Evaluation of Mechanical Behaviour of Friction Stir Processing of AA6061

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ABSTRACT

Friction stir processing (FSP) is a variation of friction stir welding (FSW) which is a solid state processing technique. It is one of the best and effective techniques that changes the mechanical properties and microstructure of the material in a single pass of the tool. FSP provides maximum performance at low production cost by using an inexpensive tool and in a very less time. In this technology, a rapidly rotating non-consumable tool having a profiled pin and shoulder of large diameter is plunged into the surface of material and then the tool is moved across the surface. In the present work, friction stir processing is done on the aluminium alloy 6061 under different rotational and translational speeds of the tool. The mechanical properties at rotating speed of 930rpm, 1190rpm and 1480rpm were evaluated and the microstructure of processed zone was analysed by using scanning electron microscope. The results show that the mechanical properties of the FSP zone are improved and the microstructure is significantly refined. Thus the process parameter, rotation speed has a significantly effect on the FSP.

Keywords: FSP, FSW, aluminium alloy 6061, microstructure.

INTRODUCTION

Friction Stir Processing (FSP) is one of the best thermo-mechanical processing techniques which use a frictional heat and stirring action to change the micro-structural and mechanical properties of the materials such as Aluminium and alloys in a single pass to achieve maximum performance in less time and cost by using a simple and economical tool. FSP is based on solid-state deformations that modify or eliminate the casting defects and refine the microstructure of alloys to improve the mechanical properties such as hardness and tensile strength. Mechanical properties were determined by different tests such as hardness test on Vickers Hardness Tester, Tensile test on UTM and chemical composition. Aluminium alloys of the 6000 series are best known to have good formidability, weld ability and high strength to weight ratio.

Friction Stir processing (FSP) was developed as a generic tool for Microstructural modification based on the basic principles of Friction Stir welding (FSW). A schematic illustration of FSP is shown in Figure. To carry out friction stir processing a location within a plate or sheet is selected and a specially designed rotating tool is plunged into the selected area. The tool has a small diameter pin with a concentric larger diameter shoulder. When descending to the part, the rotating pin contacts the surface and rapidly friction heats and softens a small column of metal. The tool shoulder and length of entry probe control the penetration depth.

Fig. 1: Schematic of Friction Stir Welding.
When the shoulder contacts the metal surface, its rotation creates additional frictional heat and plasticizes a larger cylindrical metal column around the inserted pin. The shoulder provides a forging force that contains the upward metal flow caused by the tool pin. During FSP, the area to be processed and the tool are moved relative to each other such that the tool traverses, with overlapping passes, until the entire selected area is processed to a fine grain size. The rotating tool provides a continual hot working action, plasticizing metal with a narrow zone, while transporting metal from the leading face of the pin to its trailing edge. The processed zone cools without solidification, as there is no liquid, forming a defect-free recrystallized, fine grain microstructure. Essentially, FSP is a local, thermo-mechanical metal working process that changes the local properties without influencing properties in the remainder of the structure.

LITERATURE REVIEW

Tsai and Kao [1] investigated the improvement of mechanical properties of a cast Al-Si base alloy by using friction stir processing. They reported that after FSP, the tensile properties of cast AC8A alloy could be improved considerably. Particularly the tensile elongation, which increased from < 1% to 15.4%. The tensile strength of FSPed AC8A alloy was the result of a combination of coarsening, dissolution and reprecipitation of strengthening precipitates, that was influenced by FSP parameters.

Alaa Mohammed Hussein Wais [2] studied the effect of Friction Stir Processing on mechanical properties and microstructure of the sand casting hypereutectic Al-15.6wt%Si Alloy and studied that the microstructure of hypereutectic Al-15.6wt%Si alloy was greatly refined after FSP. Very little change in material hardness was observed after FSP. Also the refinement of the microstructure demonstrated very little influence to the hardness of the material.

J. Stephen Leon, V. Jayakumar [3] worked on Investigation of mechanical properties of aluminium 6061 alloy friction stir welding and concluded that the increase in stir-probe rotation speed more than 1200 rpm enhanced the weld soundness which may be a result of softening process associated with dynamic recovery and recrystallisation process at the weld. Also the formation of fine equiaxed grains and uniformly distributed, very fine strengthening precipitates in the weld region are the reasons for the superior tensile properties of FSW joints.

K. Satya Narayana and Mathe Sharmila [4] worked on the determination of microstructure and mechanical properties of aluminium boron carbide using friction stir machining process and observed that the effect of multi-pass FSP on hardness of Al 6351- B4C composite is found to be decreasing due to heat input and grain softening during multi-pass FSP.

Kumar and Kailas [5] investigated the role of FSW tool on weld formation and material flow. They studied that there are two different types of flow of material, namely pin and shoulder driven material flows. In pin driven material flow, pin transfers the material layer by layer, while in the shoulder driven material flow, shoulder transfers the material by bulk. In shoulder driven material flow, the flow occurs from the retreating side and forges against the advancing side of the base material. In the pin driven material flow, flows material layer by layer around the pin and the layers are stacked in the weld line. The flow of material occurs below certain depth in the thickness is unaffected by the increased interaction of the tool shoulder.

EXPERIMENTAL PROCEDURE

In the present work, material used for Friction Stir Processing is AA6061. The chemical composition and mechanical properties of AA6061 are as follows.

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Zn %</th>
<th>Mg %</th>
<th>Cu %</th>
<th>Cr %</th>
<th>Mn %</th>
<th>Ti %</th>
<th>Si %</th>
<th>Al %</th>
</tr>
</thead>
<tbody>
<tr>
<td>6061</td>
<td>Max-0.25</td>
<td>0.8-1.2</td>
<td>0.15-0.4</td>
<td>0.35-0.4</td>
<td>Max-0.15</td>
<td>Max-0.15</td>
<td>0.4-0.8</td>
<td>95.8-98.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Tensile strength (Mpa)</th>
<th>Yield Strength (Mpa)</th>
<th>Elongation %</th>
<th>Vickers hardness (Hv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6061</td>
<td>301</td>
<td>276</td>
<td>12-17</td>
<td>75</td>
</tr>
</tbody>
</table>
Tool and process

For friction stir processing, a high speed steel tool which is heat treated is used.

FSP of AA6061 Specimen is done on a Vertical Milling Machine at three different rotational speeds which are 930 rpm, 1190 rpm and 1480 rpm. The process is as shown in figure.

Fig. 2: FSP tool.  
Fig. 3: FSP of AA6061 Workpiece.

MECHANICAL TESTING

Tensile Test
The tensile test was carried out in 100 kN, electro-mechanical controlled Universal Testing Machine. The specimens were loaded at the rate of 0.5 kN/min and 2.5mm/min crosshead speed as per ASTM specifications, so that the tensile specimen undergoes deformation. The specimen finally failed after necking, and the load versus displacement was recorded. The 0.2% offset ultimate tensile strength, notch tensile strength and weld nugget hardness were evaluated.

Fig. 4: Universal Testing Machine  
Fig. 5: Testing of specimen

Micro Hardness test
It is the standard method for measuring the hardness of metals, particularly those with extremely hard surfaces. The surface is subjected to a standard pressure for a standard length of time by means of a pyramid-shaped diamond. Vickers hardness is a measure of the hardness of a material, calculated from the size of an impression produced under load by a pyramid-shaped diamond indenter. The indenter employed in the Vickers test is a square-based pyramid whose opposite sides meet at the apex at an angle of 136. The diamond is pressed into the
surface of the material at loads ranging up to approximately 120 kgf, and the size of the impression (usually no more than 0.5 mm) is measured with the aid of a calibrated microscope. The Vickers number (HV) is calculated by using the formula: \( HV = 1.854(F/D^2) \),

F-Applied load (measured in kilograms-force) and \( D^2 \)-Area of the indentation (mm\(^2\))

RESULT AND DISCUSSION

Tensile Test

For many applications, the ability to support a load, or withstand an impact, without excessive deflection or failure is essential. The values of tensile strength, maximum load, and stress and strain of friction stir processed aluminium alloy 6061 were evaluated for various tool rotation speeds and tool traverse speed. The tensile test results are obtained at the cross-head speed of 2.5 mm/min.

The stress at maximum load and maximum strain for different rotational speeds of the tool which are 930 rpm, 1190 rpm and 1480 rpm are given in the tables and the graph of load v/s displacement are shown in figures asBelow:

At 930 rpm

<table>
<thead>
<tr>
<th></th>
<th>Stress at max load Mpa</th>
<th>Max. strain mm/mm</th>
<th>Max. strain mm/mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>84.800</td>
<td>0.518</td>
<td>0.518</td>
</tr>
<tr>
<td>Mean</td>
<td>84.800</td>
<td>0.518</td>
<td>0.518</td>
</tr>
<tr>
<td>SD</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Figure 7: Load v/s Displacement at 930 rpm
At 1190 rpm

Table 4: Stress and Strain 1190 rpm.

<table>
<thead>
<tr>
<th></th>
<th>Stress at max load Mpa</th>
<th>Max. strain mm/mm</th>
<th>Max. strain mm/mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>95.488</td>
<td>0.690</td>
<td>0.690</td>
</tr>
<tr>
<td>Mean</td>
<td>95.488</td>
<td>0.690</td>
<td>0.690</td>
</tr>
<tr>
<td>SD</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Figure 8: Load v/s Displacement at 1190 rpm

At 1480 rpm

Table 5: Stress and Strain 1480 rpm

<table>
<thead>
<tr>
<th></th>
<th>Stress at max load Mpa</th>
<th>Max. strain mm/mm</th>
<th>Max. strain mm/mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>107.102</td>
<td>0.771</td>
<td>0.371</td>
</tr>
<tr>
<td>Mean</td>
<td>107.102</td>
<td>0.771</td>
<td>0.371</td>
</tr>
<tr>
<td>SD</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Figure 9: Load v/s Displacement at 1480 rpm

The Load v/s Displacement graph showsthat the tensile Strength is increases with the increase in rotational speed of the tool.

**Micro Hardness Test**

The hardness of the friction stir processed (FSP) specimen of the AA6061 was measured with the help of Vickers Hardness Tester. The values of hardness measured are shown in graphs. The average hardness of base metal is 75Hv.
The hardness of the friction stir processed specimen of aluminium 6061 obtained is greater than the hardness of the base metal (al 6061). Also the hardness is increases as the rotational speed increases. The hardness is also increases as the translational speed increases. This is because of the softening of the material and refinement of the grains of the material. The effect of rotational and translational speeds of the tool on the hardness of the FSP specimen is shown in the figures.

**Microstructure Test**

The microstructure of FSP region of the defect free joints was analysed using scanning electron microscopy (SEM). The optical microscopy of FSP at cross-section of friction stir zone was observed at 100x and 200x. The microstructure of friction stir processed zone at the rotational speed of 930 rpm, 1190 rpm and 1480 rpm are shown in the figures as below.
Normally, the base metal microstructure contains elongated grains but FSP region grain size depends on the parameters such as rotational speed and translation. In the microstructure of the friction stir processed zone obvious variations were observed with softening because of recrystallisation by the dynamic recrystallisation process, and the elongated grains of the base material are changed into equiaxed fine grain structure. Defect free friction stir processed (FSP) region has smaller grain size and very fine homogeneous particles distribution. The microstructure of FSP specimen is improved as the rotational speed increases up to a limit. At lower rotational speeds, the heat produced is less and therefore the grain structure is not much refined. But at higher rotational speed the heat produced is more and this results in recrystallisation of grain structure of the material.

**CONCLUSION**

The experimental study on the mechanical behaviour of friction stir processing of aluminium alloy 6061 leads to the following conclusions and these are:

1. The fabrication of Friction Stir Processed specimen of aluminium alloy 6061 is successfully done.
2. The various mechanical properties such as tensile strength, micro hardness and microstructure of friction stir processed specimen have been evaluated after the FSP.
3. The results presented indicate that there is significant effect of process parameter like rotational speed on the mechanical properties.
4. The tensile strength of FSP of aa6061 is increases with increase in tool rotational speed.
5. The micro hardness of FSP of aa6061 is increases with increase in tool rotation speed.
6. The microstructure of FSP of aa6061 shows that the grain structure of friction stir processed zone is largely refined due to recrystallisation of the grains.
REFERENCE


