COMPARATIVE STUDY BETWEEN MECHANICAL BEHAVIORS OF FSW AND MIG WELDED AA7075 AND AA6063 ALLOYS JOINTS

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ABSTRACT

In this paper welding characteristics of AA6063 and AA7075 dissimilar aluminum alloy joints has been investigated. The central goal of the experiments is to identify the suitable method of welding and the optimal welding process parameters for mechanical properties. The weld joint fabricated by means of friction stir welding and metal inert gas welding with various functional parameters. FSW and MIG welded joint mechanical properties were compared with each other to understand the merits and demerits of the functional variables used for joining of aluminum alloys. Superior tensile strength of 150.32Mpa, elongation of 14.62% and impact strength 22 joule were obtained with FSW welded joints made by taper profile tool. This occurred due to the size of the heat affected region of FSW was narrower than MIG welded joints. Hence results show that FSW provides the joints with superior mechanical properties and it’s suitable for joining of aluminum alloys.

Keywords: Friction stir welding, Gas metal arc welding, Mechanical Properties, Process Parameters.

Cite this Article: G. Swaminathan, Dr. S. Sathiyamurthy and Dr. P. Naveen Chandran, Comparative Study Between Mechanical Behaviors of FSW and MIG Welded Aa7075 And Aa6063 Alloys Joints, International Journal of Mechanical Engineering and Technology (IJMET), 9(9), 2018, pp. 999-1009.
http://www.iaeme.com/ijmet/issues.asp?JType=IJMET&VType=9&IType=9
1. INTRODUCTION

The fabrication of aluminium alloy joints using the fusion welding technique is challenging. The fabrication of aluminium alloy joints should be prepared in such a way that to reduce the internal stresses produced during joining. Welding used can classify mainly three types such as fusion welding, pressure welding and friction welding. The friction welding technique is most suitable for joining of aluminium alloys without defects. The boundary of weld zone is slightly broader in MIG joint. However, the weld zone of FSW joint covers fine and homogeneous grains and this may be due to the energetic crystallization that materialized during the FSW process. Hence the greater tensile strength was acquired in welded joints using friction stir welding [1]. Narrow heat affected zone was formed when using FSW, broader zone was formed in case of tungsten inert gas welding and mechanical behaviors like tensile strength, etc., are within the safe zone and are better than tungsten inert gas welding method. The mechanical properties of friction stir welded aluminum 6063-T6 are lower than the base metal, but are superior than conventional welding technique [2]. In gas welding process the metals get heated and due to the heating of the metal the strength of the metal decreases and also the microstructure of the metal changes. But in friction stir welding the metal gets less heated compared to the gas welding process. Due to the less heat absorbed by the metal the strength and microstructure changes comparatively less than the gas welding process. So, comparatively friction stir welding gives accurate microstructure and tensile strength than the gas welding process [3]. Better mechanical properties were obtained FSW joints compared to MIG welded joints because of the formation of very fine, equiaxed grains and consistently scattered very fine strengthening precipitates in the weld region also the joint efficiency is 3% more in FS welding in comparison to MIG welding [4]. Less heat was generated during the process due to simple plastic distortion brought by the welding tool gesticulation and minor decline of mechanical behaviors. In the weld region an insignificant retrieval of hardness is witnessed due to crystallization of very fine grain structure. Hence friction stir welding is a very inexpensive process as it saves energy from industrial viewpoints, FSW joints has greater tensile properties and inhibits the joints from fusion related flaws [5, 6]. Due to the insufficient heat generation coarse grains were formed at weld region and binding integrity was also poor, so that hardness values increased compared with base metal [7]. Arc and Gas welded joint tensile properties were obtained 48% and 60% of lesser than maximum load bearing characteristics of base metal respectively. The variation of 46% was found when using friction stir welding [8]. Aluminum and its alloys joint were analyzed, the effect of tool pin profiles on mechanical and materials behaviors. Tensile strength, ductility, hardness and microstructure were improved after the heat treatment process. Among two tools pin profiles circular tool pin profile contributes formation of fine grain structure. The taper tool pin profile indicates greater hardness compared to circular tool pin profile [9]. The friction stir welding produced sound mechanical and metallurgical properties joints comparing with MIG. Maximum tensile strength of 232 Mpa joint was obtained and base metal strength of 400 Mpa, i.e., the reduction of tensile strength (42%) by using gas metal arc welding, in case of FSW the maximum tensile strength obtained was (340 MPa), i.e., there is a loss of strength about (15%). [10]. Superior mechanical properties were obtained double sided welded joints compared to single sided ones and same direction welds have significant progress in mechanical and metallurgical behaviors when matched to opposite direction ones [11]. Tensile test results show that FSW joints have greater strength and greater ductility related to tungsten inert gas welded joints. The ratio of tensile strength of welded joint to the tensile strength of parent metal is known as joint efficiency. The efficiency obtained 70% for friction stir welding as compared to 67% in tungsten inert gas welding [12].
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Figure 1 Friction stir welding (a) and Gas metal arc welding setup (b)

2. MATERIALS AND METHODS

2.1. Materials

In this work carried out with nine samples of Aluminium AA6063-T6 is an intermediate strength alloy generally referred to as an architectural alloy normally used in complicated extrusions and AA7075-T6 is very strong aluminium grade was used in the heavy structures like column and beams. Both the alloys sliced 100x50x6 mm with the help of power hacksaw and milling machine. The constituent of AA6063-T6 is 0.2 to 0.6 weight% Si, 0.0 to 0.35 weight% Fe, 0.0 to 0.1 weight% Cu, 0.0 to 0.1 weight% Mn, 0.45 to 0.9 weight% Mg, 0.0 to 0.1 weight% Zn, 0.0 to 0.1 weight% Cr, and balance is aluminium. AA7075-T6 is an aluminium alloy with zinc as the major alloying constituent. It is robust, with a strength equivalent to many steels, and has good fatigue strength and average machinability, but has less resistance to corrosion than many other Al alloys, the chemical composition of the AA7075-T6 aluminium alloys 0.40 weight% Si, 0.50 weight% Fe, 1.2 weight% Cu, 2.1 weight% Mn, 2.1 weight% Mg, 6.2 weight% Zn, 0.21 weight% Cr, 0.001 weight% Ni, 0.020 weight% Ti, 0.002 weight% Sb and balance is aluminium. The mechanical behaviors of the parent metal AA6063 is 85 MPa yield strength, 123 MPa ultimate tensile strength, 42% Elongation and 68.9 GPa Youngs Modulus whereas the mechanical behaviors of the parent metal AA7075 is 545 MPa yield strength, 612 MPa ultimate tensile strength, 16% Elongation and 71 GPa Youngs Modulus. Now the objective of this work is to examine the mechanical behaviors, when both the parent metals were fabricated by means of friction stir welding with various tool pin profile and gas metal arc welding. The choice of the welding electrode wire materials depends on the identical the mechanical behaviors and physical properties of the parent metal, weld dimension and existing electrode inventory [12]. A consumable filler wire 1.6 mm diameter made up of ER 4043 aluminum wire was used to fabricate the joints. ER 4043 alloys contain 5 % of silicon, 0.05% Magnesium, 0.10% Zinc, 0.05% of manganese, 0.30% copper, 0.20% of titanium and remaining of aluminium. Silicon content makes the weld pool quite fluid, more crack resistant and also suitable for 6000 series aluminum alloys. But because of this fluidity, they require a higher voltage during the welding process than other aluminum filler metals. Commercially available Argon used as shielding gas for in this work. Both Friction stir and gas metal arc welding arrangements are shown in Figure1 and Figure2 shows that the joint fabricated by both method.
2.2. Process parameters

In this work, three process parameters for friction stir welding like tool rotation speed, welding speed, axial force and for Gas Metal Arc Welding are welding current, gas flow rate and filler wire feed rate were selected shown in the Table 1. The parameters were kept constant and used to fabricate the dissimilar joints using FSW and GMAW.

Table 1: Welding Process parameters

<table>
<thead>
<tr>
<th>Sl.No</th>
<th>Process Parameters</th>
<th>Values</th>
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<tbody>
<tr>
<td>1</td>
<td>Tool Rotational Speed (rpm)</td>
<td>1000, 1100, 1200</td>
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<tr>
<td>2</td>
<td>Weld Speed (mm/min)</td>
<td>30, 45, 60</td>
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<tr>
<td>3</td>
<td>Axial Force (KN)</td>
<td>4, 5, 6</td>
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<tr>
<td>4</td>
<td>Tool Shoulder Diameter (mm)</td>
<td>18</td>
</tr>
<tr>
<td>5</td>
<td>Tool Profile</td>
<td>Circular, Taper, Triangle, Square</td>
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<td>6</td>
<td>Tool pin length (mm)</td>
<td>5.7</td>
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<table>
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<th>Sl.No</th>
<th>Process Parameters</th>
<th>Values</th>
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<tr>
<td>1</td>
<td>Welding current (amp)</td>
<td>140, 160, 180</td>
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<tr>
<td>2</td>
<td>Gas flow rate (ltr/min)</td>
<td>10, 12, 14</td>
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<tr>
<td>3</td>
<td>Filler wire feed rate (mm/min)</td>
<td>300, 360, 420</td>
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</tbody>
</table>

Figure 2: Welded Joints

Figure 3: Frictions stir welding Tool Profiles
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Table 2 Mechanical properties of Joints

<table>
<thead>
<tr>
<th>Process Parameters</th>
<th>Mechancial Properties</th>
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<tbody>
<tr>
<td>Welding Current (Amp)</td>
<td>Tensile Strength (MPa)</td>
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<td>Axial Force (KN)</td>
<td>FSW Tool</td>
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<tr>
<td>Welding Speed (mm/min)</td>
<td>Straight Tool</td>
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<td>Speed 1</td>
<td>140</td>
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<td>Speed 2</td>
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<tr>
<td>Speed 3</td>
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<tr>
<td>Speed 4</td>
<td>170</td>
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</table>

3. RESULTS AND DISCUSSIONS

3.1. Effect of process parameters on Tensile Properties

Tensile strength or ultimate strength is the utmost stress that a material can resist while being strained or dragged before deteriorating or fluting. The mechanical behaviors such as tensile strength, % of elongation of AA6063-T6 and AA7075-T6 aluminum alloy joints were estimated. At each tool rotation speed, three samples were tested. The tensile strength of FSW joints was presented in Table 3 & 4. The maximum tensile strength of 150.32Mpa was observed when using circular taper tool profile at the tool rotational speed of 1200rpm, axial force of 5KN and welding speed of 30mm/min. These outcomes show that with increasing tool rotation from 1000 rpm to 1200 rpm for other parameter fixed increase tensile strength as shown in Fig. 3 and that in four tools, the circular taper profile exhibited higher strength values. Tool rotational speed plays predominant roles on tensile strength of the friction stir welded joints. If tool rotating speed is too low simultaneously the frictional heat generation also low, it is not enough to produce plastic flow nature in and around on butting edges. The metal in the weld region cannot draw-out and recrystallize. Hence, cavities formed at a weld region of the welded joint. An increase in tool rotational speed simultaneously frictional heat also increased which increases the plasticized layer from top to the underside of the joint and thus, the cavity formation in the welded joint become reduced. If tool rotational speed is too high, the temperature of the material under the tool's shoulder and around the probe will surpass the melting point, and the welding will not be a solid-state welding. However, the maximum tensile strength obtained using GMAW joints is 136.57Mpa at welding current of 140 amps, gas flow rate of 12 liters/min and filler wire feed rate of 360mm/min.
3.2. Comparison of Tensile properties of FSW (Taper Tool) and GMAW

![Effect of Tool (Rotational Speed) & Welding current on Tensile Strength](image1)

![Effect of Axial Force and Gas flow rate on Tensile Strength](image2)

![Effect of welding speed & filler wire feed rate on Tensile Strength](image3)

Figure 4 Influence of process variables on Tensile strength

The normal tensile strength of gas metal arc welded joints is shown in Figure 4. The extreme tensile strength achieved in gas metal arc welded joint was 136.57 MPa. This shows 10% increase in tensile strength of the base metal of soft aluminum alloy by GMAW joint. FSW joints obtained the highest tensile strength 148Mpa, this indicates 17% increment in tensile strength compared to a base metal. However the tensile strength of friction stir weld joints and GMAW joints was higher than the parent metal of AA6063, but the tensile strength of friction stir weld joints was 10% greater than gas metal arc welded joints. This shows the way that friction stir welded joints were stronger than gas metal arc welded joints. The elongation of parental metal was 16.5%. The GMAW joints showed the maximum elongation of 11.09%. This shows that 33% drop of ductility in case of GMAW joints. The maximum % of elongation of FSW joints 16.14% was obtained while using the circular taper profile at a revolution speed of 1200rpm presented in Figure 5. However, % of elongations of friction stir welded joints were lesser than the parent metal, but were 25% greater than GMAW welded joints. Gas metal arc welding process variables have a solid influence on tensile strength and elongation which increase 10% and decreases 25% respectively from the parent metal. If FSW was applied the tensile strength and percentage elongation of the weld increase 16% and decrease 5% respectively in comparison to that of the parent metal. Thus, the tensile strength of dissimilar aluminium alloy was affected by both the welding processes, but affect is more in the GMAW as compared with FS welded joints. Thus heat generation and grain size formation are the important factor for mechanical properties of the joint. Comparatively in friction stir welding...
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process working temperature were less than melting temperature of parent metal since the mechanical properties not affected much in FSW process and also not much variation in grain size.

![Figure 5](http://www.iaeme.com/IJMET/index.asp)

**Figure 5** Influence of process variables on % of Elongation

### 3.3. Effect of process parameters on Impact strength

The amount of energy absorbed by the body without cracked is called impact strength. According to ASTM E-23 test specimen were sliced from the joint and Charpy test were conducted by using pendulum type impact test machine (Model IT-30). Thus, when the amount of energy absorbed by the material is larger the leaning of the material to breakage becomes reduced. The results of impact tests of GMAW joints of aluminium alloy AA6063 and AA7075 joints are presented in Table 2 & 3. It was shown that the energy stored during an impact test of the GMAW aluminium alloy joints was lower as compared to the base metal and varied from 4J to 6 J. Impact strength of GMAW welded joints was lower due to bigger grain size in the weld region of the welded joints and precipitation distribution of grains. However, friction stir welding was found that impact strength of the joints, increased to the base metal and its varied from 12J to 31J while using circular taper profile its high impact strength compared to other profile of the tool. This may occur due to grain refinement of the stirring effect in the FSW process.
3.4. Comparison of Impact strength of FSW (Taper Tool) with GMAW
Friction stir welded joints exposed a very remarkable development on impact strength. The Charpy Impact test of friction stir welded and gas metal arc welded joints conducted at normal atmospheric condition. The energy stored during an impact test of friction stir welded joints was greater than gas metal arc welded joints were presented in Table 2 & 3. In contradictory to most of mechanical behaviors of the weld joints, that were either not changed or faintly depreciated during friction stir welding of AA6063 and AA7075 alloy, impact energy storing capacity was the property which developed significantly. The mean value of impact energy storing capacity of parent metal was 22 Joules, whereas welded by friction stir welding process presented impact toughness values much higher than the parent metal (31 J) is shown in Figure 6. This may occur in friction stir welding due to stirring action simultaneously grains are refined. It was clearly shown that the impact strength of the FSW joint was 29% more than that of the base metal, but impact toughness, strength of GMAW welds joints was 70% lower than that of the parent metal. This impact toughness modification is associated with the weld structures constituted with friction stir welding and gas metal arc welding processes. The stirring action in friction stir welding process was influenced to improves the very fine microstructure formation of the weld and increases the resistance to impact load carrying capacity.
3.5. Microstructure Analysis

![Figure 7](image1.png)

**Figure 7** Microstructure of Friction stir welded joints

In the circumstance of FSW joints, it is contingent that both welded zone as well as base metal region were having more or less similar grain structure shown in figure 7 (a), (b) & (c). Though, weld zone influenced with compressed grain structure matched to the base metal. It is furthermore understood that grains are scattered equally in the welded zone. This may be due to the energetic recrystallization grew during the friction welding process.

![Figure 8](image2.png)

**Figure 8** Microstructure of Gas Metal Arc welded joints

Optical micro structure of the MIG welded joints showing the micro structure of the fusion boundary along with HAZ, weld metal and heat affected zone of a specimen made at 140Amp welding current, 12ltrs/sec of gas flow rate and 360mm/min filler wire feed rate are shown in Figure 8. From the microstructure, it was perceived that there was an significant variance in grain size of the weld zone and HAZ regions with different. This may be due to the quick cooling induced by good thermal conductivity and low thermal capacity of aluminium. The grain size of the fusion zone and HAZ are influenced by the heat input of the welding process. In the HAZ, the grains next to the fusion boundary were found to be grown larger due to the intense heat and high temperature experienced during welding. The grain structure of the fusion boundary was very coarse and columnar showing that epitaxial growth has taken place.

![Figure 9](image3.png)

**Figure 9** SEM Micrographs of the tensile fracture surface of dissimilar weld observed on AA7075 and AA6063 joints
The fractured surfaces of the tensile specimens were analyzed using SEM and are presented in Figure 9 (a), (b) & (c). Dimples of varying size and shape were observed in all the fractured surfaces which indicate that a major fracturing mechanism was ductile. From Figure 9 (a) & (b) it was perceived that as heat input rises, coarse and elongated indentations are perceived. It is also observed that small dimples are surrounded by the large ones in all the specimens and a small quantity of tearing ridge is also present. From Figure 9 (c) it was observed that the fractured surface of the specimen made by friction stir welding with Taper profile tool at 1200 rpm tool rotational speed, 5kN axial force and welding speed of 30mm/min comprises a large population of small and shallow dimples which was indicative of its relatively high tensile strength and ductility.

4. CONCLUSION

FSW is an appropriate method joining of aluminium alloys since it saves energy due to low heat involvement during the process, avoids the joints from fusion related flaws, is less expensive and has superior mechanical properties than GMAW joint. Tensile properties results indicate that friction stir welded joints provided that higher strength and higher ductility equated to GMAW joints. Greater heat concentration in the GMAW process harmfully disturbs of the mechanical and metallurgical behaviors of the welded joints. FSW joint exhibited higher strength compared to GMAW joint. Tool rotation speed was the key factor wounding the tensile strength and axial force and Welding speed was the major role in affecting the impact strength. In friction stir welding there was no change of chemical composition at the weld zone because of non consumable electrode were used. But in the GMAW filler wire were used due to that chemical composition of weld zone varied compared to FSW.

REFERENCES


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