Transactions, SMiRT 16, Washington DC, August 2001 *Paper # 2052*

SMAW Temperbead Weld Repair Without Grinding

David Gandy[1], Richard Smith[2], Ming Lau[3]

1) EPRI, Charlotte, NC
2) Structural Integrity Associates, Mooresville, NC
3) Ontario Power Generation, Toronto, Ontario Canada

ABSTRACT

ASME B&PV Code currently allows weld repairs of carbon and low alloy steel components without high temperature postweld heat treatment provided that temperbead welding techniques are rigidly enforced. Repairs using the SMAW process may be performed using the “half-bead” welding method or the “butter-bead” technique. Half-bead methods have proven difficult to control due to inaccuracies in grinding between first and second layer passes and often leads to increased radiological exposure.

This study examines temperbead welding using the SMAW process without using grinding between passes from both a metallurgical and mechanical standpoint. Furthermore, the results of several industry testing programs aimed at controlling the SMAW process to yield high toughness base metal HAZ while minimizing potential for cold high-restraint cracking and/or hydrogen delayed cracking are discussed.

BACKGROUND

Temperbead welding refers to a specific welding approach in which the heat of deposited weld layers is controlled so that sufficient heat is provided to temper each previously deposited weld layer. Welding heat is directed to the heat affected zone (HAZ) and will produce requisite strength and toughness properties without the need for any high-temperature post-weld heat treatment (PWHT). The approach employs two or more weld layers applied consecutively to generate both weld and HAZ properties that are equal or superior to the base metal. The technique is applicable to a variety of carbon and low alloy steel materials.

Temperbead weld repair techniques are designed to enable repairs to carbon and low alloy steel (LAS) components without need for high-temperature post-weld heat treatment (PWHT). Current ASME B&PV Code allows temperbead repairs without PWHT for SMAW using "half-bead" techniques or for attachments using "butter-bead" techniques. In addition, temperbead repairs are permitted using GTAW methods. These procedures are covered under ASME Section XI, IWA 4600 beginning with the 1995 edition of the code. Prior to that the procedures were found in IWA-4500.

One difficulty encountered with the SMAW temperbead approach in IWA-4600 is that the weld bead crown surface of the initial layer must be ground before the second layer is deposited. The focus of the current study was to determine whether the environmental exposure attendant to grinding these layers is tangibly beneficial. It will be seen that it is difficult to control the grinding process such that the weld bead crown of the initial layer is removed consistently and, more importantly, is unnecessary. Quality weldments possessing high toughness and good ductility heat affected zones (HAZs) are repeatably achieved with proper controls of the welding process and consumables.

INDUSTRY TEST PROGRAMS AND RESULTS

This study examines results from several industry testing programs aimed at controlling the SMAW process to yield high toughness base metal HAZ while minimizing potential for cold high-restraint cracking and/or hydrogen delayed cracking – the principal cracking mechanisms known to threaten temperbead repairs. It was shown that by using increasing diameter coated electrodes for each of the first three weld layers provided sufficient heat to cause the base material and weld HAZs to be tempered without any need for interlayer grinding.

The method minimizes the depth of the base material HAZ by applying small (3/32-inch) diameter electrodes for the initial layer. The next layer is applied with 1/8-inch diameter electrodes, and the third and succeeding layers are applied using 1/8-inch or 5/32-inch diameter electrodes. It should be noted that different researchers varied the sequential pattern, but the intent was the same – minimize penetration of the initial layer and follow with a layer deposited using a larger diameter electrode so that a higher heat input would be generated. This sequence provides the heat necessary for tempering brittle transformation products in the weld HAZ. The HAZ toughness produced will be equal or superior to the substrate material, because the cooling rate of the base material, at the weld fusion line, is much faster than the original cooling rate of the base material. This produces a superior microstructure that, upon tempering, exhibits toughness that is typically superior to the original base material.

The key parameter to evaluate for LAS temperbead applications to nuclear vessels is the HAZ toughness. Hardness is examined but it considered less important, because an acceptable toughness necessarily implies a defined capacity to sustain deformation in a cracked body without crack extension. Data are presented that demonstrate the beneficial results obtained on several LAS materials having increasing hardenability (P1, P3 Gr. 3, P4 and P5A test materials). The results of multiple procedure qualifications and experiments have been tabulated for SMAW temperbead repairs to P1 & P3 base materials, P4 and P5A base materials, and to service aged P4 and P5A materials exceeding 100,000 service hours respectively. Direct comparisons of the results obtained with and without initial layer grinding on the same heat of base material are provided for two cases involving P1 and P3 materials.

Numerous qualification and experimental data have been evaluated in terms of the impact of hardenability on the toughness properties achieved in the HAZ for SMAW temperbead welds having different low alloy steel compositions. The hardenability was measured numerically by computing the carbon equivalent based upon the base metal compositions. Additionally, the average HAZ Charpy Vee-notch impact toughness was normalized to the average base metal toughness. In this manner the effects of different test temperatures would be minimized. A tabulation of the data having the requisite available information is given in Table 1 and the HAZ/BM ratios are plotted against carbon equivalents in Figure 1.

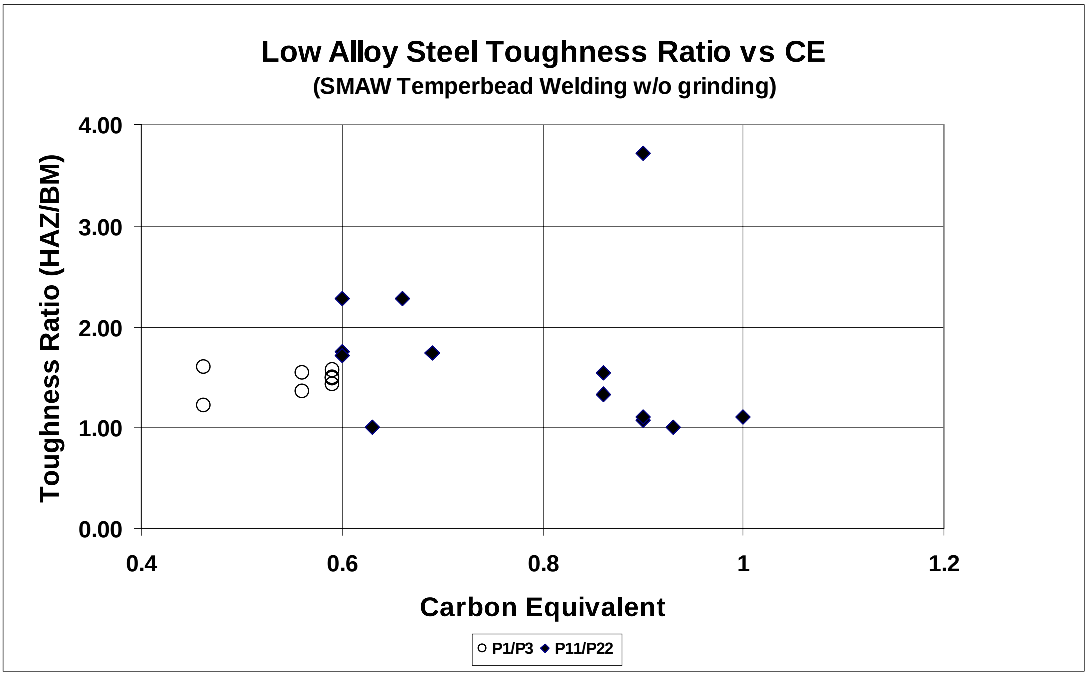

Figure 1 - Effect of C.E. Value on Low Alloy Steel Toughness Ratio for SMAW Temperbead Welds (no grinding).

Table 1 - Tabulation of Test Data used in the HAZ Toughness Evaluation

Study No.	Welding Position	CE	Base Metal (Avg.)		HAZ (avg)		HAZ/BM Ratio	Test Temp (F)	Condition	Base Material[5]	Weld Metal
			ft-lb	MLE	ft-lb	MLE					
A1	3G	0.56	71	43.3	109	63.8	1.54	30	no grinding	533-B-1	E8018-C3
A2	3G	0.56	71	43.3	96	57.3	1.35	30	With grinding	533-B-1	E8018-C3
B1	1G	0.46	54	31.6	86	66.3	1.59	0	no grinding	516/70	E7018
B2	1G	0.46	38	21.3	46	31.3	1.21	0	With grinding	516/70	E7018
C1	1G	0.59	77	49.3	110	68.7	1.43	-4	no grinding	508-2	E309L[6]
C2	1G	0.59	77	49.3	114	66.3	1.48	-4	no grinding	508-2	E309L[6]
C3	1G	0.59	77	49.3	121	71	1.57	-4	no grinding	508-2	E309L[6]
C4	1G	0.59	77	49.3	115	72	1.49	-4	no grinding	508-2	E309L[6]
D1	1G	0.6	67	n/a	117	n/a	1.75	32	no grinding	P11	E8018-B2L
D2	1G	0.6	48	n/a	109	n/a	2.27	-40	no grinding	P11	E8018-B2L
D3	1G	0.6	35	n/a	60	n/a	1.71	-80	no grinding	P11	E8018-B2L
E1	1G	0.9	112	n/a	120	n/a	1.07	32	no grinding	P22	E9018-B3
E2	1G	0.9	74	n/a	82	n/a	1.11	-40	no grinding	P22	E9018-B3
E3	1G	0.9	14	n/a	52	n/a	3.71	-80	no grinding	P22	E9018-B3
F	5G	0.69	31	30.0	54	43.0	1.74	68	no grinding	217/WC6	E8018-B2
G	5G	1	29	30.0	32	30.0	1.10	68	no grinding	217/WC9	E9018-B3
H	1G	0.63	125[1]	79.0	125	92.0	1.00	RT	no grinding	387-B	E8018-B2
I	1G	0.93	125[1]	77.0	125	98.0	1.00	RT	no grinding	217/WC9	E8018B2
J	5G	0.66	32[2]	33.0	73	59.2	2.28	RT	no grinding	P4	E8018-B2
K	5G	0.86	90[3]	82.0	139	83.0	1.54	RT	no grinding	P5	E9018-B3
L	5G	0.86	51[4]	66.0	68	62.3	1.33	RT	no grinding	P5	E9018-B3

Note:

1. 125 ft-lbs represents machine limits.
2. Service Aged - 244,000 hours.
3. Service Aged - 161,000 hours.
4. Service Aged – 244,000 hours.
5. All materials used in this study represent material heats fabricated prior to 1980 with the exception of those identified as Study No. B & C
6. 1st layer-E309L; 2nd & subsequent layers—E308L

Legend:

A1,A2 – Ontario Power Generation
B1,B2 – Alliant Energy Corp.
C1,C2,C3,C4 – Electricite de France
D1,D2,D3 -- PVRC P4
E1,E2,E3 – PVRC P5A
F -- EPRI P4 Casting
G -- EPRI P5A Casting
H -- TU Electric P1/P4
I -- TU Electric P1/P5
J --EPRI Service Aged P4
K,L -- EPRI
Service Aged
P5A

Several observations are noteworthy. First, it is seen that all of the toughness ratios are greater than unity. Two of the ratios are shown at unity, but as noted on the table comments, both the base metal and the HAZ exceeded the measuring capacity of the impact test machine (125 ft-lbs). This also indicated that these materials behaved in a ductile manner at room temperature. Second, it is noted that a HAZ toughness greater than that measured for the base metal (at the same test temperature) is obtained for a wide range of carbon equivalents. The range of carbon equivalency extends from P1 through P5 materials, and yet the result is the same. Finally, different test temperatures were involved that produced different mixtures of ductile and brittle fracture components, and yet the HAZ toughness remained greater than that measured for the base material at the same temperature.

The studies cited in this review demonstrate the excellent mechanical properties obtained in the HAZs of SMAW temperbead weld repairs. In all cases the applicable ASME requirements for toughness were met for code applications. The key to successful application of the temperbead welding process is strict adherence to controlled deposition procedures, although the process seems to be tolerant to variations attendant to manual application. The studies on P1 and P3 materials produce excellent results even without the need for higher preheat and post weld hydrogen bakes. The materials are quite resistant to hydrogen delayed cracking mechanisms due to their high toughness generated with the temperbead process. The Alliant Energy and Ontario Power Generation (P1 and P3 respectively) studies directly compare the SMAW temperbead with the "half-bead" procedures on the same base material. Results show considerable improvement in HAZ toughness between the two processes. Therefore the need to grind the weld bead crown of the initial layer away to effect good HAZ tempering appears unwarranted in these materials.

The P4/P5A studies cited (including service-aged materials) collectively demonstrate the effectiveness of SMAW temperbead repairs on these materials. The materials are more hardenable than P1 and P3 materials and require effective tempering of the HAZ. Because the results of these studies also showed excellent toughness HAZs, they confirm that the effectiveness of controlled temperbead procedures.

The results presented from fourteen (14) separate studies, by nine (9) different organizations, have been used to examine characteristics of repair welds made with the SMAW temperbead process. All materials used in the study represent materials which were fabricated prior to 1980 with the exception of two heats. Several process parameters were explored including the elimination of initial layer grinding. It was shown that the process will develop high toughness in the HAZ while minimizing potential for cold high-restraint cracking and/or hydrogen delayed cracking – the principal cracking mechanisms known to threaten temperbead repairs in very high hardenability materials. Further it was determined that by applying coated electrodes of increasing diameter for each of the first three weld layers limited the extent to the HAZ and provided sufficient heat to temper the HAZ without any need for interlayer grinding. The HAZ toughness produced will be equal or superior to the substrate material.

The key parameter used to evaluate SMAW temperbead applications for nuclear carbon and LAS materials was the HAZ toughness. Hardness was measured for information, but because good toughness necessarily implies a defined capacity to sustain deformation in a cracked body without crack extension, the hardness was considered secondary. Hardness was not needed to demonstrate process control or effectiveness. It was recognized that HAZ hardness would be important in high temperature applications. Hardness results were presented for information.

SUMMARY

Test results demonstrated the beneficial properties obtained on several carbon and LAS materials having increasing hardenability. Direct comparisons of results obtained with and without initial layer grinding on the same heats of P1 and P3 materials confirm that the SMAW temperbead process produces equivalent HAZ toughness. Grinding was unnecessary. Further, test results demonstrate that the temperbead process is sufficiently forgiving to be able to tolerate variability associated with manual application. The P4 and P5 materials in Table 1 and Figure 1 are more hardenable than the P1 and P3 materials. These results were reviewed to demonstrate that well tempered sound welds were achieved with the SMAW temperbead process without interlayer grinding and without high temperature PWHT.

REFERENCES

1. W. D. Goins & D. L. Butler, "Weld Repair of Heavy Section Steel technology Program Vessel V-7", EPRI NP-179, August 1976.
2. P. P. Holz, "Half-Bead Weld Repairs for In-Service Applications", ASME 78-PVP-10, Joint ASME/CSME Pressure Vessels & Piping Conference, Montreal, Canada, June 25-30, 1978.
3. D. W. Gandy, "EPRI/Ontario Hydro Joint Experimental Program on Temperbead Weld Repairs for P3Group3 Materials", EPRI, July 1999.
4. D. W. Gandy, Letter Report to Mr. Scott Presler, Alliant Energy Corporation, June 1999 (Half-bead coupon)
5. D. W. Gandy, Herron Testing Laboratories Test Report No. 990690451, DPRI, July 7, 1999 (Temperbead coupon)
6. M. K. Phillips, D. W. Gandy, & S. J. Findlan, "Repair Demonstrations of Reactor Pressure Vessel Flange Cladding Utilizing SMAW Temperbead Welding Techniques - Final Report", EPRI RRAC, October 1998.
7. D. W. Gandy & W. F. Newell, "Evaluation of Repair of High Energy Steam Piping Using the Temperbead Technique w/o Post Weld Heat Treatment on ASTM A335 Grade P11 Components", EPRI, January 1996. (Work performed for Consolidated Edison Company)
8. L. M. Friedman, EWI/TWI controlled Deposition Repair Welding Procedure for 1.25 Cr - 0.5 Mo and 2.25 Cr - 1 Mo Steels, EWI, WRC Bulletin 412, June 1996 pp 27 - 34.
9. C. D. Lundin and Y. Wang, "Half-Bead/Temperbead Controlled Deposition Techniques for Improvement of Fabrication and Service Performance of Cr/Mo Steels - Final Report, PVRC, January 1994.
10. EPRI RRAC, "P-No.4 and P-No.5 Valve Body Temperbead Repair Guideline for Nuclear Applications, TR-108138, August 1997.
11. D. W. Gandy & S. J. Findlan, "Temperbead Welding of P-nos. 4 & 5 Materials", EPRI, Palo Alto, CA: 1998, TR-111757.
12. Letter Report D. W. Gandy to T. Hardin (TU Electric) RE: P-No. 1 to P-No. 4 and P-No. 1 to P-No. 5 Temperbead Repair Procedures, May 30, 1995.
13. The National Board Inspection Code, 1995 Edition, Part RD (Repair Methods), RD-1000 Welding Methods as Alternatives to Postweld Heat Treatment.
14. R. Viswanathan, S. Findlan, & D. W. Gandy, "State-of-the-Art Weld Repair Technology for High Temperature and Pressure Parts - Volume 4: Weld Repair of 2-1/4Cr-1Mo Pipe/Header Girth Welds", EPRI TR-103592-V4, Final Report, September 1998.
15. R. Viswanathan, D. W. Gandy, & S. Findlan, "State-of-the-Art Weld Repair Technology for High Temperature and Pressure Parts - Volume 5: Weld Repair of 1-1/4Cr-1/2Mo Piping Girth Welds", EPRI TR-103592-V5, Final Report, October 1998.
16. EPRI Report TE-113416, “SMAW Temperbead Weld Repair Without Grinding,” November 1999.