Manufacturing of Surface Composite Al6351/SIC using Friction Stir Processing
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Abstract—Friction stir welding (FSW) is a relatively new solid-state joining process. This joining technique is energy efficient, environment friendly, and versatile. In particular, it can be used to join high-strength aerospace aluminum alloys and other metallic alloys that are hard to weld by conventional fusion welding. FSW is considered to be the most significant development in metal joining in a decade. Recently, friction stir processing (FSP) was developed for microstructural modification of metallic materials. In this study, SiC particles and Methanol paste were incorporated by using Friction Stir Processing (FSP) into the 6351 aluminum alloy to form particulate composite materials. Samples were subjected to traverse speeds of the FSP tool with and without Paste (SiC+ Methanol). Microstructural observations were carried out by employing optical microscopy of the modified surfaces. For the 100% overlapping, No. of passes caused grain modification in the processed zone.

Keywords: FSP, Micro-Hardness, Surface composition

I. INTRODUCTION
R.S. Mishra et al.[1] In FSP a rotating tool with a specially designed pin and shoulder is inserted in a monolithic workpiece, and moved along the line of interest for localized microstructural modification. Y.wang et.al.[2] A processed zone is produced by movement of material from the front of the pin to the back of the pin shown in Fig 1. FSP leads to very fine grained microstructure in aluminum alloy to achieve super plasticity. FSP is used to modify the local microstructure and does not join metals together. The sound casting characteristics of the alloy allow the production of relatively thin forms and pressure-tight castings. Yet, often the cast alloys are characterized by porosity and interdendritic regions which cause performance deterioration due to degradation in the mechanical properties. It is reported that process parameters such as tool rotating speed and transverse speed have a significant effect on production of surface composite layer.

H.sharmadi et.al.[3] in order for modification of microstructure. Friction processing was used to produce copper graphite surface composites. Five tools with different pin profile were employed in order to achieve a comprehensive dispersion. Results show that the tool with triangular pin gives rise to a better dispersion of graphite particles. The reduction in friction coefficient is due to decrease in metal–metal contact points, originated from the presence of graphite particles as a solid lubricant. Wear loss of the composites was also decreased with increase in graphite content. Base metal-copper plates (100mm*60mm*5mm) tool material – H13 steel Shoulder and pin diameter-20mm and 3mm five tools with different pin profiles Straight cylindrical(SC), Tapered cylindrical(TC), Threaded cylindrical(TH), Square(SQ), Triangular (TR) Groove width-0.9mm. Rotating speed 1600rpm. Transverse speed -20mmrpm, Tool angle 1.5degree. Wear mechanism is determined by SEM (scanning electron microscopy) and EDS (energy dispersive spectroscopy). Best Distribution- tool with triangular pin gives rise to a better dispersion of graphite particles.

The objective of this paper was to investigate the possibility incorporation of reinforcement particles into surface layer of commercially Al 6351 to form metal matrix composites by means of FSP technique. Also, the influence of no.of passes on the mechanical properties were experimentally investigated.

II. SELECTION OF MATERIAL AND TOOL
Thirteen Millimeter thick plates of Aluminum alloy 6351 plates were used in this study. The dimensions of the FSP plates were 100mm x 120mm . The FSP tool material is made of M2 steel. It has a shoulder of 20mm diameter and 4mm long pin with a (6*3)mm tapper dia. FSP was conducted using a vertical head milling machine with constant tool travel speed of 50mm per minute and rotating rate 1000rpm,710 rpm.

<table>
<thead>
<tr>
<th>Physical Characteristic of Aluminium Alloy AA6351</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Material</td>
</tr>
<tr>
<td>Density(x1000kg/m3)</td>
</tr>
<tr>
<td>Elastic modulus(Gpa)</td>
</tr>
<tr>
<td>Tensile strength(Mpa)</td>
</tr>
<tr>
<td>Yield strength(Mpa)</td>
</tr>
<tr>
<td>Hardness(HB500)</td>
</tr>
</tbody>
</table>

Table 1: Chemical Composition of Al6351

Table 2: Physical Characteristic of Aluminium Alloy AA6351
III. TOOL DESIGN

The shoulder generates most of the heat and prevents the plasticized material from escaping from the work-piece, while both the shoulder and the tool pin affect the material flow. In recent years several new features have been introduced in the design of tools.

The M2 material high carbon steel is used with the taper pin profile.

Tool Shoulder Dia. 20mm
Tool Pin Taper Dia. 6mm
Tool Pin Length 4mm

A. FSP procedure

The rolled plates of 13 mm thickness, AA 6351 Aluminum alloy, were cut into required size (100 mm x 120mm) by power hacksaw cutting and milling. The initial configuration was obtained by securing the plates in position using mechanical clamps. The direction of FSP was normal to the rolling direction. No. of passes FSP procedure was followed to composite the surface. Non-consumable tool, made of HSS were used to composite the surface. Tapered pin profiles were prepared from HSS material and it is used to composite the surface. The most predominant factors which are having greater influence is micro-hardness of friction stir processed Aluminum alloys.

B. Process Parameter:

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Feed (mmmpm)</th>
<th>Speed (rpm)</th>
<th>Tool tilt angle degree</th>
<th>No. of Passes</th>
<th>Powder</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>100</td>
<td>1000</td>
<td>0</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>1000</td>
<td>1000</td>
<td></td>
<td>3</td>
<td></td>
<td>Micro-Hardness</td>
</tr>
<tr>
<td>C</td>
<td>710</td>
<td>710</td>
<td></td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>710</td>
<td>2</td>
<td></td>
<td>3</td>
<td>With Paste</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>710</td>
<td>3</td>
<td></td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>710</td>
<td>4</td>
<td></td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1000</td>
<td>3</td>
<td></td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>710</td>
<td>4</td>
<td></td>
<td>4</td>
<td>With-out paste</td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Process parameter

C. Experimental procedure

1) Experimental work

A conventional Vertical Head Milling machine can be successfully modified into a Friction Stir Processing machine which is capable of producing defect free aluminum surface composition. During the FSP of Al alloy 6351, the rotational speed of the tool is 710, 1000, rpm. The Transverse feed rate for all the weld is 50 mm/min. and tool tilt angle 3 degree. The paste of Methanol and Sic powder is use for the filling of the no. of holes which is in zigzag pattern and slot. Figure shows the machining plates of Al alloy 6351 with different no. of passes. Which are machined by the taper tool. Tool is plunge in the work-piece is 3.6mm.

After the FSP processing with different no. of passes with the help of milling machine work-pices are shown in the different figures.
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Fig. 5: FSP processed plates of Al6351
To assess microstructure the metallographic samples were prepared for examination by using optical microscopy. The metallographic samples were cut from the cross section of FSP plates.

IV. RESULT AND DISCUSSION

A. Microstructure

The sample preparation for the microscopic investigation includes grinding, diamond polishing and electro polishing. All microstructural samples were taken from the transverse section of the processed area at the bottom of the sheet thickness.

In the present study all the experiments are conducted at 1000rpm and 710rpm rotational speed and 50mm/min traverse speed. Fig. Shows the micrographs of Al 6351+ SiC composite specimens in the stirring zone. The addition of SiC particles into Al 6351 matrix using the Al 6351 matrix. With multi pass friction stir processing with 100% overlap resulted in more heat input and so grain growth increased and SiC is distributed non-homogeneously in Al matrix.

The microstructural results using Optical Microscope show the difference in grain size and homogeneity. Different samples were taken at the R.S. to A.S. nugget region and inspected using Optical Microscope. The results show that great grain refinements are achieved. Important observation is that the Four passes Sample C & F with 1000rpm and 710 rpm respectively has higher powder distribution compare to other samples.

B. Micro-Hardness

Vickers Hardness of friction stir processed AA5052 samples were measured using Vickers hardness tester. The test load applied was 300 gms and the dwell time was 10 seconds. Various samples FS processed at different rotational speed were tested.

<table>
<thead>
<tr>
<th>Sample</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reading 1</td>
<td>66.4</td>
<td>63.5</td>
<td>66.3</td>
<td>63.4</td>
<td>65.7</td>
<td>63.4</td>
<td>59.1</td>
<td>56.1</td>
</tr>
<tr>
<td>2</td>
<td>67.4</td>
<td>64.1</td>
<td>63.2</td>
<td>60.1</td>
<td>66.4</td>
<td>63.5</td>
<td>56.3</td>
<td>56.8</td>
</tr>
<tr>
<td>3</td>
<td>64.5</td>
<td>64.7</td>
<td>64.7</td>
<td>61.8</td>
<td>64.3</td>
<td>66.5</td>
<td>57.6</td>
<td>57.0</td>
</tr>
<tr>
<td>4</td>
<td>61.6</td>
<td>69.0</td>
<td>66.9</td>
<td>59.6</td>
<td>62.0</td>
<td>66.3</td>
<td>56.2</td>
<td>56.1</td>
</tr>
<tr>
<td>5</td>
<td>63.3</td>
<td>63.7</td>
<td>66.0</td>
<td>61.7</td>
<td>62.0</td>
<td>65.6</td>
<td>56.8</td>
<td>55.4</td>
</tr>
<tr>
<td>6</td>
<td>65.2</td>
<td>58.4</td>
<td>65.0</td>
<td>64.3</td>
<td>66.8</td>
<td>63.5</td>
<td>53.6</td>
<td>54.4</td>
</tr>
<tr>
<td>Avg.</td>
<td>64.7</td>
<td>63.9</td>
<td>65.35</td>
<td>61.81</td>
<td>64.5</td>
<td>64.78</td>
<td>56.6</td>
<td>55.96</td>
</tr>
</tbody>
</table>

Table 4: Micro Hardness values

The results show that the friction stir processed area with Paste (Methanol + Sic powder) has a higher Vickers hardness value than the simple friction stir processed area material. All samples were taken from the transverse section of the processed area at the bottom of the sheet thickness.

1) Comparison based on Rotation speed at 1000 and 710 rpm

Micro Hardness graph in fig.9 and fig.10 are indicated at rotational speed at 1000rpm and 710 rpm respectively. Series 1-4 indicate the different micro hardness values of different samples in both graphs. Series 3(Sample C&F) have higher values compare to the other series. From both graph fig.1 has the higher micro hardness values which indicate the sample C. As the higher speed is selected higher micro hardness values can be achieve.

Fig. 9: Micro Hardness graph at 1000rpm rotational speed
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Fig. 10: Micro Hardness graph at 710rpm rotational speed

2) Comparison based on no. of passes

Fig. 11: Two passes graph

Fig. 12: Three passes graph

Fig. 13: Four passes graph

Comparison graph between two three and four passes is shown in the fig. In first graph Sample A & D is processed by two passes. In which the sample A has the higher micro hardness value. In second graph Sample B&E is processed by three passes. In this graph sample B has high values compare to the sample E. As in last third graph samples C, F, 1 and 2 is processed by four passes. From comparing all three graphs it can be seen that the no. of passes increases the value of micro hardness is also increase. Powder is better distributed in the four passes samples compare to the two and three passes samples.

V. CONCLUSION
The result obtained in this study lead to conclusions for processing of aa6351 material after analyzing the collect data. Using the optimal process parameter of friction stir processing of aluminum alloy for micro-hardness is determined. The optimum combination of parameters obtained from the main effect plot for mean is process parameters of 1000 rpm tool Rotation rate (rpm), 50 mm/min traverse speed and 3 degree tool tilt angle and four no. of passes has been predicted to give the best micro hardness values.

VI. FUTURE WORK
- Predict the generated forces, torque and power
- More experimental work has to be done to investigate the effect of tool design on the process and the resulting microstructure.
- Use different techniques; such as thermocouples and infrared technology to determine the temperature distribution during the process.

REFERENCES

- Considering the effect of shoulder on the mechanical deformation