TO STUDY THE MECHANICAL AND MICRO-STRUCTURAL PROPERTIES OF ALUMINIUM ALLOY AA-6061 WELDED BY TIG WELDING AT DIFFERENT WELDING CURRENT

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Abstract—Tungsten Inert Gas welding is one of the techniques which are widely used for joining the ferrous and non-ferrous metals. TIG welding process also has the advantages in the joining unlike metals. This paper deals with the study of the structural and mechanical properties of the aluminium alloy AA-6061 at different values of welding current. During the experiment welding current used as a variable parameter and the gas flow rate kept as constant. The value of optimum welding current was finding out of the three welding current. Welded specimens were investigated using optical microscopy, Vickers micro-hardness test and surface roughness tester. Optical microscopy test was used to characterize the microstructure of the base metal and of the welded zone and micro-hardness test was conducted to characterize the homogeneity of the welding and the surface roughness test was conduct to check the roughness of the welded surface.

Keywords—Aluminium alloy AA-6061, welding current, gas flow rate, TIG welding, Micro-structure, Micro-hardness, Surface roughness.

I. INTRODUCTION

TIG welding is the process of joining different materials with or without the help of filler electrode. In the TIG welding there is the use of non-consumable tungsten electrode. The TIG welding technique was discovered in 1930’s by the Russell Meredith during the Second World War. It was used for the welding of aluminum and magnesium in the air craft industry. The welding takes place due to the electric arc generation between the electrode and the work piece in the presence of inert gas which shielded the welded area during welding. Mostly Argon, Helium and there mixtures are preferred to use as a shielding gas for the better welding because these gases does not chemically react or combine with each other. The purpose of shielding is to transfer the heat from electrode to the metal and also helps to start and maintain a stable arc due to low ionization potential. To avoid the harmful side effects of the welding proper consideration should be given to the selection of process and to the design of the joint. High quality weld can be achieved with the selection of a good process variable which to be utilised. The present work deals with the study of mechanical and micro-structural properties of the aluminium alloy welded joint by using TIG welding on keeping the gas flow rate as constant and welding current as a variable.

II. LITERATURE REVIEW

Mayur [1] investigated the structural and mechanical properties of aluminum alloy AA-5083 of size 125 mm x 60 mm x 3 mm after single pass Tungsten Inert Gas welding using the filler wire as AA-5356. The aluminum alloy plates were joined by TIG welding technique to examine optimal welding current. Welded specimens were investigated using optical microscopy, tensile and Vickers’s micro-hardness tests. Optical microscopy was used to characterize transition sites of welded zone, HAZ and base metal. Results have shown that optimum weld current out of the three weld currents used (70A, 75A and 80A) is 75A. Better microstructure and mechanical properties were found in the welded joints for the weld current 75A.

Kareem [2] in this research the study of microstructure and mechanical properties of aluminum alloy AA-5052 having the thickness as 6 mm welded by MIG, TIG and friction stir welding processes was take place. From the investigation it was shown that the weldments processed by GTAW of aluminum alloy AA-5052 are mechanically more reliable than welded by GMAW. Perceivable porosity in the weldments done by GMAW was found. Friction stir welded samples have more strength than that
of MIG welded samples. The weld metal microstructure of MIG welded specimen contains equiaxed dendrites as a result of solidifications process during MIG welding while friction stir welded specimen have wrought microstructure. 

Hussain [3] investigated the effect of welding speed on the tensile strength of the welded joint. The experiments were conducted on specimens of single V butt joint having different bevel angle and bevel heights. The material selected for the specimens were aluminum alloy AA-6351. The tests were conducted on the universal testing machine. The results show that the depth of penetration of weld bed decreases with increase in bevel height of V butt joint. Maximum tensile strength was observed at weld speed of 0.6 cm/sec. It means strength of weldment is weaker than the base metal. The heat affected zone, strength increased with decreasing heat input rate. 

Sivashanmugam [4] have investigated the mechanical properties and microstructure of the aluminum alloy AA-7075 having size 300 mm x 150 mm x 6 mm by using the different welding techniques GTAW and GMAW with argon as a shielding gas. A constant current AC power source with a continuous high frequency is used with water or air cooled GMAW torch. The torch must be maintained at an angle of 90 degree to the work piece and the filler material must enter the weld pool at an angle of typically 5 degree. Surface Mechanical properties of the joint like tensile strength, hardness and impact strength have been found out. Welded joints fabricated by GMAW process have lower strength than the GTAW process. Hardness is lower in the weld metal region compared to the HAZ and BM region. High hardness is recorded in the GTAW. The impact strength value is more in GTAW as 6 J than the GMAW as 4 J. 

Naitik [5] have found out 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 effort to investigate optimal machining parameters and their contribution on producing better weld quality and higher productivity. 

Indira [6] have investigated the mechanical properties of the welded aluminum alloy AA-6351 during the Gas Tungsten Arc Welding (GTAW)/Tungsten Inert Gas (TIG) welding with non-pulsed and pulsed current welding at two different frequencies 3 Hz and 7 Hz. The specimens were selected of size 300 mm x 150 mm x 6 mm. The welding was performed with a current of 70A-74A and arc travel speed was 700-760 mm/min. AA-6351 have more ultimate tensile strength with the pulsed current welding frequency of 3 Hz. Pulse welding provide the better depth of penetration and fusion of filler material with parent metal is obtained and by this it improves strength and ductility of weldments.

III. MATERIAL SELECTION FOR TIG WELDING

In this paper a heat treatable aluminium alloy AA-6061 T651 which is mainly used for the construction of yachts, motorcycles, and in marine equipments has been used. This material in the form of rectangular sheet of the size 800 mm x 150 mm x 6 mm was purchased from M/s Mahindra Prakash Ram Prakash, chawri bazaar Delhi (India). The cutting of the material was done in the small pieces of size 200 mm x 150 mm x 6 mm as shown in figure 1. The chemical composition of the aluminium alloy AA-6061 is shown in table 1.
Figure 1 Test specimens of aluminium alloy AA-6061 T651

These surfaces of the plates were cleaned from the grease, dirt and the other foreign material by using the dirt removers, cleaning agents and other re-gents. The edges of the plates were prepared by the grinding process to make them smooth for the welding. Now the plates were to be placed on the welding table for the welding process.

**Table 1. Chemical composition of the aluminium alloy AA-6061:**

<table>
<thead>
<tr>
<th>Element</th>
<th>Silicon</th>
<th>Iron</th>
<th>Copper</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>Comp(%)</td>
<td>0.64-0.67</td>
<td>0.31-0.33</td>
<td>0.23-0.24</td>
<td>0.06-0.07</td>
<td>1.04-1.07</td>
<td>0.04</td>
<td>0.07</td>
<td>0.07-0.08</td>
<td>Each 0.05</td>
<td>Total 0.15 Remainder</td>
</tr>
<tr>
<td>Ultimate Tensile Strength:</td>
<td>301 Mpa</td>
<td></td>
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<td></td>
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<tr>
<td>Yield Strength (0.2% Offset):</td>
<td>250 Mpa</td>
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<td></td>
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<td></td>
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<td></td>
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<tr>
<td>Elongation %</td>
<td>15</td>
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</tr>
<tr>
<td>Thermal Conductivity at 77°F:</td>
<td>152 W/m K</td>
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</table>

IV. TIG WELDING MACHINE SETUP

For this experiment the TIG welding set up is available at Kewal welding works, Ludhiana (India). The grinding was done on the tungsten electrode to prepare it for the welding. The used tungsten electrode having 2% Thoriated tungsten (EWTh-2) of Red strip with 2.4 mm diameter. During this process all the welding parameters such as the gas flow rate, inert gas used, welding speed and the number of passes of the welding to be kept constant for all trails. But the welding current was used as a varying parameter. At the different value of welding current we have to find out the micro-structural and mechanical properties of the welded joints. The inert gas used for the experiment was Argon. And flow rate of the gas was kept constant during the welding of the specimen. The filler wire selected for the process of welding of the grade as AA - 4047. The filler AA-4047 wire has the more content of the silicon. The filler wire with the diameter 1.6 mm was used for the welding process.

**Welded specimen at 140,150,160 amp welding current**
At 150 ampere

Figure 2 welded specimens at different welding current

In this experiment the TIG welding technique was adopted at the three different values of welding current i.e. the welding joints were made at 140A, 150A, and 160A different welding current respectively. The welded specimens are given in the figure 2. The welded specimens were further subjected to the following micro-structural and mechanical properties tests.

V. SAMPLE PREPARATION AND MICRO-STRUCTURE EXAMINATION

The micro-structure testing of the base metal and of the welded specimens was done at M/s Spectro Analytical Lab, Okhla (India) by using Versamet Inverted optical microscope (as shown in figure 3). The zooming range of the microscope was 50-400 µm for the study of microstructure evolution. The specimens were prepared by using the standard as ASM 9, 2004 for the microstructure testing. For the microstructure testing from the welded base material a piece was cut in the flat form having size as 50 mm x 10 mm x 6 mm. After cutting the flat size pieces were grinded.

Optical microscope

After that the polishing were done on the surfaces of the specimens with the help of grit size rough emery papers. For the polishing purpose different types of grades were used of the grit emery papers. The grit size papers used for polishing have the grades as 180, 220, 320, 400, 600, 800, 1000 and 1200. After the polishing the specimens were passed through the etching process.

The etching process was done with the help of etching liquid solution. The etching process was the final process after polishing. During the etching process Brasso-Liquid mixture were used having HF (Hydro-fluidic acid) as 0.5 %. After etching microstructure of the specimens was captured on an Microscope at 200X magnification with the help of a camera along the weld.

5.1 Micro-hardness testing

The micro-hardness of the aluminium alloy AA-6061 T651 was investigated at M /s Spectro Analytical Lab, Okhla (India) by using the Mitutoyo MGHK1 Vickers hardness tester (as shown in figure 4).

Vickers hardness tester

The testing method used for the hardness testing was IS1501 (Part1):2013. The prepared samples were placed on the hardness tester. After finding the values of the diameters as D1 and D2 (used for the horizontal and vertical position of microscope) the hardness value will be find out. The hardness value was found out on the both sides of the located centre at a distance of 2.5 cm in the left side and right side.

5.2 Surface roughness testing

The surface roughness of the welded specimens was investigated at Jind Institute of Engineering & Technology, Jind (India) by using the Mitutoyo SJ-201 surface roughness tester as shown in figure 5. The value of surface roughness was investigated along the welded part of the specimen.
VI. RESULTS

6.1 Micro-structure test of the base alloy
The microstructure of the base alloy was investigated by using optical microscope at 200X magnification. The microstructure shows that the base alloy contains longer elongated fine grains. Observed results after the microstructure testing:

<table>
<thead>
<tr>
<th>Grain size</th>
<th>Porosity</th>
<th>Oxide/ Inclusion</th>
<th>Silicon Eutectic</th>
<th>Primary Silicon</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.005 - 0.010 mm</td>
<td>Few Sports (up to .02 mm)</td>
<td>Negligible</td>
<td>Satisfactory</td>
<td>Not Present</td>
</tr>
</tbody>
</table>

The grain size of the particles of the aluminum alloy AA-6061 was 0.005-0.010 mm in the microstructure. Oxide/Inclusions were negligible on the surface of the base material. Only few sports of porosity (up to .02 mm) were present. Primary Silicon was not present in the microstructure of the base material.

6.1.1 Microstructure of the welded part at the welding current as 140 ampere
The microstructure of the welded part consists of interdendritic network of aluminum silicon eutectic in matrix of aluminum solid solution.

6.1.2 Microstructure of the welded part at the welding current as 150 ampere
After the perfect preparation (by polishing and etching) of the specimen the microstructure of the welded part welding at 150 ampere was taken out by the optical microscope. During the welding we have to use the filler wire of grade AA-4047 which has more amount of silicon in it. Due to this the microstructure consists of inter-dendritic network of the aluminum silicon eutectic in matrix of aluminum solid solution. The microstructure of the specimen was shown with the magnification as 200X and with a zooming range of 50-400 µm.

6.1.3 Micro Structure of the welded part at the welding current as 160 ampere
For the micro-structure testing the welded specimen welding at 160 ampere was being placed on the optical microscope. The used Versamet Unitorn 5463 inverted optical microscope would capture the microstructure of the welded part with the zooming range as 50-400 µm. The results observed from the microstructure defines that the structure consists of interdendritic network of aluminum silicon eutectic in the matrix of aluminum solid solution.
6.2 Micro Hardness Test

6.2.1 Micro-hardness of the welded part at the welding current as 140 ampere
The specimen welded at 140 ampere welding current of the size 50 mm x 10 mm x 6 mm was placed on the Vickers hardness testing equipment after the polishing with emery papers to check the micro-hardness. The weight applied for the testing was one kilogram. Hardness (HV1): Where HV defines the Vickers hardness and 1 define for the weight as one kilogram which was selected to check out the hardness of the specimen at a particular weight. Hardness value from the centre of the welded part at a distance of 2.5 mm towards the right side was 75HV1 (75 define hardness value and 1 define the weight in kilogram) and 2.5 mm towards the left side was 76HV1 (76 define hardness value and 1 define the weight in kilogram).

6.2.2 Micro-hardness of the welded part at the welding current as 150 ampere
The micro-hardness value for the welding current 150 ampere was 68 and 70. The hardness value on the right 2.5 mm away from the centre towards the right was 68HV1 (where 68 define the hardness value and 1 for weight in kilogram). And value of hardness on the left side as 2.5 mm away from the centre was 70HV1 (where 70 define the micro-hardness value and 1 defines the weight in kilogram).

6.2.3 Micro-hardness of the welded part at the welding current as 160 ampere
The hardness value for the right was 79HV1 (where 79 is the hardness for 1 kilogram weight) and the hardness value for the left side was 81HV1 (where 81 define the hardness value and 1 defines weigh in kilogram).

6.2.4 Comparison of micro-hardness at different welding current:
The micro-hardness values (as given in table 2) of the different specimen welded at different welding current has been found out with the Vickers hardness tester are:

<table>
<thead>
<tr>
<th>Welding current applied (in ampere)</th>
<th>Right side</th>
<th>Left side</th>
</tr>
</thead>
<tbody>
<tr>
<td>Welding current as 140 ampere</td>
<td>75</td>
<td>76</td>
</tr>
<tr>
<td>Welding current as 150 ampere</td>
<td>68</td>
<td>70</td>
</tr>
<tr>
<td>Welding current as 160 ampere</td>
<td>79</td>
<td>81</td>
</tr>
</tbody>
</table>

Table 2 Micro-hardness values of welded specimens

Variation of hardness value at different welding currents

![Variation of hardness values at different welding current](image)

6.3 Surface roughness testing

6.3.1 Surface roughness testing of the welded parts
Surface roughness of the welded parts was investigated by using the Mitutoyo SJ-201 surface roughness tester. The readings were taken by the tracing of the stylus over the welded part. Surface roughnesses of the specimens are:

<table>
<thead>
<tr>
<th>Welding current (In ampere) (µm)</th>
<th>Welded specimen</th>
<th>Surface roughness</th>
</tr>
</thead>
</table>
Tungsten Inert Gas welding proves its capability to join the dissimilar metals together. TIG welding is especially used for joining the aluminium alloys. This paper investigates the effect of welding current on the micro-structural and mechanical properties of the aluminium alloy AA-6061 T651.

The following conclusions are derived from this experiment:

The TIG welding has proved that it being the suitable process for joining aluminium alloy AA-6061 T651 and to make the defect free joint by using the various combinations of process parameters. The micro-hardness of the welded part welded at 160 ampere is increased by 6% and 16% as compared to the welding carried out at 140 ampere and 150 ampere. There is the alternative change in the micro-hardness value with the increasing of welding current during this experiment. The microstructure consists of interdenticr network of aluminium silicon eutectic in matrix of aluminium solid solution. There is also the variation of surface roughness of the welded part with the changing the value of current. The value of the surface roughness is alternatively changed with the increasing value of current. The surface roughness value was less at the welding current as 160 ampere means it provides smoother surface at the more value of welding current.

REFERENCES


