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Mechanical and tribological characterization of stir-cast Al-SiCp composites

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Abstract

In the current scenario, hard ceramic particles reinforced aluminum matrix composites have a massive number of applications in aircraft, automobile, structural, non-structural, marine and transportation applications like the drive shaft, connecting rod and brake drum. The foremost objective of this investigation is for assessing the mechanical and the tribological behavior of silicon carbide particulate reinforced with AA6351 composites was manufactured by a liquid metallurgy process (Stir casting). The weight fraction of silicon carbide (SiC) varied from 0 to 12 in steps of 4. Hardness and tensile strength of the obtained composite and the plain alloy were investigated. The microstructure of manufactured composite and the plain alloy were assessed by an scanning electron microscope (SEM). SEM analysis confirmed the nearly homogeneous dispersion of SiC particles in Al matrix. The wear resistance, tensile strength and hardness of the composites have significantly improved by the presence of reinforcement content.

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Keywords: Mechanical properties, Stir casting, Wear, Scanning electron microscope (SEM), Aluminum matrix composites (AMCs)

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1. Introduction

Titanium, aluminium, nickel and magnesium alloys are the popular matrix metals presently in vogue, which are particularly suitable for automotive, defence and aerospace applications [1]. In the recent decades, particulate reinforced aluminium matrix composites (PRAMCs) exhibit attractive physical and mechanical properties like excellent hardness, superior strength, good specific modulus and outstanding wear resistance [2]. Extensively used fabrication process for aluminum matrix composites involve squeeze casting, vacuum casting, stir casting, insitu casting, powder metallurgy and compo casting [3]. Among those avaliable techniques, liquid state stir casting method is more flexible, simple, convenient and cheap [4]. Stir casting process, the matrix material was melted above the re-crystallization temperature in the furnace and the reinforcement particles were added into the molten metal to prepare the aluminum matrix composite (AMC) [5]. The properties and structure of the composite depends on the matrix, reinforcement, shape, mass fraction and micron (or) nano size particles [6]. The PRAMCs can be reinforced with several types of reinforcement particles like B_4C, SiC, Al_2O_3, WC, ZrB_2, TiB_2, Si_3N_4, TiC and graphite to get various preferred properties [7]. Size and weight fraction of the reinforcement works as an essential role in manipulating the tribological and mechanical properties of the composites [8]. Some recent outcomes have endeavored to produce the silicon carbide particulates reinforced aluminium matrix composites and then were reported in the literature [9-12]. V. Umasankar et al., [9] analyzed the effect of SiC particles on microstructure and mechanical properties of AA6061/SiC composites fabricated by powder metallurgy method. They reported on the influence of SiC particle on the hardness and breaking load of AA6061/SiC AMCs. G. H. Majzoobi et al., [10] have shown that the SiC addition to AA7075 alloys enhances the mechanical and tribological properties of the composite. Raja Thimmarayan et al., [11] examined the influence of different particle sizes of SiCp content in the matrix and they stated the mechanical behavior of SiC particle reinforced AA6082 composites fabricated by stir casting method. Rajesh Kumar Bhushan et al., [12] reported that the production of AA7075/SiC composite by stir casting method and they showed the mechanical properties of produced composite are superior to the unreinforced plain alloy.

From the literature, it is evident that very few information is available on AA6351 alloy based ceramic particles reinforced composites. To the best of our knowledge, no work is done on AA6351/SiC composite. In the present investigation, the Al6351 aluminum alloy was reinforced with a different weight fraction of silicon carbide particulates (4wt%, 8wt% and 12wt%) to prepare the composite and compare the microstructure, mechanical and tribological properties with unreinforced plain alloy.

2. Experimental Procedure

2.1 Materials and producing of composites

The Al6351 aluminum alloy was used as matrix material. The chemical composition of AA6351 is Si 1.0, Fe 0.60, Cu 0.10, Mn 0.5, Mg 0.7, Cr 0.25, Zn 0.10, Ti 0.20, and the balance is aluminum (wt.%). A batch of 500g of the Al6351 aluminum alloy was melted in a graphite crucible using an electrical resistance furnace. The reinforcing particle was SiC (80-100µm) supplied by Krishmet India Pvt., Chennai. Silicon carbide (SiC) particles were preheated at 500^oC. The gauged quantity of SiC particles was added to molten aluminum. The composite mixture was stirred frequently for ten minutes at every interval of two minutes. The composite mixture maintained at a temperature of 800^oC was poured into preheated die. Both manufactured composite and plain alloy were subjected to hardness test, compression test, wear test, tensile test and microstructure characterization. Fig. 1 shows the schematic diagram of stir casting setup.

2.2 Microstructure characterisation and Testing

2.2.1 Microstructure

The samples are polished using a normal metallographic procedure. Keller's reagent is used as an etchant and the microstructure of the specimens were observed consequently by optical microscope (De-Winter) and Scanning electron microscope (Tescan Vega-3).

2.2.2 Mechanical Testing

The macrohardness was measured using Brinell hardness tester at a load of 500g applied for a duration of ten seconds at five different locations on all samples. The tensile test was conducted on the plain alloy and manufactured composite using the computerised universal tensile machine (FIE Pvt. Ltd., Model:Unitek 94100). The tensile specimens was prepared as per ASTM E8 standard.

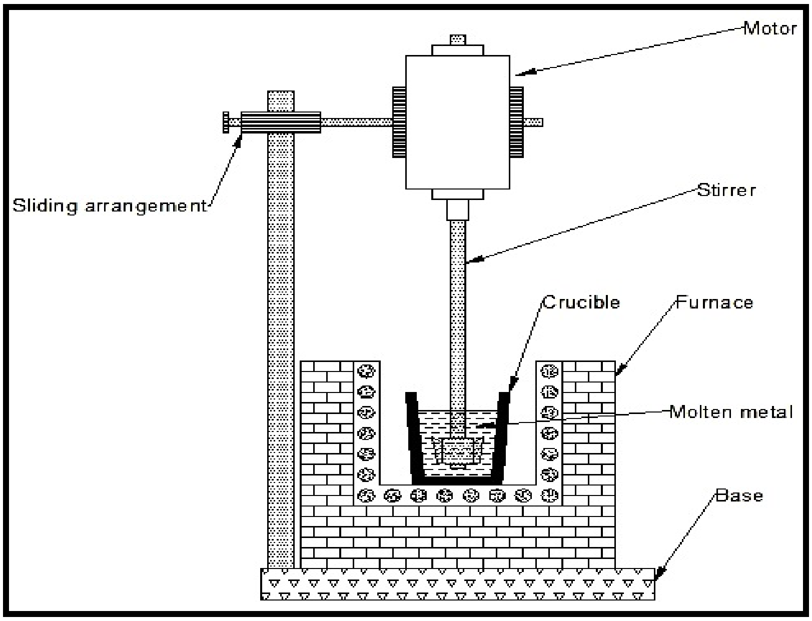

Figure. 1. Schematic diagram of stir casting setup.

2.2.3 Wear Testing

Wear behavior was analysed using a pin-on-disc wear apparatus (DUCOM TR20-LE, Bangalore, India). Wear test samples of dimension, the diameter of 8mm and a length of 32mm, were prepared from the produced composites. The wear was measured by weight loss, as a difference of weights of the wear pins, before and after wear tests to an accuracy of 0.0001 g. The wear test was conducted at a sliding distance of 1200m, the normal force of 15N and sliding velocity of 1m/s [2,8]. The counter disc was made of EN32 steel having a hardness of HRC 60.

3. Results and discussion

3.1 Microstructure of AA6351/SiC AMCs

The optical and SEM micrograph of as cast unreinforced plain alloy are shown in fig 2. The microstructure shows the dendritic pattern of as cast AA6351 plain matrix alloy. Figure. 2. displays the dendritic pattern caused by rapid solidification. The microstructure of unreinforced AA6351 base matrix alloy displays α-Al dendritic structure surrounded by eutectic Si particles and this can be ascribed to the super cooling rate obtained in a metal mold. The solubility limit of alloying elements of AA6351 such as Silica (Si) and Magnesium (Mg) is noted to be greater than their solubility limit.

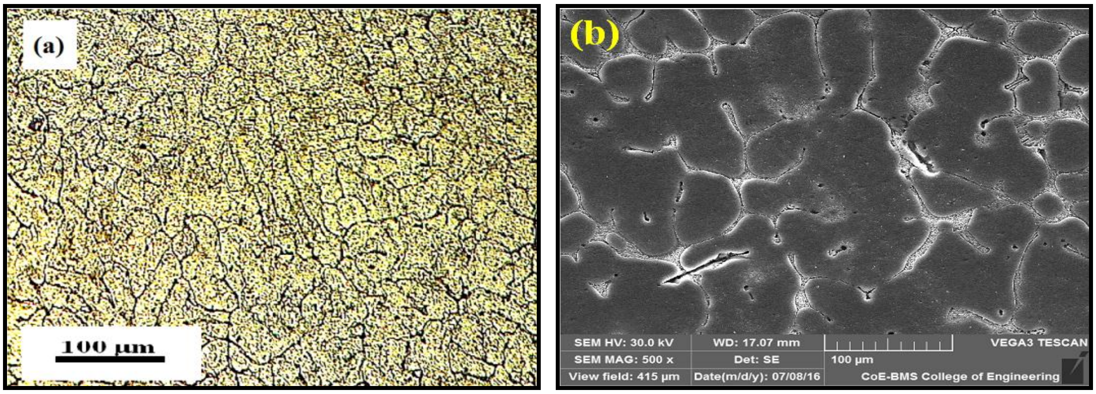

Figure. 2 (a) Optical micrograph and (b) SEM micrograph of cast AA6351 alloy.

Figure 3(a-c) displays the SEM microphotographs of the manufactured composite. Microstructural examination exhibited a nearly homogeneous dispersion of SiC particles is noticed in the AMCs. It is also noticed from the figure that the SiC particles are almost evenly bonded to the aluminum matrix. Nearly homogeneous dispersion of SiCp in the matrix is an chief requirement to achieve the higher mechanical properties of the composites.

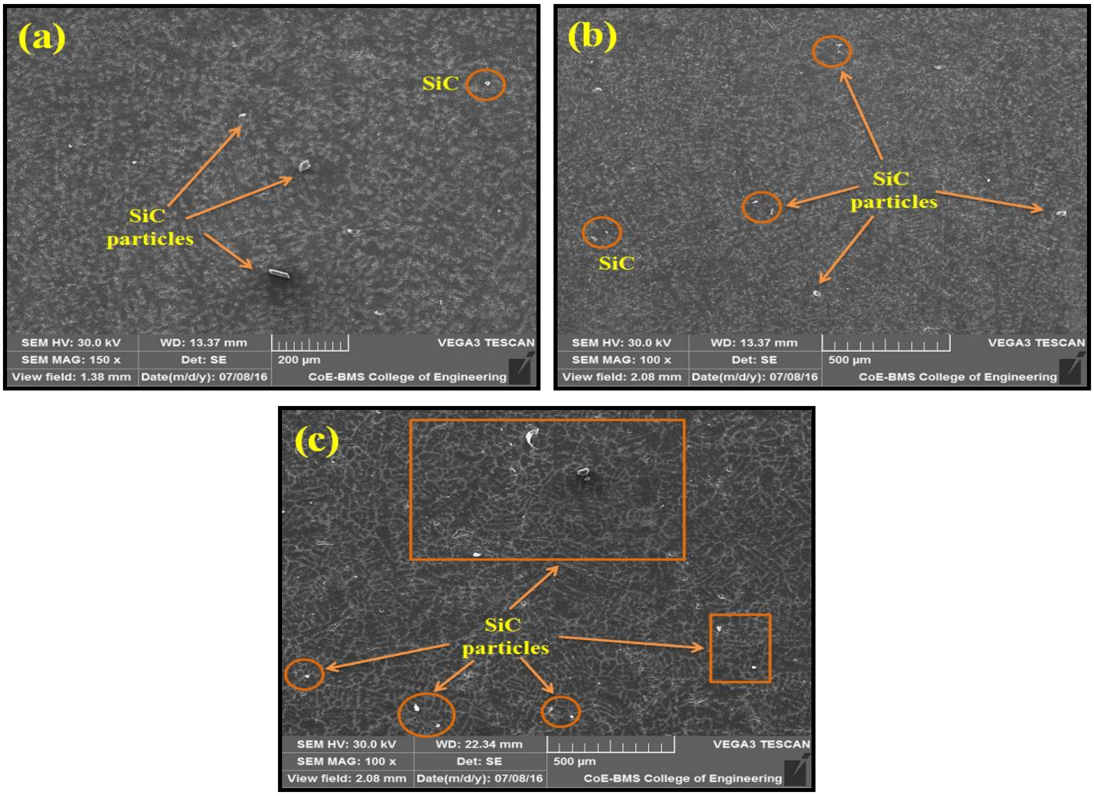

Figure. 3. SEM images of (a) Al6351/4wt% SiC AMCs, (b) Al6351/8wt% SiC AMCs and (c) Al6351/12wt% SiC AMCs.

3.2 Hardness Properties

Fig. 4. shows the influence of SiC on the hardness of the plain matrix alloy and produced composites. The hardness has been noticed to increase with the increase in SiC particles and it is significantly higher than the hardness of the plain AA6351 matrix alloy. It may be due to the hard SiCp work as hindrances to the indentation,

which contributes to enriching the hardness of the produced composite. An increase in SiC particles offers more resistance to plastic deformation, thereby increasing hardness of the composite. The hard SiC particles in the melt and resulted in good interfacial bonding between reinforcement (SiC) and matrix alloy (AA6351). This good interfacial bonding of reinforcement (SiC) particles enriches the hardness of the composites [2]. Hence, the Al6351/12wt%SiC AMCs revealed greater hardness compared to plain matrix alloy.

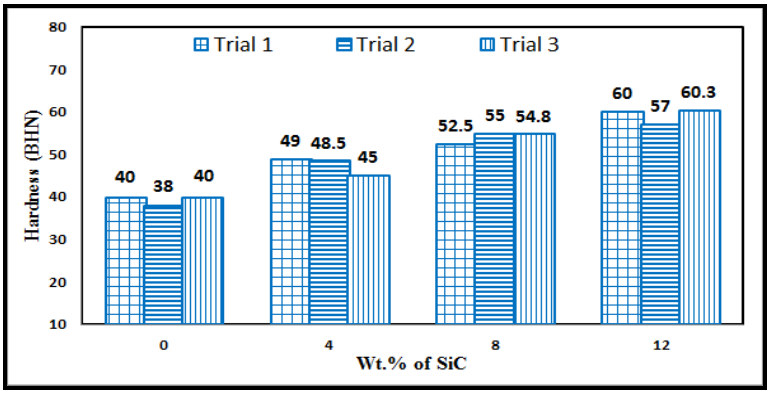

Figure. 4. Variation of hardness with varying content of SiCp.

3.3 Tensile strength

The tensile strength of the Al6351 plain alloy and the produced composites are shown in fig 5. The tensile strength of the composites increases linearly with the increase in SiC particle content. Inclusion of SiC particles in the matrix alloy creates a massive amount of dislocation densities during solidification due to thermal mismatch between matrix alloy (AA6351) and SiC particles. Hence, the SiC particles can effectively work as a barrier to dislocation movement. Thereby it enriches the tensile strength of the produced composites. The superlative strength is obtained at Al6351/12 wt.% SiC AMCs.

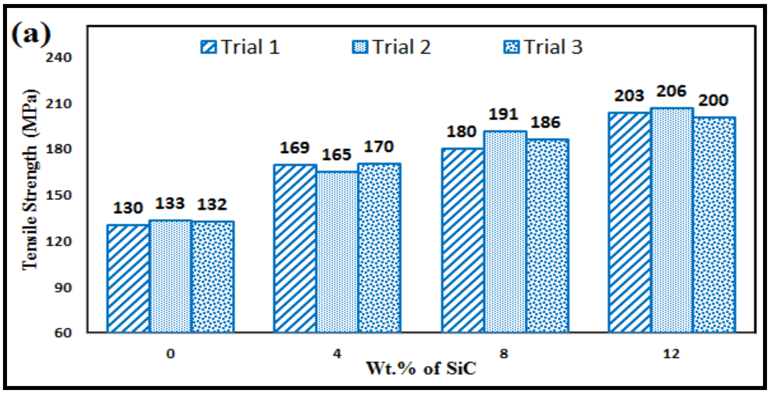

Figure. 5. Tensile strength of the AMCs.

3.4 Sliding wear behaviour of composites

Fig. 6. depicts the inclusion of SiC particulates in the plain matrix enriches the sliding wear resistance in comparison to the plain unreinforced alloy. The enrichment of the wear resistance can be attributed to the following facts. (i) The hard ceramic particles enrich the hardness of the composites, which contributes to enhances the wear resistance of the composite. (ii) Excellent interfacial bonding between the plain alloy and the reinforcement particles. (iii) The thermal mismatch between the plain matrix alloy and the reinforcement particles enriches the dislocation density, enhanced dislocation densities resists the plastic deformation of the material, during sliding. Hence, the amount of wear is dramatically increased with the increase in sliding time [2,6].

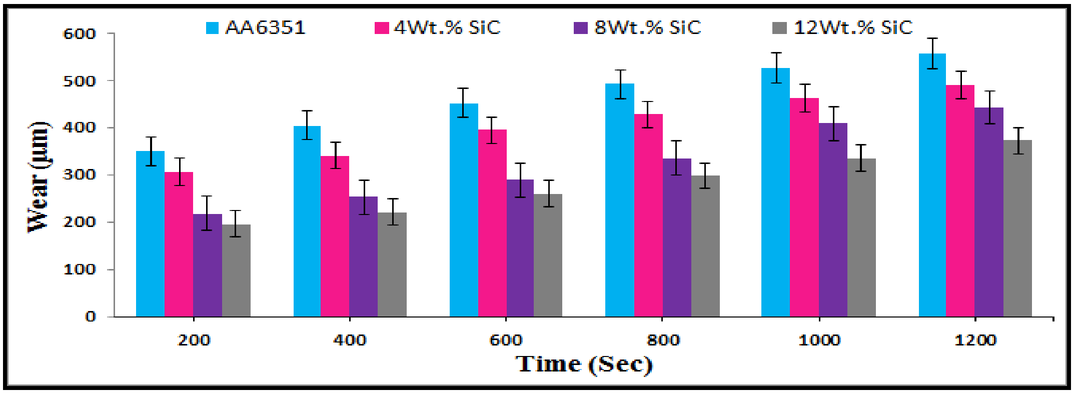

Figure. 6. Effect of reinforcement on wear for sliding time of 1200sec.

The wear of the unreinforced plain alloy reveals the 349.64 microns to 557.22 microns from 200sec to 1200sec and the wear of the AA6351/12%SiC composite reveals the 196.40 microns to 372.65 microns from 200sec to 1200sec. 12%SiC particles in AA6351 matrix alloy resulted in superior wear resistance of the composites. The amount of wear has drastically decreased with increases in the weight fraction of reinforcement particles. Manufactured composite reveals the minimum amount of wear when compared to the unreinforced plain alloy [6].

4. Conclusions

The Al6351/SiC composites were effectively produced by the stir casting method. The test results showed that produced the composite sample revealed superior hardness, tensile and compression strength. The produced composites reinforced with 12wt% of SiC revealed excellent mechanical and tribological properties than the unreinforced plain alloy. Enhancement of wear resistance of AA6351 matrix alloy was noticed by the increase in SiC content. The optical micrographs exhibited the nearly homogeneous dispersion of the SiC particles in the matrix.

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