Effect of Boron carbide and Silicon carbide reinforced particles on the mechanical and metallurgical properties of friction stir welded joints of AA-6063 alloy

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Abstract- Friction Stir Welding (FSW) is a solid state joining process. It is used worldwide, especially in automobile defense and aerospace industries. Welding of similar and dissimilar aluminium alloy exhibits poor weld ability by fusion process. Friction stir welding is a technique in which the material that is being welded does not melt and recast. The welding parameters such as tool rotational speed, welding speed and tool pin profile plays an important role in deciding the weld quality. In the present study, an attempt is made to weld the AA6063 plates by doping SiC and B4C reinforced particles in welding zone during FSW. The selected material was Friction stir welded at constant tool rotational and welding speed of 1600 rpm and 60 mm/min respectively. High chrome high carbon non-consumable cylindrical left handed thread pin profile tool with 4.8 mm pin length and 6 mm pin diameter was used to generate frictional heat and plastic deformation. B4C and SiC particles are doped in a series of holes at the interfaces of plates to be joined to modify the properties of joint. The mechanical and metallurgical properties of welded joint were investigated. From results it was observed that by doping reinforced particles tensile strength and micro hardness improved as compare to joint welded without using reinforced particles. Boron carbide provides better results as compare to silicon carbide. Doping of B4C and SiC particles during Friction Stir welding causes grain refinement in welded joints.

Keywords: Friction Stir Welding, AA 6063, Tool Rotational Speed, Reinforced Particles, Tensile Strength, Micro hardness, Microstructure.

I. INTRODUCTION

Friction stir welding (FSW) is an innovative welding process commonly known as a solid state welding process. This opens up whole new areas in welding technology. It is particularly appropriate for the welding of high strength alloys which are extensively used in the aircraft industry. High strength aluminum alloys are difficult to join by conventional fusion welding techniques. To overcome from this problem a new welding technique Friction Stir Welding is invented in 1991 by Wayne Thomas. Its main characteristic is to join material without reaching the fusion temperature. In this technique specially designed tool is inserted into an adjoining edge of the sheets to be welded and the tool is moved across the length of the joint. The tool is used to produce the frictional heat and these produced heat soft the edges of joining plates and the soft material of two plates are mixed mechanically. The systematic diagram of FSW process is shown in Figure 1. A welding tool has three main part shank, shoulder, and pin. Welding tool shank is fixed in a vertical milling machine chuck and is rotated about its longitudinal axis. The work piece, with square mating edges, is fixed on a fixture, and a clamp or anvil prevents the work piece from spreading or lifting during welding. The rotating tool is slowly plunged into the work piece until the shoulder of the welding tool forcibly contacts the upper surface of the material. By keeping the tool rotating and moving along the seam to be joined, the softened material is literally stirred together forming a weld without melting [1].The welding tool is then retracted, generally while the spindle continues to turn. After the tool is retracted, the pin of the welding tool leaves a hole in the work piece at the end of the weld. These welds require low energy input and are without the use of filler materials and distortion [2]. The half-plate where the direction of rotation is the same as that of welding is called the advancing side, with the other side designated as being the retreating side as shown in Figure. 1[3]
II. EXPERIMENTATION

A. Friction Stir Welding of AA6063 alloy:

The material under investigation was Aluminium 6063 alloy under the form of rolled plates of 5 mm thickness and chemical composition of AA-6063 alloy is presented in Table no. 1.

Table 3.1 Chemical Composition of Aluminium Alloy 6063

<table>
<thead>
<tr>
<th></th>
<th>Al</th>
<th>Mg</th>
<th>Si</th>
<th>Fe</th>
<th>Cu</th>
<th>Mn</th>
<th>Zn</th>
<th>Cr</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAL</td>
<td>0.014</td>
<td>0.300</td>
<td>0.500</td>
<td>0.065</td>
<td>0.018</td>
<td>0.004</td>
<td>0.002</td>
<td>0.028</td>
<td></td>
</tr>
</tbody>
</table>

Four specimens of size 100 mm x 77 mm with grooves of 2 mm diameter and depth of 4.9 mm were welded together perpendicular to the rolling direction. Two specimen are welded with single pass Friction Stir Welding process by doping SiC particles and B₄C particles of size approximate 4 µm and one specimen was friction stir welded without doping particles. Initially the drilled holes were filled with SiC and B₄C particles. The selected specimens were welded together by adopting constant tool rotational speeds and welding speed of 1600 rpm and 60 mm/min respectively. A welding tool made up of High chrome high carbon steel with 20 mm tool shoulder diameter, 6 mm pin diameter and 4.8 mm long was used for present research work. The machine used for the production of joints was fully automated vertical milling machine. Table 2 shows the Friction stir welding parameter used for experimentation.

Table 2. Friction stir welding parameter used for experimentation

<table>
<thead>
<tr>
<th>Plate No.</th>
<th>Tool Rotational Speed (rpm)</th>
<th>Welding Speed (mm/min)</th>
<th>Reinforced particles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1600</td>
<td>60</td>
<td>SiC</td>
</tr>
<tr>
<td>2</td>
<td>1600</td>
<td>60</td>
<td>B₄C</td>
</tr>
<tr>
<td>3</td>
<td>1600</td>
<td>60</td>
<td>Without</td>
</tr>
</tbody>
</table>

A special designed fixture was firmly fixed on the machine bed with help of clamps and then plates were held in the fixture properly for Friction Stir Welding. The set up is shown in Figure no. 2.
B. Mechanical and Metallurgical Testing:
Mechanical testing includes tensile, impact and micro hardness testing. For tensile testing the specimens are prepared according to ASTM E8M-04 and its testing was done on Universal testing machine. Figure 3 shows the dimensions of actual tensile tested specimens.

For microstructure testing the specimens were ground with 400 grit followed by 600, 800, 1000, 1200, 1500, and 2000 grit (SiC) paper until a uniform surface finish was attained. Initial polishing was undertaken using (1μm) diamond compound for 5 minutes and final polishing was completed using aluminum oxide. The polishing conducted in one direction until all evidence of prior polishing was eliminated. The sample was then rotated 90° and the process were repeated. Enchant having ASTM code E602-78I (Methanol 25ml, Hydrochloric acid 25ml, Nitric acid 25ml and Hydrofluoric acid 1drop) was applied for (15) seconds.

III. RESULT AND DISCUSSIONS

Results obtained from, tensile testing, Impact testing, Micro hardness testing and Microstructure Testing are discussed in detail.

A. Effect of Boron Carbide and Silicon carbide particles on Ultimate Tensile Strength:
Figure 4 shows that addition of boron carbide particles in friction stir welded joints improves the tensile properties. The tensile strength of friction stir welded joints is increased with the use of reinforced particles (boron carbide and silicon carbide). The presence of reinforced particles during the FSW increases the nucleation sites and consequently reduces grain size of the matrix and result in formation of fine grains. Boron carbide is uniformly dispersed with base metal and result in strong bonding between the B4C particles and aluminium [4].
It is also observed that the UTS is increased with the addition of SiC reinforced particles during friction stir welding. Micro particles of reinforced particles precipitate on grain boundary and prevent grain growth hence fine grain structure. Homogenous dispersion of SiC particles in base metal and good bonding between SiC particles and base metal resulted in increase of UTS values as compared to joints welded without reinforced particles [5].

B. Effect of Boron Carbide and Silicon carbide particles on Impact strength Strength:

From figure 5 it is observed that the impact strength of the weld zone is decreased with addition of boron carbide and silicon carbide particles during Friction stir Welding of AA6063 alloy. The reason for the decrease in impact strength value is grain refinement provided by B₄C particle and high value of hardness[6].

C. Effect of Boron Carbide and Silicon carbide particles on microhardness of Stir zone:

From the Figure 6 it is observed that the microhardness of the stir zone is increased with addition of silicon and boron carbide particle during Friction Stir welding. Micro hardness at stir zone increases due to presence and pinning effect of hard SiC and B₄C particles as compared to the joints those Friction Stir Welded without doping SiC and B₄C particles. The presence of reinforced particles is considered for more effective formation of fine grain structure due to the restrain of grain boundary and the enhancement of the induced strain [7]. The B₄C particle are uniformly mixed with aluminium 6063 and strong bonding are formed between them, which also help in increase the hardness of stir zone. This is the reason that highest value of microhardness is achieved in weldments produced by doping B₄C particles. The dynamic recrystallization during FSW produced finer grain in weld zone. [8][9].
D. Microstructural characteristics of Friction Stir welded Joints:

The typical microstructure of as received conditions (base material) is shown in Figure 7. The microstructure comprises of the coarse grains of aluminum with the hardening precipitates of Mg$_2$Si.

Figure 7. Microstructure of Base material AA 6063

Figure 6. Effect of boron carbide and silicon carbide on microhardness of stir zone

Figure 8. Microstructure of Stir Zone of welded joint
Figure 8, shows the dispersion of Boron and Silicon carbide particles in the stir zone at tool rotational speeds of 1600 rpm and welding speed of 60 mm/min. It is revealed that homogeneous dispersion of B$_4$C and SiC particles is achieved at selected parameters. The dispersion of B$_4$C and SiC particles is considered for more effective formation of fine grain structure due to the restrain of grain boundary and the enhancement of the induced strain. However the higher hardness and tensile strength is achieved by doping B$_4$C and SiC particles as compared to joints welded without doping B$_4$C and SiC particles. Mainly, the micro hardness value depends on the presence and uniform distribution of these particles.

IV. CONCLUSION

The correlation of mechanical properties and microstructure with the process parameters for the optimization of process is a unique approach which has been the main motivation behind this project. Following conclusions were derived from the results of this experimental work.

- The tensile strength and micro hardness is increased with the use of B$_4$C reinforced particles during the FSW and having maximum value 197 MPa and 130 Hv respectively as compare to SiC particles.
- Use of B$_4$C and SiC particles tends to decrease in impact strength and the maximum impact strength is obtained in joints welded by doping SiC particles.
- The micro structure studies revealed that grain refinement and homogeneous dispersion of B$_4$C and SiC particles is achieved with the selected friction stir welding parameters.

V. REFERENCE