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A Review Study on A-TIG Welding of 316(L) Austenitic Stainless Steel

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Abstract

Austenitic stainless steels are widely used in the application of aircraft engine parts, heat exchangers, furnace parts etc. It contains both chromium and nickel. Nickel and chromium aids stability of austenite over wide range of temperatures and high corrosion resistance respectively. 316L austenitic stainless steel is low carbon (0.03%) steel, developed from 316 austenitic stainless steel and contains carbon (0.08%). The causes of decreased contents of carbon, minimizes the problem of harmful carbide precipitation during welding. Activated Tungsten Inert Gas (A-TIG) welding can increase the joint penetration and weld depth-width ratio, thereby reducing angular distortion of the weldment. This paper address the A-TIG welding, and their significance & advantages.

Keywords: *316L austenitic stainless steel, A- TIG welding and Marangoni convection, Arc Constriction Effect.*

1. Introduction

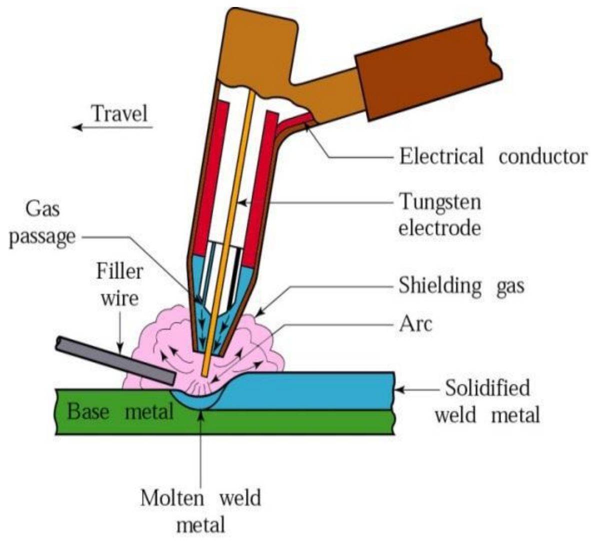

Figure.1 Gas Tungsten Arc Welding Process (GTAW)

Tungsten Inert Gas (TIG) welding is also called as Gas Tungsten Arc Welding (GTAW). It is an arc welding process where coalescence is produced by heating the work piece with an electric arc struck between tungsten electrode and work piece. To avoid atmospheric contamination of the molten weld pool, a shielding gas (argon or helium) is used. Argon is more widely used than helium because it is heavier gas, producing better shielding at lower flow rate. The shielding gas displaces the air surrounding the arc and weld pool. This prevents the contamination of the weld metal by the oxygen and nitrogen in the air. The process may be operated autogenously (without filler) or filler may be added by feeding a consumable wire or rod into the established weld pool. The arc is struck either by touching the electrode with a metal tungsten piece or using a high frequency unit. Then the welding torch (holding electrode) is brought near to the work piece. When electrode tip reaches within a distance of 2 to 3mm from the work piece, a spark jumps across the air gap between the electrode and the work piece. Then the air path gets ionized and arc is established is shown in Fig.1

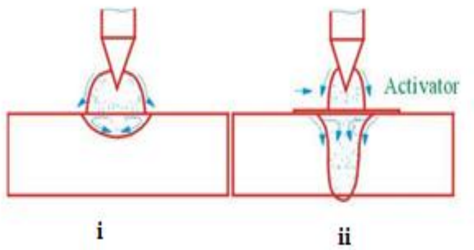

Figure.2 (i) TIG welding and (ii) A-TIG welding

Tungsten Inert Gas (TIG) welding is one of the most popular welding processes in various manufacturing industries due to the obtained good weld bead surface and a very high quality weld metal without any weld defects. However, compared to other arc welding processes, such as gas metal arc welding, plasma arc welding or submerged arc welding, the shallow penetration of the TIG welding restricts its ability to weld thick structures in a single pass, thus its productivity is relatively low is shown in Fig.2(i). Therefore, in order to increase the TIG welding production, the demand for control of the weld shape with a deep penetration is steadily increasing and has been a concern for a long time. The principal disadvantages of TIG its to limited penetration ability in a single pass, poor tolerance to some material composition and the low production. To improve the penetration of TIG welding, thorough analysis has been done. Theoretical studies supplemented with experimental investigations suggest that the weld penetration is dominated by surface tension temperature gradients over the pool. The presence of some surface-active species that increase the melt surface tension with temperature induces thermo-capillary flows deep into the weld and results in deeper penetrations A-TIG process can achieve in a single pass, a full penetration weld in stainless steel up to 10mm thickness without the use of bevel preparation and the addition of filler wire. The weldment aesthetics are observed to be unaffected. In recent years, attentions have been paid to a new variant welding process A-TIG welding, firstly developed by the E.O.Paton Electric Welding Institute in the year 1960. Compared with the conventional TIG welding, the A-TIG welding process, in which a very thin coating of activating flux is applied to the surface of the material before welding is shown in Fig.2(ii) can greatly increase the penetration depth under the same welding conditions. The A-TIG welding can greatly increase welding productivity, reduce the welding cost as well as welding distortion.

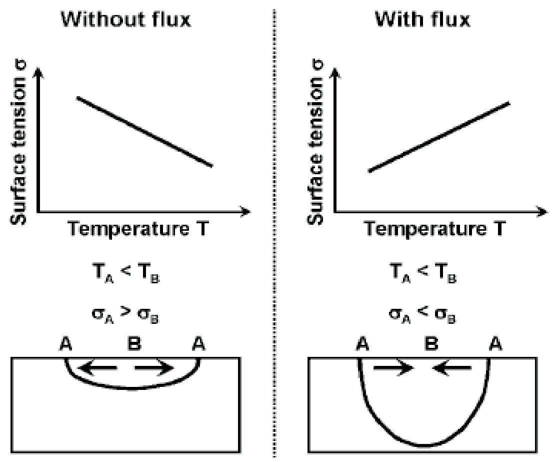

Figure.3 Schematic diagram of Marangoni Convection

During A-TIG welding, activated flux changes the convection movement in the weld pool form centrifugal to centripetal as shown in the Fig.3. This indicated that the surface tension gradient introduces centripetal Marangoni convection in the molten pool. In A-TIG, the temperature coefficient of surface tension on the molten pool changed from a negative to a positive value. Therefore, the surface tension at the pool centre was higher than at the pool edge. In this condition, the fluid flow of the molten pool surface easily transfers from the pool edge to the centre and then downward . It was also found that there was reduction of the angular distortion using weld parameters. In case of conventional TIG welding, angular distortion increases continuously with increase in current. It is clear that for any value of current maximum distortion in A-TIG is quit lower than the all the value of TIG welding. So distortion is not the problem against increase in current density

A-TIG welding is used to increase the weld penetration. In A-TIG welding fluxes are mixed with solvent and applied on the weld plate before welding. These fluxes constrict the welding arc and increase the penetration compared to normal TIG welding process. Various fluxes like of MnO_2, TiO_2, MoO_3, SiO_2, and Al_2O_3 are used for the A-TIG welding processes for the various materials. Oxide based flux powder mixed with methanol and ethanol provided good spread ability and convertibility. Smooth and clean surface were achieved by using oxide base flux. The penetration depth and bead width were increased using different values of current.

1.1 Significance of A-TIG Welding Process

The implementation of the A-TIG welding process would result in a significant increase in weld penetration in austenitic stainless steels and overcomes penetration variability as a result of chemical composition differences between heats of material. It would also result in reduced heat input reduction in distortion, reduction in cost, improved productivity and overall improved quality. Use of activated flux has also been found to improve the mechanical properties of the welds compared to conventional TIG welds.

1.2 Mechanism of A-TIG

There are two mechanisms that play important role in activating the effect of flux.

1.2.1 Marangoni effect: It refers to the convection movements due to the surface tension gradient on the weld pool surface. During TIG welding the surface tension gradient is negative and the convection movements are centrifugal and it leads to shallow penetration. The addition of activated flux induce an inversion of the convection currents changing the sign of the surface tension gradient, resulting convection movements changed to centripetal. Hence, the penetration depth increases.

1.2.2 The arc constriction effect: a) The flux acts as an insulating layer reducing the current density at the outer radius of the arc column and thus increases the current density at the center, increased magnetic force which leads to strong convective flow downwards in the weld pool and thus to significantly increased weld depth. b) The flux powder (Titanium dioxide) also causes the formation of an anode spot on the surface of the joint which attracts the electrons from the cathode (Tungsten electrode) causing deeper penetration. c) Negative ion formation at the edge of the arc could increase current density at the centre of the anode and thus increase the weld depth. It increases the production rate by three times as compared to manual TIG process and it gives consistent quality and excellent bead appearance.

2. Literature Review

Heiple et al. (1982) revealed that surface active elements in the molten pool change the temperature coefficient of surface tension from negative to positive, thereby reversing the Marangoni convection direction from outward to inward. As the direction of the fluid flow in the molten pool becomes inward, the joint penetration increases dramatically.[1]

Howse et al. (2000) associated the greater penetration of activated TIG welding to a constriction of the arc. Information on these processes is necessary to determine the TIG penetration capability improvement function of the activated flux. Because austenitic stainless steels have a higher coefficient of thermal expansion and lower thermal conductivity than carbon and alloy steel, it can induce a large amount of shrinkage and distortion after welding fabrication. Determining the effect of the activated flux on weld distortion is essential to improving the performance of the stainless steel activated TIG technique. This study used five different kinds of oxide fluxes to investigate the effect of single component flux on the morphology and distortion of Type 316L stainless steel TIG welds. Aside from studying the microstructure and hardness of activated TIG weld metal, this study investigated the theoretical and experimental mechanisms for increasing the A-TIG penetration capability.[2]

Paulo et al. (2000) concluded that without activating flux weld depth achieved is very less and bead width is unnecessarily high. Best result is achieved in case of silicon dioxide, and highest penetration. CaO and Al oxide is not advisable to use because they are giving same or near result as conventional TIG welding.[3]

Tseng et al. (2001) reported that an austenitic stainless steel exhibits considerably higher thermal expansion than other stainless steels, and the thermal conductivity is generally lower than that of carbon steel. Such characteristics cause a serious thermal stress in applications with temperature fluctuations, heat treatment of complete structures, and on welding. During welding, the arc heats a joint plate is locally and the temperature distributions in the weldment are not uniform. Heating and cooling cycles induce non uniform thermal strains in both the weld metal and the adjacent base metal. The thermal strains produced during heating then produce plastic upsetting. These non-uniform thermal stresses combine and react to produce internal forces that cause shrinkage and distortion.[4]

Huang (2009) investigated that one of the most notable techniques is to use an activated flux in TIG welding process. This novel variant of the TIG process is called A-TIG welding, which uses a thin layer of activated flux on the surface of the joint. The primary benefit of using flux is to reduce the heat energy required for TIG penetration.[5]

Kuang-Hung et al. (2011) conducted the study on performance of activated TIG process in austenitic stainless steel welds. To obtain high quality welds and stable weld arc, the A-TIG process requires large diameter electrodes to support a given level of the weld current. TIG welding with SiO_2 and MoO_3 fluxes achieves an increase in weld depth and a decrease in bead width, respectively. The SiO_2 flux can facilitate root pass joint penetration, but the Al_2O_3 flux led to a deterioration in the penetration compared to the conventional TIG process for Type 316L stainless steel welds. A-TIG welding can increase the joint penetration and weld depth-to-width ratio, significantly reducing the angular distortion of the weldment. Since the activated TIG welding can increase the arc voltage, the amount of heat input per unit length in a weld is also increased and therefore the delta-ferrite content in weld metal will be increased. The addition of oxide flux does not significantly affect the hardness of Type 316L stainless steel activated TIG weld metal.[6]

Kuang Hung Tseng (2011) expressed that MoO_3 flux assisted TIG welding technique can produce a significant improvement in power density of heat source and weld aspect ratio, resulting in low angular distortion and residual stress levels. The MoO_3 flux assisted TIG welding associated with a rapid cooling rate of the welds, therefore exhibiting higher ferrite content in austenitic stainless steel 316L weld metals during the solidification after welding.[7]

Cheng Hsien Kuo (2011) found that the surface appearance of TIG welds produced with oxide flux formed residual slag. TIG welding with SiO_2 powder can increase joint penetration and weld depth-to-width ratio and therefore the angular distortion of the dissimilar weldment can be reduced. Furthermore, the defects susceptibility of the as welded can also be reduced.[8]

Chih-Yu Hsu et al. (2011) reported that TIG welding is used to increase the penetration. A-TIG welding is carried out using the paste of flux is applied before welding. This flux constrict the welding arc and increase the penetration compared to normal TIG welding process. Various fluxes like MnO_2, TiO_2, MoO_3, and $SiO_2$are used for the A-TIG welding processes for the various materials. In A-TIG, the temperature coefficient of surface tension on the molten pool changed from a negative to a positive value. Therefore, the surface tension at the pool centre was higher than at the pool edge. This indicated that the surface tension gradient introduces centripetal Marangoni convection in the molten pool. In this condition, the fluid flow of the molten pool surface easily transfers from the pool edge to the centre and then downward.[9]

Ahmadi et al. (2012) conducted the experiment to study the effect of activating fluxes on 316L stainless steel weld joint characteristic in A-TIG welding using the Taguchi method. The Experimental results showed that weld penetration depth is increased due to the increase in the current and the decrease in the welding speed. Activating fluxes not only increases the weld penetration depth, but also decreases the weld width, which is important in terms of welding distortion. Activating fluxes improve the joint mechanical properties by decreasing the grain size of heat affected zone.[10]

Kuang-Hung (2012) revealed that Cr_2O_3 flux assisted TIG welding can create a high depth-to-width ratio weld. Since the A-TIG welding can reduce the heat input per unit length in welds and the residual stress of the weldment can be reduced. TIG welding with Cr_2O_3 flux can increase the retained ferrite content of stainless steel 316L weld metal and in consequence, the hot cracking susceptibility is reduced.[11]

Hsien Kuo Cheng et al.(2012) investigated their study the Performance of Dissimilar A-TIG Welds.The experimental results indicated that the SiO_2, Fe_2O_3 and Cr_2O_3 fluxes can increase joint penetration in both of the 316L stainless steel and the JIS G3131 mild steel. The CaO flux only can increase the joint penetration of the mild steel. The reversed Marangoni convection are considered to the main factors for increasing penetration of A-TIG on dissimilar welds in this study. Furthermore, TIG welding with SiO_2 powder can significantly reduce the angular distortion and increase the tensile strength of the dissimilar weldment.[12]

Kuang-Hung Tseng (2013) found that in A-TIG welding the flux is mixed with the solvent. Oxide based flux powder mixed with methanol and ethanol provided good spreadability and convertibility. Smooth and clean surface were achieved by using oxide base flux. The penetration depth and bead width were increased using different values of current. It was also found that there was reduction of the angular distortion using weld parameters.[13]

Sambherao et al. (2013) conducted the study on Use of activated flux for increasing penetration in austenitic stainless steel while performing GTAW. A significant increase in penetration (around 300 %) was obtained in welds done with a TiO_2 activating flux. This effect is mainly due to not only the arc constriction produced by the flux and consequent increase in the arc force but the reversal of Marangoni convection also. Al_2O_3 produced only a small increase in weld depth, therefore it can be proposed that the fluid flow appears to be in the outward direction when Al_2O_3 flux is added. When Fe_2O_3 mixed with TiO_2 flux was used, the oxygen content in the weld pool increased to a larger extent as Fe_2O_3 is unstable. This reversed the Marangoni convection very sharply, leading to even more increase in the weld depth than that when only TiO_2 flux was used. It is recommended that combination of fluxes such as mixture of TiO_2 and Fe_2O_3 flux should be used to achieve desirable properties of the weld.[14]

Nilesh Ghetiya et al. (2014) expressed that a mathematical model was developed to predict the weld penetration and bead width in A-TIG welding of mild steel. The developed relationships can be used to predict the penetration and bead width in activated TIG welding of mild steel within the range of parameters. In A-TIG welding process, the temperature coefficient of surface tension on the molten pool is changed from negative to positive value. Therefore the surface tension at the center is higher than the edge of metal, which produce shallow and high depth of penetration in the weldment.[15]

3. Conclusion

- During TIG welding the surface tension gradient is negative and the convection movements are centrifugal and it leads to shallow penetration. The addition of activated flux induce an inversion of the convection currents changing the sign of the surface tension gradient, resulting convection movements changed to centripetal. Hence, the penetration depth increases.
- A-TIG welding can increase the joint penetration and weld depth-to-width ratio, by significantly reducing the angular distortion of the weldment.
- TIG welding with SiO_2 and MoO_3 fluxes achieves an increase in weld depth and a decrease in bead width respectively. The SiO_2 flux can facilitate root pass joint penetration.

- Without activating flux weld depth achieved is very less and bead width is unnecessarily high.

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