The Maintenance and Integrity of Thick Walled Pressure Vessels by Using Temper Bead Welding Technique

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Abstract

This paper investigates the Temper Bead welding (TBW) technique using the Flux Cored Arc Welding (FCAW) process. The FCAW process increases productivity, improves welding efficiency and provides a more cost-effective method of Temper Bead Welding (TBW) repairs compared with the other commonly used TBW techniques such as manual metal arc welding (MMAW) and gas metal arc welding (GMAW) which use solid wire. An automatic welding rig was created so that the TBW process could be tested using flux cored wire under different conditions. An experimental investigation was conducted to find the optimal welding parameters of the TBW using FCAW. This experimental investigation was done in order to provide the desired mechanical properties and microstructures without Post-Welding Heat Treatment (PWHT).

Due to the difficulties encountered in the determination of residual stresses, the weld penetration depth into the base material was used as a guide to control residual stresses. In this study, analytical solution was used to support the use of TBW to repair damaged structures. This solution was based on statistical and experimental data. These data were used to establish the relationships between the technological parameters of TBW and the factors responsible for the quality of the required structure.

Keywords: Temper bead welding, Flux cored arc welding, Solid wires, Post welding heat treatment, Manual metal arc welding, Gas metal arc welding and Penetration

Introduction

According to the ASME standard, the conventional repair welding for wall steel constructions, which have a thickness of more than 40 mm requires PWHT to achieve the desired microstructure properties. The microstructure of the welding surrounded area is affected by the heat of the welding process. This affected area is known as the heat-affected zone (HAZ). The desired microstructure properties of HAZ are these properties which are as close as possible to the parent material properties. For some structures, however, PWHT is very expensive or difficult. Publications to date [1,2], have shown that the temper bead welding (TBW) can provide the desired microstructure properties of the welding without PWHT. The TBW provides that satisfactorily and solid wire welding processes such as MMAW or GMAW are applied to TBW successfully.

TBW is used to heat-treat the welded part or parts during the welding process instead of PWHT. TBW employs a multiple-pass deposition of the welding metal. Each layer of beads provides heat for the thermal treatment of the microstructure of the previous weld bead or the layer, as shown in figure 1. TBW techniques have been used successfully for a number of repairs in USA and Canada, by using manual metal arc welding (MMAW) process or gas metal arc welding (GMAW) process, and its use is accepted and specified by the ASME Boiler and Pressure Vessel codes [3].

The quality of the temper bead-welding repair is very sensitive to some welding parameters [2] specific to the welding process employed. These parameters are the welding position and its effect on the bead shape, the bead deposition sequence, the welding current, the traverse speed, the arc length, the wire feeding speed, the torch angle, the preheat and inter-run temperatures and the heat inputs.

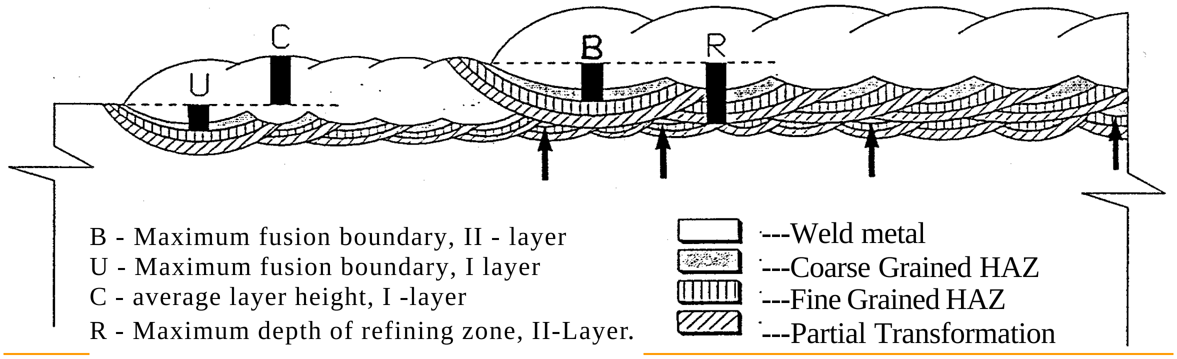

Figure 1. Two-layer section shown schematically exhibiting approximately 85% refinement of the first layer coarse grained HAZ by the second layer [3].

There are several industry-attractive aspects of TBW that need further investigation. One of these is the application of the flux-cored arc welding (FCAW) process that uses hollow welding wire filled with flux. There has been limited research into the effectiveness of this process [2,3] but a preliminary study [4 and 5] indicates that FCAW might have a number of advantages over the commonly used solid wires such as MMAW or GMAW process. The welding parameters that can provide the required microstructure and minimum residual stresses in thick walled weldments need to be established to validate the application of flux cored arc welding (FCAW).

The Relationship between the Welding Parameters and the Depth of Penetration

The depth of penetration is a direct result of the welding heat input. It is necessary to have a desirable depth of penetration to gain sufficient bonding between the parent material and the welding material. Normally, the process of quickly heating and cooling the welding region is associated with residual stresses and different grain sizes across the HAZ. The welding heat source is the applied electrical power (E) and the amount of the welding heat input (H) depends on the welding traverse speed (v) along the parent material beside the applied electrical power.

$$E = I * V * \eta \qquad \text{Watt}\text{--} \quad (1)$$

Where

I is the welding electrical current in Amp,
V is the welding voltage in volt and
η is the electrical power transmission efficiency.

(η) can be considered equal one in case of measuring I and V as close as possible to the welding spot.

Welding heat input can be calculated by applying equation (2)

$$H = (0.06 * I * V) / v \qquad \text{kJ/mm}\text{------------------------------------} \quad (2)$$

Where

v is traverse speed in mm/min

In the FCAW process, the welding electrical current (I) is adjusted automatically according to the wire feeding speed. The welding voltage adjusted for the welding electrode size. It is clear, therefore, that the effects of (I) and (V) are limited and controlled, which means that the traverse speed (v) has the main effect on the welding heat input (H). Another parameter that should be considered is the arc length (A). The (A) represents the intensity of the welding heat source.

Experimental work

The investigation was conducted by using the automatic welding rig shown in figure 2. The traveling mechanism (A) was operated with constant speeds varying from 120 mm/min to 700 mm/min. The wire feeding system (15) was operated at 820 to 5600 mm/min. The welding machine (B) was worked at up to 400A.

Experimental data was collected to study the relationship between the depth of penetration and the welding main parameters as presented in Table 1. The welds were divided into three groups, Group 1, Group 2 and Group 3. In each group only one parameter was changed. For Groups 1 and 2 the arc length was changed, for Group 3 the traverse speed was changed. Two different gases were used in the manufacturing of the welds, for Groups 1 and 3, Argon Shield 100 gas was used, but for Group 2 CO2 gas was used. Commercially manufactured C-Mn steel plates of 10 and 12 mm thickness were used for all welds in this investigation. A steel plate of 12 mm thickness was used for Groups 1 and 2, but a plate of 10 mm thickness was used for Group 3. The voltage for Groups 1; 2 and 3 were 30, 29 and 29 volts respectively. The electrical current for welds of Groups 1; 2 and 3 were 350, 380 and 380 respectively. The weldments (see Table 1) were manufactured using the basic flux-cored wire (AWS A5.20:E70T-4).

Table 1. The temper bead welding carried out using different Shield gases and Traverse speeds.

Group No.	Pass No.	Traverse Speed mm/min.	Arc length (A) mm.	Penetration (P) Mm.
1	1	620	25	5
	2	620	29	4.5
	3	620	23	6
2	4	620	23	4.5
	5	620	28	4
	6	620	25	5
3	7	1000	25	4
	8	253.5	25	8
	9	600	25	6

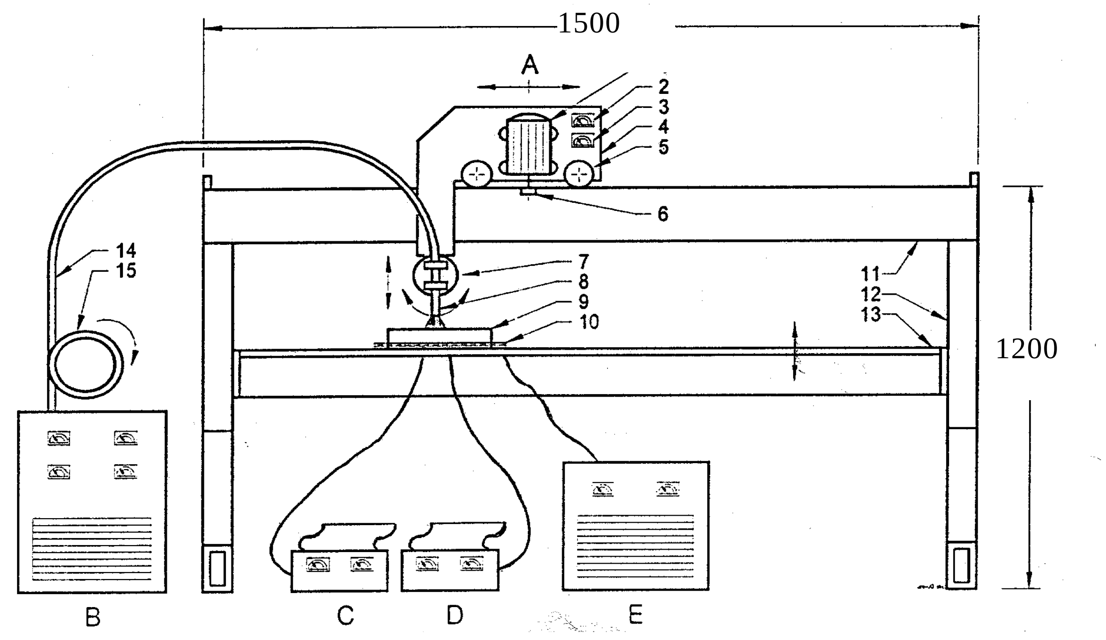

Figure 2. Experimental Installation

A) Traveling mechanism
B) Welding machine
C) 12-channel chart recorder.
D) Real time-temperature chart recorder.
E) Preheating elements controller.
1. 240V low speed motor.
2. Fine current control for motor.
3. Travel speed gauge.
4. Frame carriage.
5. Steel wheels.
6. Gear.
7. Variable head.
8. Welding torch.
9. Work piece.
10.Electrical heating elements.
11. Main frame. (horizontal beam)
12. Main frame. (Supporting legs)
13. Table
14. Welding lead.
15.Welding wire feeding system.

Results and Discussion

By applying Merit Function " χ^2 " on Groups 1 and 3, a mathematical relationship between the depth of penetration (P) as output and the traverse speed (v) and the arc length (A) as inputs can be presented as following:

$P = -0.0054\, v + 0.93\, A - 0.023\, A^2$ …………………… (3)

From equation (3), the relationship between the depth of penetration (P) and either the traverse speed (v) at different arc lengths or the arc length (A) at different traverse speeds can be plotted as shown in Figures (3) and (4) respectively.

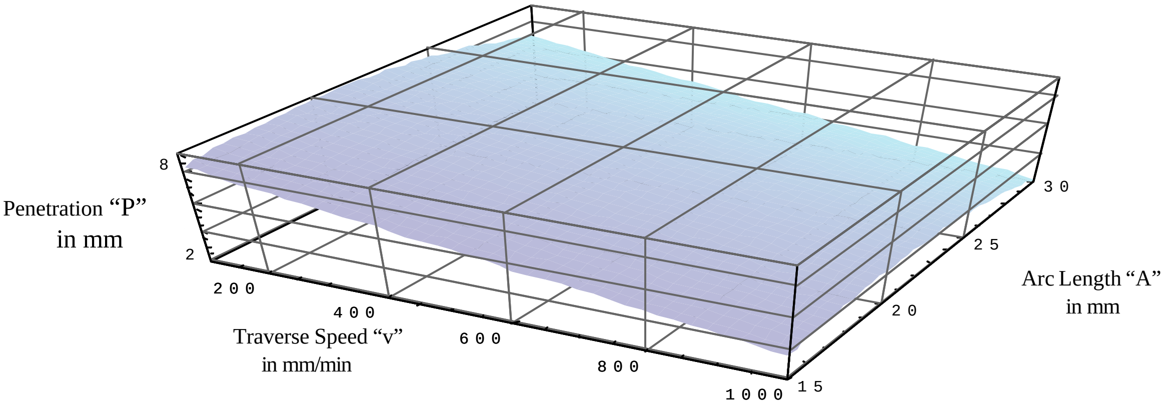

Figure 3. The relationship between Traverse Speed "v", Arc Length "A" and Penetration "P" of welds (groups "1" and "3", Argon Shield 100 gas).

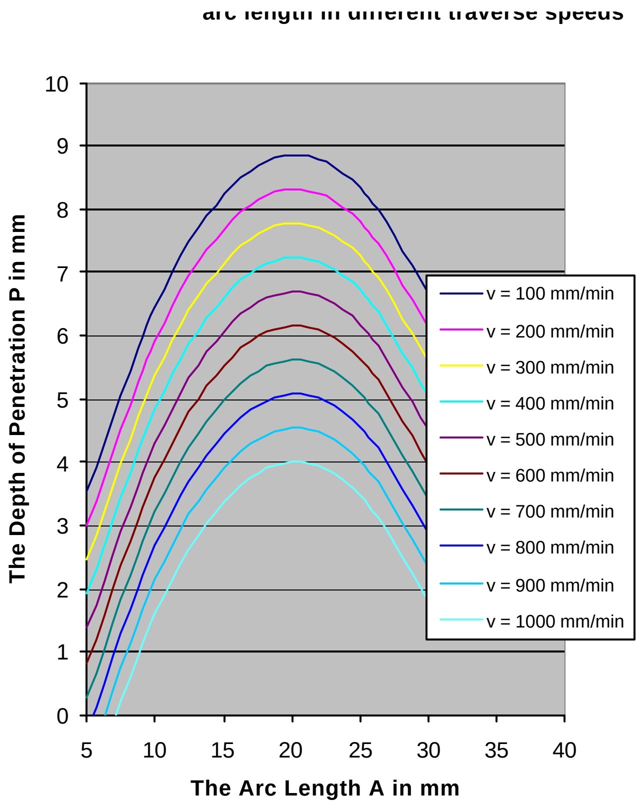

Figure 4. The relationship between the depth of penetration (P) and the arc length (A) in different traverse speeds.

The relationship between the depth of penetration (P) and the arc length (A) at different traverse speeds (as shown in Figures 3 and 4) demonstrates that a decrease in the traverse speed at the same arc length is associated with an increase in the depth of penetration. Between arc length 5and 20.22 mm, any increase in the arc length at the same traverse speed is associated with an increase in the depth of penetration. Therefore, with increasing heat, the spark heat, more heat transfers through the parent material. In the case of the small arc length, the welding torch absorbed a fraction of the heat. The heat conductivity of the torch material is higher than that of the low carbon steel, so less heat transfers to the parent material. Also at this stage, the same penetration was achieved when an increase in the arc length was associated with an increase in the traverse speed. Furthermore, any increase in the arc length between 20.22 and 30 mm was associated with a decrease in the depth of penetration as the surrounding ambient absorbs more heat.

A comparison of the results from [4&5] for FC wires and the results from [7] for solid wires, reveals that FC wires achieved deeper penetration for the same welding conditions (heat input, arc length and traverse speed). Therefor if the same welding conditions, to achieve the same depth of penetration, then FC wires should be operated in faster speed than the solid wire. Therefore, the FCAW process can provide higher productivity than solid wire processes.

Conclusion

Using FCAW process with TBW technique will increase the productivity, improve welding operation and efficiency and provide a more cost-effective method of weld repairs to the industry in comparison with the other commonly processes known with TBW technique such as MMWA and GMAW.

Reference

[1] Lundin,C.D., "Overview of Results from PVRC Program on Half-Bead / Temper-Bead / Controlled Deposition Technique for Improvement of Fabrication and Service Performance of Cr-Mo Steel", 1996, WRC Bulletin 412, p. 16 - 26.

[2] Lau, T. W., Lau M. L. et al., "Development of Controlled Deposition Repair Welding Procedures at Ontario Hydro", 1996, WRC Bulletin 412, p. 35 - 42.

[3] Edgley J. S. and Pitrun M., "The Temper Bead Weld Repair of the Hazelwood Steam Drums", Pressure Vessels and Pipwork Conference, Sydney April 27 - 28, 1993.

[4] Ibrahim R. N., and Shehata T., "Effect of Flux Wire on Tempered Bead Welding Technique to Repair Damaged Carbon Steel Structure", ICM8, 8th International Conference on the Mechanical Behavior of Materials, Canada, British Colombia, May 16 - 21, 1999.

[5] Ibrahim R. N., and Shehata T., "Effect of Welding Operation Parameters on the Depth of Penetration in Flux Cored Arc Welding Applications", 9th International Conference on Pressure Vessels Technology, Australia, Sydney, April 9 - 14, 2000.

[6] Sato, M., Suda, K. et al., “How to Weld Using Flux Cored Wires” Journal of Japan Welding Society, 1996, 65, (6), p. 13 – 20.

[7] Ahmed, N. U. and Jarvis, B. L., “The effect of welding condition on the thermal cycles in single electrode submerged arc welding” Australian welding journal, V43, 3rd. Quarter 1998.

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