Welding of Thin Steel Plates Using Submerged Arc Welding Process†

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Abstract

The limitation to use submerged arc welding process in welding of thin steel plates(e.g., 3 mm thickness) is considered to be one of the disadvantage of this process. In welding of thin plate using square-groove butt joint, there is some problems like lack of penetration or burn through as a result of small change in welding variables, which must be controlled to reach the optimum welding conditions. The problem was solved and the optimum welding conditions for full penetration, i.e good penetration and good reinforcment height were reached. These welding conditions include the welding parameters, type of proper backing material and type of flux.

KEY WORDS: (SA Welding) (Square Groove-butt joint) (Thin Plate Steel) (Welding Current) (Welding Speed) (Root Opening) (Backing Condition) (Penetration).

1. Introduction

Many of operating variables of submerged arc welding have a direct and / or interaction effect on weld bead size and shape. Therefore, an understanding of these variables and their effects are crucial for planning a properly controlled application of the process. This understanding is also useful to analysis the quality problems within a given application.

In welding of thin plate using square-groove butt joint, there are some problems like lake of penetration or burn through as a result of small change in welding variables. Thus, welding procedures and techniques must be controlled to reach the optimum welding conditions.

This work was directed towards the reaching of the optimum welding conditions (full penetration, i.e good back bead , and good reinforcement height) for welding of plan carbon steel thin plate(3 mm thickness) using submerged arc welding process. In this research work, the factors which affect the weld bead shap such as welding current , welding voltage, welding speed, root opening and the type of backing will be studied.

2. Experimental

2.1 Materials

The base materials used in the experimental work were carbon steel plates. A 6 mm thick plates were used to make bead on plate (BOP) deposits to invistigate the effect of welding variables on penetration. The welding condition that give penetration near to 3 mm was selected to apply it to square butt weld of 3 mm plates. These plates were cut into 1000 x 150 mm pieces, and both surfaces were cleaned to remove dirt and oxides.

A 17-EH14 electrode wires(AWS-A5) with diameter of 2 mm along with AWS-F7A2 or with AWS- F 7A6 fluxes were used as the welding consumables. **Table 1** shows the chemical composition of base metal and electrode wire.

Copper backing plates with dimention of 150 x70x20 mm were U- grooved and used as shown in **Fig.1. Figure 2** shows schematic diagram of the experimental installation and the position of of copper plates . Another type of backing was adopted in this work. That is the use of flux copper backing. Here, the

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Table 1 Chemical composition of base metal and filler wire

Material	Composition, wt%				
	C	Si	Mn	S	P
Base Metal	0.15	0.23	0.63	0.043	0.032
Filler wire A5.17-EH14	0.11	0.03	1.88	0.017	0.012

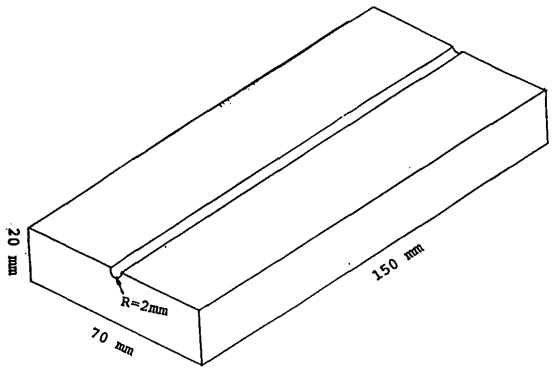

Fig.1 Dimention of used copper backing strip

same types of fluxes were used as backing. In this case a 5 mm flux height was held against the bottom of the joints by using copper plates held by an inflated hose.

2.2 Submerged arc welding procedure

The submerged arc welding machine used was a constant current type. For BOP deposits, 100 mm long run-off tabs were welded on both sides of the plates.The run-on tabs allowed enough time to adjust the welding current and voltage, while the run-off tabs absorbed the crater of the bead. Thus, for each run a long deposit of acceptable quality could be achieved. For square butt welds, the prepared faces were tack welded with a root opening ranging from 0 to 1.5 mm, and run-on and run-off tabs were welded in the same way as for BOP welds. All welds were made under the same conditions of restraint.

In order to generalized the outcome of the present work, the wire was vertically set to the base metal and the wire extension was adjusted to 20 mm. The height and width of scattered flux were fixed at 30 and 80 mm respectively.

3. Results

3.1 Bead on plate welding

The effect of welding variables on BOP welding penetration are shown in **Table 2** and **Fig. 3**. With increasing the travel speed from 60 to 80 cm/min at constant current and voltage, the penetration decreases.

Generally, the penetration decreases with increasing the travel speed and decreasing the current, i.e. decreasing the amount of heat input.

From the above observed results, the following welding conditions were adjusted and tested in case of 3 mm butt joint welding:

welding current = 270 to 300 A
welding voltage = 28 V
welding speed = 100 cm/ min

3.2 Butt Joint Welding

3.2.1 Without backing

The effect of welding conditions on the penetration and bead appearance in case of butt joint welding are given in **Fig. 4** and **Table 3**. It was

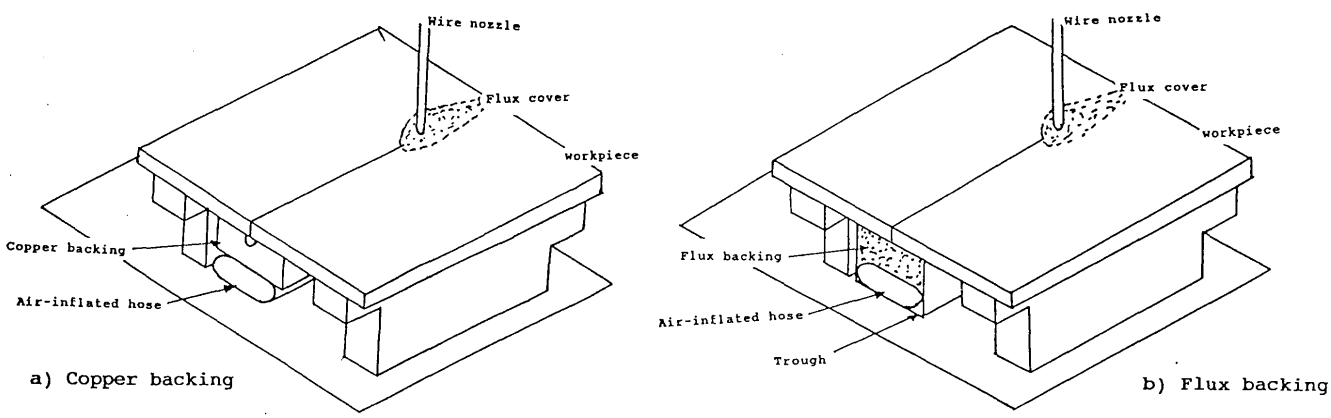

Fig.2 Schematic diagram of the experiamental installation

Table 2 Effect of welding variables on bead on plate welding penetration

Plate Thickness mm	Welding Current A	Travel Speed cm/min	Welding Voltage V	Heat Input J/mm	Penetration mm
6	400	60	36	1440	5.2
	400	60	32	1280	4.6
	400	80	32	960	4.2
	370	80	30	832	3.5
	330	80	30	742	2.9
	330	100	30	594	2.5
3	300	100	28	504	2.2
	270	100	28	454	1.85
	250	100	28	420	1.6

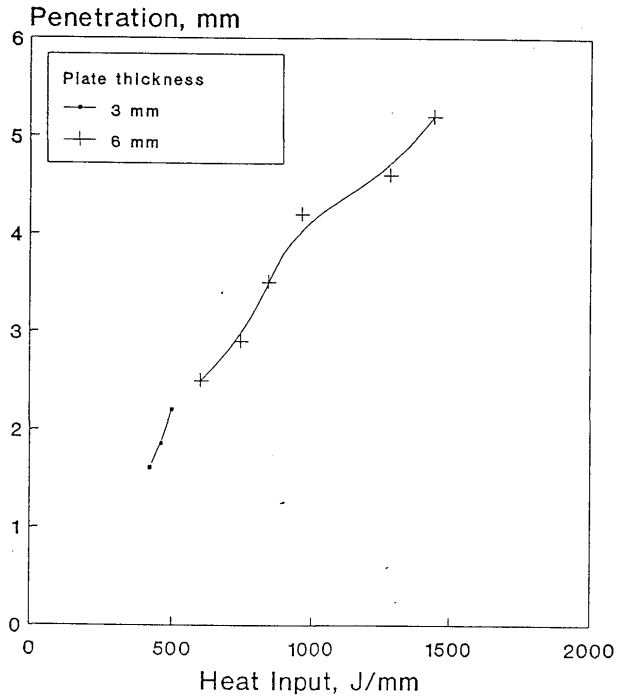

Fig.3 Effect of heat input on the penetration for 6 mm and 3 mm plate thickness in case of bead on plate welding

observed that; at welding current of 270 A and root opening ranging from 0 to 0.3 mm incomplete penetration was observed. However, with root opening ranging from 0.3 to 1.4 mm, melt through was observed.

3.2.2 Copper backing

The effect of using copper backing was analyzed at three different steps. First with small groove, second without groove and finally with big groove. The test results are summarized and shown in **Fig. 5** and Table 3.

In case of copper backing with small groove, incomplete penetration at root opening from 0 to 0.6 mm was observed. However at root opening from 0.6 to 1.0 mm and from 1.0 to 1.4 mm discontinuous penetration and melt through were observed respectively as shown in **Fig. 6**.

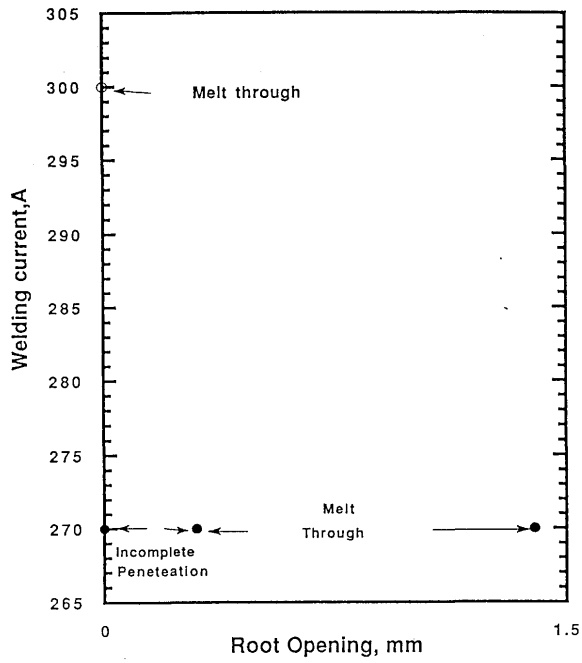

Fig.4 Effect of root opening and welding current on the penetration in case of butt joint welding without backing

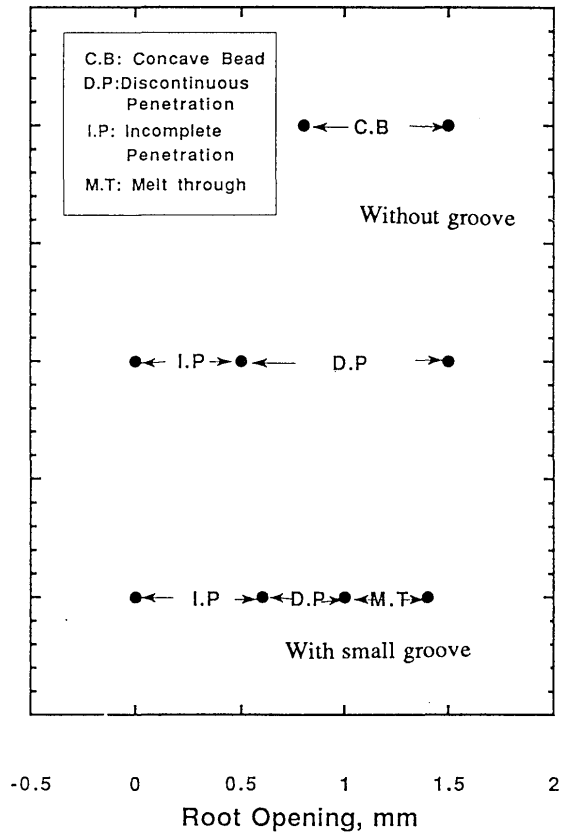

Fig.5 Effect of root opening on the penetration in case of butt joint with copper backing(at 270 A)

Table 3 Effect of welding conditions on butt welding (travel speed 100 cm/min)

Welding Condition	Welding Current A	Welding Voltage V	Root Opening mm	Welding Results
Without backing	300	28	0	Melt-through along the weld line
	270	28	0 - 1.4	< 0.3 mm, Incomplete penetration. > 0.3 mm, Melt through
With copper backing & small groove	270	28	0 - 1.4	< 0.6 mm, Incomplete penetration. 0.4 to 1.0 mm Discontinuous penetration along the weld line. > 1.0 mm, Melt through.
	270	28	0 - 1.1	From 0.5 to 1.1 mm a discontinuous penetration along the weld line occurs.
Copper backing without groove	270	28	0 - 1.5	< 0.5 mm, Incomplete penetration. 0.5 to 1.5 mm Discontinuous penetration along the weld line. 0.8 to 1.5 Concave bead.
Copper with big groove	340	28	0	Dull back bead
Flux backing AWS-F7A2	270	28	.3-1.25	0.3-0.7mm, Discontinuous penetration 0.6-1.25 mm, Uniform penetration
	270	28	.4-1.0	0.6-1.0 mm, Uniform penetration
	290	28	.3-1.25	0.3-0.6mm, Discontinuous penetration 0.6-1.25 mm, Uniform penetration
	300	28	.3-1.15	0.3-0.5mm, Discontinuous penetration 0.5-1.15 mm, Uniform penetration
	300	28	0	Discontinuous penetration
	320	28	0	Discontinuous penetration
	340	28	0 - 1.0	Uniform penetration along the weld line
Flux backing AWS-F7A6	340	28	0 - 1.0	Nonuniform penetration

In case of copper backing without groove, discontinuous penetration was obtained at root opening from 0.5 to 1.25 mm and the weld bead was concave at root opening from 0.8 to 1.5 mm.

In case of copper backing with large groove , at welding current of 340 A and zero root opening, the back bead was dull as shown in **Fig. 7**.

3.2.3 Flux backing

The test results which obtained by using two types of flux, AWS-F7A2 and AWS-F7A6, are summarized and shown in Table 3 and **Fig. 8**.

In case of AWS-F7A2 flux, discontinuous penetration was obtained at welding current of 270 A and root opening from 0.3 to 0.7 mm. On the other hand a good and uniform penetration was obtained at root opening from 0.7 to 1.25 mm at the same welding current. While at welding current of 290 A, discontinuous penetration was observed at root opening from 0.3 to 0.6 mm and uniform penetration was obtained at root opening from 0.6 to 1.25 mm. With increasing current and adjusting the root opening until 1.0 mm, good and uniform penetration was observed as shown in **Fig. 9**. However with increasing the root opening to 1.4 mm concave bead surface and melt through were obtained.

In case of AWS-F7A6 flux, nonuniform penetration , concave bead surface and melt through were observed at welding current of 340 A and root opening ranging from 0 to 1.4 mm, as shown in **Fig. 10**.

4. Discussion

The physical behavior of the weld pool has an important influence on the practicability of fusion

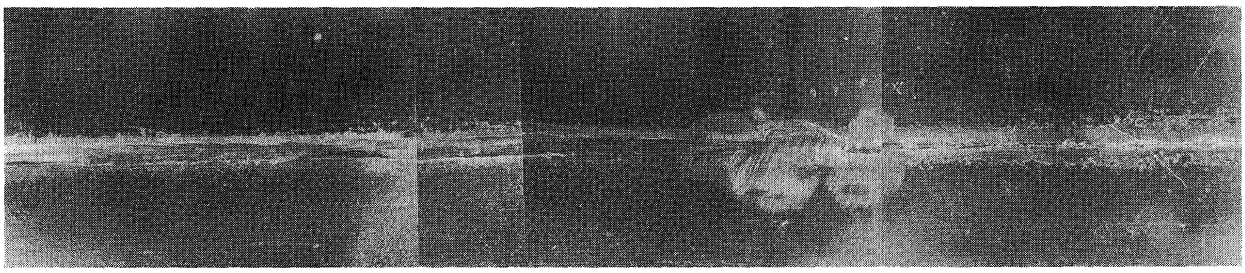

Fig.6 Appearance of back bead when using copper backing with small groove at different root opening

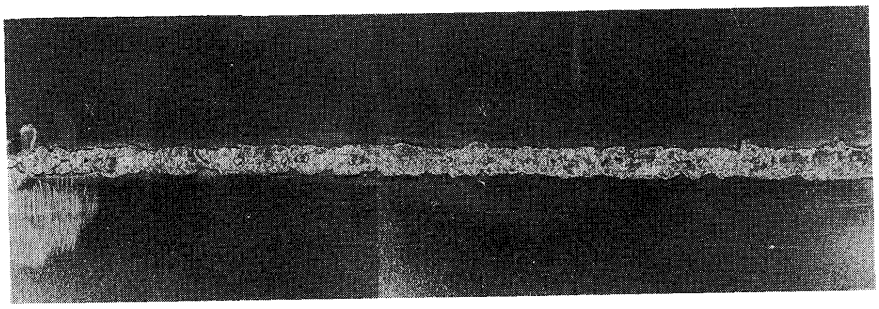

Fig.7 Appearance of back bead when using copper backing with big groove at different root opening

welding, and physical effects may limit the range of welding parameters at which a specific process is operable. A greater understanding of these phenomena could improve the quality of joints and the applicability of fusion welding.

The flow pattern in SAW has been studied by several invistigators [1, 2]. A depression is formed at the forward edge of the pool, and metal that is melted at the front of the weld pool flows underneath and on either side of the depression. At the rear of the pool the flow reverses and the metal streams back along the pool surface and the pool is elongated, as shown schematically in **Fig. 11**. However, the reverse stream along the weld pool surface was relatively weak and the dominant effect was rearward flow [3].

4.1 Effect of Welding current and Welding Speed

This type of weld pool may become unstable at high current and/or high welding speed. That was concluded from the test results and it can be explained from the point of view of metal stream during welding. There are three metal streams were observeed [3], one originating from filler metal running along the

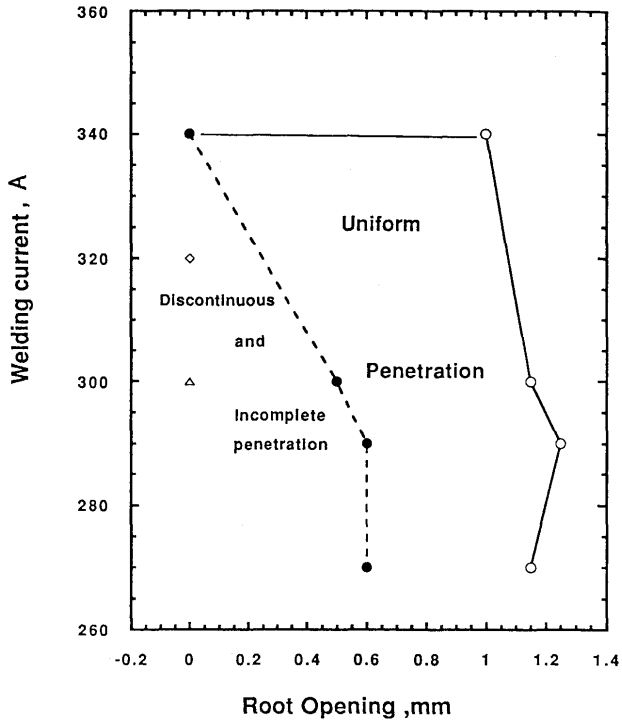

Fig.8 Effect of root opening and welding current on the welding penetration in case of butt joint welding with F7A2 flux backing

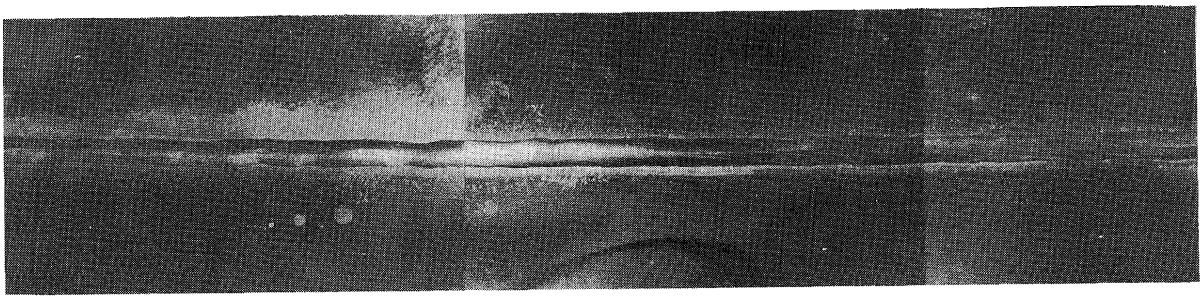

Fig.9 Appearance of back bead when using flux backing (AWS-F7A2) at different root opening

Fig.10 Appearance of back bead when using flux backing (AWS- F7A6) at different root opening

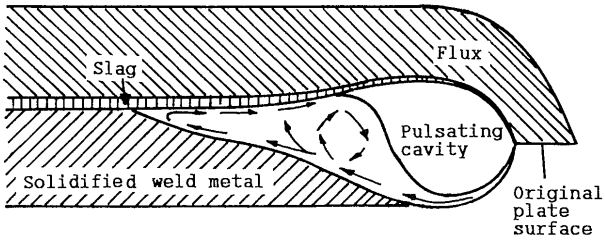

Fig.11 Schematic illustration of the flow pattern in submerged arc welding pool

centerline of the weld pool, and the other two originating from the parent metal and flowing initially along the edges of the weld pool. Under certain welding conditions, these three streams of metal do not flow together and the finished weld contains cavities and/or nonuniform penetration as shown in Table 3.

Also, the increase in welding current causes an increase in the arc force which results in high depression of the liquied surface to the penetration depth to some limits. Over that limits the resulting turbulence gives rise to cavities and/or melt through.

4.2 Effect of Root Opening

In square butt- welding the arc pressure tends to move the molten metal towards the base metal and prevent it from falling by gravity to close the root opening and form the back bead. Increasing the root opening results in a decrease in arc pressure and increase the tendency of molten metal to penetrate the root opening by gravity to form the back bead. But with large root opening melt through will be occured.

4.3 Effect of Backing

Copper backing supports the weld , conducts heat well to quench the weld buddle and helps in the formation of back bead without melt through .

In case of flux backing, flux support and press the weld, though permite the use of wider root opening. The maximum height of back bead in case of AWS-F7A2 flux when used as backing was 2mm.

According to American Petroleum Inistitute Specification (API), the maximum height of back bead and reinforcement is 3.18 mm for wall thickness <12.7 mm. So that the height of back bead obtained by using AWS-FA2 flux as backing is accepted.

The coarse grain size of AWS-F7A2 (12x150 mesh) gives chance for gases to escape more than the fine grain size of AWS-F7A6 flux (20x200) which prevent gases and leads to irregular back bead. Uniform penetration was obtained at welding current of 340 A, root opening ranging from 0 to 1.0 mm , welding voltage of 28 V and welding speed of 100 cm/min.

5. Conclusion

(1) Welding current and welding speed have the great infuence on welding penetration.
(2) It is difficult to obtain a good penetration without using a backing technique at root opening ranging from 0 to 1.4 mm.
(3) Flux backing technique is better than copper backing to obtain good penetration at wide range of root opening and welding current. However, the kind of flux affect on the properties of back bead.
(4) For square butt welding of 3 mm thick steel plate, acceptable penetration and bead hight can be obtained at root opening ranging from 0 to 1.0 mm, welding current of 340 A , welding voltage of 28 V and welding speed of 100 cm/min.

Acknowledgement

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