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Microstructure and Mechanical Properties of Multi Pass Friction Stirred Processed Aluminium Silicon Carbide Metal Matrix

Prasanthi S*, Satyanarayana K, V V Murali Krishna G

[1*,2] Mechanical Department, SRKR Engineering College, Bhimavaram, Andhra Pradesh, India

[3] Mechanical Department, BVC Institute of Technology and Science, Amalapuram, Andhra Pradesh, India

ABSTRACT

Aluminium alloys of the 6000 series are known to have good formability, weldability, and high strength- to-weight ratio. The major alloying elements in the heat-treatable 6000 series are silicon and magnesium. Both elements are required for precipitation strengthening. Strengthening can be enhanced further by refining the grain size to a few micrometers and lower. This can be achieved by friction stir processing (FSP). An improvement in the mechanical properties was accomplished due to the micro structural modification of Aluminium alloy by multi pass friction stir processing (MP-FSP) which is a solid state micro structural modification technique using a frictional heat and stirring action. Samples with one through three passes with 100% overlap were created using friction stir processing (FSP) in order to locally modify the micro structural and mechanical properties of Aluminium Alloy. The micro structural properties in terms of particles distribution, and also the mechanical properties in terms of hardness and Surface Roughness of the processed zone were addressed with respect to the number of passes and traverse speeds.

In the present study, 2.5% (by weight) Sic particles were incorporated by using Friction Stir Processing (FSP) into the 6351 Aluminium alloy to form particulate composite layered materials. Samples were subjected to constant rotational and traverse speeds of the FSP tool with and without Sic reinforcements. Samples were subjected to machining by Friction stir machining process on CNC machine with constant rotational and transverse speed by using HSS tools having 16mm and 18mm as diameter. Micro structural observations were carried out by employing optical microscopy of the modified surfaces. Mechanical properties were evaluated by Hardness test on vikers Hardness tester and Surface Roughness Values by Surface Roughness tester.

Keywords : Stir Processing, Friction Stir Processing, PZ, Hardness Measurements, Vickers Hardness Testing,Al2o3, Al-Si , Metal-Matrix Composites, MMC

I. INTRODUCTION

FRICTION STIR PROCESSING: Selection of material specific properties is the key parameter in many industrial applications, especially in the aircraft and automotive industries. However, processing of such alloys with specific properties, like high strength, suffers from certain limitations in terms of cost and time of production, apart from the reduction in ductility. High strength accompanied by high ductility is possible with materials having fine and homogenous grain structures. Hence there arises a necessity to develop a processing technique that would produce a material with small grain size that satisfies the requirements of strength and ductility as well as the cost and time of production. There are new processing techniques like Friction Stir Processing (FSP).

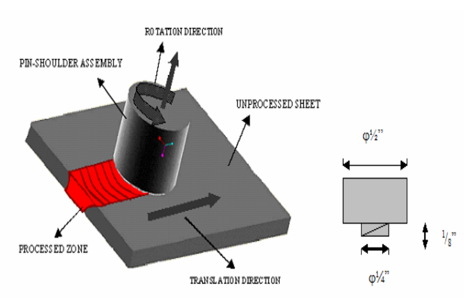

Figure 1 : Schematic of Friction Stir Process

FSP is a new and unique thermo mechanical processing technique that alters the micro structural and mechanical properties of the material in a single pass to achieve maximum performance with low production cost in less time. In the present work, FSP is investigated as a potential processing technique for aluminium alloys because of various advantages it offers over other processes as mentioned above.

To process a sheet by friction stir, a specially designed cylindrical tool is used which while rotating is plunged into the selected area. The tool has a small diameter pin with a concentric larger diameter shoulder. When the tool is plunged into the sheet, the rotating pin contacts the surface and friction between the sheet surface and the Shoulder rapidly heats and softens a small column of metal, enabling the transverse movement of the tool through the material. The tool shoulder and length of the probe control the depth of penetration. it is not lost as flash. The shoulder also generates the majority of the heat required to raise the temperature of the material so that it can be readily plasticized. The primary role of the tool pin is to act as a 'mini' solid state extrusion pump, in order to transport material up and down the PZ, and around the pin. Furthermore, the pin also helps to break up and disperse large particles, oxides or impurities contained within the material.

II. METHODS AND MATERIAL

2.1 FSP TOOLING

The tool design is a very important factor in FSP. By using a carefully designed tool piece, the quality of the weld, or processed track, can be improved and productivity can be increased. There are several features that could be altered. A typical friction stir tool consists of two major parts, which are the tool shoulder and the tool pin. The key function of the tool shoulder is to constrain the material under the tool so that it is not lost as flash. The shoulder also generates the majority of the heat required to raise the temperature of the material so that it can be readily plasticized. The primary role of the tool pin is to act as a 'mini' solid state extrusion pump, in order to transport material up and down the PZ, and around the pin. Furthermore, the pin also helps to break up and disperse large particles, oxides or impurities contained within the material.

Figure 2: 3D view of the tool used

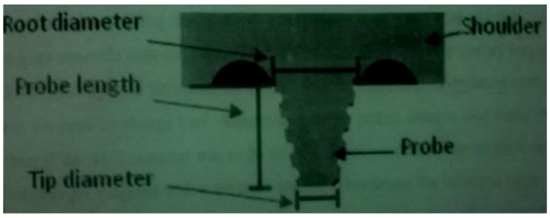

Figure 3 : Probe Dimensions

2.2 SELECTION OF MATERIAL

Alloys 6000 series contain Silicon and Magnesium in approximate proportions to form magnesium silicide, thus making them heat-treatable. In this series is 6351, one of the most versatile of heat-treatable alloys. The magnesium-silicon (or magnesium-silicide) alloys possess good formability and corrosion resistance, with medium strength.

2.3 MECHANICAL PROPERTIES

The performance of any metal is evaluated based on the properties of the metal like Physical, Electrical, Magnetic and Optical properties among the mechanical properties plays major role. The different mechanical properties are Tensile, Hardness, Bend and Impact Test etc.

2.4 HARDNESS TEST

Macro and micro hardness testing is a quick and simple way of determining the local yield stress of a material. Hence, the technique was used for obtaining the hardness profiles across the process zones in the FSP samples, in order to investigate local variations in mechanical properties as a functional of the experimental variables.

Figure 4: Micro Vickers Hardness Tester

Hardness measurements were carried out using a Vickers hardness testing machine. The samples were prepared by grinding and polishing to create a flat and parallel surface to the machine stage. When the hardness testing machine is operated, a pyramid shaped diamond penetrates the surface of the material with a set force, generating an indentation into material.

2.5 SURFACE ROUGHNESS

Surface roughness, often shortened to roughness, is a component of Surface texture. It is quantified by the deviations in the direction of the normal vector of a Real surface from its ideal form. If these deviations are large, the surface is rough; if they are small, the surface is smooth.

Figure 5: Surface Roughness Tester

Roughness is typically considered to be the high frequency and short wavelength component of a measured surface. However, in practice it is often necessary to know both the amplitude and frequency to ensure that a surface is fit for a purpose. Roughness is often a good predictor of the performance of a mechanical component.

2.6 MICROSTRUCTURAL ANALYSIS

The Metallographic specimens were prepared by mounting and grinding and polishing by using Al2O3 powder, Diamond paste and etche with Keller's reagent.

Figure 6: Optical Microscope

Micro structural observations were carried out by employing optical microscope of the cross sections perpendicular to the tool transverse direction.Microstructural observations were carried out at 400X by optical microscope.

2.7 CHEMICAL COMPOSITION

CHEMICAL COMPOSITION OF Al ALLOY 6000 SERIES

Alloys 6000 series contain Silicon and Magnesium in approximate proportions to form magnesium silicide, thus making them heat-treatable. In this series is 6351, one of the most versatile of heat-treatable alloys. The magnesium-silicon (or magnesium-silicide) alloys possess good formability and corrosion resistance, with medium strength. Alloys in the heat-treatable group may be formed in the T4 temper (solution heat-treated but not artificially aged) and then reach full T6 properties by artificial aging.

Table 1: Chemical Composition of Al 6351 alloy

Al	Mg	Si	Cu	Ti	Mn	other
Bal	0.8-2.5	0.4-0.8	0.15-1.8	Max. 0.64	Max. 0.35	0.05

2.8 CHEMICAL COMPOSITION OF AL-SI CASTING ALLOYS

Al-Si alloys are commonly used as a casting material. This class of Al alloys has a low molten viscosity, and allows components with complex geometries to be produced with minimal defects and low shrinkage [Elliot, 1983; Barnes, 2001]. However, in order to improve the performance of the alloy to meet the other demanding requirements, additional alloying elements are commonly added. Depending on the composition and the Silicon (Si) content, the microstructure that develops will vary, and this will in turn lead to alterations to the properties of the alloy.

Table 2: Chemical Composition of Al-Sic alloy

Al	Mg	Si	Cu	Ti	Mn	Other
Bal	0.8-2.5	0.4-2.5	0.15-1.86	Max. 0.80	Max. 0.48	0.05

III. LITERATURE REVIEW

Friction stir processing (FSP) is a recent technology for surface modification and developing surface and bulk reinforcement MMCs and this friction stir processing can be done to aluminium alloys of 6000 series and especially for Al6351. The processing of aluminium and its alloys has always represented a great challenge for researchers and technologists. Aluminium and its alloys mostly used in automotives and aerospace industries because of its low density and high strength to weight ratio. Metal-Matrix composites (MMCs) are represented a new class of structural materials as conventional metals and alloys approach their development limits and with proper processing, the reinforcement of a metal matrix with various particulate reinforcements can yield MMC with significantly improved properties like lower density, higher specific modulus and higher specific yield strength. The addition of ceramics reinforcements (SiC) raised performance limits of the aluminium alloy 6351 and however the presence of reinforcements in matrix makes it brittle. Instead of bulk reinforcements, if the ceramic particles would be added it could improve the wear resistance and hardness.

R.S.Mishra et al. demonstrated that the FSP is a versatile technique with a comprehensive function for the fabrication, processing and synthesis of materials. The microstructure and mechanical properties of processed zone can be controlled by optimizing the tool design and FSP parameters. The depth of the processed zone can be adjusted by changing the length of the tool pin, and large volume of materials can be produced by multiple passages. The effect of particle refining, mixing and consolidation of powder mixtures provided by FSP can be investigated without the interference of reaction between reinforcement and matrix.

PREPARATION OF WORK PIECES THROUGH STIR CASTING

This involves incorporation of ceramic particulate into liquid aluminum melt and allowing the mixture to solidify. Here, the crucial thing is to create good wetting between the particulate reinforcement and the liquid aluminum melt. The simplest and most commercially used technique is known as vortex technique or stir-casting technique. The vortex technique involves the introduction of pre-treated ceramic particles into the vortex of molten alloy created by rotating impeller.

Figure 7: Preparation of Work Pieces through Stir Casting

IV. EXPERIMENTAL SETUP

A CNC milling machine was used for friction stir processing (FSP) of aluminium alloy. The machine was a maximum speed of 6000rpm and 10-horse power. The materials used in this work are commercial Al6351 alloy (tempered condition) rolled plates with nominal composition as shown in table. The surface plates were cleaned with grinding paper and methanol before processing. Work pieces were prepared with a length, width, thickness (100x50x4) mm3 respectively. A shallow groove of size 1mmx1mm was machined through the centre surface of the substrate.A hardened HSS tool was used that consists of a shoulder with diameter of 16mm and 18mm, pin with a tapper diameter of (2 x 3) mm and length 2mm respectively. This tool is fitted into the tool holder and work piece is rigidly clamped to machine table using fixtures.

Table 3: Experimental Details

Exp .No	Rot.Speed	Trans. Speed	Material	No of Passes
1	1000 rpm	20mm/ min	Al 6351	1 pass
2				2 pass
3				3 pass
4			Al 6351+Sic	1 pass
5				2 pass
6				3 pass

V. RESULTS AND DISCUSSION

The hardness of Al 6351 base alloy with single pass has increased compared to Al 6351 base alloy without FSP. For the multi-pass test specimens the hardness is found to be decreased due to grain softening caused by excessive heat input and non-uniform distribution of silicon. For Al 6351-SiC composite with single pass, the hardness is found to increase compared to Al 6351 base Alloy with single pass; this is due to the inclusion of hard SiC particles into the Al matrix. However the effect of multi-pass FSP on hardness of both Al 6351 base alloy and Al 6351-SiC composite is found to be decreasing due to heat input and grain softening during multipass FSP.

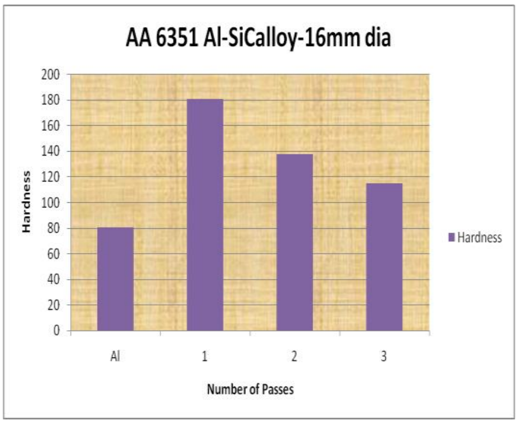

Figure 9: Variation of hardness of AA 6351Al-Sic (16mm) alloy

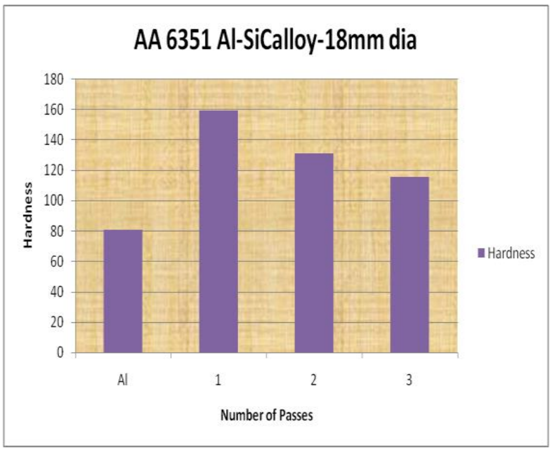

Figure 10: Variation of hardness of AA6351Al-Sic(18mm) alloy

Surface roughness is measured using surface roughness tester. For both 16mm and 18mm Al+Sic diameter tools surface roughness decreases as the number of passes increased.

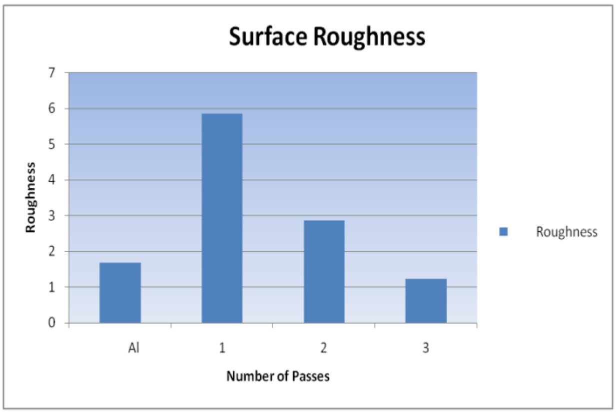

Figure 11: Variation of Roughness of AA 6351Al-Sic (16mm) alloy

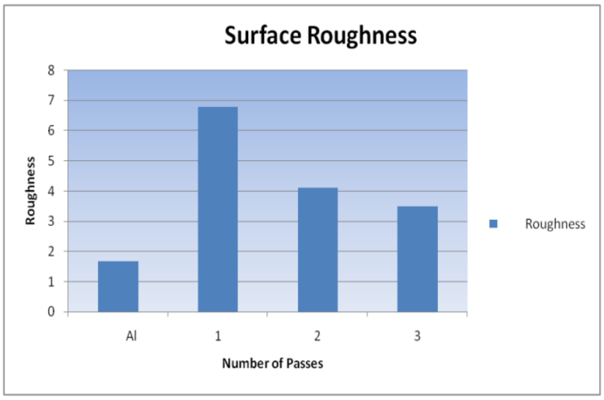

Figure 12: Variation of Roughness of AA 6351Al-Sic(18mm) alloy)

Microstructure of the Al 6351 FSPed nugget cross-section was observed by optical microscope. In the present study all the experiments are conducted at 1000rpm rotational speed and 20mm/min traverse speed. As the no. of passes increased, with 100% overlap a refinement of Silicon flakes is observed and volume % of silicon increased to 44.81%. In the third pass, the Silicon flakes are further refined and volume % of Silicon is found to be 42.8%.It is noticed that the grain size is reduced for 100% overlapping specimens compared to specimens with single pass (without overlapping).Withmultipass 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

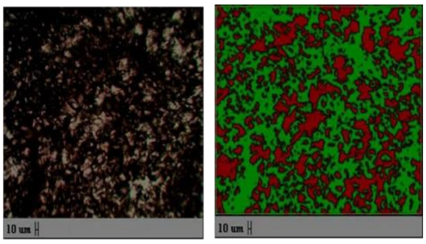

Figure 13: Microstructure of Al 1-pass

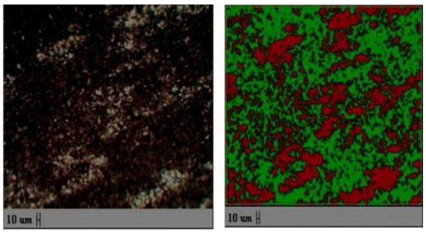

Figure 14: Microstructure of Al 2-pass

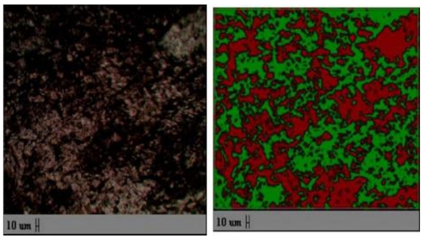

Figure 15: Microstructure of Al 3-pass

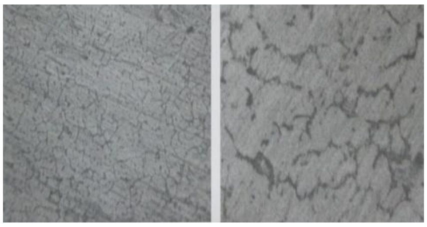

Figure 16: Microstructure of Al+SiC (18mm) 1 pass

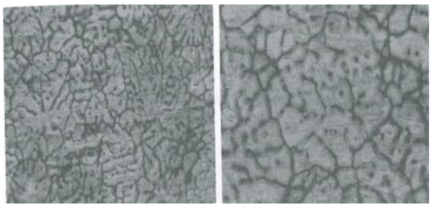

Figure 17: Microstructure of Al+SiC (18mm) 2 pass

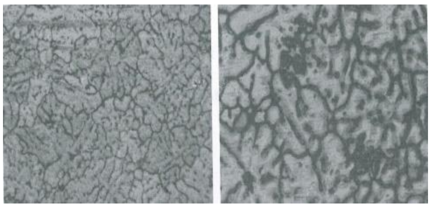

Figure 18: Microstructure of Al+SiC (18mm) 3 pass

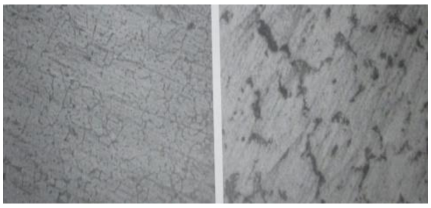

Figure 19: Microstructure of Al+SiC (16mm) 1 pass

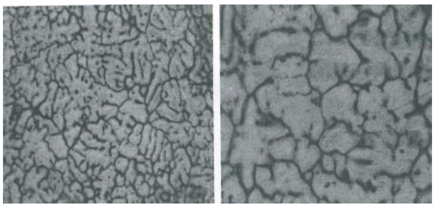

Figure 20: Microstructure of Al+SiC (16mm) 2 pass

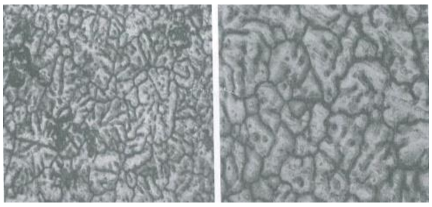

Figure 21: Microstructure of Al+SiC (16mm) 3 pass

VI. CONCLUSION

The aluminium alloy 6351 was successfully processed by the FSP. The micro structure, hardness and surface roughness were evaluated. The results are summarized as follows

- ✓ Increasing the percentage of overlapping resulted in limited change in the grain size, but provided more sub grain formation.
- ✓ A reduction in the strength and micro-hardness of multi-pass FSP samples occurred due to the precipitate dissolution and the limited re-precipitation by the thermal cycle of FSP.
- ✓ The highest micro-hardness of Al 6351/SiC powder composite can be attributed to the presence of reinforcement particles.
- ✓ It has been demonstrated that FSP other than 100% overlapping multipass was an appropriate method to modify the micro-structure and mechanical properties of 6351 Al-alloy.
- ✓ FSP resulted in fine and equiaxed grains in the stirring zone and overlapping area.
- ✓ With further research efforts, FSP could be conducted for mechanical behaviour of these composites, like fatigue, wear and creep, response etc.....

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