Optimizing of TIG welding parameters of Aluminium alloy (AL6061-T6)

Manpreet Singh¹, Navjot singh², Jujhar Singh³

¹M. Tech. scholar, Mechanical Engineering Department, Rayat Bahra Institute of Engineering and Bio-Technology, Mohali, Punjab
²Asstt Prof., Mechanical Engineering Department, Rayat Bahra Institute of Engineering and Bio-Technology, Mohali, Punjab
³Asstt Prof., Mechanical Engineering Department, IKG Punjab Technical University, Kapurthala, Punjab

ABSTRACT

Aluminium and its alloys play a critical role in engineering material field; Due to its light weight and resistance to corrosion. Aluminum has become one of the leading materials used by industry where steel or other high strength materials are under question. The welding of aluminium alloys is challengeable by conventional arc welding processes and generally welded by Tungsten Inert Gas (TIG) welding. This TIG welding is limit due to low welding strength of 35-50 percent of the base metal. An attempt has been made to achieve better mechanical properties of welded joint that are closer to the properties of base metal. The performance is measured in terms of ultimate tensile strength with varying parameters like welding current, shielding gas flow rate and preheating. Microstructural characterization of welded joint was carried out to understand the structural property correlation with process parameters. The results show that with increase in welding current and gas flow rate, the tensile strength of welding joint is increases.

Keywords: TIG Welding, welding current, tensile strength, HAZ.

1. INTRODUCTION

Aluminium and its alloys play a critical role in engineering material field. Aluminium is a strongly electro-negative metal and possesses a strong affinity for oxygen; this is apparent from the high heat of formation of its oxide. For this reason, it is isolated until well into the nineteenth century although it is among the six most widely distributed metals on the surface of the earth Sheasby and pinner (2001). In the domain of joining processes of aluminum and its alloys, the tungsten inert gas (TIG) welding process continues its apex position due to its versatility and flexibility in adaptation. Chennaiah (2015).

Tungsten Inert Gas (TIG) or Gas Tungsten Arc welding (GTAW) is the arc welding process in which arc is generated between non-consumable tungsten electrode and work piece. The shielding gas protects the tungsten electrode and the molten metal weld pool from the atmospheric contamination. According to Singh (2006) the shielding gases generally used are argon, helium or their mixtures. A constant current AC power source with a continuous high frequency is used with air water or air-cooled TIG torch. The electric arc can produce temperatures of up to 19,400ºC and this heat can be much focused as local heat.

Zhang et.al (2016) investigated the comparison of microstructure and mechanical properties of TIG and laser welding joints of a new Al–Zn–Mg–Cu alloy with the thickness of 2mm was selected as the base metal (BM). For the TIG welding, an Al–Mg alloy with the diameter of 1.6 mm was used as filler wire; for the laser welding, none filler metal was used. After welding, the defects in the joint were investigated using X-ray radiography and macrograph of the cross-section of joints was observed using a stereoscopic microscope. Results shows the ultimate tensile strength of TIG and laser joints is about 436.2Mpa and 471.1Mpa, and the elongation of them is about 7.5% and 5.1% respectively. Leo et.al (2016) studied the role of post weld heat treatment (PWHT) on microstructure and mechanical properties of hybrid welding of the annealed AA5754 alloy. The microstructure and hardness of the base material and welds were analyzed. Ultimate tensile strength of weld with PWHT at temperature 350º shows state 19% greater with respect to the untreated weld and similar to that of BM. Therefore, a targeted PWHT can improve the mechanical strength of AA5754 laser hybrid weld. Untreated and PWHT
Thakur et al. (2016) presented a review on influence of TIG welding parameters and stated the important parameters for strength of TIG welding of Aluminium structures. Kumar et.al (2015) studied the mechanical and micro structural properties of aluminium alloy AA6061 welded by TIG welding size 200 mm x 150 mm x 6 mm welding using the filler wire as AA-4047. The aluminum alloy plates were joined by TIG welding technique to examine micro hardness, microstructure of weld and surface roughness of welded specimen. Results showed that optimum weld current out of the three weld currents used (140A, 150A and 160A) was 160A. The micro-hardness of the welded part welded at 160 amperes was increased by 6% and 16% as compared to the welding carried out at 140 ampere and 150 ampere and the surface roughness value was less at the welding current as 160 ampere. Chennaiah et.al (2015) investigated the effect of Pulsed TIG Welding Parameters on the Microstructure and Micro-Hardness of AA6061 Joints. Results showed that the effect of pulse frequency on the micro hardness is determined by pulse duration and peak current. The micro hardness (HV100) of the weld metal produced using 160 A peak current for 4 ms pulse duration showed that increase in pulse frequency from 0 to 25 Hz decreases the micro hardness up to 64.80 HV followed by continuous increase in the hardness 84.68 HV at 100 Hz pulse frequency. Ishak et.al (2015) studied the effect of filler on weld material structure of AA6061 aluminum alloy by tungsten inert gas welding. This study presented an appropriate welding filler to join similar AA6061 aluminum alloys using the tungsten inert gas (TIG) process. The TIG welding of AA6061 was butt joined with three different fillers: ER5356, ER4043 and ER 4047. It was found that welding by using filler ER5356 produced a finer grain size and the highest strength of 171.53 Mpa compared to the weld joints using fillers ER4043 and ER4047 with values of 167.34 Mpa and 168.03 Mpa, respectively.

Zhu et.al (2014) studied AA2219 aluminum alloy was successfully welded by variable polarity tungsten inert gas (TIG) welding, and the effect of post weld heat treatment (PWHT) process on the microstructure, mechanical properties, and corrosion behavior of the welded joints was investigated. The results showed that, by implementing PWHT, the microstructure of the joint was more homogeneous than the welded joint. Meanwhile, the tensile strength was increased by 44% and the joint efficiency reached 76%. Moreover, the corrosion resistance of the PWHT joint was superior to that of the welded joint. Rao and Deivanathan (2014) analyzed and optimization of joining similar grades of stainless steel by TIG welding. The parameters like current, filler materials and welding speed was the variables in the study. Welding was performed in single pass by the manual gas tungsten arc welding procedure with direct current electrode negative (DCEN), using Argon gas shielding. Three different stainless steel filler rods, namely 316L, 347L and 309L were used to weld three pairs of SS310 plates respectively and three current ranges 80,100,120 was used for experiment. The mechanical properties and microstructure of 310 austenitic stainless steel welds was investigated which shows that Welding current 120A and electrode 309L has produced greater tensile strength of 454.6MPa while a welding current 80A and electrode 316L has produced minimum tensile strength of 51.79MPa.

Patel and Patel(2014) have analyzed the effect of TIG welding parameters such as welding current, gas flow rate, welding speed, that are influences on responsive output parameters such as hardness of welding, tensile strength of welding, by using optimization philosophy. The efforts were taken to investigate optimal machining parameters and their contribution on producing better weld quality and higher productivity. Narayanan et.al (2013) found out the Influence of Gas Tungsten Arc Welding Parameters in Aluminium 5083 Alloy welding with different flow rate of gas and different welding current 200 and 250A. After welding, tensile testing, Micro hardness testing and Macrostructure and Microstructure study tests was done on specimen. From this study it was shown that maximum ultimate strength is 281MPa, hardness of weld metal is 73.5 HVN at welding current 200A and gas flow rate 15 LPM. Jabbari (2013) studied the Effect of the Preheating Temperature on Process Time in Friction Stir Welding of Al 6061-T6. In this study an analytical model was developed to simulate the contact Temperature in the friction stir welding (FSW).This second order equation which contains thermal characteristics and welding parameters was compared and validated by experimental data in the literature. The effect of the preheating temperature on the process time was investigated. The results show that the increase of the preheating temperature not only develops the weld quality, but it also decreases the total process time.

Liua et.al (2012) investigated the mechanical properties and Microstructural features of aluminum 5083 (Al 5083) weldments processed by gas tungsten arc welding (GTAW) and gas metal arc welding (GMAW). Weldments processed by both methods were mechanically softer than the parent material Al5083 and could be potential sites for plastic localization. It was revealed that Al5083 weldments processed by GTAW are mechanical more reliable than those by GMAW. Liu et.al (2011) Tungsten inert gas weld was carried out on super-light magnesium-lithium alloy plates with a thickness of 2 mm, using argon gas as a protecting atmosphere. The microstructure and mechanical properties of the welded joints were investigated. The results indicate that the microstructure in the fusion zone is fine, and the microstructure in the heat-affected zone is coarser than the parent metal. The tensile strength of the welded joint is about 84% that of the parent metal.
Hussain et al. (2010) investigated the effect of welding speed on tensile strength of the welded joint by TIG welding process of AA6351 Aluminum alloy of 4 mm thickness. Welding was done on specimens of single V butt joint with welding speed of 1800 - 7200 mm/min. From the experimental results it was revealed that strength of the weld zone is less than base metal and tensile strength increases with reduction of welding speed.

Kumar and Sundarrajan (2009) investigated the improvement of mechanical properties of AA 5456 Aluminum alloy welds through pulsed tungsten inert gas (TIG) welding process. Taguchi method was employed to optimize the pulsed TIG welding process parameters of AA 5456. Analysis of variance was employed to check the adequacy of the developed models. The effect of planishing on mechanical properties was also studied and observed that, there is 10–15% improvement in mechanical properties after planishing. This is due to fact that, internal stresses are relieved or redistributed in the weld. Microstructures of all the welds were studied and correlated with the mechanical properties. Lakshmi Narayanan (2009) found out the effect of welding processes such as GTAW, GMAW and FSW on mechanical properties of AA6061 aluminium alloy. Rolled plates of 6 mm thickness have been used as the base material for preparing single pass butt welded joints. The filler metal used for joining the plates is AA4043 (Al-5Si (wt. %)) grade aluminium alloy. In this work, tensile properties, micro hardness, microstructure and fracture surface morphology of the GMAW, GTAW and FSW joints was evaluated, and the results was compared. From this review, it is found that FSW joints of AA6061 Aluminium alloy showed superior mechanical properties.

2. EXPERIMENTAL WORK

The material under investigation is 6.00 mm thick Aluminium alloy 6061-T6. A non-consumable tungsten electrode of 3.15 mm shielded by argon gas is used to strike the arc with base metal. Filler rods (2.6 mm) of Aluminium alloy 4047 are recommend for welding of this alloy for getting maximum strength. The chemical composition of base metal and filler rod are tabulated in Table 1-4. Sample plates of size 110 x 40 x 6mm were prepared by milling machine. TIG 250 AC welding set is used in experiments as it will be provide required welding current, voltage, required flow rate of argon gas which concentrates required heat input in the welding area. In order to remove oil, moisture and oxide layer from base metal, they were thoroughly wire brushed, cleaned with acetone and preheated at 150°C in the muffle furnace to preheat the samples before welding. The preparation of specimen for welding and parameters are discussed in following subsections.

Composition and mechanical properties of the base material and filler metal

Table 1: Composition of the base material Al 6061-T6

<table>
<thead>
<tr>
<th>Element</th>
<th>silicon</th>
<th>copper</th>
<th>iron</th>
<th>manganese</th>
<th>magnesium</th>
<th>chromium</th>
<th>zinc</th>
<th>titanium</th>
<th>other elements</th>
<th>aluminium</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>0.64-0.67</td>
<td>0.23-0.24</td>
<td>0.31-0.33</td>
<td>0.06-0.07</td>
<td>1.04-1.07</td>
<td>0.04</td>
<td>0.07-0.08</td>
<td>0.15</td>
<td>remainder</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Properties of base metal Al 6061-T6

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultimate Tensile Strength</td>
<td>310Mpa</td>
</tr>
<tr>
<td>Yield Strength (0.2% Offset)</td>
<td>270Mpa</td>
</tr>
<tr>
<td>Elongation</td>
<td>15 %</td>
</tr>
<tr>
<td>Modulus of Elasticity</td>
<td>70-80Gpa</td>
</tr>
<tr>
<td>Thermal Conductivity at 77°F</td>
<td>152 W/m K</td>
</tr>
<tr>
<td>Vickers micro hardness</td>
<td>120VHN</td>
</tr>
<tr>
<td>Melting Point</td>
<td>Approx. 580°C</td>
</tr>
<tr>
<td>Density</td>
<td>2.7 g/cm³</td>
</tr>
<tr>
<td>Co-Efficient of Thermal Expansion (20-100°C)</td>
<td>23.5x10-6 m/m °C</td>
</tr>
</tbody>
</table>

Table 3: Composition of filler wire 4047

<table>
<thead>
<tr>
<th>Element</th>
<th>Silicon, Si</th>
<th>Iron, Fe</th>
<th>Copper, Cu</th>
<th>Zinc, Zn</th>
<th>Manganese, Mn</th>
<th>Magnesium, Mg</th>
<th>Remainder (each)</th>
<th>Aluminum, Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content (%)</td>
<td>11-13</td>
<td>0.80 max</td>
<td>0.30 max</td>
<td>0.20 max</td>
<td>0.15 max</td>
<td>0.10 max</td>
<td>0.15</td>
<td>Remainder</td>
</tr>
</tbody>
</table>
Table 4: Welding process parameter for experimentation

<table>
<thead>
<tr>
<th>SR.NO</th>
<th>PARAMETER</th>
<th>RANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Welding current</td>
<td>80,100,120 Amp</td>
</tr>
<tr>
<td>2</td>
<td>Voltage</td>
<td>20V</td>
</tr>
<tr>
<td>3</td>
<td>Gas flow rate</td>
<td>8, 10, 12 LPM</td>
</tr>
<tr>
<td>4</td>
<td>Preheating temperature</td>
<td>50,100 ºC</td>
</tr>
<tr>
<td>5</td>
<td>Electrode material</td>
<td>98% W + 2% Zr</td>
</tr>
<tr>
<td>6</td>
<td>Electrode diameter</td>
<td>3.15mm</td>
</tr>
<tr>
<td>7</td>
<td>Filler rod</td>
<td>Al 4047</td>
</tr>
<tr>
<td>8</td>
<td>Filler rod diameter,</td>
<td>2.6 mm</td>
</tr>
</tbody>
</table>

Specimens preparation

In this experiment the work pieces of aluminium alloy 6061-T6 are prepared according to American Society of Mechanical Engineers (ASME). Total 36 rectangular shape plate pieces are cut into a dimension of 110 x 40 x 6mm by hydraulic press machine. After cutting the pieces, the edge preparation is done by grinding machine, to make V shape groove of 60º for the proper penetration of weld metal. Pictorial view of specimen shown in Figure 1.

![Figure 1: Pictorial view of specimen before welding](image1)

Welding procedure

First of all the specimen are cleaned of dirt, grease and other foreign materials by using cleansing agents, dirt removers or other re-agents. After cleaning of work pieces, welding set-up is prepared and tested. Further, the parameters are adjusted according to required level and made ready for welding. Then two pieces are taken which are set up in such a way so as to maintain a 2 mm root gap. Then 18 numbers of welded samples are made by carrying out welding with different levels of current, gas flow rate and preheating of samples. A photographic view of welded specimen for testing are shown in Figure 2 shows the samples for tensile test.

![Figure 2: Pictorial view of a welded specimen for testing](image2)

3. RESULTS AND DISCUSSIONS

Tensile test results

Tensile test is performed on AIMIL universal testing machine, to examine the regions from where failure/fracture has occurred and to find tensile test of the welded samples. The tensile test results indicate that for most of the samples, tensile strength is satisfactory. The different parameters have an different effect on the tensile strength of the welded joint. Each specimen is tested for a particular parametric range and each parameter participates in the tensile strength of the specimen. Table 5 shows the percentage effect of different parameters on tensile strength of the joint.
Table 5: ANOVA results for tensile strength

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>DF</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Percentage effect (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>1533.056</td>
<td>3</td>
<td>511.0188</td>
<td>80.23542</td>
<td>-</td>
</tr>
<tr>
<td>A- Welding Current</td>
<td>693.12</td>
<td>1</td>
<td>693.12</td>
<td>108.8273</td>
<td>45.02</td>
</tr>
<tr>
<td>B- Gas Flow Rate</td>
<td>692.3602</td>
<td>1</td>
<td>692.3602</td>
<td>108.708</td>
<td>44.98</td>
</tr>
<tr>
<td>C- Preheating</td>
<td>147.5762</td>
<td>1</td>
<td>147.5762</td>
<td>23.17104</td>
<td>9.59</td>
</tr>
<tr>
<td>Residual</td>
<td>89.1659</td>
<td>14</td>
<td>6.368993</td>
<td>-</td>
<td>0.41</td>
</tr>
<tr>
<td>Total</td>
<td>1622.22</td>
<td>17</td>
<td>-</td>
<td>-</td>
<td>100</td>
</tr>
</tbody>
</table>

The percentage effect of each parameter on tensile strength is shown in Figure 2. It can be clearly seen that tensile strength is mostly influenced by the welding current. In pie chart, 45.02% of the region is covered by the welding current. Gas flow rate is the second parameter which contributes almost same (44.98%) as welding current on the tensile strength. Preheating has very less effect (9.59%) on the tensile strength. Rest of the region in Figure 3 shows the effect of errors found less than 1%.

![Pie chart showing percentage of different parameters in contribution to the tensile strength](image)

Figure 3: percentage of different parameters in contribution to the tensile strength

Effect of welding current and gas flow rate on tensile strength

The effect of welding current and gas flow rate on tensile strength of the welding joint varies directly with welding current as shown in the Figure 3. A change in welding current and gas flow rate show a relative change in tensile strength. However the increase in gas flow rate showed increase in tensile strength. When the current is reduced even for higher levels of gas flow rate it is found that a marginal decrease in tensile strength is observed. Hence an optimal range of gas flow rate is found in the range of 10-12 LPM for economical welding strength. But for high current, the effect of gas flow rate cannot be rejected. It protected the weld surface to come in direct contact of air, which can contaminate the welding region and cause poor weld joint.

![3D graph showing effect of welding current and gas flow rate on tensile strength](image)

Figure 4: Effect of welding current and gas flow rate on tensile strength

Figure 4 shows the effect of shielding gas flow rate of 8 LPM, 10 LPM and 12 LPM on tensile strength of weld joint for different current levels of 80 A, 100 A and 120 A. It seen from the figure 4 that tensile strength of welded joint is increases by the change in shielding gas flow rate in increasing order till the maximum value of 12 LPM reached that shows the
maximum tensile strength of 202.69MPa, 198.13Mpa and 185.86Mpa for weld joint at 100°C preheat. This graph revealed that with the increase in both gas flow rate and welding current, tensile strength of welded joint is increases up to optimum level. Maximum value of tensile strength is achieved at 12 LPM when optimal range of welding current was used.

**Effect of preheating and gas flow rate on the tensile strength**

The effect of preheating and gas flow rate on tensile strength of the welding joint varies as shown in Figure 5.

![Figure 5: Effect of preheating and gas flow rate on tensile strength](image)

Figure 5 shows the effect of shielding gas flow rate on tensile strength of weld joint at constant current for both preheated temperatures i.e. 50°C, 100°C. It shows that tensile strength of welded joint is increases by the change in shielding gas flow rate in increasing order till the maximum value of 12 LPM reached. It shows the maximum tensile strength of 194.5MPa for weld joint at 50°C preheats and 202.69Mpa for the 100°C preheated samples. From the above results it is revealed that with increase of gas flow rate and preheats of samples the tensile strength of welded joint is increases.

**Effect of welding current and preheat on tensile strength**

Welding current is the main parameter which contributes most to the tensile strength of a welded joint. An increase in welding current has a huge impact on tensile strength compared to preheating temperature. The effect of preheating of samples is less but cannot be ignored as it is an important parameter to make a good welded joint. The effect of preheating on tensile strength is shown in figure 6.

![Figure 6: Effect of welding current and preheat on tensile strength](image)

Figure 6 shows the effect of welding current on tensile strength of weld joint for both 50°C and 100°C temperature preheated samples. As welding current increases for a constant value gas flow rate of 12 LPM, the tensile strength increases till a maximum value of 194.5Mpa for current value of 120A, with 50°C preheating temperature, on the other hand for 100°C preheating temperature its maximum value is found to be 202.69Mpa.
Microstructure Analysis

Microstructural characterization study is conducted on metallographically polished and chemically etched samples to investigate morphological characteristics of grains and secondary phases. Micrographs of welded pieces are taken with the help of Leica microstructure tester at IIT ROPAR. Etchant used for etching is a mixture of 25 ml methanol, 25 ml hydrochloric acid, 25ml nitric acid and 1 drop of hydrofluoric acid is used for 10-20 seconds on tests samples. After 10-20 sec the samples are washed with water and dried with air dryer. These samples have been studied under Leica microscope and microstructures of base metal, heat affected zone (HAZ) and weld metal are studied to check the difference in microstructure after welding and photographs are taken. The microstructure of base metal is shown in figure 9 and different welded samples it is shown in figures 10-13.

Figure 7: Microstructure of base metal Al 6061-T6 at 50X

Figure 8: Microstructure of welded sample 1 at 20X and 50X

Figure 9: Microstructure of welded sample 18 at 20X and 50X

Figure 10: Microstructure of welded sample 16 at 20X and 50X
The micrograph as shown in figure 7 is for sample number 18 with the maximum tensile strength of 202.69Mpa at 120A welding current and at 12 LPM gas flow rate. From this micrograph it is clearly revealed that with the increase in input current and gas flow rate and with preheating of samples the grain structures is refined with closely packed grains, due to which tensile strength of welded joint at high current is higher than welded joints at lower welding current and gas flow rate. Unlike that of the base metal weld zone and HAZ, has fine and equiaxed grains and the grain size is much smaller than that of the BM. This structure is produced by the recrystallization and static grain growth after welding.

CONCLUSIONS

In the present work, butt welding of aluminium alloy 6061-T6 is carried out by tungsten inert gas (TIG) welding, at various levels of welding current, gas flow rate and preheat of samples. The responses considered are the ultimate tensile strength and Microstructure of joints. Based on the experimental results the following conclusions are drawn.

- Optimum parameter setting for tensile strength is obtained at welding current of 120A, gas flow rate of 12LPM and preheating temperature of 100ºC with a maximum tensile strength 202.69Mpa.
- For tensile strength the percentage contribution of gas flow rate is 44.98% and welding current is 45.02%.
- Different welding input parameters have changed the microstructure of welded joint.
- The microstructures with elongated and fine grains have higher tensile strength than others.

REFERENCES


