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Fabrication and Analysis of Bulk SiCp Reinforced Aluminum Metal Matrix Composites using Friction Stir Process

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***Abstract*—**In this study, Friction Stir Processing (FSP) a recent grain refinement technique was employed to disperse micron-sized (2 μm) SiCp particles into aluminum alloy AA6063. The feasibility to fabricate bulk composites through FSP was analyzed and experiments were conducted at different traverse speeds and wider volumes of the specimens. Micro structural observation were carried out by employing optical microscopy test of the cross sections in both parallel and perpendicular to the tool traverse direction. Mechanical property including micro hardness was evaluated in detail at various regions on the specimen. The composites had an excellent bonding with aluminum alloy substrate and a significant increase of 30% in the micro hardness value of metal matrix composite (MMC) as to that of the base metal has observed. The observations clearly indicate that SiC particles were uniformly distributed within the aluminum matrix.

***Keywords*—**Friction Stir Processing; Metal matrix composite; Bulk composite

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I. Introduction

THE potential for metal matrix composites(MMC) in common and aluminum matrix composite (AMC) in specific is mammoth and in certain technology areas their use have been well established already where general unreinforced have reached their limits .AMC's have become a indispensible requirement in automotive engineering. It is extensively used in hot reciprocating applications such as pistons in engine where hot strength and resistance to thermal fatigue are markedly improved. It is also used in motor industries for better fuel economy, lower exhaust emission and improved engine performances. AMCs have also emerged in aerospace, defence and in high end sophisticated sporting application which represents a breakthrough in growing acceptance of these composite materials. The increase in lightness fatigue resistance, stiffness, better thermal and electrical properties have paved a vital role in various above fields. Friction stir welding (FSW) which was invented by the welding institute in UK in the year 1991. This technique was used to join two different alloys using simple non consumable tool. On gradual integration and research in FSW led to the birth of a novel technique Friction Stir Process. This unique process is used to make MMC. FSP was basically developed by Mishra et al (2003) in Micro structural modification and fabrication of metal matrix composites which are based on the basic principles of FSW.

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There are several methods to produce MMCs;

1. Stir casting
2. Squeeze casting
3. Molten metal infiltration
4. Powder metallurgy
5. Plasma spraying
6. Cast sinter
7. Casting high energy laser melt treatment [6].

But these above techniques have many drawbacks such as;

- Dispersion of reinforcement in a uniform manner is a critical and arduous task
- Problem of interfacial reaction between reinforcement and metal matrix
- Formation of detrimental phases
- Limitation of particle size in each process
- Further more critical control of processing parameters is necessary to obtain solidified microstructure in surface layer [8].

The above challenges can be avoided in FSP because this process is carried out at temperatures below melting point of substrate, as well energy efficient, eco friendly and versatile. Since FSP causes intense plastic deformation material mixing with thermal exposure yielding to significant microstructure refinement. Due to better densification and homogeneity of processed zone, it is favorable than any other process [3].

There are two types of modifications in FSP

i. In volume FSP(VFSP)
   Where modification is in full thickness of material
ii. Surface FSP(SFSF)

Where modification of surface of processed material up to a desired depth.[3]

In recent years, some researches about studying upper surface modification of light metal alloy have been reported. In Mishra's paper, 5083Al-based SiCp reinforced surface composite was made within 50–200_m range (Mishra et al., 2003). Morisada reported that MWCNTs/AZ31 surface composite was fabricated by changing travel speed (Morisada et al., 2006). Several deep grooves processing was also studied by Lee et al. (2006). According to above researches, surface composites were attempted by changing base materials, reinforced materials and processing way. However, there is still an unsolved problem on MMCs fabricated by FSP. The reinforced materials are apt to agglomerate but difficult to transfer to wider and deeper region. Thus, the upper surface

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composites were published in the past papers, the successful research on widely dispersed bulk MMCs was rarely reported till now[1]. The objective of this paper was to investigate the possibility of incorporation of reinforcement particles into surface layer of commercial aluminum alloy to form metal matrix composites by means of FSP technique to produce bulk MMCs. The experiments were designed to make research on the feasibility to produce wider, deeper bulk MMCs by FSP with smaller particle size of SiC at different feed rates.

II. Experiment Methods

The base metal used in the experiment was commercially available AA6063-T4 aluminum alloy rolled plate of a nominal composition and the reinforced particles used was green Sic powder having a average diameter <d> ~3micron and purity ~99.9%.The aluminum plate were cut in a rectangular shape of dimension (100*50*10mm).FSP tool was made of high speed steel and hardened to 60 hrc. The tool pin was 6 mm diameter, shoulder diameter of 18 mm. The complete process was done in a CNC vertical machining center machine of 20 HP spindle. The tool was rotated in clock wise direction; the tool rotation was kept constant at 1000 rpm. The advancing speed was varied to 30, 40 and 50 mm/min. The plate was fixed in a vice tightly and an ambient air cooling was maintained throughout the process.

A groove was cut using a slitting saw cutter of width 1.2, 1.5, 1.8 mm and depth 6 mm exactly in the centre of the specimen plate's .SiC powder was deposited in the groove. In order to prevent sputtering of SiC and depose from the groove during FSP a modified tool which was devoid of a pin and the shoulder being chamfered for 2 mm was employed to close the gap in the groove after which surface repair was conducted [6].

Vickers hardness test were carried out using 0.5kg load for 10 sec. The micro hardness was measured along for 3mm under the surface. Optical microscopy test was carried out to see the dispersion of reinforcement into the base metal. The test was conducted along the cross section and perpendicular to the processed zone.

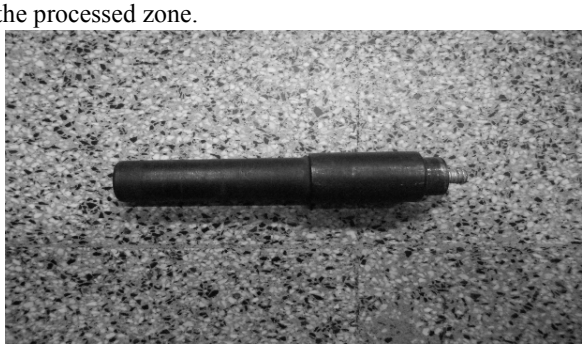
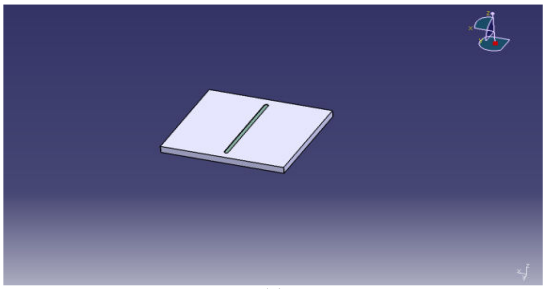
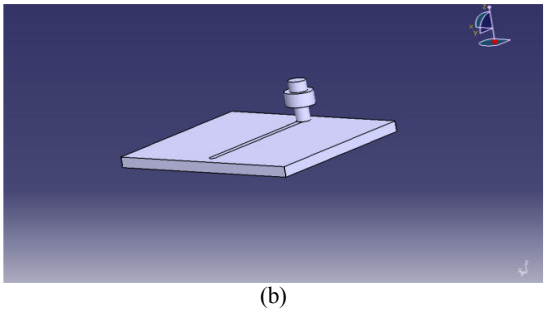


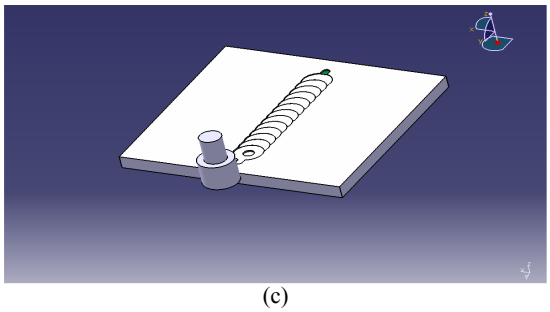
Fig.1 FSP tool



(a)



(b)



(c)

Fig. 2 The FSP procedure
a) Cutting groove at the centre and inserting SiC_p in the specimen plate
b) Using a modified tool the groove is closed
c) FSP tool is plunged and surface repair is undertaken.

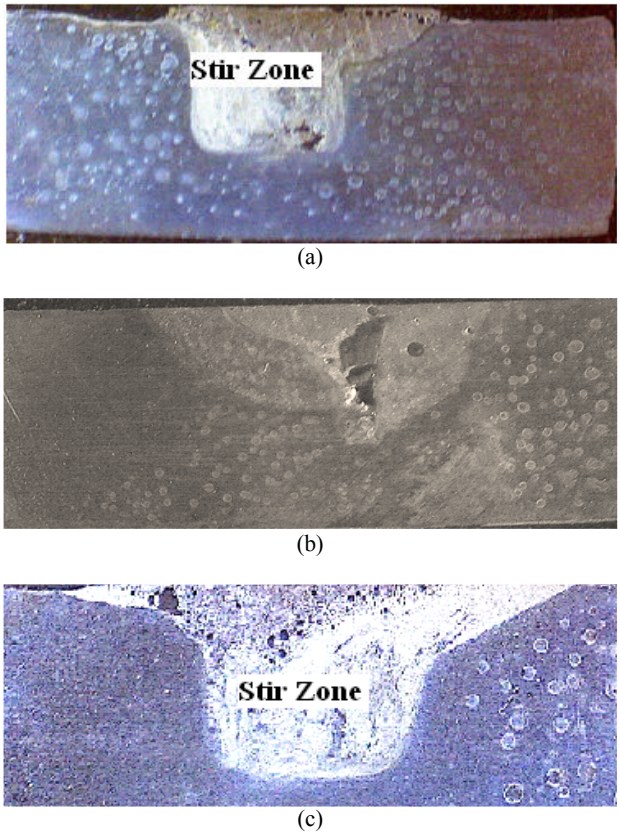
In fig 3.4, the SiC particles, stir zone and parent metal are seen. Fig 3.4 (C) shows that the SiC particles are dispersed in a fine manner in the matrix. The Fig 3.4 (b) shows the SiC particles embedded in the matrix. It also shows the SiC carbide particles that have chipped off from the surface during machining.

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III. Results And Discussions

A. Macrograph

The micro structural changes of AA6063 alloy processed by various friction stir parameters are shown. The macro structural examination of the friction stir processed specimens at 10X magnification is shown in the Fig.s below.



(a)

(b)

(c)

Fig. 3 The cross section of the macrograph shows weld with silicon carbides, TMT Zones and parent metal at various width.
(a) 1.2mm (b) 1.5mm (c) 1.8mm

B. Microstructure

After the fabrication of Al MMCs the microstructure of stir zone was observed by optical microscope. The result is shown in the Fig. 4. The black color spot indicate the presence of SiC. The yellow color indicates the Al base metal. The stir zone of the specimens after FSP was characterized by fine and equi-axed grain growth, which is a result of recrystallization. It is caused by co-existence of severe plastic deformation and frictional heat. There are two discrete reasons for grain size variations: (1) Heat input that cause annealing which increases the grain size. (2) Continuous dynamic recrystallization [4]. The phenomenon which forces thermo-mechanically processed material to have smaller grains is called recrystallization[2].

This is caused due to the stirring action of FSP tool pin which created new nucleation sites resulting to reduction of the grain size[4]. But from the results obtained we can conclude that uniform grain growth occurred predominantly due to dynamic recrystallization. To produce a fine grain structure either tool rotation speed or traverse speed can be varied. On varying the spindle speed results were not possible and almost insignificant[4]. So in this paper only traverse speed was varied and result obtained was significant and positive.

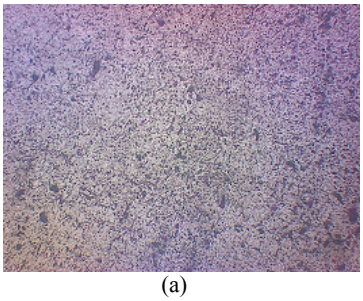
Since the heat input and dynamic recrystallization are two important factors affecting the growth in stirzone higher traverse speed led to lower heat due to short period of time. So at lower traverse speed heat developed was huge. Additionally tool also generates sheer force to make SiCp flow and disperse in wider region resulting to 6 x 5 mm cross-section in the bulk composite.

The temperature evolved during the process was enough to melt the base metal below the melting point, due to this reinforced particle were easily bounded by softening metal and rotated with the pin of the tool.

The FSP tool was made of two parts Shoulder and Pin. Shoulder is the main heat source. The vertical rapid transfer and rotation of base metal mainly rely on screwed pin from advancing side to the reversing side, but only limits to the range of pin diameter [1]. The interface condition of stir zone resulted in good interface bonding as in Fig. 4.(b)(ii)

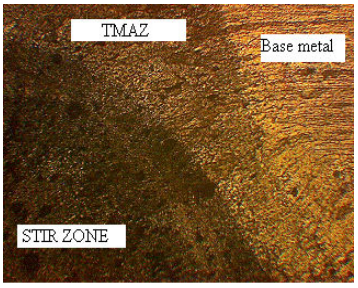
The narrow thermal mechanical affected zone (TMAZ) reflects materials flowed range indirectly. In Fig. 4.(c)(i)TMAZ of the stir zone was not distinct in the sides but on other stir zones it was distinct as shown in the Fig.4(b)(i).It shows that the recrystallization has not occurred properly in TMAZ. In Fig. 4.(c)(i) the TMAZ at bottom was not distinct because of slower heat transfer [4].

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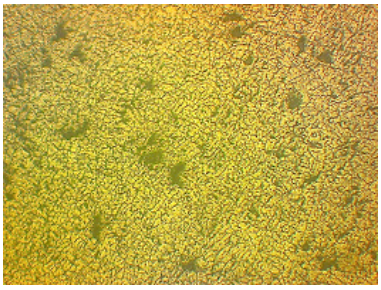


(a)

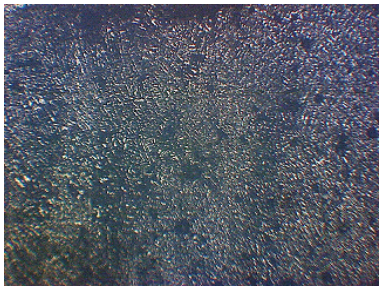
Feed 30 mm/min



(b) (i)

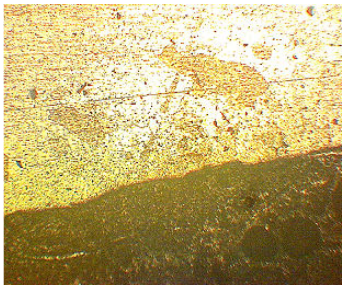


(b)(ii)

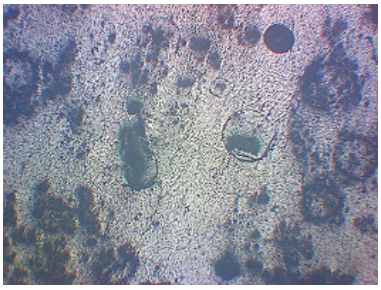


(b) (iii)

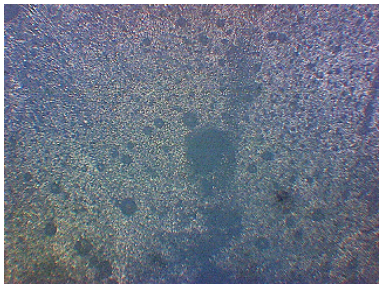
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(c)(i)

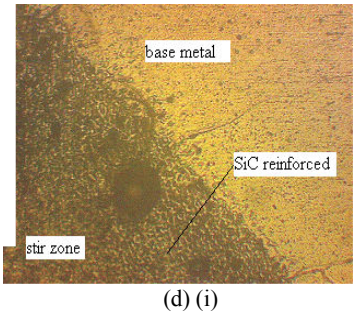


(c) (ii)

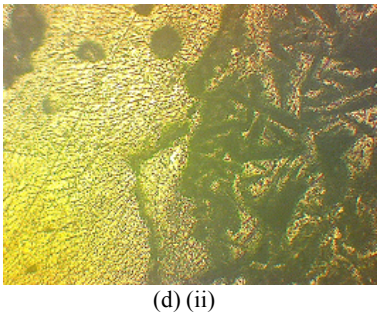


(c)(iii)

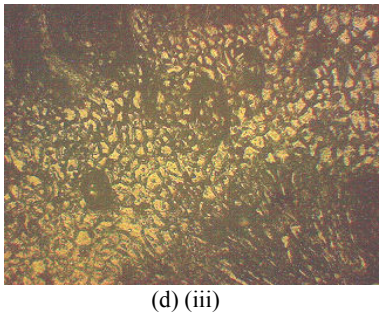
Feed50mm/min



(d) (i)



(d) (ii)



(d) (iii)

Fig. 4 (a) The microstructure of the parent metal AA6063. (b),(c),(d) of (i) Shows the fsp zone with the parent metal.(b),(c),(d) of (ii) shows the processed zone with the dispersion fragmented particles perpendicular to the processed zone. (b),(c),(d)of (iii) Shows complete fsp zones with fine grains of Aluminum solid solution with SiC particles trapped in the cross sectional view

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IV. Microhardness Testing

The micro hardness of the composite was tested using 0.5 kg load. The hardness value has increased from 40 Hv to 62 Hv. The hardness values were tested at different depths. The result clearly showed that at lower traverse speed the hardness value is high. Since the shoulder supplied enough heat and force, the Sic particle at full depth were dispersed well in the base metal. As a result micro hardness was enhanced by SiCp.

The possible factors that influence the micro hardness in MMC's are 1) Orowan strengthening 2)Grain and substructure strengthening 3)Hall-petch relationship 4)Quench hardening resulting from the dislocation generated to accommodate the different thermal contraction between the particles and matrix. 5) Work hardening due to the strain dislocation between elastic reinforcing particles and plastic matrix [2]

But from the results observed the experiments clearly shows that the hardness has increased only because of 1) dispersion of SiC particles as a harder phase in pure Al matrix 2) Severe grain size refinement with respect to base metal due to dynamic recrystallization 3) Quench hardening resulted from thermal contraction between sic and matrix 4) Enhanced dislocation. The results did obey the hall-petch relationship, which says smaller grain size results in higher hardness [2]. At lower traverse speed the hardness was high because the recrystallization occurred at higher temperature at slower rate.

Since the dynamic recrystallization dominates the annealing affect which is due to lower heat and force development at higher feed rate the hardness was low .It can be seen that micro hardness values inside the regions of the stir zone have been reduced because of annealing-induced growth[4].

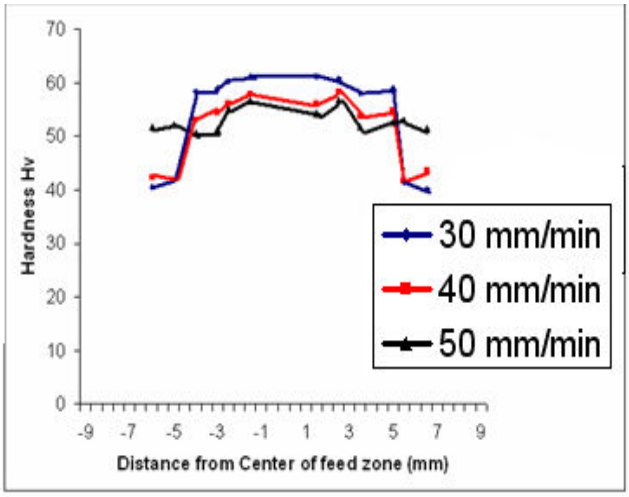


Fig. 5 Variation of the microhardness Hv distributions of the friction stir processed AA6063 alloy and base metal

V. Conclusion

- The SiC_p/AA6063 wider and deep bulk composite was fabricated successfully by using friction stir process.
- Good interface conditions between particles and base metal were formed during this process.
- The distribution of the fabricated MMCs did not limit to the surface composites under the tool shoulder or agglomerate.
- The conditions have shown that the variation in the groove width of the stir zone has an effect on the micro hardness.
- The SiC particles could flow beyond the Thermal Mechanical Affected Zone (TMAZ) under the shoulder.
- The micro hardness is also found to be 30% higher than that of the base metal.
- The OM results also show that finer and homogenous microstructure is obtained. The results have also shown the fine dispersion of SiC particles in the stirzone and the Thermo Mechanically Transformed Zone(TMTZ).
- Another interesting observation is that the particles are arranged in an equaxied manner in the metal matrix.

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