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Effect of SiCp addition on the indentation hardness of as-cast Al metal matrix composites

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ABSTRACT: The indentation hardness of Al-SiCp metal-matrix composites synthesized by stir casting process was investigated. Stir casting method was selected as the casting method due to its simplicity, flexibility and applicability. This method allows a conventional metal processing route to be used which minimizes the cost of the product. The silicon carbide particles to be used were first ball milled for size reduction. These particles were then sieved in a mechanical shaker to obtain different particle sizes. SiC particles of size 74µm corresponding to mesh 200 were selected for addition to the Al matrix. The composite was prepared by adding preheated SiC particles to the Aluminium melt via stir casting. Test specimens were prepared by varying the wt% of SiC (1%, 3%, 5%, 7% and 9%). As the SiCp additions were increased, the hardness of the composite increased to a large extent. This can be attributed to the uniform distribution of the SiC particles in the Al matrix via stir casting method.

KEYWORDS: SiCp, indentation hardness, as-cast Al metal matrix composites.

1 INTRODUCTION

The mechanical properties that can be obtained with metal matrix composites (MMCs) in combination with their relatively low cost processing methods have made them attractive for numerous applications in various fields including aerospace, automotive and sports industries [1, 2]. More specifically, particulate MMCs (PMMCs) have been shown to offer improvements in strength, wear resistance, structural efficiency, reliability and control of physical properties such as density and coefficient of thermal expansion, thereby providing improved engineering performance in comparison to the unreinforced matrix [1-7]. PMMCs are attractive not only for their aforementioned mechanical properties, but also because of the low cost availability of reinforcements.

Furthermore, problems associated with the continuously reinforced MMCs, such as microstructural non-uniformity, fibre-to fibre contact and extensive interfacial reactions can be avoided [5]. PMMCs have attracted considerable attention on account of the use of discontinuous reinforcements. This minimizes problems associated with fabrication of continuously reinforced metal-matrix composites such as fiber damage, fiber mismatch and inter-facial reactions. For applications subjected to severe loads or extreme thermal fluctuations such as in automotive components, discontinuously-reinforced metal matrix composites have been shown to offer near isotropic properties with substantial improvements in strength and stiffness, relative to those available with monolithic materials [6].

One of the major challenges when processing MMCs is achieving a homogeneous distribution of reinforcement in the matrix as it has a strong impact on the properties and the quality of the material [1-8]. To obtain a specific mechanical/physical property, ideally, the MMC should consist of fine particles distributed uniformly in a ductile matrix and with clean interfaces between particle and matrix. However, the current processing methods often produce agglomerated particles in the ductile matrix and as a result they exhibit extremely low ductility [9,10]. Clustering leads to a non-homogeneous response and lower macroscopic mechanical properties. Particle clusters act as crack or de-cohesion nucleation sites at stresses lower than the matrix yield strength, causing the MMC to fail at unpredictable low stress levels

[11,12]. Possible reasons resulting in particle clustering are chemical binding, surface energy reduction or particle segregation [13].

Stir casting technique is currently the most common practiced commercial method for processing MMCs. This approach involves mechanical mixing of the reinforcement particulates/particles into a molten metal bath. A simplified apparatus is shown in Fig. 1, and typically is comprised of a heated crucible containing molten aluminum metal, with a motor that drives a paddle, or mixing impeller, that is submerged into the melt. The reinforcement is poured into the crucible above the melt surface and at a controlled rate, to ensure a smooth and continuous feed. As the impeller rotates at moderate speeds, it generates a vortex that draws the reinforcement particles into the melt from the surface. The impeller is designed to create a high level of shear, which helps strip adsorbed gases from the surface of the particles. The high shear also engulfs the particles in molten aluminum, which promotes wetting. Proper mixing techniques and optimized impeller design are required to produce adequate melt circulation and homogeneous distribution of the reinforcement.

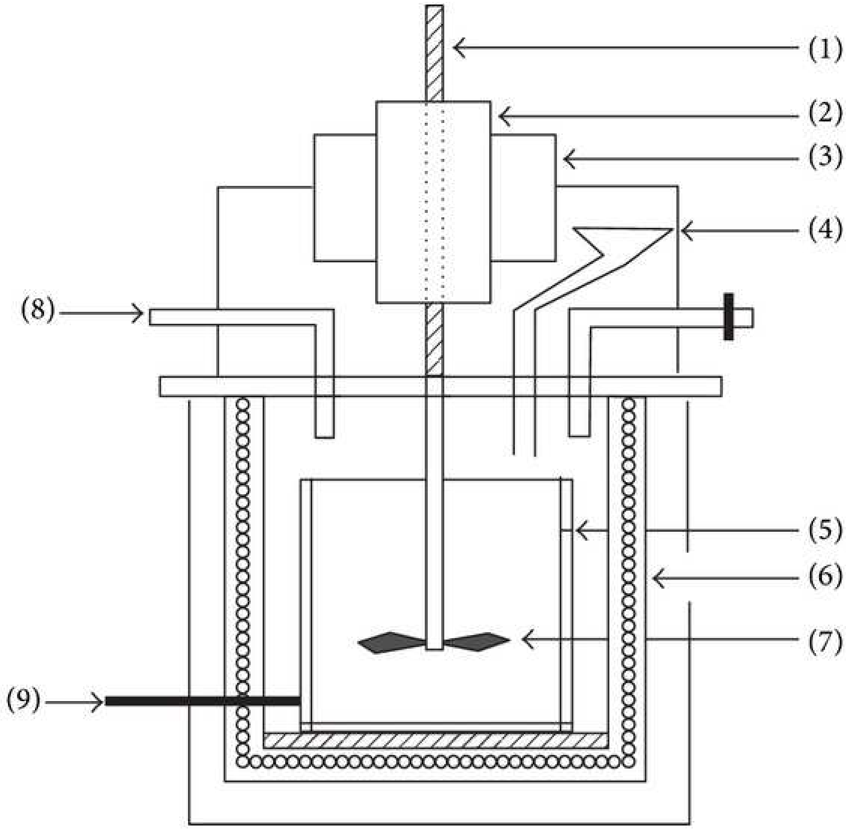

Fig. 1: Schematic of stir casting setup. (1) Stirrer spindle, (2) sliding mechanism with impeller position control unit, (3) electric motor, (4) sprue, (5) crucible, (6) electric furnace, (7) impeller, (8) argon gas inlet, and (9) thermocouple; [14]

In the present work, Al-SiCp PMMC was produced by stir casting process, whereby the SiC particulates were introduced into the molten metal through a vortex introduced by mechanical agitation. SiCp additions were varied for each castings i.e. 1 wt%, 3 wt%, 5 wt%, 7 wt% and 9 wt%. After casting the microstructure of the composite was studied by scanning electron microscope. The distribution of the SiC particles in the Al matrix was observed and the wear behaviour of the composite was studied under dry sliding conditions.

2 MATERIALS AND METHODS

2.1 PREPARATION OF SIC PARTICULATES

The coarse SiC particulates were ball milled to finer size in a ball mill containing cast iron balls as the grinding medium. The procedure was carried out for eight hours. After size reduction, the SiC particulates were then poured into the top sieve of a nested column of sieves with wire mesh cloth to perform sieve analysis by a mechanical shaker. After sieving was complete, SiC particle size of 74µm corresponding to mesh size 200 was separated and weighed. The 74µm SiC particles were then used for the production of the composites.

2.2 PREPARATION OF STIRRER

For the agitation of the molten metal, a graphite stirrer was constructed out of a cylindrical graphite block. The stirrer was made into graphite shaft of 2 inch diameter and a feet length as shown in Fig. 2 (a).

2.3 SELECTED PRODUCTION TECHNIQUE

Stir casting process was used as a production technique to produce aluminum based silicon carbide particulate metal matrix composites. Stir casting is a primary process of composite production whereby the reinforcement ingredient material is incorporated into the molten metal by stirring. Its advantages lie in its simplicity, flexibility and applicability to large quantity production. It is also attractive because, in principle, it allows a conventional metal processing route to be used, and hence minimizes the final cost of the product. This liquid metallurgy technique is the most economical of all the available routes for metal matrix composite production [4]. The setup is shown in Fig. 2 (c).

2.4 SPECIMEN PREPARATION

Commercially pure (99.99%) aluminium was melted in a crucible placed in a muffle furnace and superheated to 850^0C. Meanwhile SiC particles were preheated in a furnace for 3 hours at a temperature of 1000^0C. The preheating of SiC particles was carried out to oxidize the surfaces of the particles and to improve their wettability with the aluminum matrix. The molten metal was then stirred by a graphite stirrer at 650 rpm and preheated SiC particles were then added to the melt as a vortex formed due to stirring as shown in Fig. 2 (b). Stirring was carried out for 2 minutes in the furnace for each casting. The melt was then poured into cylindrical metal molds and cooled to room temperature.

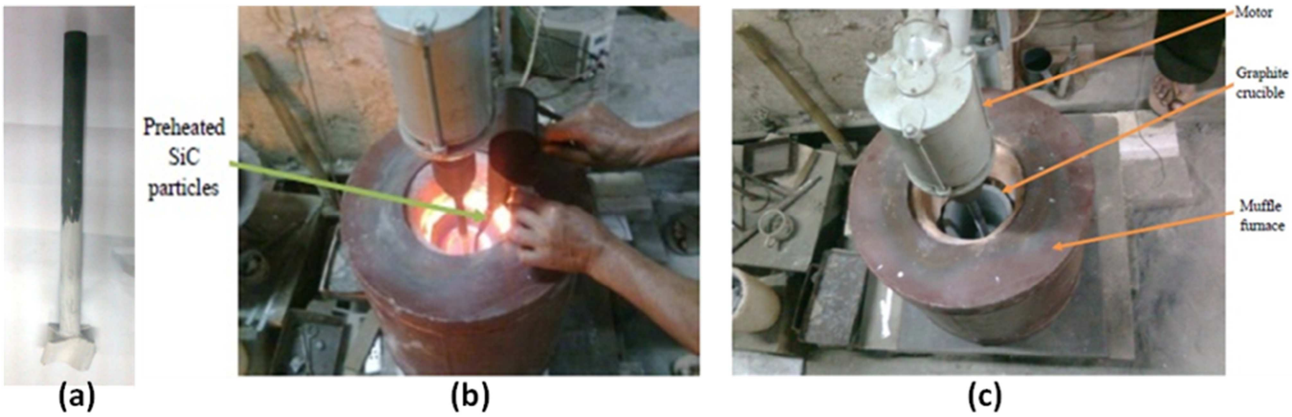

Fig. 2 (a) Graphite stirrer, (b) Addition of SiC particles into the melt, (c) Stir casting setup

2.5 MICROSTRUCTURAL ANALYSIS

The test specimens required for analysis were machined to cylindrical specimens and were then ground in successive steps using silicon carbide abrasive papers of various grit sizes. The ground specimens were then finely polished on a velvet cloth using a suspension of alumina (Al_2O_3) powder in acetone. The specimens were then washed and dried with acetone before mounting. The microstructures of the specimens were studied using a metallurgical microscope.

2.6 HARDNESS TEST

The hardness values of the samples were determined (ASTM-E10) using the Brinell hardness tester. The **Brinell hardness test** was conducted by applying 500 kg load **(L)** for 15 seconds with a ball of 10 mm diameter **(D)** on the surface of the sample of the different cast product of aluminium based SiC metal matrix composites. Then the diameter of the impression **(d)** has been measured by the scale. Then the hardness was calculated by the equation (1) given below:

$$\mathbf{HB} = \frac{2L}{\Pi D(D-\sqrt{D2}-d2)} \qquad (1)$$

3 Results and Discussions

3.1 Microstructure evaluation

Fig. 3 shows the microstructures of the composites in the unetched condition with varying SiC additions. As the SiC wt% is increased the volume fraction of SiC in the matrix increases. The particle shape of the SiC particles as noticed in Fig. 3 is not similar. There is a mixture of elliptical and irregular shaped particles as seen in the microstructures of the composite in Fig. 3. From the SEM micrographs it is evident that the distribution of the SiC particles in the Al matrix has been successful. There is slight agglomeration of SiC particles in composite with 7 wt% SiC addition as shown in Fig. 3 (d). A massive agglomerated mass of SiC particles can be seen in composite with 9 wt% SiC addition as seen in Fig. 3(e). This problem could arise due to poor wettability of the particle due to reasons like non-uniform preheating of the SiC particles, buoyancy of the particles due to trapped gases in the molten metal. The problem could also arise due to early solidification of the melt before the distribution of the SiC particles. It can be said that as SiC particle additions are increased there is a tendency towards agglomeration, which could be minimized by uniform preheating.

3.2 Hardness evaluation

The hardness values of the composites increases to a large extent with an increasing percentage of SiC additions as shown in Table 1. The hardness value of pure Al and that of composite with 1 wt% SiC addition is almost same. This is noteworthy that the hardness value of the composite increased from 15.5 HB in case of composite with 1 wt% SiC to 34 HB for 9 wt% SiC additions to the composite, which is about twice that of the composite with 1 wt% SiC. This is certainly due to the increase in SiC additions to the composite which acts as a reinforcement for the aluminium matrix. A problem was encountered while measuring the hardness of the globular phases as it was difficult to locate the indentation exactly on the SiC particles. That is why hardness values are averages of five to six measurements. While the accuracy of the measurements may not be very high, it nevertheless suggests that upon SiC additions the metal matrix composites have higher hardness than pure Al.

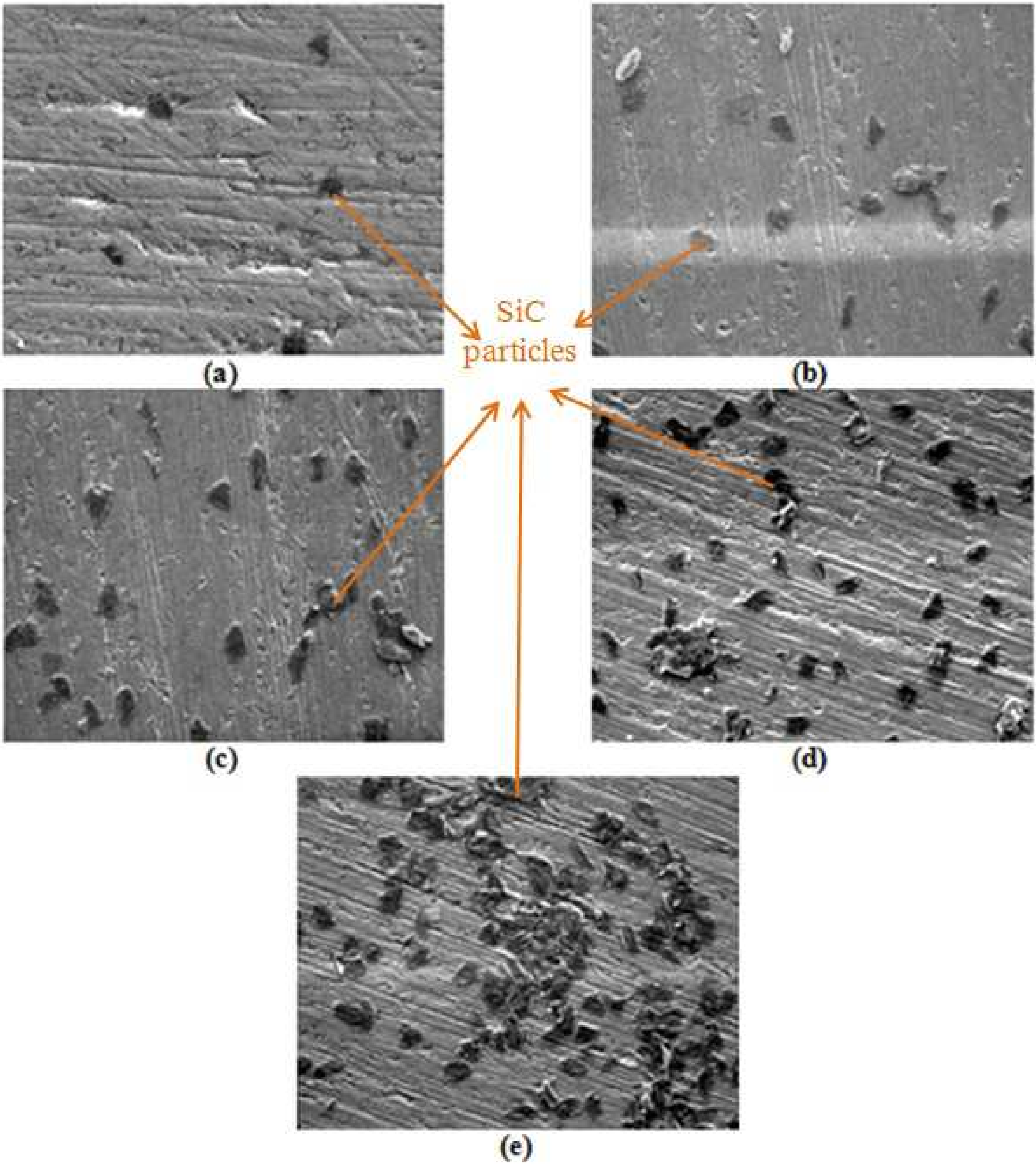

Fig. 3 Microstructure [Magnification : 250X] of composite with (a) 1 wt% SiC, (b) 3 wt% SiC, (c) 5 wt% SiC, (d) 7 wt% SiC and (e) 9 wt% SiC in the unetched condition.

Table 1 Brinell hardness values

Composite	Pure Al	Al + 1 wt% SiC	Al + 3 wt% SiC	Al + 5 wt% SiC	Al + 7 wt% SiC	Al + 9 wt% SiC
Brinell hardness (HBN)	15	15.5	19	25	28	32

4 CONCLUSIONS

The microstructure of the composite with varying SiC additions was studied in relation to the stir casting method. It can be said that stir casting method is a viable option for low cost production of particulate metal matrix composites. This method yields a composite with uniform particle distribution. Although problems may arise due to poor wettability of particles and buoyancy due to trapped gases, the casting method can be optimized to yield better results. The quality of the composite improves in terms of hardness and wear resistance by increasing reinforcement. The addition of 9 wt% SiC increases the hardness of the composite by two times.

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