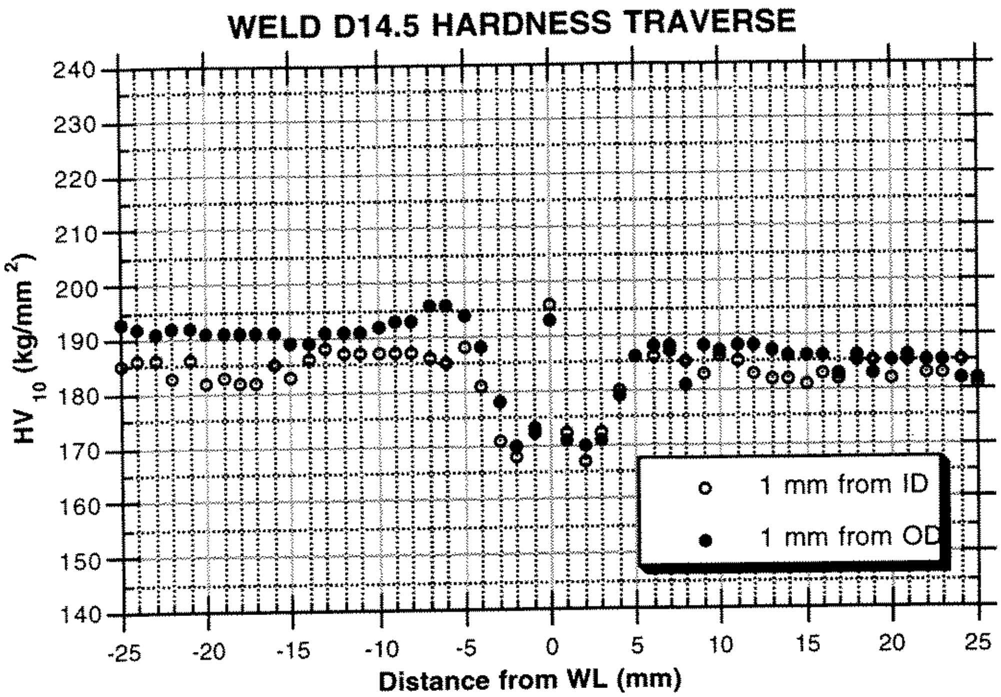


Figure A2. Hardness Test Results D14.3-4



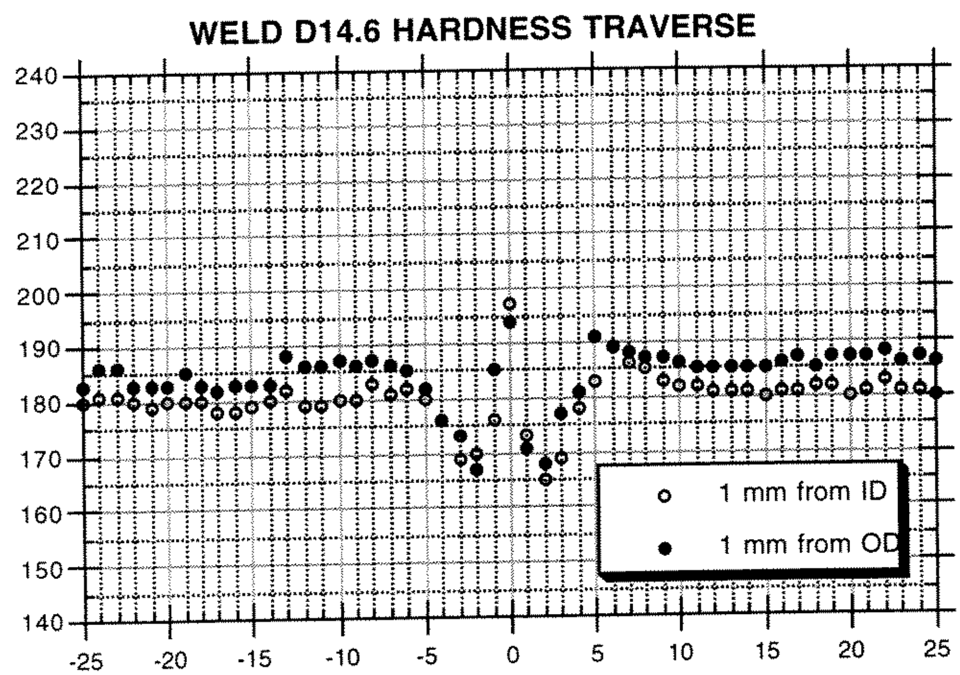


Figure A3. Hardness Test Results D14.5-6