Effect of Process Parameters on Mechanical Properties of Friction Stir Welded Dissimilar AA6061 T6 and AA5086 H32 Aluminium Alloy Joints

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Abstract

The current research work focuses on the comparative analysis of effect of tool pin profile and material position on leading and trailing side of the welding tool on weld quality of dissimilar AA5086 H32 and AA6061 T6 aluminum alloy joints fabricated using friction stir welding technique. Five different tool pin profiles viz. hexagonal (HX), Square (SQ), Threaded cylinder (TC), pentagonal (PT) and Straight cylindrical (SC), are used to fabricate joints by changing the position of material on advancing and retreating side of the tool. Five specimens were fabricated by keeping AA6061-T6 on advancing side of the tool for different profile welding tools.
and another five were fabricated by keeping AA5086-H32 on advancing side of the tool. The joints were inspected for visible defects like pin hole, surface cracks, tunnel defect, etc. and it was observed that FSW can be successfully employed to join dissimilar AA5086 H32 and AA6061 T6 aluminum alloy sheets. Out of the five profiles of the welding tools used in this study, square pin profile was observed as superior in terms of producing sound quality joints.

**Keywords:** Friction stir welding, aluminium alloys, comparative analysis, tensile properties, microstructure.

### 1. INTRODUCTION

The decision making problems having multiple attributes in industrial applications needs to be solved with statistical tools like MCDM, fuzzy based matrix approach etc. [1-7]. The popularity of light structural materials like aluminium and its alloys in industrial and manufacturing sector is escalating day by day due to amalgamation of several characteristics like higher strength to weight ratio, higher corrosion resistance [8]. The conventional fusion welding techniques like GMAW, laser beam welding, TIG welding, MIG welding, plasma arc welding, presents numerous difficulties and drawbacks in joining aluminium and its alloys and to produce sound quality welds of these alloys is still a challenge for researchers, technologists and Engineers [9]. Loss of strength, 30% to 50% of the parent material, is a major drawback of traditional fusion welding techniques which can be justified due to presence of porosities and induction of residual stresses during the process. Involvement of high heat in the conventional fusion welding methods leads to the loss of alloying elements and weld distortion. Due to these difficulties in conventional welding methods, soft materials like aluminum alloys are placed in “difficult to weld” category [10]. In recent years, Friction stir welding (FSW) is emerging as an alternate to traditional methods for welding of aluminium alloys. The aluminium alloy joints produced using FSW show superior ultimate tensile strength than that of joints produced using conventional techniques and reported in the literature as high as 80% to 100% of the base metal [11]. FSW method was invented and patented in 1991 at The Welding Institute, UK by Wayne Thomas et al. In FSW, a cylindrical revolving tool having profiled probe is forced in to the workpiece until the shoulder of the welding tool plunges in to the top shell of the metal piece and then fed transversely along the weld line. Figure 1 illustrates the schematic view of FSW process. The stirring action of the probe inside the material of the work piece softens and deforms the material plastically [13]. The simultaneous transverse feeding and rotation of the welding tool causes asymmetric temperature distribution on either side of the tool, resulting in variation in mechanical and microstructural properties on each side [14]. FSW is one of the most significant inventions of the past decades in the field of joining the light structural materials due to its versatility, efficiency and environment friendliness. The weld quality of copper alloys joints [15-16], aluminium alloy joints [17-18], and
Effect of Process Parameters on Mechanical Properties of Friction Stir Welded ... 23
titanium alloys joints fabricated using FSW technique, was found to be acceptable in the literature. The quality of weld produced by FSW process is decided by parameters like rotational speed of the welding tool, transverse speed, axial load, welding tool material properties, tilt angle of the tool, etc.

The temperature distribution and flow of softened material is governed by these parameters which in turn determine the quality characteristics of the joint produced. For the joining of similar and dissimilar aluminium alloys, FSW has proved itself a better practice than TIG and MIG welding, LBW and riveting. Aluminum alloy 5086 and 6061 has numerous applications in the field of aerospace, shipbuilding and automotive. Various aluminium alloys has been studied by different researchers to examine the control of FSW parameters on weld quality of the produced joints but it seems that effect of process parameters on dissimilar FS welded 5086 H32 and 6061 T6 alloy joints has not been studied till date. The current research work focuses on the comparative analysis of effect of tool pin profile and material position on leading and trailing side of the welding tool on weld quality of dissimilar AA5086 H32 and AA6061 T6 aluminum alloy joints fabricated using friction stir welding technique. The quality characteristics of the joints are measured in terms of mechanical properties like tensile strength, joint efficiency and microhardness.

2. MATERIALS AND METHODOLOGY
The current experimental investigation is an attempt to explore the feasibility of employing FSW method in joining dissimilar AA6061 T6 and AA5086-H32 grade aluminum alloy sheets of 5 mm thickness. Two workpieces, one from each alloy, of size 150 mm x 75 mm x 5 mm are butted together to ensure square butt
configuration. The composition and material properties of aluminium alloys are given in Table 1 and Table 2 respectively.

Table 1. Chemical Composition by wt%

<table>
<thead>
<tr>
<th>Material</th>
<th>Mg</th>
<th>Mn</th>
<th>Si</th>
<th>Fe</th>
<th>Cu</th>
<th>Zn</th>
<th>Cr</th>
<th>Ti</th>
<th>Ni</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA5086 H32</td>
<td>4.2</td>
<td>0.59</td>
<td>0.07</td>
<td>0.16</td>
<td>0.15</td>
<td>0.08</td>
<td>0.06</td>
<td>0.01</td>
<td>Balance</td>
<td></td>
</tr>
<tr>
<td>AA6061 T6</td>
<td>0.91</td>
<td>0.09</td>
<td>0.52</td>
<td>0.32</td>
<td>0.21</td>
<td>0.095</td>
<td>0.11</td>
<td>0.04</td>
<td>Balance</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Mechanical Properties

<table>
<thead>
<tr>
<th>Material</th>
<th>UTS(MPa)</th>
<th>Yield Strength(MPa)</th>
<th>% Elongation</th>
<th>Hardness(HV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA5086 H32</td>
<td>286</td>
<td>248</td>
<td>12</td>
<td>88</td>
</tr>
<tr>
<td>AA6061 T6</td>
<td>312</td>
<td>240</td>
<td>26</td>
<td>107</td>
</tr>
</tbody>
</table>

The holding and clamping of the plated to be welded is done on a special fixture as shown in Figure 2. The fixture was designed and fabricated to withstand the welding forces without obstructing the rotating spindle of FSW machine. H13 hot die steel is used as tool material to fabricate the welding tools of selected pin profiles. Figure 3 shows the pin profiles viz. straight cylindrical (SC), Square (SQ), Threaded cylinder (TC), pentagonal (PT) and hexagonal (HX), used to fabricate joints by changing the position of material on advancing and retreating side of the tool. The experiments were carried out by keeping other process parameters fixed at some justified values, given in table 3. Ten specimens were fabricated by keeping AA6061-T6 and AA5086 H32 on alternate sides of the tool for different profile welding tools. The nomenclature of so produced welded specimens is given in Table 4.

Figure 2: Experimental setup  Figure 3: Tool pin profiles

Table 3. FSW process parameters
ASTM E8 M04 standard of American Society for Testing of Materials is followed for preparation of samples for tensile test of the welding joints to measure tensile properties. Micro Hardness of the welded specimens is measured using Micro Vickers Hardness testing machine using a load of 200g for 10 seconds.

**Table 4.** Nomenclature of welded specimens

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Specimen No.</th>
<th>Position of Material</th>
<th>Tool Pin Profile</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Advancing Side</td>
<td>Retreating Side</td>
</tr>
<tr>
<td>1</td>
<td>S-1</td>
<td>AA6061-T6</td>
<td>AA5086-H32</td>
</tr>
<tr>
<td>2</td>
<td>S-2</td>
<td>AA5086-H32</td>
<td>AA6061-T6</td>
</tr>
<tr>
<td>3</td>
<td>S-3</td>
<td>AA6061-T6</td>
<td>AA5086-H32</td>
</tr>
<tr>
<td>4</td>
<td>S-4</td>
<td>AA5086-H32</td>
<td>AA6061-T6</td>
</tr>
<tr>
<td>5</td>
<td>S-5</td>
<td>AA6061-T6</td>
<td>AA5086-H32</td>
</tr>
<tr>
<td>6</td>
<td>S-6</td>
<td>AA5086-H32</td>
<td>AA6061-T6</td>
</tr>
<tr>
<td>7</td>
<td>S-7</td>
<td>AA6061-T6</td>
<td>AA5086-H32</td>
</tr>
<tr>
<td>8</td>
<td>S-8</td>
<td>AA5086-H32</td>
<td>AA6061-T6</td>
</tr>
<tr>
<td>9</td>
<td>S-9</td>
<td>AA6061-T6</td>
<td>AA5086-H32</td>
</tr>
<tr>
<td>10</td>
<td>S-10</td>
<td>AA5086-H32</td>
<td>AA6061-T6</td>
</tr>
</tbody>
</table>

The hardness values were obtained at 2 mm steps to a distance of 12 mm in advancing side (A) and retreating side (R) of the weld centre line. Then microstructure was revealed with the help of metallurgical microscope with a magnification power of 600X, with the help of camera mounted on the eye piece of the microscope. Then still photographs have been taken and visualized on computer screen.

### 3. RESULTS AND DISCUSSION

#### 3.1 Tensile testing

Three testing samples were prepared from each joint and put under tensile testing on universal testing machine to measure the values of UTS, % elongation and efficiency of the joint. Figure 4, Figure 5 and Figure 6 shows the variation of UTS, % elongation and joint efficiency of the joints produced using different pin profile and material position. It can be clearly seen through the obtained results that the geometry of the tool pin and position of material affects the tensile properties of FS welded joints. Out
of the five profiles of the tool pins used in this study, square pin profile was observed as superior in terms of producing sound quality joints and tensile strength decreases significantly for pentagonal, hexagonal, threaded cylindrical and straight cylindrical pin profile tool for both the materials on alternate side of the tool. The joints fabricated by keeping AA5086 H32 on advancing side of the tool were observed to have lower tensile strength.

Figure 4: Variations of ultimate tensile strength
Figure 7 shows the tensile test specimens before and after fracture. Welded specimens failed in region corresponding to the outer HAZ. The ultimate tensile strength of the AA6061 T6 and AA5086 H32 is 312 MPa and 286 MPa respectively. The highest and lowest values of ultimate tensile strength in this experimental run is observed as 217.8 MPa and 129.3 MPa respectively when 6061 T6 kept on advancing side of the tool. The highest and lowest values of ultimate tensile strength is found to be 207.7 MPa and 114 MPa respectively when 5086 H32 kept on advancing side of the tool.

3.2 Microhardness
The microhardness of all welded samples was evaluated on a plane at right angle to direction of welding using Vickers microhardness tester by applying 200g load for 10 seconds. The microhardness of AA6061 T6 and AA5086 H32 is 107 HV and 88 HV respectively. Microhardness of each specimen is determined on both sides of weld
centerline at an interval of 2 mm. The plots of micro hardness are shown in Figure 8 and Figure 9 for AA6061 T6 and AA5086 H32 on advancing side of the tool respectively. The hardness of the stir zone is highest for pentagonal profiled tool irrespective of the position of material on advancing side of welding tool. For AA6061 on advancing side of welding tool, the maximum hardness in the nugget zone is 92.7 HV for pentagonal profiled tool and least hardness is 72.8 for straight cylindrical tool. For AA5086 on advancing side of welding tool, the maximum hardness in the weld nugget zone is 89.2 HV for pentagonal profiled tool and least hardness is 74.2 for straight cylindrical tool. It is noticed that hardness of nugget zone is lower than that of the parent Aluminium alloys.

![Figure 8: Variation of Microhardness (AS-6061 T6)](image)

![Figure 8: Variation of Microhardness (AS-5086 H32)](image)
3.3 Microstructure

The results of microstructure study reveal that the size of grains in stir zone is larger as compare to the grain size of parent metals. Thus larger grain sizes are generally associated with the decrease in strength due to dislocations on intersecting planes with each other and obstructing motion. It would be therefore expected that the friction stir welds would exhibit a lower strength within the weld nugget and thus the ultimate tensile strength of friction stir welds approaching or less to the parent metal. This is proved by mechanical test results. Surrounding the weld nugget of the friction stir welds was an area that had experienced both thermal and mechanical changes. The grains within the region were of similar size to those within the HAZ. The microstructure of the specimen with best weld quality is found for square pin profile tool when 6061 T6 was kept on advancing side of the tool. For the straight cylindrical pin profile tool, tunnel defects are found irrespective of the position of materials. The prepared samples and micrographs of weld nugget for selected samples are shown in Figure 9 and Figure 10 respectively.

![Samples for microstructural analysis](image1)

**Figure 9:** Samples for microstructural analysis

![Micrographs of sample S2 and sample S9](image2)

**Figure 10:** Micrographs of sample S2 and sample S9
4. CONCLUSIONS

The present experimental work was an attempt to enhance the influence of FSW parameters on the quality of joint produced and the following conclusions can be derived:

1. FSW was effectively employed to join dissimilar AA5086 H32 and AA6061 T6 aluminum alloy sheets of 5 mm thickness and it was revealed that pin profile and position of materials significantly affects the weld quality.

2. Square pin profiled tool shows superior weld quality irrespective of the material position on either side of the tool.

3. The joints fabricated by keeping 6061 T6 on advancing side exhibits higher UTS as compared to those fabricated by keeping 5086 H32 on advancing side, irrespective of the pin profile.

4. For the straight cylindrical pin profile tool, tunnel defects are found for both the materials on advancing side of the tool.

REFERENCES


