WELDABILITY TESTING OF THE HP 70W STEEL
FINAL REPORT

February 1998

by

Yoni Adonyi, Ph. D.

LeTourneau University, Longview, Texas

Report Prepared for the Carderock Division, Naval Surface Warfare Center and sponsored by the Federal Highway Administration

EXECUTIVE SUMMARY

This work is a review of the simulative-, small- and full-scale weldability test performed on the High-Performance (HP) 70 W steel. The results of Gapped Bead-on-Plate (GBOP) testing (performed at U. S. Steel Research, LeTourneau University), Implant testing (Naval Surface Warfare Research Center) and Tekken testing (Bethlehem Steel Research) were analyzed, together with the results of the weldability tests performed at bridge fabricators High Steel, Egger Steel and Trinity Industries.

Based on simulative weldability testing, it was found that the HP steel needed lower preheat temperatures by 100-150°F than presently specified for the conventional ASTM A 709 Grade 70W steel, in order to avoid heat affected zone cracking for up to 2-inch in thickness. When welding full-scale test girders, no cracking was found in the single-pass fillet welds or multi-pass butt welds, even when welded at ambient temperature. Matching and undermatching consumables were used. Work is underway to further refine SAW welding wire/flux combinations having matching strength and corrosion resistance.

1. 0 BACKGROUND

The present study is part of a nationwide effort directed toward finding better steels to cost-effectively build bridges for America's infrastructure. The Office of Naval Research and the American Iron and Steel Institute (AISI) including steel producers such as U. S. Steel, Bethlehem Steel and Lukens Steel, started in 1994 a cooperative research program to develop High-Performance Steels (HP) at 70 and 100 ksi yield strengths. Since improved weldability was one of the criteria chosen, welding consumable manufacturers (Lincoln Electric, ITW and ESAB) and some bridge fabricators (High Steel, Egger Steel, Trinity Industries) have been involved in the project. Lehigh University and Northwestern University have also been developing new steel chemistries for the project. The University of Nebraska in Lincoln, Lehigh University and the Federal Highway Administration (FHWA, the sponsoring Federal Agency) were assigned testing of experimental girders. LeTourneau University has been involved mostly in simulative weldability testing for hydrogen-induced cracking susceptibility.

3. 0 OBJECTIVE

The scope of this work was to study the weldability of the HP 70W steel using a combination of simulative, small- and full-scale weldability tests. The outcome of this study was intended to be the basis for updating the welding specification for conventional ASTM A 709 Grade 70W steel to the high-performance (HP) version. This report summarizes the weldability information developed at the above enumerated different locations.

4.0 METHODOLOGY

The various testing procedures used in this applied research/ developmental stage of the study are described separately below.

4.1 G-BOP Testing Procedure

Gapped Bead On Plate (GBOP) testing was used to determine the weld metal susceptibility to hydrogen induced cracking of single-pass shielded metal arc welding (SMAW) and submerged arc welding (SAW) deposits (Figure 1). Testing was performed at three locations: U. S. Steel Research, LeTourneau University and Trinity Industries, Montgomery, AL. The base metal thickness was 2-inches. Three levels of diffusible hydrogen H2, H4 and H8 (or 8 ml/100g) diffusible hydrogen were targeted. The diffusible hydrogen was measured using the mercury method specified in the American Welding Society AWS A 4.3-93 standard specification. For the LeTourneau and Trinity testing, the samples were prepared and collected on site at the time of GBOP testing and stored in liquid nitrogen for actual hydrogen measurements at a remote location.

The weld metal specified tensile strengths were 70, 80 and 90 ksi. Arc energies ranging from 25 to 130 kJ/in were used, while the majority of the testing was performed at 25 and 50 kJ/in. Four levels of preheat temperatures (50°F - undercooled, 72°F- room temperature, 150°-175°F and 225°-250° F ranges) were chosen for the experiments. Post-weld evaluation included cutting and mounting each weld for metallographic evaluation and hardness measurements in the heat affected zone (HAZ) and fusion zone (FZ).

4.2 Y-groove (Tekken) Testing

The Y-groove testing was performed in accordance with Japanese Industrial Standard JIS Z-3158 (1966) method for 2-inch-thick plate at Bethlehem Steel Corporation, Homer Research Laboratories (Figure 2, Ref. 3). One heat input (25 kJ/in arc energy), SMAW was used with E 9018 electrodes at two levels of diffusible hydrogen: 1) 4.7 ml/100g and 2) 10.7 ml/100g. Post-weld evaluation included Vickers hardness testing in the weld HAZ using 2.5 kg load.

4.3 Implant Testing

The implant testing was performed at the Naval Surface Warfare Center (NSWC), Carderock Division, Materials Processing Branch, using Gas Metal Arc Welding (GMAW), 40 kJ/in arc energy, a weld deposit having 120 ksi tensile strength and hydrogen added to the shielding gas to produce 7.8 ml/100g diffusible hydrogen, Figure 3. Post weld evaluation included metallographic evaluation and Rockwell hardness measurements using a 1 kg load.

4.4 Welding Procedure Specimen (WPS) and Trough Testing

Several bridge fabricators performed WPS qualifications in accordance with the requirements of the AWS D1.5-95 Bridge Welding Code (Refs. 5, 8, 9), as well as the Trough Test developed by the Navy (Figure 4). Variables included: strength level of the SAW and SMAW deposits, preheat level and heat input. Unfortunately, the number of weld passes and/or interpass temperatures were not always unified among the fabricators and diffusible hydrogen measurements were not performed at these sites, except for the case of Trinity Industries (Ref. 7). Non-destructive and destructive testing were performed after welding.

Table I shows the consumables and preheats used at High Steel (Ref. 5) to fabricate samples T1-T6 Trough tests and W1-W6 and W3a WPS tests. Heat inputs of ~30, 96 and 135 kJ/in were used. Single-electrode, Direct Current Reverse Polarity (DCRP, or electrode positive) were used to weld the 2-inch-thick plates.

Table II shows the WPS test parameters used at Egger Steel (Ref. 8). Seven WPS plates were fabricated using undermatching L61/860 electrode/flux SAW consumables, heat inputs of 23, 40, 61 and 80 kJ/in and 125° and 175°F preheat levels. The maximum interpass temperature was maintained below a specified 600°F.

Table III shows the parameters used for the WPS plates welded at Trinity Industries. One heat input (40 kJ/in), two weld deposit strengths were included in the matrix, with Direct Current Straight Polarity (DCSP) and DCRP electrode polarities and two different preheat levels (i.e. room temperature and 250°F). The same table shows the corresponding levels of diffusible hydrogen measured on-site for certain combinations - see circled numbers, in ml/100g units (Ref. 7).

4.5 Small and Full Scale Girder Welding

The details of fabrication of two 30-foot-long test girders at High Steel are included in Ref. 5. Another two girders were fabricated at Lincoln Steel Company in Lincoln, Nebraska for testing at the University of Nebraska. Girder extensions of A 709 grade 50W were welded to HP 70W using L61/860 electrode/flux combination. The first bridge bid in the US to use the HP 70W was fabricated at Trinity Industries and delivered to the State of Tennessee. This bridge, as well as a second one was fabricated at Egger Steel and delivered to Nebraska, are complete and carrying traffic.

5.0 RESULTS AND DISCUSSION

5.1 G-BOP Test Results

Detailed results of the tests are included in References 1 and 2. Three separate factors affecting the weld metal hydrogen-induced cracking are discussed below.

5.1.1 Diffusible Hydrogen Effect on Minimum Preheat

When plotting selective weld metal cracking results (Figures 5, 6), it becomes clear that at low levels of diffusible hydrogen (1.7 ml/100g), no preheat would be needed to weld the HP 70W up to two inches in thickness, if single-pass SAW welds would be used. For comparison, the conventional A 709 Grade 70 would have been required by the AWS D1.5-95 code to be preheated to 212°F (Ref. 10). While a 2-inch plate could not be welded in single-pass SAW welding process, the simulative test can be considered representative of the first weld pass acting as preheating source for the subsequent passes. However, when the diffusible hydrogen exceeded 5.0 ml/100g, a minimum of 125°F preheat was needed to avoid cracking. Again, this result is lower when compared to the D1.5-95 code requirement (i.e. 248°F)

Note that the comparable hydrogen levels for these simulative tests would be within the H4 specified by the AWS D1.5 Code. This "H" level is only a designator that the consumable is capable of producing weld metal at or below the level indicated. Bridge fabricators should consider implementing control over low-hydrogen welding practices when joining the HP 70W in the future, in addition to only purchasing low-hydrogen consumables. These low-hydrogen welding practices involve everything from properly protecting and storing consumables to fabrication practices that include soaking preheats, avoiding contaminations and condensations within the joint, etc. Nevertheless, because in the case of the widely used Submerged Arc Welding (SAW) process the welding flux can be the major source for hydrogen pickup, it would be important to purchase and maintain fluxes that have been proven to be able to produce low levels of diffusible hydrogen.

5.1.2 Heat Input Effect on Minimum Preheat

Cooling rate in the weld metal and HAZ are important factors in avoiding cold-cracking. The possibility of using increased heat input instead of preheat to lower the weld metal hardenability and increase the diffusivity of hydrogen was investigated. Figure 7 shows the GBOP results for two levels of diffusible hydrogen and increasing heat input. As the heat input exceeded 50-60 kJ/in, no cracking was experienced up to 130 kJ/in at 5.8 ml/100g diffusible hydrogen.

5.1.3 Welding Process Effect on Minimum Preheat

GBOP testing using the SMAW welding process resulted in higher minimum preheat predictions than when the SAW welding process with equivalent arc energy was used. The difference was traced back to the heat transfer efficiency differences between the two welding processes (Ref. 1,2). Extensive weld metal hardness surveys showed a consistently higher hardness in SMAW GBOP welds than in SAW welds. Therefore, separate preheating guidelines will eventually have to be considered for single-pass SMAW welds, especially for temporary (tack) welds.

5.2 Y-groove (Tekken) Testing

The results are shown in Table IV. Because of the severity of this simulative test, as well as difficulties in measuring small discontinuities, it is customary to ignore any cracking results lower than 1 percent. Therefore, the data indicated that no preheat would be necessary to avoid HAZ cracking at and below 4.7 ml/100g diffusible hydrogen levels when using SMAW electrodes and at a low heat input (25 kJ/in). At higher diffusible hydrogen level (10.7 ml/100g), a minimum preheat of 250°F was needed to avoid HAZ cracking.

To verify the reason for this high preheat, the maximum hardness was measured in the HAZ and peak values of 404 to 376 HV (Vickers Hardness units) were found as the preheat increased from Room Temperature to 250°F. At the same time, the average HAZ hardnesses decreased from 396 to 361 HV (Ref. 3). These values were somewhat higher than those measured at U.S Steel (Ref. 1), but within the range predicted by the "HAZ Calculator" software developed at the University of Graz, Austria (Ref. 12).

Note that the Tekken test has been widely recognized as a highly restrained test (Ref. 11, Yurioka), it is customary to subtract ~100°F from the minimum preheat predicted by the severely restrained test when applying it to less restrained production conditions. Therefore, no preheat (if ambient temperature is

~70°F)would be necessary to avoid HAZ cracking at diffusible hydrogen levels below 5 ml/100g, while a 150°F preheat would be needed when high diffusible hydrogen levels would be encountered (>10 ml/100g). This conclusion is in agreement with the preheat results predicted for the weld metals in # 5.1.1., or 150°F lower than the preheat specified in the D1.5-95 Code.

5.3 Implant Test Results

The results of the Implant test performed at the NSWC are shown in Figure 8. The HP 70W specimens did not fail at all, indicating very good resistance to HAZ cracking, even at high levels of diffusible hydrogen. This apparent contradiction with the results of the Tekken test were resolved by comparing the HAZ hardnesses in the 0.25-inch diameter implant rod (average 252 HV), almost 100 HV lower as compared with the HAZ hardnesses measured in the 2-inch-thick Tekken specimens (Ref. 3). This difference could mean 60-70 ksi lower tensile strength in the Implant weld HAZ, the most likely reason for the overall good behavior. These unrealistically low HAZ hardnesses made the test inconclusive. Therefore, it was concluded that the Implant test should not be used further to predict weldability of the HP steels.

5.4 WPS and Trough Testing Results

The results of the WPS tests performed at High Steel are summarized in Table V. For the L61/860 electrode/flux combination, single-electrode as per AWS 4.9, the all-weld metal yield strength varied between 75.6-76.3 ksi, while the heat input varied between 96-133 kJ/in. The Charpy V-notch toughness results were in the 51-60 ft•lbf range at 0°F. These results surprisingly overmatch the HP 70W properties in yield strength at high heat inputs.

Trough testing resulted in partial failures. The reduced ductility tensile specimens showed clear evidence of hydrogen damage ("fish-eyes"). Subsequent testing at the Navy lab showed extremely high (17.4 ml/100g) diffusible hydrogen levels in the weld metal (Ref. 6).

For comparison, the results of the WPS test performed at Egger Steel are summarized in Table VI for the same L61/860 electrode/flux combination, when parallel electrodes were used. The resultant all weld metal yield strengths were different for the two levels of heat input chosen. While at 23 kJ/in the resultant yield strength matched the minimum 70 ksi (70-73 ksi), at 80 kJ/in heat input, it dropped to 58 ksi. The impact toughness values of the all-weld metal samples were lower than of the HP 70W base metal, i.e 36-69 ft•lbf at -20°F.

The results of the WPS test performed at Trinity Industries are summarized in Table VII. The Lincoln LA100/800H wire flux combination, multi-electrode AWS 4.11 was used at 91.4 kJ/in heat input, two-wire AC/DC welding, using a 250°F preheat temperature. The all weld metal yield strength varied between 83.8-92.6 ksi, while the tensile strength was 85.5-98.0 ksi. This combination overmatched the 70 ksi minimum yield strength requirement for the base metal by an average of 18 ksi or 25 percent. The average toughness at -30°F varied between 101-168 ft•lbf, which is compatible with the base metal.

For comparison, the results obtained at High Steel for the same LA100/800H wire/flux combination showed even more overmatching, i.e. 99-104 ksi yield strength, or 45 percent over the 70 ksi yield strength of HP 70W, 107-117 ksi tensile strength and 69-125 ft•lbf toughness at 0°F.

To better understand the results of the above tests, the reader is encouraged to study and interpret the results included in the individual reports (Refs. 5, 8, 9).

6.0 CONCLUSIONS

A) Single-pass Welds, Simulative Weldability Tests (G-BOP, Tekken, Implant)

A1 - The factors affecting delayed (cold) cracking were, in a decreasing order of importance:

1 - level of diffusible hydrogen;
2 - weld metal yield strength;
3 - heat input;
4 - welding process.

A2 - Normal ambient conditions (or preheat to 70°F in case the outside temperature is lower) would be sufficient to avoid cold cracking in HP 70W steels up to 2-inch-thickness provided that:

1 - low-hydrogen (less than 5 ml/100g) practices are employed, and
2 - undermatching weld metal is used (less than 70 ksi yield strength),
3 - the heat input is greater than 50 kJ/in, and
4 - the SAW process is used.

Note that all the above conditions have to be simultaneously present in order to avoid weld metal cracking. A summary preheat comparison table is shown below.

Recommended Minimum Preheat Temperatures for 2-inch-thick Plate, 50 kJ/in heat input SAW Welds.

	Diffusible Hydrogen Level		
	H4	**H8**	**H16**
Conventional A 709 -70W	212°F	248°F	248°F
High-Performance 70W	70°F	100°F	150°F

A3 - Although diffusible hydrogen was not measured on-site, the validity of the above conclusions was supported by the successful fabrication of test girders at three different independent bridge fabricators.

B) Multiple-pass Welds (Procedure Qualifications, Trough tests, Welding of Flange Splices)

B1 - When preheats of 125-175°F and proper fabrication practices were used, no weld metal or HAZ cold-cracking was encountered. When cracking did occur in some cases, the hydrogen-induced cracks were confined to the weld fusion zone.

B2 - In spite of the large scatter in welding and testing conditions, the weld tensile properties matched or exceeded the base metal properties. The only common trend was a decrease in tensile and yield strengths with increasing heat input.

B3 - More work is needed to establish the relationship between the results of the single-pass weldability tests and the properties of the multipass actual welds.

7.0 REFERENCES

1. Adonyi, Y et al., 1995. "G-BOP Testing of HP 70W Steels Using the SMAW Process", Unpublished Report, US Steel Technical Center, November 1995

2. Adonyi, Y et al., 1996. "G-BOP Testing of HP 70W Steels Using the SAW Process", Interim Report, LeTourneau University, July 1996

3. Snyder, J. et al. 1996 "Tekken (Y-groove) Testing of HP 70W", Bethlehem Steel Company, Homer Research Laboratories

4. Focht, E. et al. 1995 "Development of High Performance Steels for Bridge Construction", CDNSWC Report TR-61-95/16, Naval Surface Warfare Research Center, August 1995.

5. Nickerson, R., et al. 1996 "Management, Operation and Maintenance of HP for Bridge Construction" Welding of girders and WPS testing at HIGH STEEL, Unpublished Report, Sept. 1996

6. Wong, R. et al. 1996 "Diffusible Hydrogen Measurement Report" Navy Surface Warfare Research Center, Carderock Division

7. Adonyi, Y et al., 1997. "On-site Diffusible Hydrogen Testing", Report for TRINITY Industries, Montgomery, Al, LeTourneau University, July 1997

8. Nickerson, R., et al. 1997 "Management, Operation and Maintenance of HP for Bridge Construction" Welding of girders and WPS testing at EGGER STEEL, Unpublished Report,

9. Nickerson, R., et al. 1997 "Management, Operation and Maintenance of HP for Bridge Construction" Welding of girders and WPS testing at LINCOLN STEEL, Unpublished Report, Sept. 1997

10. American Welding Society, "Bridge Welding Code" AWS D1.5-95

11. Yurioka, N., 1990. "Weldability of Modern High Strength Steels", First United States-Japan Symposium on Advances In Welding Metallurgy, pp. 51-64, American Welding Society, 1990.

12. Buchmayr, B., 1989. "HAZ-Calculator; A Software System for Welding Engineers", International Conference Proceedings, "Trends in Welding Research", Gatlinburg, TN, June 1989.

8.0 ACKNOWLEDGMENT

The author would like to thank the FHWA and AISI for sponsoring the work, as well as Mr. R. Nickerson, NBE Ltd, Ms. M. Quintana, Lincoln Electric, R. Wong and J. DeLoach for very helpful comments and suggestions.

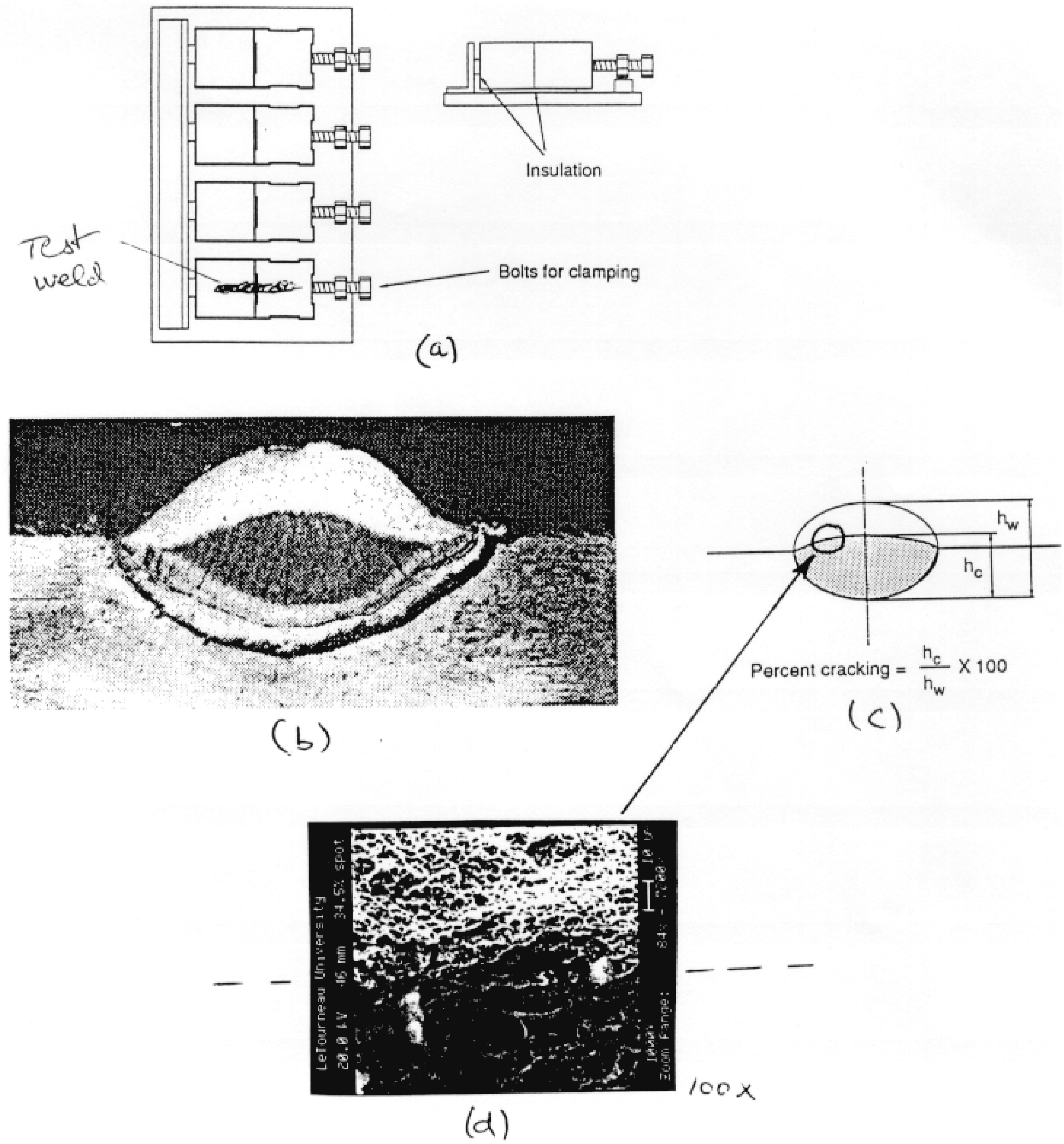
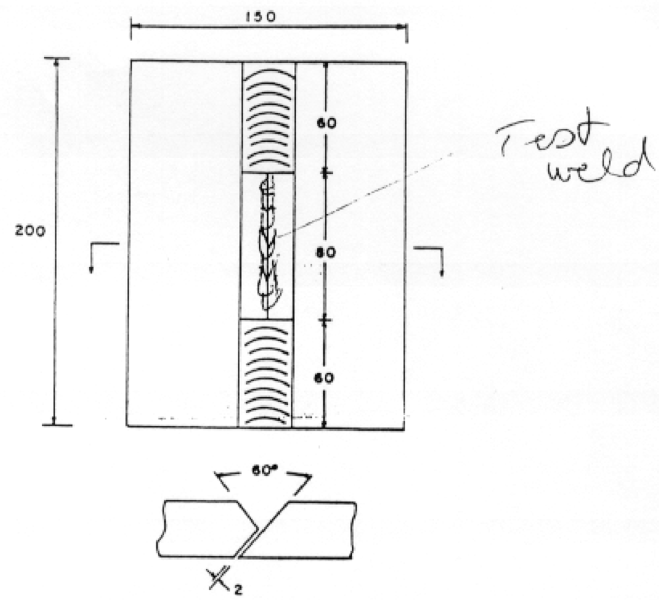


Figure 1. Schematic representation of the GBOP fixture setup (a), typical appearance of the crack face (b), measurement principle (c) and a Scanning Electron Micrograph showing the boundary between the hydrogen-induced brittle failure and ductile rupture.



The Tekken (Y groove) test.

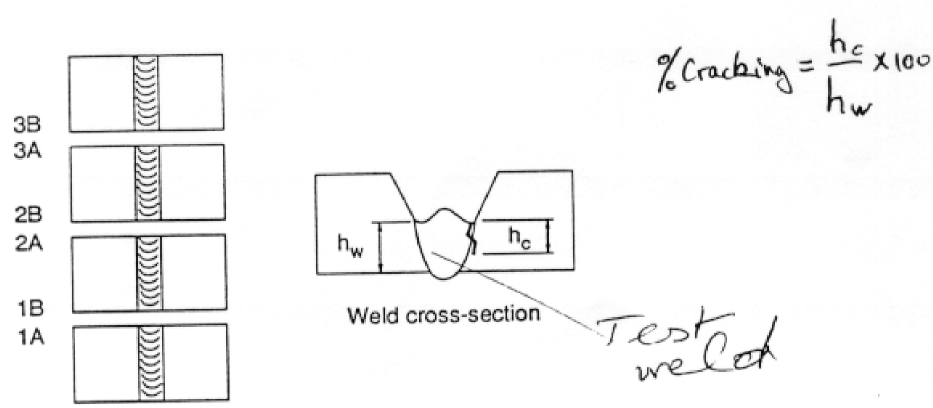


Figure 2. Schematic representation of the Y- groove (Tekken) testing fixture setup (a) and crack length measurement principle (b).

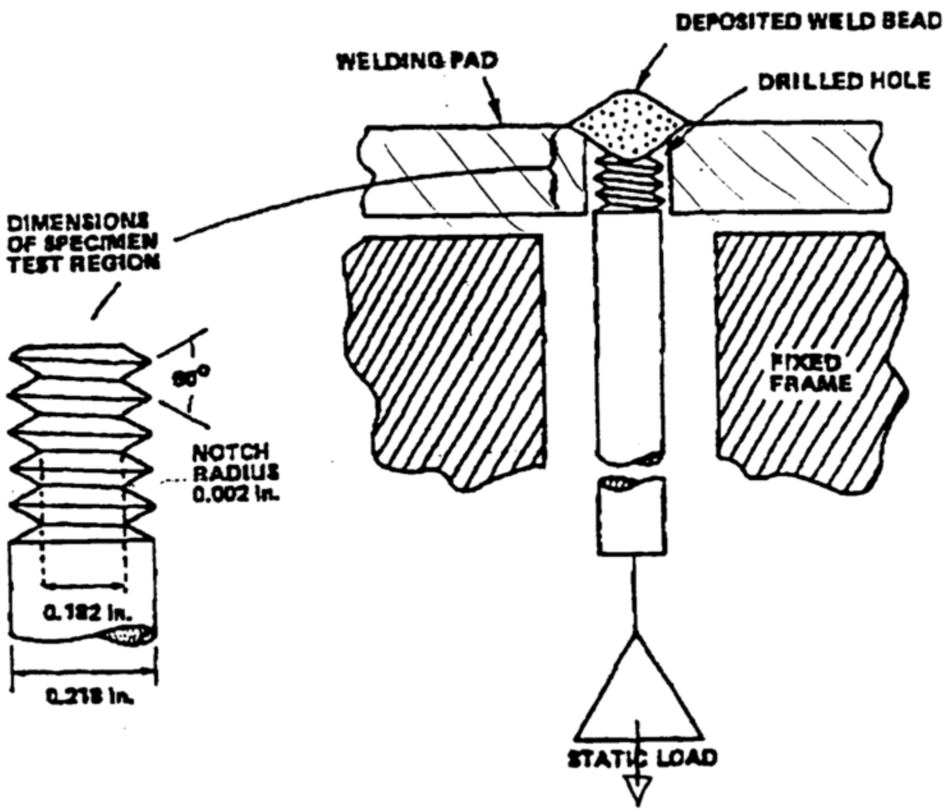
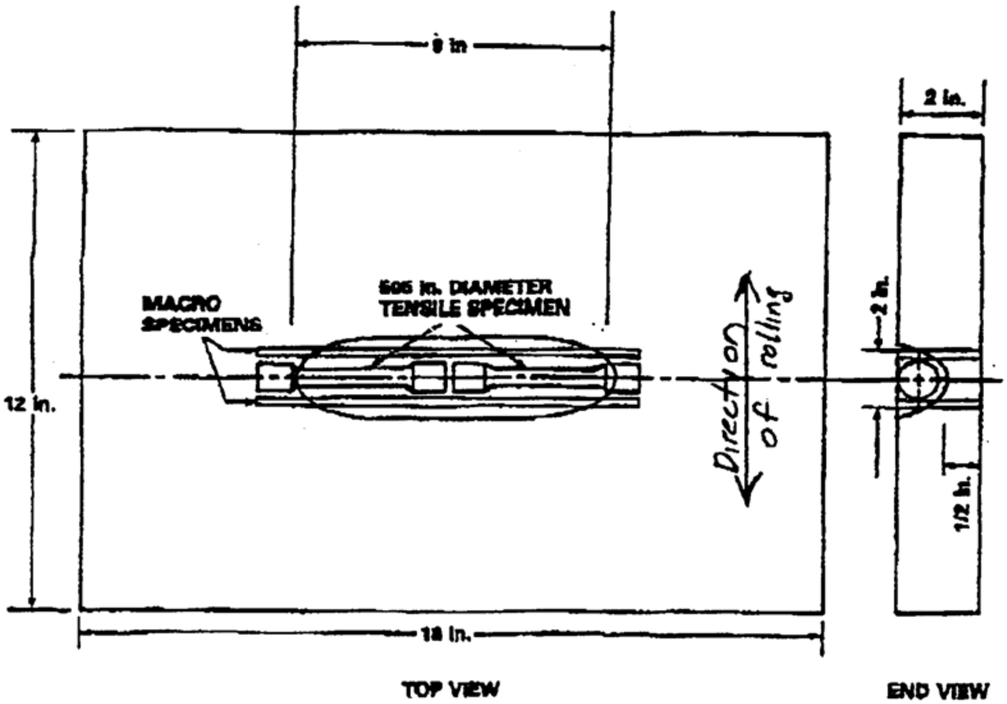


Figure 3. Schematic representation of the Implant test setup. Welding over the rod causes change in the heat affected zone properties in the notched region subjected to static loading.

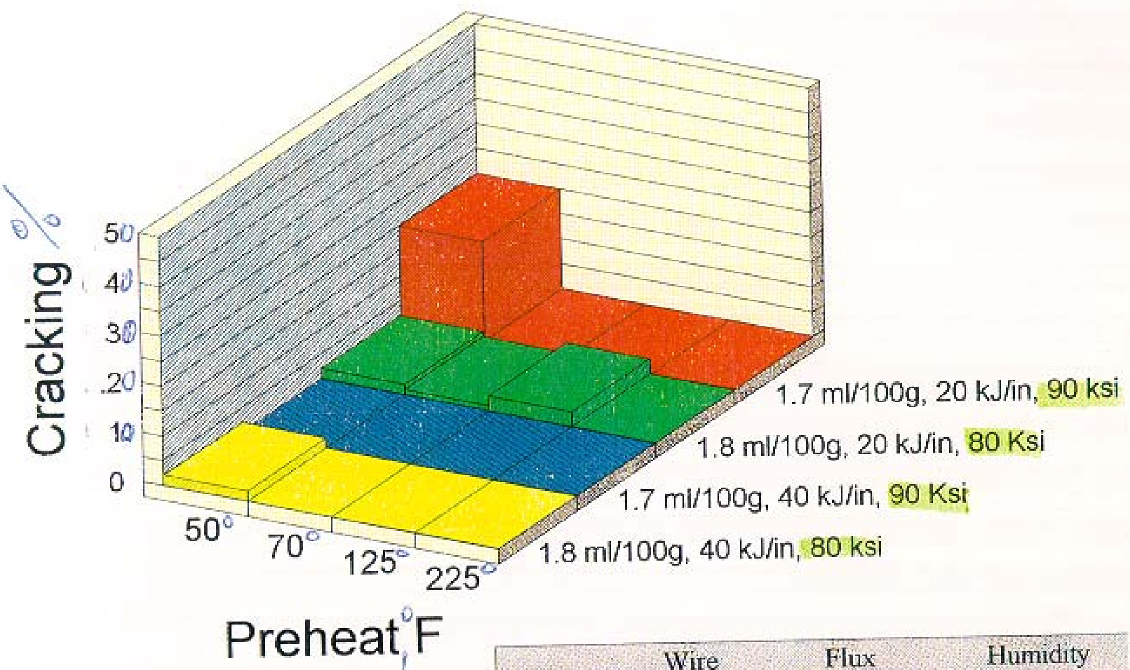


TEST PROCEDURES

1. ESTABLISH DESIRED PREHEAT TEMPERATURE.
2. DEPOSIT WELD BEAD.
3. ESTABLISH DESIRED INTERPASS TEMPERATURE.
4. CONTINUE STEPS 2 AND 3 UNTIL WELDMENT IS COMPLETED.
5. HOLD 14 DAYS, REMOVE TENSILE SPECIMENS, AND MACRO SPECIMENS ADJACENT TO TENSILE SPECIMENS.
6. EXAMINE AT 10X-50X MAGNIFICATION.

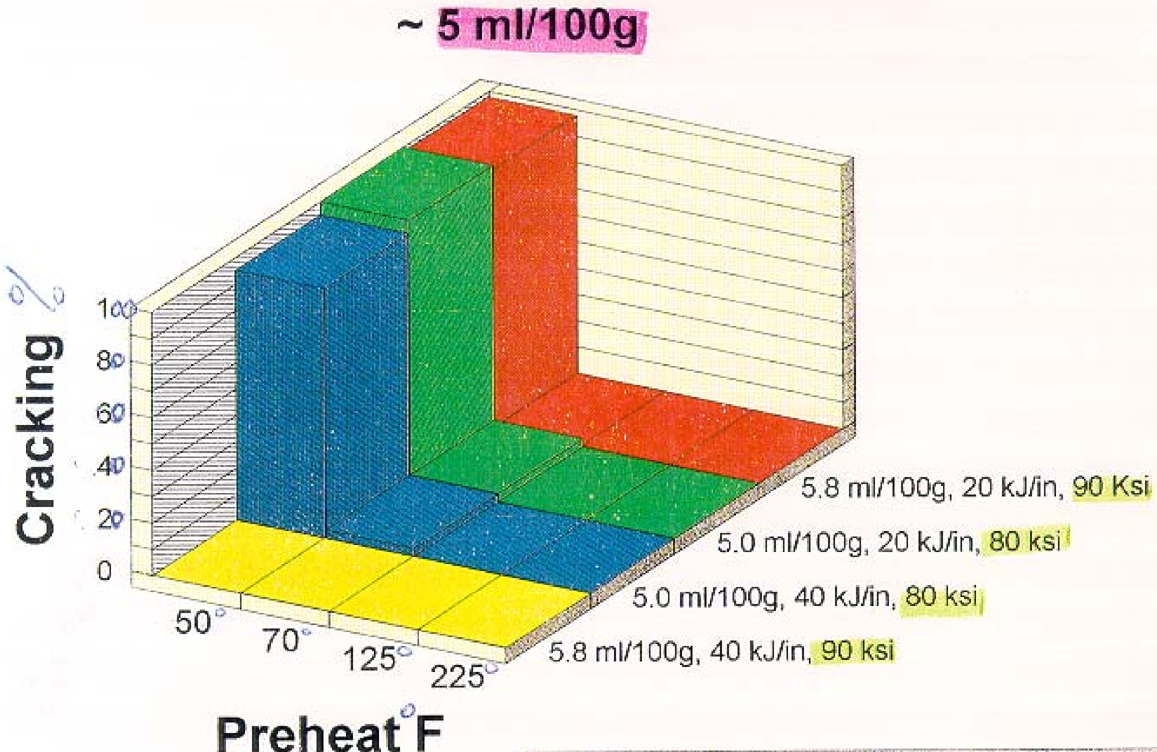
Figure 4. Schematic representation of the Trough test for quantifying possible hydrogen-induced cracking in multipass weld deposits.

1.7 & 1.8 ml/100g



	Wire	Flux	Humidity
90 ksi	LA 85	8500H2	20 & 40 - 66 %
80 ksi	LS3	8500H2	20 - 73%
			40 - 79%

Figure 5. GBOP test results showing the weld metal cracking change with preheating temperature for low diffusible hydrogen levels (1.7-1.8 ml/100g. The weld deposit strengths are nominal values.



	Wire	Flux	Humidity
90 ksi	LA 85	8500	20 & 40 - 60%
80 ksi	LS3	8500	20 - 80%
			40 - 91%

Figure 6. GBOP test results showing the weld metal cracking change with preheating temperature for a medium diffusible hydrogen level (~ 5.0 ml/100g. The weld deposit strengths are nominal values.

GBOP, Cracking vs Heat Input, 90 ksi nominal deposit strength

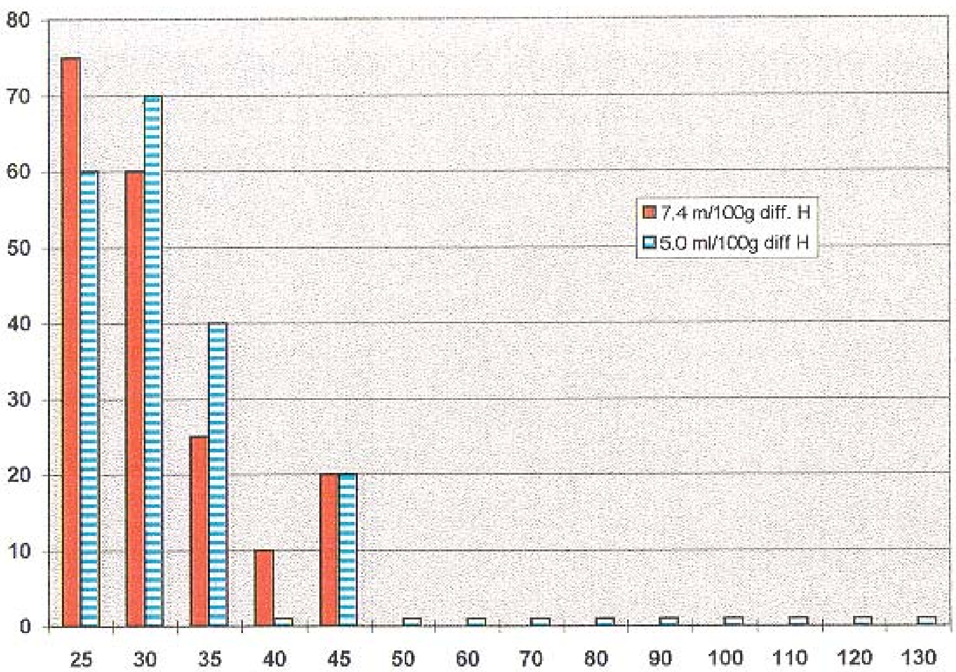


Figure 7. GBOP test results showing the weld metal cracking change with SAW arc energy, no preheat. The weld deposit strength of 90 ksi used was a nominal value.

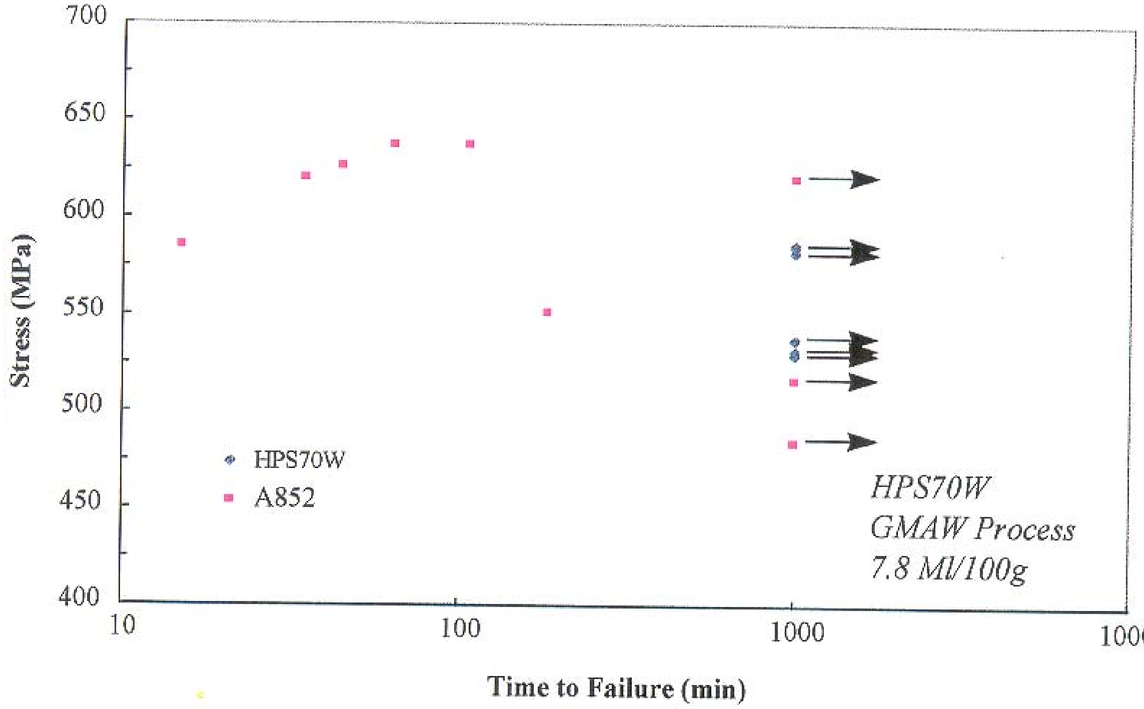


Figure 8. Implant test results showing the applied stress versus time to failure in the notched heat affected zone.

Specimen Number	Type of Test	Consumables			'Preheat'
		LA100/ 880M	L61/ AXXX10	E7018	
T1	Trough		X		75°F or ambient
T2	Trough		X		100°F to 110°F
T3	Trough	X			75°F or ambient
T4	Trough	X			100°F to 110°F
T5	Trough			X	75°F or ambient
T6	Trough			X	100°F to 110°F
W1	WPS		X		75°F or ambient
W2	WPS		X		100°F to 110°F
W3, W3a	WPS	X			75°F or ambient
W4	WPS	X			100°F to 110°F
W5	WPS			X	75°F or ambient
W6	WPS			X	100°F to 110°F

Table I. Summary of types od test, welding consumables and preheat temperatures used at High Steel (Ref. 5)

Specimen Number	Consumables	Preheat[1]	Volts[2] (DC+)	Amps	Travel Speed	Heat input Kj/in.
1A	L61/ AXXX10	175°F	27	350	25	22.68
1B	L61/ AXXX10	125°F	27	350	25	22.68
1C	L61/ AXXX10	50°F or ambient	28	620	29	40
1D	L61/ AXXX10	175°F	30	800	18[3]	80
1E	L61/ AXXX10	175°F	32.5	850	23.5	61
1F	L61/ AXXX10	50°F or ambient	27	350	25	22.68
1G	L61/ AXXX10	50°F or ambient	30	800	18	80

Table II. Summary of types od test, welding consumables and preheat temperatures used at Egger Steel (Ref. 3)

TRINITY INDUSTRIES, INC.
FHWA SUPPLEMENTAL TESTIMG HPS 70W STEEL
MAY 7, 1997

S.O. 25424

	1	3	3	4	5	6.	7	8	9	10	11	12	(TENN 1"	PQR) 1 1/2"
880M (BAGS) a. Wire b. Preheat c. Heat Input d. Wires e. Polarity	LA100 RT 40kj 1 Pos 17.7*			LA100 RT 40kj 1 Neg 12.5			LA85 RT 40kj 1 Pos			LA85 250F 40kj 1 Pos			LA100 150F 71kj 2** (1) 14.9	LA100 150F 71kj 2** (1)
880M (PAILS)* a. Wire b. Preheat c. Heat Input d. Wires e. Polarity		LA100 RT 40kj 1 Pos 11.3			LA100 RT 40kj 1 Neg 9.3			LA85 RT 40kj 1 Pos			LA85 250F 40kj 1 Pos			
800M (PAILS)* a. Wire b. Preheat c. Heat Input d. Wires e. Polarity			LA100 RT 40kj 1 Pos 2.8			LA100 RT 40kj 1 Neg 3.1			LA85 RT 40kj 1 Pos			LA85 250F 40kj 1 Pos	LA100 250F 91.4kj 2** (1) 4.0	LA100 250F 91.4kj 2** (1)

Fixed Conditions (1-12 only)
-Diffusible hyd. Tests (Plates 1-6 only)
-2" Plate
-Interpass 400F
-Heat Input 40kj
-All Single Electrode
-550 Amps @ 28 volts, 23"/min.
-Stickout 1" + 1/4"

* Hermetically Sealed
** Multiple Electrodes (AWS D1.5,4.11)
(1) DC + lead wire/AC trail wire
RT Room Temperature

* ml/100g — DIFFUSIBLE HYDROGEN —

TABLE III

TEST ID	SMAW Electrode	Arc Energy	Diffusible Hydrogen, ml/100g	Preheat, deg F	Percent HAZ cracking, %
B				73	**32**
D				150	**0**
F			4.7	200	**0**
H				250	**0**
	E 9018	**25 kJ/in**			
I				73	**19**
C			10.7	150	**11**
E				200	**36**
G				250	**0**

Table IV. Summary of the Tekken test results, based on report from Bethlehem Steel Homer Research Laboratories (Ref. 3)

Speci men#	Preheat, F	Consumable	Heat input, kJ/in	Avg. YS, ksi	Avg TS, ksi	Avg CVN, at 0F
W1	90	L61/AXXX10	133	**75.6**	**87.7**	**51**
W2	110	L61/AXXX10	97	**76.3**	**88.3**	**60**
W3	90	LA100/880M	135	**99**	**117**	**125**
W4	110	LA100/880M	30	**104**	**107**	**69**
T1	90	L61/AXXX10	133	**72.5**	**84.5**	**NA**
T2	110	L61/AXXX10	97	**76.5**	**88.5**	**NA**
T3	90	LA100/880M	135	**97**	**100**	**NA**
T4	110	LA100/880M	30	**97**	**103**	**NA**

Table V. Summary of selected SAW welding parameters used and average mechanical properties, High Steel (Ref. 5)

Specimen/ Property	1A	1B	1C	1D	1E (LOST	1F	1G
Yield Str. (ksi)	71.5	70	67.25	61.25		73	57.75
Tensile Str. (ksi)	87	87.5	85.5	75.5		87	77.5
Y/T ratio	0.82	0.80	0.79	0.81		0.84	0.75
CVN; ft-lbs @-20^{0}F	41	46	38	69		46	36

Table VI. Summary of the WPS test results, Egger Steel (Ref. 8)

Flux	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12
Polarity/ Preheat	+	+	+	-	-	-	RT	RT	Rt	250	250	250
880M from sealed bags	90 YS 97 TS 12% 64 RA 104 ft•lbf (-25°F)			98 YS 104 TS 17% 46 RA 123 ft•lbf (-25°F)			79 YS 88 TS 24% 70 RA 82 ft•lbf (-25°F)			77 YS 87 TS 21% 71 RA 62 ft•lbf (-25°F)		
880M. hermeti-cally sealed pails		98 YS 103 TS 24% 71 RA 106 ft•lbf (-25°F)			101 YS 106 TS 21% 76 RA 135 ft•lbf (-25°F)			75 YS 85 TS 24% 71 RA 121 ft•lbf (-25°F)			70 YS 81 TS 25% 74 RA 124 ft•lbf (-25°F)	
800H pails			92 YS 102 TS 26% 74 RA 143 ft•lbf (-25°F)			103 YS 110 TS 20% 73 RA 123 ft•lbf (-25°F)			75 YS 86 TS 26% 86 RA 162 ft•lbf (-25°F)			75 YS 86 TS 27% 72 RA 166 ft•lbf (-25°F)

Table VII. Summary of the mechanical test results obtained by Trinity Industries (see parameters in Table III)