Effects of Flux Coated Tungsten Inert Gas Welding on 304L Austenitic Stainless Steel

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Abstract: Tungsten inert gas welding is a popular welding technique in applications in which quality and accuracy are of prime importance. However, TIG welding is limited to materials having thickness of 3mm which leads to lesser productivity when compared to other welding techniques. Various researchers have tried different methods to overcome this limitation and one of these studies resulted in the use of an activating flux applied prior to the welding. In the present investigation, 304L SS was used as base material and an attempt has been made to study the effects of activating flux on weld morphology of welds obtained in the presence and absence of activating flux in Tungsten inert gas welding and mechanical properties of both welds were compared. Microstructure study was carried out to check if there are any changes in the microstructure in the welds obtained from the use of flux. Silicon dioxide (SiO\textsubscript{2}) powder was used as activating flux to study the effects. The experimental results briefly suggest that in the presence of flux, an increase in depth of penetration can be achieved. With the presence of flux during TIG welding, improvement in tensile strength and hardness value was obtained.

1. Introduction

Out of all materials, steel is the most frequently used for different applications. It should be expected that this metal, due to its properties, will remain the most useful and most frequently used material for product manufacturing. As austenitic stainless steel have good resistance to corrosion and better mechanical properties, they are extensively used in high performance pressure vessels, medical industry, nuclear and chemical process industries. AISI 304L is widely used among different grades of stainless steels because of its good resistance to corrosion and great formability. Although, for the several last decades, we have been intensively developing modern welding procedures, such as laser, electron beam and hybrid, their widespread use has yet to be seen. Thanks to its high quality welds, mobility, simplicity and low equipment costs, TIG welding has remained dominant. However the potential problems of TIG welding process lie in the limited thickness of material which can be welded in a single pass leading to low productivity. If the welding current is increased in an attempt to increase the penetration, the weld becomes excessively wide with proportionally little gain in the penetration.

1.1 TIG welding

GTAW or TIG welding process is an arc welding process uses a non consumable tungsten electrode to produce the weld. The weld area is protected from atmosphere with a shielding gas generally Argon or Helium or sometimes mixture of Argon and Helium. A filler metal may also feed manually for proper welding. GTAW most commonly called TIG welding process was developed during Second World War. The use of TIG today has spread to a variety of metals like stainless steel, mild steel and high tensile steels, Al alloy, Titanium alloy. Like other welding system, TIG welding power sources have also improved from basic transformer types to the highly electronic controlled power source today. GTAW is easily performed on a variety of materials, from steel and its alloys to Aluminium, Magnesium, Copper, Brass, Nickel, Titanium, etc. Virtually any metal that is conductive lends itself to being welded using GTAW. Its clean, high-quality welds often require little or no post-weld finishing. This method produces the finest, strongest welds out of all the welding processes. However, it’s also one of the slower methods of arc welding.

1.2 Basic mechanism of TIG welding

Gas Tungsten arc welding (GTAW), also known as Tungsten inert gas (TIG) welding which uses an arc between work piece to be welded and non consumable Tungsten electrode under a shielding gas is an extremely important arc welding process. It has been a popular choice of welding process when a high level of weld quality or considerable precision welding operation is required. It is commonly used for welding hard-to-weld metals such as stainless steel, magnesium, aluminium and titanium. The weld area is protected from atmosphere by an inert shielding gas (helium or argon), and a filler metal is normally used. The power is supplied from the power source (rectifier), through a hand piece or welding torch and is delivered to a tungsten electrode which is fitted into the hand piece. An electric arc is
then created between the tungsten electrode and the work piece using a constant-current welding power supply that produces energy and conducted across the arc through a column of highly ionized gas and metal vapours. The tungsten electrode and the welding zone are protected from the surrounding air by inert gas. The electric arc can produce temperatures of high range and this heat can be focused to melt and join two different part of material. The weld pool can be used to join the base metal with or without filler material. Schematic diagram of TIG welding and mechanism of TIG welding is shown below.

![Figure 1: Schematic Diagram of TIG Welding](image)

1.3 Advantages and limitations of TIG welding

The TIG welding process enjoys widespread use because of its ability to provide high quality welds with higher production rate, for a wide range of ferrous and non-ferrous alloys. TIG welding has the following advantages:

- It has the ability to join a wide range of material types and thicknesses
- TIG welding has higher electrode efficiencies, usually between 93% and 98%, when compared to other welding processes
- Excellent weld bead appearance, minimum of weld spatter and slag, makes the weld clean up fast and easy
- GTAW provides lower heat input when compared to other welding processes
- Forms narrow concentrated arc, due to this weld bead characteristics are easily controlled

This process has some limitations also:

- The higher heat input in TIG welding, generally restricts its use to thicker base materials.
- The use of argon based shielding gas is more expensive than 100% carbon dioxide (CO2)

- Slow welding process amongst all welding processes
- Restricted to weld up to 3 mm thickness stainless steel plates.

TIG welding is chosen over other arc welding processes because of its high-quality weld deposit. The major advantage of the TIG welding process is its improved mechanical and metallurgical properties. TIG welding process was used in welding of thin section of stainless steel materials and welding of the root pass of various components. The major limitations of the TIG welding process are its lack of ability to weld thicker materials in a single pass, poor tolerance to variation in minor element compositions and low productivity. The thickness of stainless steel material that can be welded in a single pass is limited to 3 mm using argon as shielding gas.

Improvements in the penetration have long been sought in many arc-welding processes. One of the most notable techniques is the use of activating flux in TIG welding process. Activated tungsten inert gas (A-TIG) welding process that increases the penetration was first proposed by Paton Electric Welding Institute in the 1960s. Activating flux is a mixture of inorganic material suspended in a volatile medium. A thin layer of flux is applied on the surface of the joint to be welded by brush before welding. A-TIG technique makes it possible to intensify the conventional TIG practices for joining the thickness of 8-10 mm by single pass full penetration welds, with no edge preparation, instead of multipass procedures. In fact, the penetration capability is up to 300% compared with the conventional TIG welding process. [1]

1.4 Working principle of Activated-TIG welding (A-TIG)

A novel variant of the TIG welding process is the activated flux or activated tungsten inert gas (A-TIG) welding process which overcomes the limitations of TIG welding process. In A-TIG welding, a thin coating of an activated flux is applied on the surface of the material prior to welding which leads to a drastic increase in the weld bead penetration. The fluxes are supplied in powder form and are mixed with acetone and painted onto the surface to be welded. The acetone evaporates, leaving a layer of the flux adhering to the surface of the material to be welded. The activated flux applied on the joint area constricts the arc which in turn increases the current density, and the electromagnetic force acting on the molten pool increases the depth of penetration (DOP) compared to that of the conventional TIG welding at the same welding parameters.
The A-TIG welding process is an emerging process for welding of different metals and alloys. The process is gaining importance as the DOP achievable during ATIG welding is 300% more when compared to conventional TIG welding. Increased DOP during A-TIG has been attributed to the constriction of arc as well as the reversal of Marangoni convection. It has been demonstrated that the plate thickness up to 12 mm can be easily welded in a single pass with an increased productivity of 2-4 times. It has been demonstrated that the use of A-TIG welding in stainless steels reduces residual stresses and distortions significantly.

Several mechanisms have been proposed for the improvement in the DOP in A-TIG welding. One of them is arc constriction put forth by Howse and Lucas. This mechanism proposes that the electrons present in the ionized vapors of the flux ingredients are captured at the periphery of the arc and, thus, current flow is restricted to the centre of the arc. Thus, the constricted arc leads to formation of narrow but deeper weld pool. [1] The other mechanism proposed by Heiple and Roper suggests that the positive surface tension gradient generated in the molten weld metal by the addition of elements such as oxygen which can reverse the surface tension of the molten weld metal by the addition of elements such as oxygen which can reverse the surface tension gradient produces a strong inward fluid flow; this reversed mode of Marangoni convection current transfers heat towards the root of the weld pool resulting in narrower and deeper weld. [2]

2. Literature Survey

Huang recommended TIG welding for quality welds with good surface finish. TIG welding offers clean weld metals since no flux is used like in other fusion welding processes and the use of inert gas for shielding precludes oxygen getting into the weld metal in any form. When used correctly, this process facilitates welding in all positions and enables excellent control over the weld pool. [3]

Tseng et al investigated the effect of activated tungsten inert gas (activated TIG) process on weld morphology, angular distortion, delta-ferrite content, and hardness of 6 mm thick 316L austenitic stainless steels. Five kinds of oxide fluxes, MnO2, TiO2, MnO3, SiO2 and Al2O3 were used. The experimental results indicated that the SiO2 flux facilitated root pass joint penetration, but Al2O3 flux led to the deterioration in the weld depth and bead width compared with conventional TIG process. Activated TIG welding can increase the joint penetration and weld depth to width ratio, thereby reducing angular distortion of the weldments. On the basis of the present results, it is considered that the centripetal Marangoni convection and constricted arc plasma as a mechanism in increasing the penetration of activated TIG joint. The arc voltage developed with SiO2 flux is higher than those with other flux powders. [4]

Kuang-Hung Tseng investigated new activated flux developed at National Pingtung University of Science and Technology (NPUST) to systematically investigate the influence of oxide-based flux powder and carrier solvent composition on the surface appearance, geometric shape, angular distortion, and ferrite content of austenitic 316L stainless steel tungsten inert gas (TIG) welds. The flux powders comprising oxide, fluoride, and sulphide mixed with methanol or ethanol achieved good spreadability. For the investigated currents of 125 to 225 A, the maximum penetration of stainless steel activated TIG weld was obtained when the coating density was between 0.92 and 1.86 mg/cm2. The depth of finger-like profile in the conventional TIG weld increased in conjunction with the current because of the induced strong arc pressure. The arc pressure also raised the penetration capability of activated TIG welds at high currents. The results show that higher current levels have lower ferrite content of austenitic 316L stainless steel weld metal than lower current levels. [5]

Lin and Wu indicated the role of TIG welding in producing components for aerospace, military, power plants, and automotive industries. They investigate the effects of activating fluxes and welding parameter to the penetration and depth-to-width ratio (DWR) of weld bead of Inconel 718 alloy welds in the tungsten inert gas (TIG) welding process. In addition, the experimental procedure of flux-bounded TIG (FB-TIG) welding with the same welding conditions and flux produced full penetration of weld bead on a 6.35mm thickness of Inconel 718 alloy plate with single pass weld. [6]

Sakthivel et al. claimed that only about 3 mm of full penetration can be achieved in a single pass welding while welding stainless steels with TIG welding. Creep rupture behaviour of type 316L(N) austenitic stainless steel base metal and its weld joints fabricated both by single-pass activated TIG (A-TIG) and multi-pass conventional TIG (MP-TIG) welding processes were studied. The A-TIG weld
joint displayed higher rupture lives than the MPTIG weld joint. [7]

Morisada et al. identified the limitation of TIG welding in welding thicker sections due to its shallow penetrating characteristics. A new advanced active flux tungsten inert gas (AA-TIG) welding technique, named cap active flux tungsten inert gas (CA-TIG) welding using atmospheric oxygen, was proposed to increase the penetration depth of a weld. The penetration depth was increased by the reversal of the Marangoni convection due to the entrained oxygen, and it reached three times deeper than that of the conventional TIG welding. Additionally, no degradation of the tungsten electrode was observed because it was protected by the inert gas. [8]

Chern et al. investigated the effects of the specific fluxes used in the tungsten inert gas (TIG) process on surface appearance, weld morphology, angular distortion, mechanical properties, and microstructures when welding 6 mm thick duplex stainless steel. They identified that additional advantages are offered by A-TIG welding, such as improvement in mechanical strength and reduction in angular distortion. [9]

3. Experimentation

3.1 Applications and chemical composition of SS304L

Because of corrosion resistive properties of austenitic stainless steels it is attractive candidate materials for use in industries such as

1. Domestic tool industry: For manufacturing of refrigerators, tabletops, stoves, pots, pans, flatware, coffee urns etc.
2. Brewing industries: It is used for manufacturing of pipelines, yeast pans, fermentation vats, storage, railway cars etc.
3. Shipping and aeronautical industries: Because of high wear resistance stainless steel is used for manufacturing of panels, nut, bolts, screws and other fasteners.
4. Nuclear power plant: Because of high corrosion resistance stainless steel is used for manufacturing of heat exchangers, storage tanks etc.

Table 1: Chemical composition of the SS 304L plate

<table>
<thead>
<tr>
<th>Alloy elements</th>
<th>Weight %</th>
</tr>
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<tbody>
<tr>
<td>C</td>
<td>0.06</td>
</tr>
<tr>
<td>Si</td>
<td>0.42</td>
</tr>
<tr>
<td>Mn</td>
<td>0.032</td>
</tr>
<tr>
<td>S</td>
<td>0.014</td>
</tr>
<tr>
<td>Cr</td>
<td>18.67</td>
</tr>
<tr>
<td>Ni</td>
<td>8.53</td>
</tr>
<tr>
<td>Fe</td>
<td>Balance</td>
</tr>
</tbody>
</table>

3.2 Welding process variables

The values of control variables are fixed based on the specification of welding machine, thickness of the material and available literature. They are presented in table number 2.

<table>
<thead>
<tr>
<th>Table 2: Welding process variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Welding voltage</td>
</tr>
<tr>
<td>Electrode tip angle</td>
</tr>
<tr>
<td>Shielding gas</td>
</tr>
<tr>
<td>Oxide flux powder</td>
</tr>
<tr>
<td>Root gap</td>
</tr>
<tr>
<td>Weld configuration</td>
</tr>
<tr>
<td>Filler material</td>
</tr>
<tr>
<td>Electrode diameter</td>
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</table>

3.3 Experimental procedure

Activated flux is comprised of the metallic oxides and halides. Metallic oxides are Cr₂O₃, TiO₂, and SiO₂ etc. These fluxes are commercially available in the form of powder. Silicon dioxide flux powder of 40 - 150 meshing (105-420 microns) along with acetone (pure acetone for laboratorial purpose) is used as suspension medium. The uniform mixture of silicon dioxide flux and acetone is made in flask. Before welding a thin layer of this mixture was brushed on to the joint of plates. The coating density of the flux was about 5-6 mg/cm² or of 0.2 mm thickness.

4. Result and discussion

The specimens for tensile testing, hardness testing and microstructural studies were taken as per specifications given in schematic diagram. From
both sides 5mm material is discarded to remove defects in weld pool at start and end of welding. Sample 1 is for tensile test, sample 2 is for metallographic test and sample 3 is for hardness test.

Specimens for tensile test were prepared and the size of these specimens was decided as 300 mm x 20 mm x 6 mm. The specimens of dumbbell shaped were made for tensile testing according to ASME section IX.

4.1 Effect on depth of penetration

Depth of penetration obtained by conventional TIG welding process was 3mm and almost complete depth of penetration of about 6mm was obtained by Activated-TIG welding process. From figure 5 shows the macrostructure of welds obtained by without flux and without flux respectively and it can be clearly seen that the weld width was more without flux as compared to with flux with respect to the depth of penetration.

4.2 Effect on mechanical properties

Figure 7 presents the experimental results for the tensile strength and hardness value of weld joints obtained by using conventional TIG welding
and Activated-TIG welding. It can be clearly seen that the weld joint made by using Activated-TIG welding exhibit better mechanical properties compared to conventional TIG welding.

4.3 Study of microstructure

Microstructure study was done to check if there is any degradation in the weld zone because of the use of flux. Microstructure of plate shows annealed structure with ferritic matrix whereas microstructure of HAZ shows coarse mixed grain and microstructure of weld zone shows transformed structure with dendritic pattern. There was no degradation in microstructure of weld zone with the use of flux when compared to conventional TIG weld.

![Figure 8: Microstructure of (a) plate, (b) heat affected zone, (c) weld zone](image)

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5. Conclusion

1. Depth of penetration obtained by Activated-TIG welding was more compared to conventional TIG welding. It can be seen that depth of penetration was 200% more in Activated-TIG welding compared to conventional TIG welding.

2. Weld obtained by conventional TIG welding was shallow and wide whereas weld obtained by A-TIG welding was deep and narrow. Due to shallow and wide weld, there was more welding distortion in conventional TIG welding.

3. Tensile strength and hardness value of the weld joint was more in Activated TIG welding. Weld joint obtained by A-TIG welding exhibit better mechanical properties compared to conventional TIG welding.

4. There was no degradation in microstructure of welds made by addition of flux during TIG welding when compared to the microstructure of weld obtained in TIG welding without addition of flux.

REFERENCES


