Effects of welding parameters on penetration depth in mild steels A-TIG welding

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Abstract

A-TIG welding is a welding method in which TIG welding is conducted by covering a thin layer of activating flux on the weld bead beforehand. The most benefit of this process is the gain in weld penetration depth. A-TIG welds were produced on mild steel plates with TiO$_2$ flux. The emphasis of this paper lies in introducing the effects of various process parameters (welding current, welding speed, powder/acetone ratio of the flux, arc length and electrode angle) in mild steel A-TIG welding. The weld penetration depth was the measured metallographically. An optimum value was determined for each welding parameter.

KEYWORDS - A-TIG welding parameters, Mild steel A-TIG welding, A-TIG flux, A-TIG flux solvent, A-TIG flux compositions

1. Introduction

TIG welding process produces high joint quality shallow welds [1]. Therefore, only thin sheets can be welded with a single pass. The A-TIG process is developed to overcome this problem. In this, a thin flux layer is covered on the joint area prior welding and dried in several minutes. Then conventional TIG welding is done [1]. The use of the fluxes in A-TIG welding increases penetration and productivity due to the reduction in the number of weld passes required to make the joint. This welding process is successively applied to austenitic stainless steels [2], ferritic stainless steels [3], and mild steels [4]. The number of published papers about mild steel A-TIG welding applications are less than ten [4-10].

The welding parameters determine the weld bead geometry and weld penetration depth in an electric arc welding process [11]. There are several studies in the literature about the effects of welding parameters on weld spot size of electric spot welding of mild steel sheets [12]. Although a lot of research done on A-TIG welding of austenitic stainless steels [13] there are no papers which explain the effects of welding parameters on A-TIG mild steels in detail. The studies on mild steel A-TIG welding applications showed the importance of welding current [5,7], the flux chemical composition[4], the acetone ratio of the flux[4], the arc length[4] and the welding speed[7] on weld penetration. Therefore the welding current, the welding speed, the arc length, the electrode angle and the composition of the welding flux were chosen as the A-TIG welding parameters. In the present study, the effects of these welding parameters on mild steel A-TIG welding penetration was investigated by macrostructure examinations.

2. Materials and methods

A standard St42 plate in the normalized condition is used for the current effect investigation. The plate is machined into 120x250x10 mm size rectangular plates. The plates are cleaned with acetone and then they are dried in still air. Pure TiO$_2$ powder is mixed with acetone into a paste and painted on the surface of the plates by a brush. Then the plates are kept in still air for 15 minutes to evaporate acetone of the paste allowed to evaporate leaving flux on the surface before welding.

Bead-on plate welds are made by a conventional TIG machine to investigate the effect of welding parameters on the depth of penetration. A 2% thoriated tungsten electrode rod of 2.4 mm diameter is used in welding. The shielding
gas is pure argon. The shielding gas flow rate is kept constant at 12 litter/minute. The welding parameter variables in this research are welding current, welding speed, arc length, TiO₂/acetone volume ratio and electrode angle. The welding parameters and their ranges employed in this study are given in Table 1. In every welding test set only one parameter was varied. For every welding parameter condition both a A-TIG and a TIG weld were produced.

Table 1. Welding parameters and their ranges.

| Welding parameters       | Units             | Ranges   |
|--------------------------|-------------------|----------|
| Welding current          | Amperes           | 70-210   |
| Welding speed            | Millimeters/second| 8-24     |
| Arc length               | Millimeters       | 1-5      |
| TiO₂/acetone volume ratio| Percentage        | 14-34    |
| Electrode angle          | Degrees           | 70-100   |

Three weld cross-sections were taken at several locations along the length of each bead on plate weld. Samples for metallographic examination were prepared using standard procedures including mounting, grinding, polishing, and etching with nital. Macrostructure of the joints were examined by an optical microscope. The cross-section of the welds were photographed. The photographs are taken by an Olympus PME 3 apparatus. The dimension of the penetration depth was measured on cross-sectional macrographs of the weld. For each welding condition three measurements were obtained and the average value was calculated. The weld penetration depth of A-TIG weld is named as \( D_{A-TIG} \) and the depth of TIG weld is named as \( D_{TIG} \) respectively. Then the penetration depth ratio (\( D_{A-TIG} / D_{TIG} \)) of the welds were calculated for each welding condition.

3. Results

Figure 1 shows the cross-sections of TIG and A-TIG welds. In these welds 0.33 powder/acetone volume ratio, 10 mm/s welding speed, 80 degrees electrode angle and 3 mm arc length were kept constant. Two different weld currents were used: 120 Amperes and 180 Amperes. The welds which were welded with the same parameters gave roughly equal weld width. A-TIG welds have greater weld penetration than the TIG welds. The first results indicates the effectiveness of the welding flux.

![Figure 1](image)

Figure 1. Macrostructures of TIG and A-TIG welds. (a) TIG 120 Amperes, (b) A-TIG 120 Amperes, (c) TIG 180 Amperes and (d) A-TIG 180 Amperes.
Figure 2 shows the effect of the TiO$_2$/Acetone volume ratio on weld penetration depth ratio. In these welds the welding current was 180 Amperes, the electrode angle was 80 degrees, the welding speed was 10 mm/s and the arc length was 3 mm. The TiO$_2$/Acetone volume ratio has a distinct effect on weld penetration. The $D_{A-TIG}/D_{TIG}$ first increased with TiO$_2$/Acetone volume ratio up to 0.17 and then subsequently showed a declining trend.

Figure 2. Effect of the TiO$_2$/Acetone Volume Ratio on Weld Penetration Depth Ratio.

Figure 3 shows how the penetration depth ratio of the welds ($D_{A-TIG}/D_{TIG}$) varies with the welding current. In these welds the welding speed was 10 mm/s, the powder/acetone volume ratio was 0.17, the arc length was 3 mm and the electrode angle was 80 degrees. In electric arc welding operations, the increase in welding current causes a higher weld energy that increases the weld penetration depth. Figure 3 indicates that the penetration depths of the welds increased with the welding current as expected.

Figure 3. The Relation between Weld Penetration Depth Ratio and the Weld Current.

The Figure 4 shows the effect of the welding speed in weld penetration depth ratio. In these welds the welding current was 150 Amperes, the powder/acetone volume ratio was 0.17, the arc length was 3 mm and the electrode angle was 80 degrees. The $D_{A-TIG}/D_{TIG}$ ratio decreased with the speed.
Figure 4. The Relation between Weld Penetration Depth Ratio and the Welding Speed.

Figure 5 shows the effect of the arc length on weld penetration ratio of mild steel A-TIG and TIG welding processes. In these welds the welding current was 180 Amperes, the powder/acetone volume ratio was 0.17, the welding speed was 10 mm/s and the electrode angle was 80 degrees. The penetration increased with the arc length. The penetration ratio reached a peak value at 3 mm arc length and then it decreased.

![Figure 5](image)

Figure 5. Effect of the Arc Length on Weld Penetration Depth Ratio of A-TIG and TIG Welds.

Figure 6 indicates the relation between the weld penetration depth ratio and the electrode angle. In these welds the welding current was 180 Amperes, the powder/acetone volume ratio was 0.17, the welding speed was 10 mm/s and the arc length was 3 mm. The penetration ratio increased with the electrode angle.

![Figure 6](image)

Figure 6. The Relation between Weld Penetration Depth Ratio and the Electrode Angle.

4 Discussion

The photographs of Figure 1 proved that A- TIG welds had greater weld penetration depths than the TIG welds which were welded with the same welding current. This difference was due to the welding flux. Dissociation of the TiO₂ particles of the flux occurred [14] during the A-TIG welding operation which increased the active surface tension in the weld pool [15]. In this case, the liquid metal movement in the pool became vertical [16]. Thus, the vertical liquid metal movement in the A-TIG weld pool increased the penetration depth [17].

Figure 2 indicates us the importance of the TiO₂/Acetone volume ratio. After the evaporation of the acetone residual TiO₂ powder was left on the plate. The thickness of the residual powder is directly depended on the TiO₂/Acetone volume ratio [18]. The thickness of the powder increased with the TiO₂/Acetone volume ratio. The least penetration ratio is obtained for the 0.14 flux ratio. In this welding condition minimum amount of TiO₂ dissociation occurred during welding. A small amount of oxygen was dissolved in the weld pool so increase in the surface tension
was also small. Therefore, a shallow weld was produced in the A-TIG welding operation. The oxygen transferred to the weld pool increased with the thickness of the residual TiO$_2$ layer. The maximum $D_{\text{A-TIG}} / D_{\text{TIG}}$ ratio was obtained at the 0.17 flux ratio. This flux ratio gave the optimum oxygen atom amount in the pool. When the oxygen amount exceeded the optimal limit a thin oxide layer formed on the pool surface which decreased the weld penetration [19]. The fall of the penetration thickness happened as the TiO$_2$/Acetone volume ratio exceeded the 0.17 ratio limit.

The increase in the weld current causes a greater energy formation in the weld zone. This great energy input enlarges the weld geometry [11]. The weld width and the weld penetration depth increased as shown in Figure 1. But, the growth in weld penetration depth with the weld current was not equivalent for TIG and A-TIG welds. The $(D_{\text{A-TIG}} / D_{\text{TIG}})$ was 1.15 at 80 Amperes, 1.32 at 130 Amperes and 1.78 at 180 Amperes as shown in Figure 3. The activating flux effect on the weld penetration became pronounced with the current. The melted and vaporized activating flux amount increased with the current and this enlarged the vertical movement in the weld pool and the arc constriction effect of the flux [1]. Therefore, the penetration of A-TIG welds increased much more than the TIG welds. The slope of the curved increased beyond 170 Amperes. Similar results were obtained in A-TIG welding of high alloyed steels [18].

In electric arc welding operations the increase in welding speed causes a lower weld energy input which decreases the weld penetration depth [11]. The weld pool size and solidification time of the weld gets smaller with the welding speed. At a low welding speed the weld pool solidifies in a longer period which causes a high amount of TiO$_2$ dissociation in A-TIG welds. Therefore, more liquid metal motion and deep penetration can be obtained. The advantages of A-TIG welds are lost at high welding speeds as shown in Figure 4.

Figure 5 shows the effect of the weld arc length in A-TIG welding. When the arc length is very short the speed of electrons in the arc is low. The bombing effect of the electrons is low when the arc length is short and heating of the weld pool is small. This welding condition produces a shallow weld. The bombing effect of the electrons becomes bigger by extending the arc length from 1 mm to 3 mm as shown in Figure 5. The electron speed, the anode diameter and the temperature of the anode increased with the arc length exceeds 3 mm arc length [19]. Then the penetration decrease because the anode diameter enlarges [20] and the efficiency of the welding heat transfer to the work piece decreases [11].

The electrode angle in A-TIG welding process affects the diameter of the weld plasma column diameter [21]. The plasma column diameter, arc pressure and current density at the anode root increases with the electrode angle [23]. The penetration depth increases parallel with the arc pressure and current density as shown in Figure 6.

## 5. Conclusions

The welding current, welding speed, TiO$_2$ powder/acetone ratio of the flux, arc length and electrode angle on penetration of mild steels A-TIG welding were investigated. The results clearly show that all these parameters can increase the penetration capability of the welding process. The principal results may be summarized as follows:

- The welding current increases the weld penetration depth in A-TIG welding than TIG welding.
- The welding speed continuously decreases the weld penetration depth in A-TIG welding.
- The electrode angle increases the weld penetration depth.
- The best penetration depth was obtained with the 0.17 TiO$_2$ powder/acetone ratio.
- The 3 mm arc length gave the best penetration depth.
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