Influence of AA-GTA Welding on the Weld Metal Penetration

Mohd Majid, Abhishek Shrivastava

Abstract— **Gas tungsten arc welding (GTAW) is suitable for welding up to 6 mm thick materials. Thus, with a view to enhance the process capabilities of GTAW process advance activated gas tungsten arc welding (AA-GTAW) was used to fabricate V-groove joints on 10 mm thick plate of 304L stainless steel. Joint was fabricated using AA-GTAW process in which a mixture of 4% oxygen and 96% pure argon was used as shielding gas. It was observed that, addition of oxygen to the molten pool control the Marangoni convection from the outward to inward direction due to which depth to width ratio (d/w) of the weld significantly increases.**

Index Terms—**AA-GTAW, d/w ratio, GTAW, Marangoni convection**

I. Introduction

GTA welding is one of the widely used welding technique in various industries for welding stainless steel, titanium alloys and other non-ferrous metals for high quality welds [1]. However, this welding technique is restricted up to 6 mm thick materials only thereby surpassed by other welding processes having high productivity such as GMAW, PAW etc.

In order to improve the process capabilities various researchers introduced active flux gas tungsten arc welding (A-GTAW) in which metered quantity of various types of surface active elements such as CaO, Fe_2O_3, Cr_2O_3, MnO_2 and SiO_2 were smeared onto the surface to be welded and the effect on bead geometry, angular distortion etc were studied[2].

In GTAW molten pools, there is always a temperature gradient on the molten pool surface with high temperatures at the pool center under the arc and low temperatures at the pool edge.

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For GTA welding without flux, the surface tension decreases as the temperature increases. The surface tension being the highest at the edge of the weld pool and the lowest at the center of the weld pool.

For GTAW welding with oxide fluxes, adding surface active element oxygen to the molten pool can drastically change the temperature dependence on the surface tension. However, in spite of increased penetration there were other problems involved in A-GTAW such as oxidation of electrode, erosion of flux by shielding gas during welding etc [3].

Further, in order to eliminates the drawbacks of A-GTAW process another technique known as advanced activated gas tungsten arc welding (AA- GTAW) was introduced which improves the d/w ratio through the addition of active elements such as oxygen or carbon dioxde into the shielding gas [4-6]. The basic purpose of shielding gas is to protect the weld pool and the electrode from oxidation by atmospheric oxygen and other contaminations. But in the case of AA-GTAW the shielding gas is supplied in two envelopes i.e. outer envelope and inner envelope.

AA-GTAW which is a recently developed technique increases the weld penetration and protect the electrode from oxidation [8]. The outer envelope consist of a gas mixture of an active gas and an inert gas while the inner envelope consist of a pure inert shielding gas. The pure inert gas protects the tungsten electrode from getting oxidized while the active gas in the outer envelope increases the d/w ratio [9].

With the addition of certain surface active elements such as oxygen, selenium, sulfur etc which when added into the weld pool above a certain concentration, reverse the direction of Marangoni convection. This is known as reverse Marangoni convection. This produces an inward force from the edges towards the center of the weld pool which changes the weld shape from wide and shallow to narrow and deep [7].

There are the mechanisms which may be responsible for increased weld penetration during AA-GTA welding;

(A) Due to the addition of surface active elements in the weld pool, the surface tension increases with an increase in the temperature of the weld pool thus changing the direction of flow from outward to the inward direction [9].

(B) Double shielding atmosphere constrict the arc resulting in deeper penetration [5].

Austenitic stainless steel AISI 304 has high corrosion resistance and possess good mechanical properties, therefore it is used in various modern industries like chemical, dairy processing, nuclear, ship manufacturing etc. There is a continuous need to improve the welding processes to cope with the changing demand of the industries and applications. Advancing the capabilities of GTAW process would offer fabrication of a wide range of thickness of steel. Undertaking this study would be beneficial for understanding the aspects of newly developed technique AA-GTAW.

II. EXPERIMENTAL

The base material used in the present work was AISI 304 stainless steel in the form of plates of size 300x80x10 mm and the filler wire used was AISI 308L of diameter 2.4 mm. The composition of the base plate as well as filler wire is provided in table 1.

Table 1: Chemical composition (wt%) of the base metal and the filler used.

Alloy element	C	Si	Mn	P	S	Cr	Ni	Fe
Base (AISI 304)	0.06	0.42	1.89	0.032	0.014	18.67	8.53	Bal.
Filler (ER 308L)	0.08	1.0	1.59	0.045	0.03	18.15	10.02	Bal.

The present study was accomplished in two phases. The first phases constitutes of bead-on-plate welds using GTAW and AA-GTAW processes in order to determine the penetration capabilities of both the processes. While in the second phase the effect of penetration on the number of passes required to complete a single v-groove weld was studied.
Prior to welding, the surface of the plate was ground in order to remove all rust, scale, etc. direct current electrode negative (DCEN) polarity power source was used. Welding was performed using thoriated tungsten electrode (W-2%, ThO_2, 2.4 mm diameter). The vertex angle of the electrode was 60˚. The diameter of the filler wire used is 2.4 mm. The welding process parameters employed are shown in table 2.

Table 2: Welding parameters employed for GTAW and AA-GTAW processes.

No. of passes →	1	2	3	4	5
Current (A) →	120	120	150	160	140
Flow rate (L/min) →	8	10	10	15	15

The welding was performed using both GTAW as well as AA-GTAW processes. Plasma welding torch having a double nozzle structure as shown in figure 1 was used to get double gas shielding condition. The steel plates were welded using AA-GTAW with pure argon supplied as the inner shielding gas and a gas mixture of Ar + 4% O_2 as the outer shielding gas. The plates were tack welded using C-clamps and tab in- out were placed. An interpass temperature of 120^{o}C was maintained between subsequent passes.

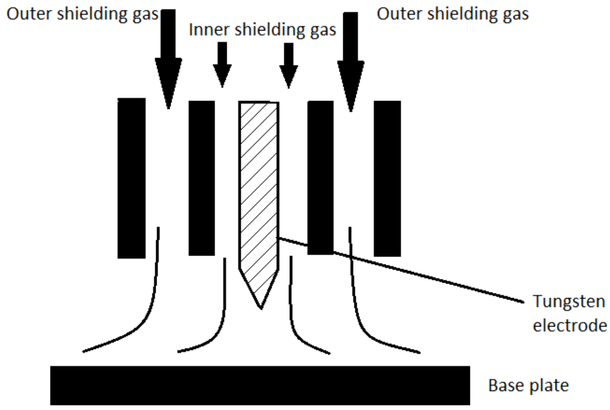

Figure 1: Schematic diagram for double shielding torch for AA-GTAW process.

In addition of the macro analysis of the welds, the micro-hardness tests were performed with a Vickers micro-hardness tester with a dwell period of 20s and a load of 500 grams.

III. RESULTS

Depth to width ratio (d/w) of bead on plate was measured using stereozoom microscope. It was observed that d/w ratio of the bead made by AA-GTAW increases significantly as compared to that of bead made by GTAW process. Figure 2 shows the actual penetration of beads made by GTAW and AA-GTAW processes.

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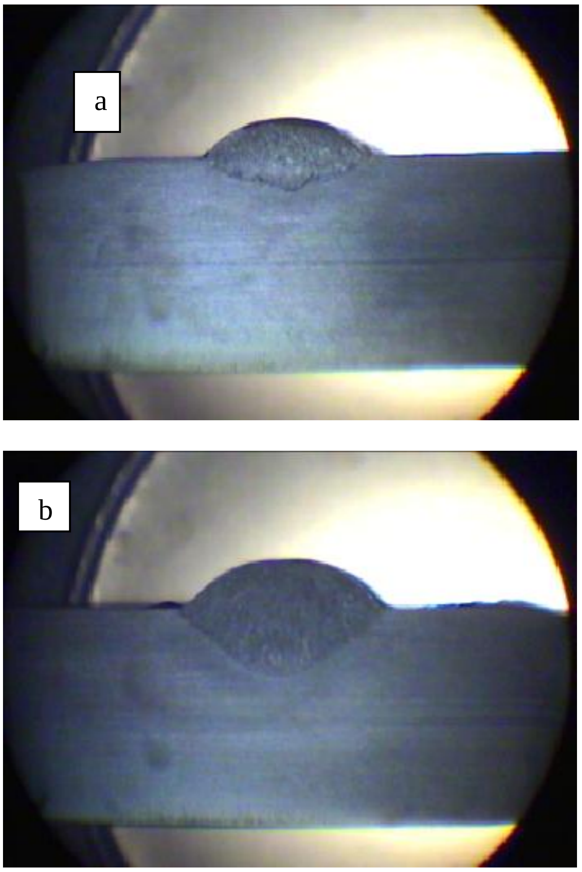

Figure 2: Penetration of bead on plate weld (a) conventional GTAW (b) AA-GTAW

Also it was observed that welding of 10 mm thick plate using AA-GTAW process was completed in four passes including the root pass while with GTAW process with same welding parameters the welding was completed in five number of passes as shown in figure 3. Thus it can be observed that due to significant increase in penetration or d/w ratio the number of passes required to complete the weld by AA-GTAW process gets reduced.

It is clear from the bead on plate weld as shown in figure 2 that d/w ratio in AA-GTAW weld increases by 49.83 %.

The figure 2 shows that the bead obtained using GTAW has a wide and shallow profile while the bead obtained by AA-GTAW has a narrow and deep profile. In GTAW welding the Marangoni convection is responsible for the shape of the weld pool. Generally with an increase in the temperature of the weld pool the surface tension decreases resulting in a wide and shallow shape of the weld bead as shown in figure 4(a). This is because the central region of the weld pool has a higher temperature as compared to the edges of the weld pool. This temperature gradient produces an outward force away from the center of the weld pool. It gives the weld a wide and shallow shape.

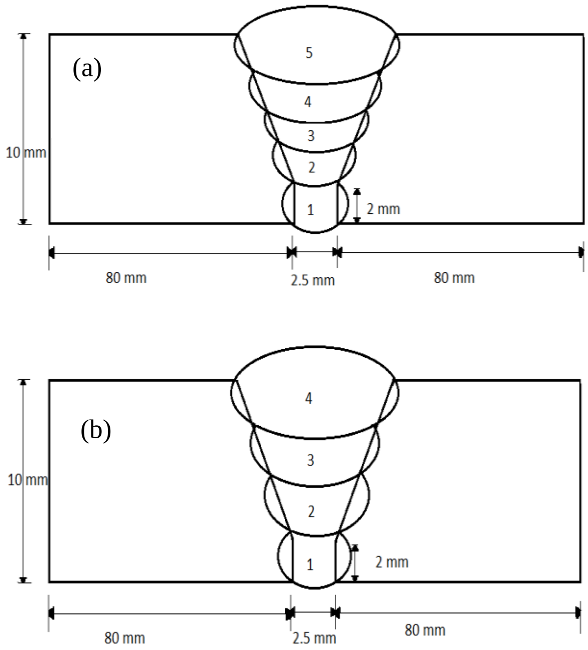

Figure 3: Schematic showing the number of passes (a) GTAW (b) AA-GTAW

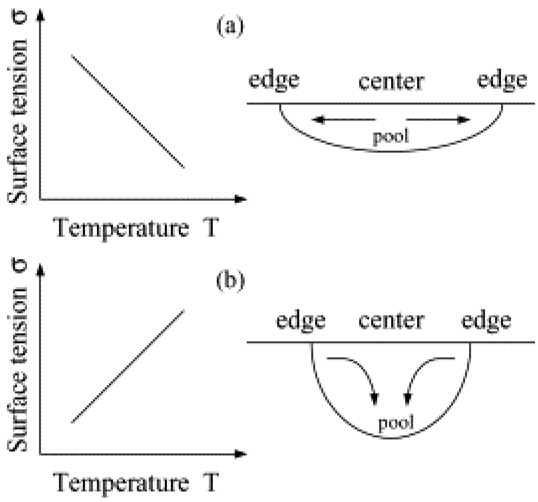

Figure 4: Schematic of Marangoni convection mode in weld pool.

But there are certain surface active elements such as oxygen which when added into the weld pool above a certain concentration, reverse the direction of Marangoni convection as shown in figure 4(b). This is known as reverse Marangoni convection. This produces an inward force from the edges towards the center which changes the weld shape from wide and shallow to narrow and deep [6].
The addition of oxygen in the shielding gas leads to the formation of an oxide layer above the weld pool. This oxide layer acts as a barrier between the weld pool and atmospheric oxygen, preventing its absorption into the weld pool.

The micro-hardness profile measured along the mid-thickness line of the cross section of the joint prepared using GTAW and AA-GTAW are shown in figure 5 respectively. In general, the micro-hardness of the joint obtained by AA-GTAW process is higher than joints obtained by GTAW. The increase in micro-hardness can be attributed to the refinement of grains in advanced A-GTAW process with the maximum value of micro-hardness obtained at the center of the weld pool with least value obtained at the base metal.

The value of micro-hardness is maximum in the weld zone, intermediate in the heat affected zone and least in the base metal in case of AA-GTAW process. While in case of GTAW the maximum value of micro-hardness is obtained in the heat affected zone and least in the base metal.

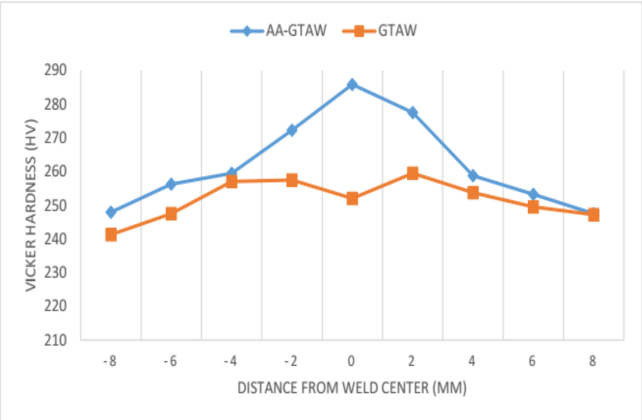

Figure 5: Micro-hardness profile showing micro-hardness at different points in AA-GTAW and GTAW weld joint.

IV. Conclusion

In the present study, attempt has been made to study the effect of AA-GTAW welding on the weld metal penetration and micro-hardness of the AISI 304 stainless steel joints. The main findings are summarized as follows:

1. With the addition of oxygen in the shielding gas the direction of Marangoni convection is reversed from outward to inward which makes the weld pool deep and narrow.
2. The weld depth/width ratio with AA-GTAW has increased with the addition of oxygen in the outer shielding gas as compared to conventional GTAW due to inward Marangoni convection.
3. A thick oxide layer is formed over the weld pool which could prevent the weld pool from atmospheric oxygen.
4. The number of passes required to complete the weld has reduced in the case of AA-GTAW which shows the applicability of the process for fabrication of thicker plates and heavy structures.
5. The micro-hardness of the AA-GTAW weld joint is more than that of the conventional GTAW process. This may be due to refinement of grains in the fusion zone.

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