Middle-East Journal of Scientific Research 25 (7): 1536-1543, 2017
ISSN 1990-9233

DOI: 10.5829/idosi.mejsr.2017.1536.1543

Effect of SiC_p Addition on the Wear Behaviour of As-Cast Al-SiC_p Metal Matrix Composite Fabricated by Stir Casting Method

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Abstract: The wear behaviour of Al-SiCp metal-matrix composites fabricated by stir casting process was investigated under dry sliding conditions. The silicon carbide particles were first ball milled and then sieved to obtain different particle sizes. SiC particles corresponding to mesh 200 (74µm) were selected for reinforcement. The composite was prepared by stir casting process where preheated SiC particles were added to the Aluminium melt. Test specimens were prepared by varying the wt% of SiC (1%, 3%, 5%, 7% and 9%). The wear behaviour of the composite was studied by performing dry sliding wear test using a pin-on-disc wear tester by varying the applied load from 10-20 N for a duration of 10 minutes at sliding speed of 750 rpm and also by varying the sliding speed of the disc (counter body) from 650-850 rpm for a duration of 10 minutes with an applied load of 20 N. It was observed that, as the applied load and sliding speed increases, the wear rate also increases but decreases with increasing SiCp addition. Hence, the use of stir casting process aids in the homogeneous distribution of the SiC particles in the matrix which increases the wear resistance of the particulate metal matrix composite.

Key words: Al-SiC_p metal matrix composites · Wear behaviour · Stir casting · Dry sliding wear test

INTRODUCTION

Metal matrix composite (MMCs) are low cost attractive materials in the field of automobile and aerospace industries [1, 2]. It is reported by researchers that particulate MMCs (PMMCs) have improved tensile strength, wear resistance, structural efficiency, reliability and control of physical properties such as density and coefficient of thermal expansion [1-7]. Moreover, problems of conventional MMCs such as microstructural non-uniformity, fibre-to-fibre contact and extensive interfacial reactions can be avoided [5]. For applications under severe loads PMMCs have been shown to offer isotropic properties with substantial improvements in strength and stiffness, relative to those available with monolithic materials [6].

It is very important to distribute the filler in the matrix to have desired property, yet it is difficult to achieve the uniform distribution of filler particles in MMCs [1-8]. The agglomerated particles in the matrix lead to exhibit low ductility [9-10]. Moreover, cluster particles at as active sites for crack nucleation causing the MMC to fail at unpredictable low stress levels [11-12]. The probable reason of agglomeration are chemical binding, particle segregation and 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

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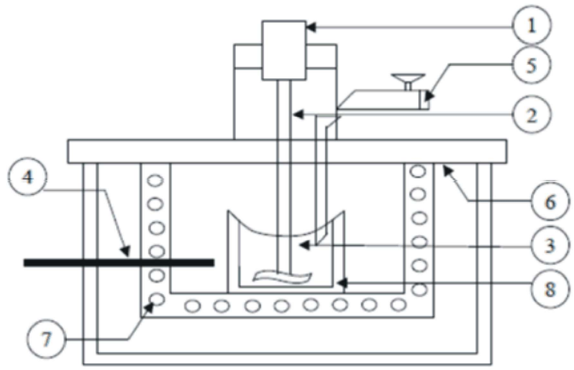

Fig. 1: Schematic view of setup for fabrication of composite (1) Motor, (2) Shaft, (3) Molten aluminium, (4) Thermocouple, (5) Particle injection chamber, (6) Insulation hard board, (7) Furnace, (8) Graphite crucible [14]

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 that promotes wetting. Proper mixing techniques and optimized impeller design are required to produce adequate melt circulation and homogeneous distribution of the reinforcement.

In the present work, Al-SiC PMMC was produced by stir casting process, whereby the SiC particulates were introduced into the molten metal through a vortex introduced by mechanical agitation. SiC_p additions were varied for each casting. 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.

MATERIALS AND METHODS

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.

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).

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).

Specimen Preparation: Commercially pure (99.98%) aluminium was melted in a crucible placed in a muffle furnace and superheated to 850°C. Meanwhile SiC particles were preheated in a furnace for 3 hours at a temperature of 1000°C. 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.

Microstructural Analysis: The specimens for microstructural analysis were machined to cylindrical shapes. Standard techniques were followed for the preparation for observation. Grinding was done on silicon carbide abrasive papers, final polishing being done on a velvet cloth using a suspension of alumina (Al_2O_3) powder. The microstructures were studied using a scanning electron microscope (SEM). Surface morphology of the worn samples was studied by SEM.

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 (P) for 15 seconds with a ball of 10 mm diameter (D) on the surface of the sample of the different

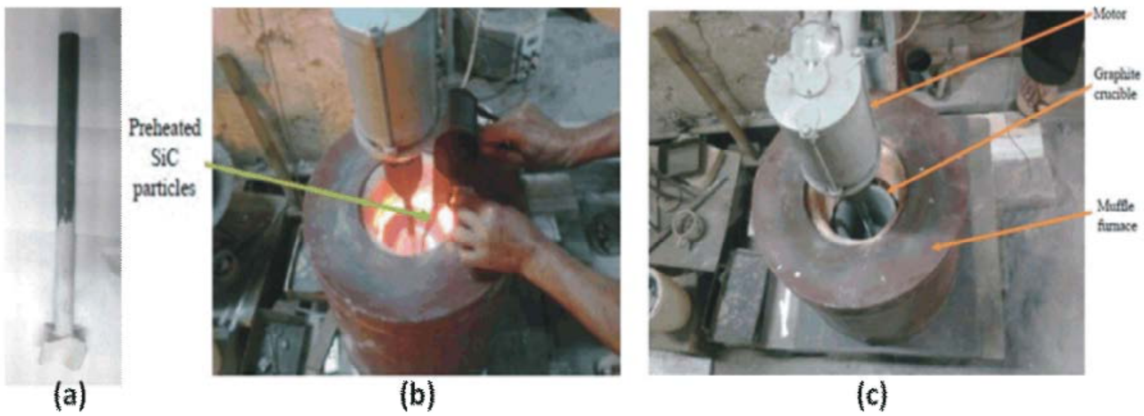

Fig. 2: (a) Graphite stirrer, (b) Addition of SiC particles into the melt, (c) Stir casting setup

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 given below:

$$BHN = \frac{2P}{\pi D(D - \sqrt{D^2 - d^2}} \quad (1)$$

Wear Test: A pin-on-disc test apparatus was used to study the wear behaviour of the composites as per ASTM G99- 95a standards. Medium carbon steel discs of 8 mm thick and 120 mm track diameter were used as the counter body during the tests. The average hardness of the counter body was RC 60. The initial weights of the samples were measured using a single pan electronic weighing machine with an accuracy of three decimal digits. During the test, the pin was pressed against the rotating disc. Two different parameters (Load and sliding speed) were selected for the wear test and their effects were observed. The wear rates of the specimens were calculated for three different loads (10 N, 15 N, 20 N) at 750 rpm for a duration of 10 minutes and three different sliding speeds (650 rpm, 750 rpm and 850 rpm) at applied load of 20 N for a duration of 10 minutes.

RESULTS AND DISCUSSIONS

Hardness Evaluation: The hardness values of the composites increases to a large extent with an increasing percentage of SiC_p 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_p to 34 HB for 9 wt% SiC_p additions to the composite, which is about twice that of the composite with 1 wt% SiC_p. 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.

Microstructure Evaluation: Fig. 3 shows the microstructures of the composites in the unetched condition with varying SiC additions. As the SiC_p wt% is increased the volume fraction of SiC particles in the matrix increases. The shape of the SiC particles as noticed in Fig. 3 is dissimilar. 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 homogeneous distribution of the SiC particles in the Al matrix has been successful via stir casting method. However, there were problems noticed in the composite with 7 wt% SiC_p and 9 wt% SiC_p additions. There is slight agglomeration of SiC particles in composite with 7 wt% SiC_p addition as shown in Fig. 3 (d). A massive agglomerated mass of SiC particles can be seen in composite with 9 wt% SiC_p 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.

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 (BHN)	15	15.5	19	25	28	32

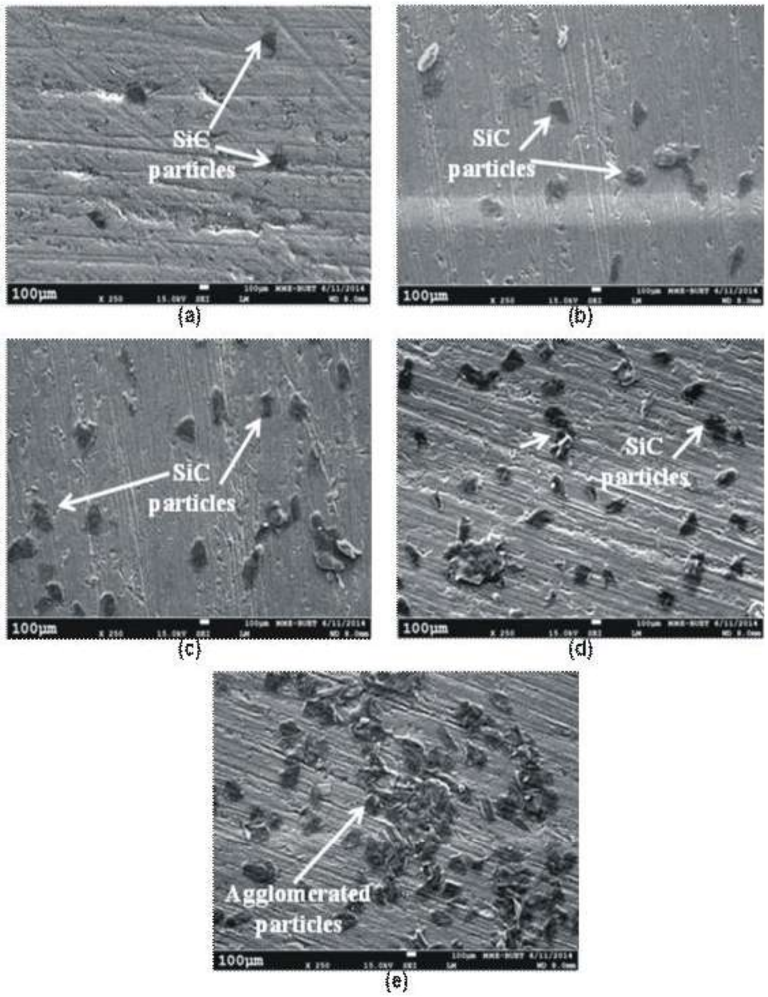

Fig. 3: Microstructure [Magnification: 250X] of composite with (a) 1 wt% SiCp, (b) 3 wt% SiCp, (c) 5 wt% SiCp, (d) 7 wt% SiCp and (e) 9 wt% SiCp in the unetched condition

Wear Behaviour: The wear tests were carried out for pure Al specimen and composites with SiC_p additions, as it was clear from hardness values that pure Al would have very high wear rate and composite with high SiC addition, viz., 9 wt% SiC_p would have low wear rate. It was necessary to show the influence of SiC addition on the composite.

Fig. 4 shows the wear rate of composites with different SiC_p additions as a function of load where the test was carried out at a constant rpm of 750 for duration of 10 minutes. Initially the wear rate increases rapidly, which is followed by a gradual increase in the wear rate.

The rate of wear is found to be the highest in the case of pure Al followed by composite with 1 wt% SiC_p addition and lowest in the case of composite with 9 wt% SiC_p additions. For composite with 1 wt% SiC_p there is a sharp increase in the wear rate after at a load of 20 N.

Fig. 5 shows the wear rate of composites with different SiC_p additions as a function of sliding speed where the test was carried out for a period of 10 minutes at an applied constant load of 20 N. The wear rate of all samples increased dramatically during the initial period. The wear rate of pure Al and composite with 1 wt% SiC_p addition increased staggeringly after the initial period. On the contrary, the other specimens did not show a dramatic increase, but a steady increase in the wear rate was noticed. Lowest wear was observed for the composite with 9 wt% SiC_p.

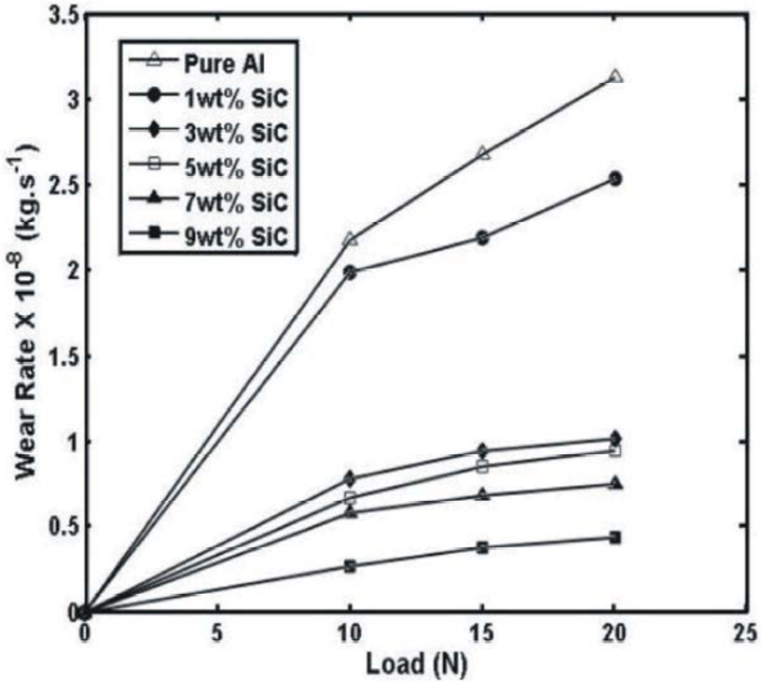

Fig. 4: Wear rate of composites with different SiC additions as a function of load

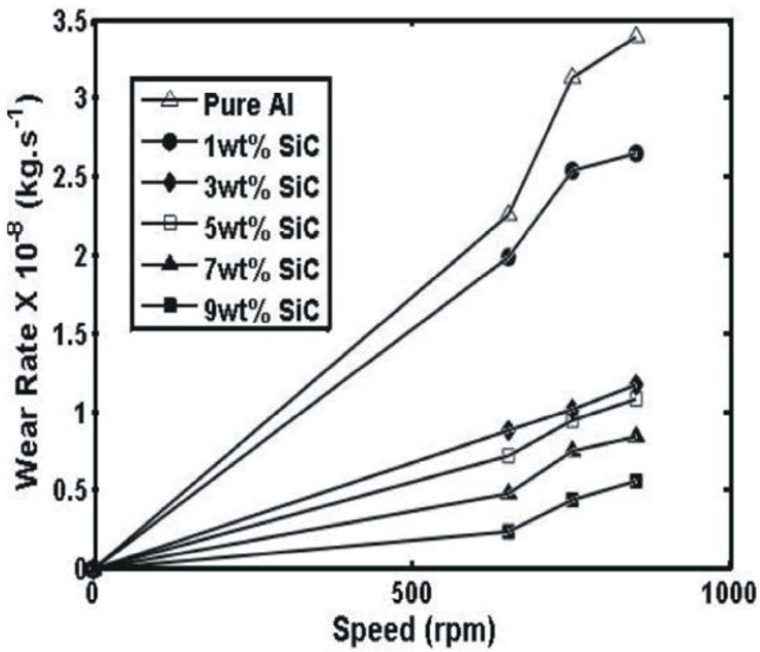

Fig. 5: Wear rate of composites with different SiC additions as a function of sliding speed

It can said from Fig. 4 that the wear rate of composite with 9 wt% SiC_p is seven times lower than pure Al and nearly six times lower than that of composite with 1 wt% SiC_p addition.

The wear rate of all the samples with an applied load of 20 N for 10 minutes at a speed of 850 rpm has been represented in Fig. 5. Very low wear rate was observed for composite with 9 wt% SiC_p relative to other composite and pure Al.

From both the graphs it is clearly evident that pure Al followed by the composite (Al+SiC_p) with 1 wt% SiC_p has the highest wear rate among all other samples and the

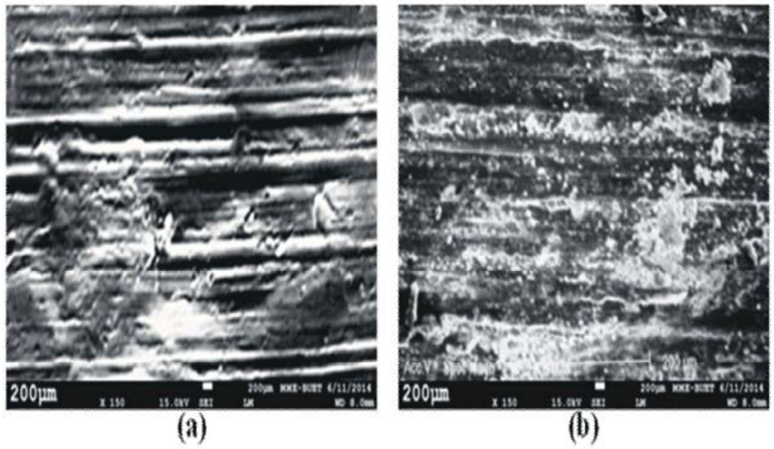

Fig. 6: SEM micrographs of the worn samples [Magnification: 150X] (a) Pure Al (unreinforced), (b) Composite (Al + 9 wt% SiC_p) subjected to wear test with applied load of 20 N at 750 rpm for 10 minutes

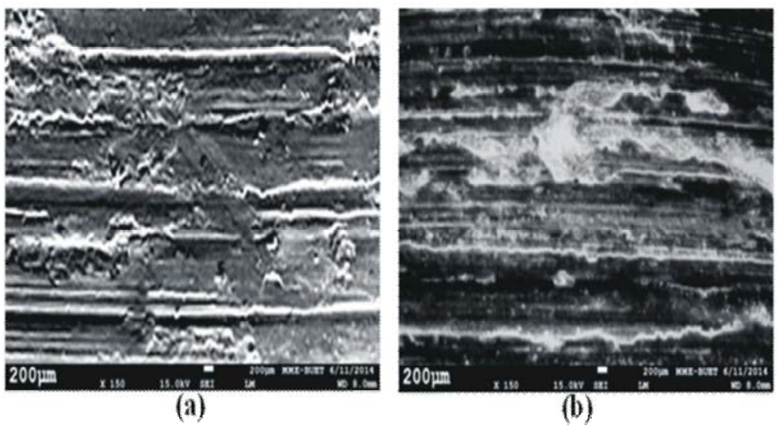

Fig. 7: SEM micrographs of the worn samples [Magnification: 150X] (a) Pure Al (unreinforced), (b) Composite (Al + 9 wt% SiC_p) subjected to wear test with applied load of 20 N at 850 rpm for 10 minutes

composite (Al+SiC_p) with 9 wt% SiC_p has the lowest wear rate among the samples. When applied load and speed was increased, there was a sudden increase in wear rate of all the specimens. Fig. 6 shows the SEM micrographs of the worn samples of Pure Al and composite with 9 wt% SiC_p additions subjected to wear test with maximum load of 20 N for a period of 10 minutes at sliding speed of 750 rpm.

The micrographs show the presence of grooves and valleys on the worn surface of all samples, suggesting that mainly abrasive wear is the most probable form of wear mechanism. The extent of abrasive wear is found to be the highest for pure Al, as was evidenced by the worn surface to contain deep and wide grooves and as well as by the highest wear rate. The abrasive wear is found to be lowest for the composite with 9 wt% SiC_p additions, as was evidenced by shallow grooves as well as by the lowest wear rate among all composite samples. This can be attributed to the presence of SiC particles in the matrix which act as reinforcement. Since, the hardness of composite with 9 mass% additions is greatest, this also attributes to its low abrasive wear.

Fig. 7 shows the SEM micrographs of the worn samples subjected to wear test with a load of 20 N for 10 minutes at a maximum sliding speed of 850 rpm. Grooves and valleys were observed on the worn surface. It suggests that form of wear mechanism may be abrasive wear. Ploughing was seen as the main form of abrasive wear in both samples. From Table 1 it is evident that the hardness value of pure Al with no reinforcement is the lowest as a result of which the wear rates as seen in Fig. 4 and Fig. 5 is the highest. On the contrary, composite with 9 wt% SiC_p additions have lower wear rates then the former and show minimum abrasive wear. This can be attributed to the matrix containing higher amount of SiC particles.

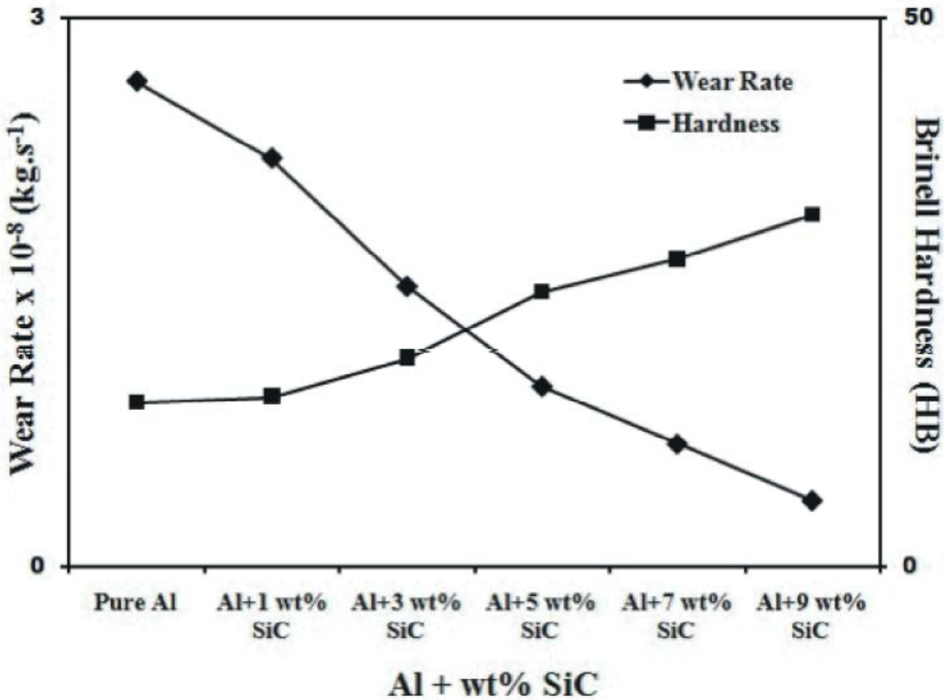

Fig. 7: Dependence of Wear Rate and Hardness on Reinforcement with SiC

For the production of metal matrix composites via stir casting method, several factors need undeniable attention, including the difficulty of achieving a uniform distribution of the reinforcement material, wettability between the two main substances, porosity in the cast metal matrix composites and chemical reactions between the reinforcement material and the matrix alloy. The gas layers might be the main factor for the poor wettability [14]. Firstly, gas layers can cause the buoyant migration of particles, making it difficult to incorporate the particles into the melt. Secondly, even the particles can be suspended in the melt by vigorous agitation. In order to achieve the optimum properties of the metal matrix composite, the distribution of the reinforcement material in the matrix must be uniform and the wettability or bonding between these substances should be optimized. If optimization is unsuccessful then the main idea, i.e. uniform distribution of the reinforcement particle in the metal matrix cannot be achieved.

From all the data, it can be confirmed that reinforcing the Al metal matrix with hard SiC particles improves the quality of the metal without sacrificing its ductility. The hard SiC particles increase the hardness of the metal and improve wear resistance. From Fig. 8 it is clearly evident that as the SiC_p additions are increased the hardness of the composite increases, which in turn increases the wear resistance of the composite.

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 yields a composite with uniform particle distribution. 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 and thereby increases the wear resistance of the composite by almost seven times at higher loads and six times at higher sliding speeds compared to unreinforced Al. Furthermore, increasing the addition of wt% SiC increases the wear resistance of the composite by six times at higher load and by nearly five times at higher sliding speed. Hence, reinforcing Al with SiC particles and increasing the wt% of the particles can lead to a composite with better wear resistance.

ACKNOWLEDGMENT

The authors would like to thank the Materials and Metallurgical Engineering department of Bangladesh University of Engineering and Technology for their ardent support.

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