THE INFLUENCES OF THE FRICTION STIR PROCESSING ON THE MICROSTRUCTURE AND HARDNESS OF AA6061 ALUMINIUM SHEET METAL

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ABSTRACT

Friction stir processing (FSP) is an emerging surface engineering technology that can eliminate casting defects locally by refining microstructures, thereby improving the mechanical properties of the material. In this study, the influence of the Friction Stir Processing (FSP) on the microstructure and mechanical properties in terms of hardness for commercially available AA6061 Al sheet metals was studied and investigated. Samples were subjected to FSP by varying the number of passes using cylindrical geometry type high speed steel tool fixed in the Vertical milling machine. Micro structural observations were carried out by employing optical microscopy on the modified surfaces. From the microstructural evaluation, it was observed that the grain size of the processed area was around 70% decreased as compared to unprocessed parent metal. This is expected due to grain refinement by the FSP tool in the materials during processing. The hardness results showed that by increasing the number of passes the hardness of the produced composite surfaces increases steadily. It was noted here that the strength of stirred surface area was around 1.75 times higher than the unstirred surface area.

Key words: Friction stirs processing, microstructure, mechanical properties

1. INTRODUCTION

Recently friction stir processing (FSP) was developed by Mishra et al. [1,2] as a generic tool for microstructural modification based on the basic principles of FSW (Fig.1). In this work, a rotating pinned tool is fixed in the vertical milling machine (fig 2). The tool is inserted in a monolithic work piece for localized microstructural modification for specific property enhancement. For example, high-strain rate superplasticity was obtained in commercial 7075Al alloy by FSP [1–3]. Furthermore, FSP technique has been used to produce surface composite on aluminum substrate [4], homogenization of powder metallurgy aluminum alloy [5], microstructural modification of metal matrix composites [6] and property
enhancement in cast aluminum alloys [7]. FSW/FSP is emerging as a very effective solid-state joining/processing technique.

![Fig. 1 Schematic drawing of friction stir processing](image)

Dispersion of nanosized reinforcements on metallic substrate to produce surface metal matrix nanocomposite (SMMNC) and the control of its distribution are difficult to achieve by conventional surface treatments [9]. The processing of SMMNC at temperatures below melting point of substrate, is beneficial as unwanted interfacial reaction between reinforcement and matrix can be avoided [8, 10]. Much attention has been paid to friction stir processing (FSP) as a surface modification technique based on friction stir welding (FSW) [11]. FSP is also one of a solid-state processing technique to refine the microstructure. This is carried out using the same approach as friction stir welding (FSW), in which a non-consumable rotating tool with a specially designed pin and shoulder is plunged into the plate to be processed and traversed along the line of the plate. Localized heating is produced by the friction between the rotating tool and the workpiece which increases the local temperature of the material to the range where it can be plastically deformed. As the rotating tool traverses along the plate, metal is essentially extruded around the tool before being forged by the large down pressure. During this process, the material undergoes intense plastic deformation resulting in significant grain refinement [8, 12-16]. The local heating due to friction and forging action of the tool deform and process the material at elevated temperature. Since the material flows at elevated temperatures, the process also offers the possibility of redistributing the particles in metal matrix composites [17-20]. The main objective of the present study is to investigate the effect of FSP on the microstructural and strength improvement of AA 6061 Al sheet metal.

2. EXPERIMENTAL PROCEDURE

2.1 Friction stir processing (FSP)

The starting materials were monolithic cold-rolled plates of AA 6061 aluminium alloy with a nominal composition as shown in the table 1. The surface of plates was cleaned with grinding paper before processing. The dimensions of the workpiece were 50 mm×100 mm×3 mm. The plate was subjected to a FSP as shown in the macrograph in Fig. 2; the tool used to carry out the FSP is also shown as a inset (Fig. 2) which is composed of a plain cylindrical shoulder with pin. The tool was made from high speed steel with the dimensions of 12 mm shoulder diameter and 4 mm pin diameter with length of 2 mm. The designed FSP tool was...
mounted in vertical milling machine and the workpiece was rigidly fixed on the machine table. First the pin is plunged (0.3 mm depth) into the workpiece surface to be processed and then the tool was allowed to rotate in forward direction with rotation speed ($\omega$) of 550 rpm. The traverse speed of 60mm/min was used during FSP. These parameters were optimised by carrying out several trial and error experiments. All FSP studies were carried out at room temperature.

Table 1. Chemical Composition (wt %) of aluminium alloy AA6061

<table>
<thead>
<tr>
<th>Chemical Composition</th>
<th>Si</th>
<th>Fe</th>
<th>Cu</th>
<th>Mn</th>
<th>Mg</th>
<th>Zn</th>
<th>Ti</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>6061</td>
<td>0.4</td>
<td>0.7</td>
<td>0.15</td>
<td>0.15</td>
<td>0.8</td>
<td>0.25</td>
<td>0.15</td>
<td>Bal</td>
</tr>
</tbody>
</table>

Fig. 2. Macrograph showing the FSP tracks on the AA6061 plate

2.2 Characterization

The FSP samples for microstructural characterization were cut from the unstirred, shoulder stirred and pin-stirred zone of the plate. The samples were polished with emery paper up to 1200 grit followed by polishing with alumina suspension and diamond paste on a velvet cloth. Further, samples were etched with Keller reagent to distinguish the grain boundaries, identify precipitates and difference in composition. Finally, the microstructure investigation was carried out using optical microscopy.

2.3 Mechanical property evaluation

The mechanical property in terms of hardness tests were carried out to assess the effect of FSP on the AA6061 Al alloy sheet metal. Vickers micro hardness tests were carried out using a Wolpert Wilson Micro hardness tester. A load of 50 g and a dwell time of 20 s were used. The average micro hardness measurements were made on the FSP treated surfaces.
3. RESULTS AND DISCUSSION

The effect of friction stir processing on the microstructure and strength in terms of hardness for AA 6061 aluminium alloy is discussed here below:

3.1. Microstructural evaluation

![Fig. 3. Microstructure of parent metal AA 6061](image)

![Fig. 4. Microstructure of AA 6061 after FSP: (a) Two pass (b) Four pass](image)

The microstructure of AA 6061 Al alloy in as-received condition (parent metal) is shown in Fig. 3. From the Fig. 3, it can be clearly seen that the average grain sizes of AA 6061 is around 85 µm for unprocessed samples (i.e. parent metal). After friction stir processing, the microstructures of AA 6061 for two pass and four pass is shown in Fig.4. It can be noted clearly here that the material grain sizes are completely refined after FSP due to sever plastic deformation engendered by the FSP tool in the parent metal during processing. The grain size of AA 6061 after FSP is around 35 µm which was decreased by 2.4 times as compared to unprocessed parent metal for four passes. Further, the grain size of the alloy was decreased markedly with respect to number of passes. This is to the fact that the rotation speed of FSP tool and its travelling speed were expected to cause more heat input which might affects the thickness of the surface layer and as a result that refines the grain size of the material.
3.2. Micro hardness evaluation

The variation of Vicker’s hardness with different areas of AA6061 Al alloy processed by FSP is shown in Table 2. From the result it can be observed that in the case of AA6061 Al alloy the hardness of stirred zone is around 35 %, 37 %, 45 % & 49 % greater than unstirred zone with respect to number of passes for single, double, three & four passes respectively. This is expected due to grain refinement in the structure obtained by severe plastic deformation. Further it can be noted in the sample that as the number of passes increases the hardness of stirred zone increases rapidly first (up to three passes) and then increases slightly. This is due to the fact that the strengthening of the material reaches saturated condition up to three passes and beyond which there is no significant improvement in the strength. Hence in this work the samples are processed via FSP up to four passes. The hardness variation with number of passes for AA 6061 Al alloy is also shown in Fig. 5. For instance, the variation of hardness with distance measured from parent metal (left)-to-centre of stirred zone-to-parent metal (right) of AA 6061 al alloy for double passes is also shown in Fig. 6.

![Fig.5. Variation of hardness with number of passes processed via FSP AA 6061 Al alloy](image1)

![Fig.6. Variation of hardness with distance measured from parent metal (left)-to-centre of zone-to-parent metal (right) for AA 6061 Al alloy processed via FSP (No. of pass = 2)](image2)
Table 2. Variation of Hardness with different areas of AA6061 processed by FSP

<table>
<thead>
<tr>
<th>Samples</th>
<th>No. of Passes</th>
<th>Hardness, HV0.5 (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Left end (parent metal)</td>
</tr>
<tr>
<td>AA6061</td>
<td>1 pass</td>
<td>865</td>
</tr>
<tr>
<td></td>
<td>2 pass</td>
<td>967</td>
</tr>
<tr>
<td></td>
<td>3 pass</td>
<td>975</td>
</tr>
<tr>
<td></td>
<td>4 pass</td>
<td>982</td>
</tr>
</tbody>
</table>

4. CONCLUSIONS

In the present study, the plain AA 6061 Al-alloy surface was successfully modified by FSP. The microstructure and micro hardness were evaluated and investigated. The following conclusions were made based on present investigation:

1. It was demonstrated that FSP was an appropriate method to modify the microstructure and mechanical properties of AA 6061 Al-alloy. This is to fact that FSP decreased the grain size and increased the hardness of processed material.

2. The rotation speed of FSP tool and its travelling speed were expected to cause more heat input which affects the thickness of the surface layer which refines the grain size of the material.

3. The micro hardness of the stirred surface of AA 6061 Al–alloy was increased significantly compared with the unprocessed surface. Further, it was noted that the hardness was increased from around 160 to 185 % higher than the unprocessed surface which was due to grain refinement.

4. With further research efforts and increased understanding, FSP could be conducted for improving the mechanical behaviour, like fatigue and creep response and new tool design for light weight based materials and metal matrix composites.

5. REFERENCES