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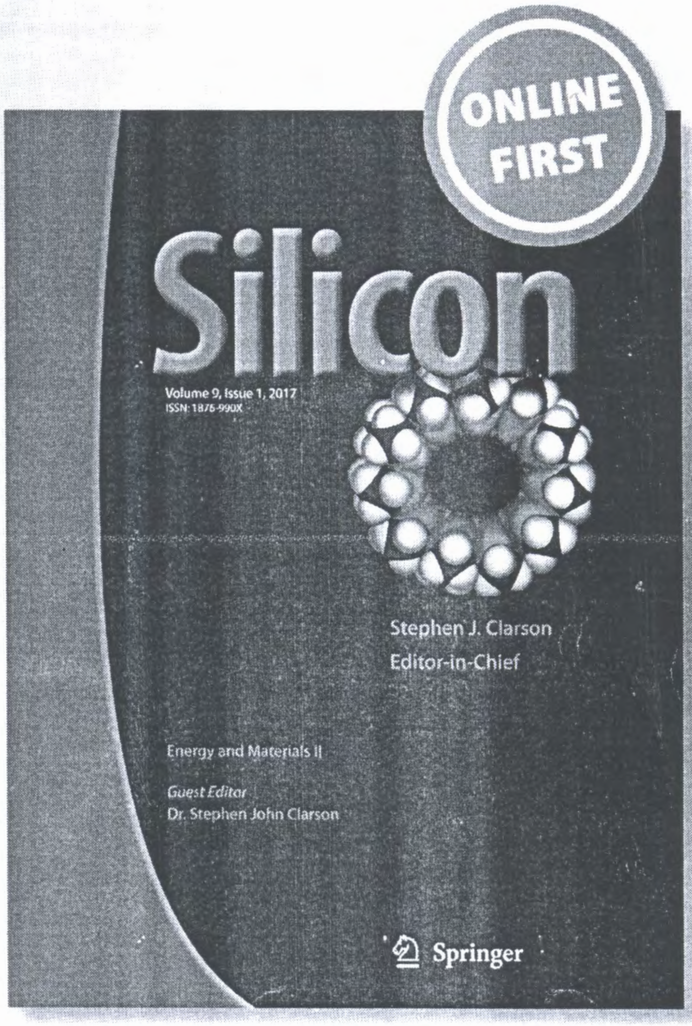

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ORIGINAL PAPER

Aluminum Silicon Carbide Particulate Metal Matrix Composite Development Via Stir Casting Processing

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Abstract In this paper, conventional simple methods of producing MMC with attained properties through the dispersion of silicon carbide in the matrix are investigated. To achieve these objectives a two-step mixing method of stir casting technique was employed. Aluminum (99.66 %C.P) and SiC (320 and 1200 grits) were chosen as matrix and reinforcement materials respectively. Experiments were conducted by varying the weight fraction of SiC for 2.5 %, 5.0 %, 7.5 % and 10 %. The result indicated that the stir casting method was quite successful to obtain uniform dispersion of reinforcement in the matrix. This was evident by the improvement of properties of composites over the base metal. Reinforced Aluminum Silicon Carbide (ASC) showed an increase in Young's modulus (E) and hardness above the unreinforced case and marginal reduction of electrical conductivity was recorded for the composites. The silicon carbide of 1200 grits (3 μm) showed increased Young's modulus (E) and hardness of 1517.6 Mpa and 26.1 Hv values at 7.5 % volume fraction silicon carbide; when compared with the silicon carbide 320 grit (29 μm). Also; the electrical conductivity properties of the two grit sizes of the silicon carbides were less than the base metal for all the volume fractions of silicon carbide.

Keywords Particulate · Aluminum composite matrix · Electrical properties · Silicon carbide

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1 Introduction

Metal matrix composites (MMC) are a range of advanced materials that are combinations of metal and hard particles, which are usually ceramics [1]. This product can be used for a wide range of applications. The MMC have superior properties to the base metal. These properties include improved thermal conductivity, abrasion resistance, tribology, creep resistance, dimensional stability, and exceptionally good stiffness. Like all composites, aluminum matrix composites are not a single material but a family of materials whose stiffness, strength, density, thermal and electrical properties can be tailored [2].

According to Beffort [3], Aluminum Matrix Composites (AMC), are used for specific applications such as main cargo bay struts in the space shuttle. The material used was 6061/B/50f. Also, A359/SiC/20p is used for brake disks and drums; 2014/Al_2O_3/10-20p (Al-4.4Cu-0.5Mg-Si-Mn), 6061/ Al_2O_3/10-20p (Al-1.0Mg-0.6Si-Cu-Cr) and 7005/Al_2O_3/10p (Al-4.6Zn-1.4Mg-Mn-Cr-Zr-Ti) are used in bicycle frames, drive shafts and cylinder liners. A357/SiC/10-20p (Al-7.0Si-0.5Mg), A359/SiC/10-20p (Al-9.0Si-0.5Mg), A339/SiC/10-20p (Al-12Si-1.0Mg-1.0Ni-2.25Cu), A360/SiC/10-20p (Al-9.5Si-0.5Mg) and A380/SiC/10-20p (Al-8.5Si-3.5Mg) are applicable in brake drums and brake discs; also while 6061/Al_2O_3/10p is used in automobile drive shafts; 6092/SiC/17.5p and

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2009/SiC/15p-T4 are used in fan exit guide vanes of jet engines and Al/Nextel610/45f is used for electrical conductors.

Also an aluminum matrix composite processing route entails the using of aluminum as the metal matrix with mixing particles to form composites. It has already found commercial use on account of the fact that conventional processing techniques such as powder metallurgy, vacuum hot pressing, co-spray deposition process, squeeze casting, and stir casting methods can be readily adopted for the processing of such materials [4]. However, the stir casting method is preferred to other methods because it is simple and processing parameters can be readily varied and monitored [5–7]. The designed stir casting system for this work is shown in Fig. 1.

In the production of liquid metal matrix composites, stir casting is generally accepted as a particularly promising route, currently practiced commercially [8]. By using this approach, there are many advantages such as simplicity, flexibility and ability to produce large quantity of product. 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 [2]. The stir casting technique is the most economical of all the available routes for metal matrix composite production [9], it allows very large sized components to be fabricated. The cost of preparing composites material using a stir casting method is about one-third to half that of competitive methods, and for high volume production it is projected that the cost will fall to one- tenth [10].

In preparing metal matrix composites by the stir casting method, there are several factors that need considerable attention. These include the difficulty of achieving a uniform distribution of the reinforcement material, wet ability between the two main substances, porosity in the cast metal matrix composites, and chemical reactions between the reinforcement material and the matrix alloy [8]. In order to achieve the optimum properties of the metal matrix composite, the following steps should be taken. The distribution of the reinforcement materials in the matrix alloy must be uniform, and the wettability or bonding between these substances should be optimized [6]. In order to overcome the difficulty of achieving a uniform distribution of dispersion of silicon carbide particles in the aluminum matrix, the help of a two-step mixing method of the stir casting technique was employed. For the wettability, the pre-treatment of the silicon carbide helps in this direction and the tenacity of the bond between particles and matrix.

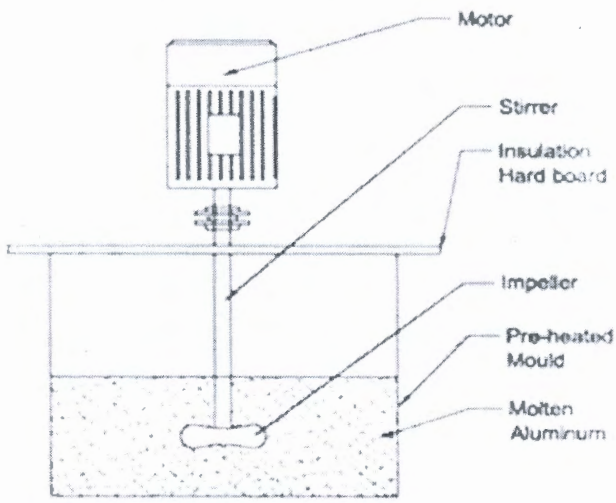

Fig. 1 The Schematic View of the Designed Stirrer

Table 1 The Compositions in Percentage of Aluminum Ingot Obtained from Aluminium Rolling Mills, Ota, Ogun State

Fe	Si	Mn	Cu	Zn	Ti	Mg	Pb	Sn	Al
0.232	0.078	0.000	0.0006	0.0016	0.006	0.0027	0.0012	0.007	99.66

The focus of this study is to develop aluminum silicon carbide matrix composites, using the stir casting system. Also, the effect of silicon grit sizes of the mechanical and electrical properties of the material is assessed.

1.1 Materials and Methods

In this work, the stir casting method was used to prepare samples of AMCs using 1170Al reinforced with silicon carbide (SiC) particulates of 3 μm and 29 μm sizes respectively. The chemical composition of aluminum and silicon carbide are presented in Tables 1 and 2 respectively.

The liquid metallurgy route (stir casting technique) was adopted to prepare the cast composites as described above. A batch of 5.0 Kg of 1170Al was melted at 750 °C in a graphite crucible using an oil-fired tilting furnace for 25 minutes. The temperature of the melt was measured using a K-type thermocouple. The molten metal was then poured into a mold preheated at 450° f for 3 hours and the melting was agitated with the help of a stirrer to form a fine vortex. The SiC particles of 2.5 wt% which was preheated at a temperature of 1100° C for 3 hours was added into the vortex with mechanical stirring at 500 rpm according to Abbassipour et al. [2] for about 5 mins. The experiment was repeated for different particle sizes (3 μm and 29 μm)

Table 2 The Chemical Composition in Percentage of Silicon Carbide (SiC)

C	Al	Fe	Si	SiO_2	Magnetic Iron	SiC
0.50	0.30	0.20	0.80	0.0016	0.04	97.6

Table 3 The Mechanical and Electrical Properties of AlSiC Composite of Different Volume Fraction of Silicon Carbide

S/N	Volume fraction Weight of SiC.	Grit Size	Modulus (N / mm^2)	Yield Strength (MP$_a$)	Hardness (H$_v$)	Electrical Conductivity (MΩ / m)
1	2.5%	320 (29 μm)	1 233.87	28.51	21.56	66.35
		1200 (3 μm)	1293.43	35.45	23.95	67.84
2	5.0%	320 (29 μm)	793.22	27.21	21.41	61.85
		1200 (3 μm)	1028.56	33.69	23.60	67.70
3	7.5%	320 (29 μm)	1092.88	24.25	22.65	61.33
		1200 (3 μm)	1517.59	30.26	26.06	64.15
4	10%	320 (29 μm)	720.41	18.10	21.25	48.74
		1200 (3 μm)	878.93	22.25	25.90	56.63
5	Base Metal A11170	402.41	40.80	19.10	70.25	

and each size with different weight percentage (2.5, 5.0, 7.5 and10 wt%) of SiC were fabricated by the same procedure.

1.2 Tensile Test

All specimens produced through the stir casting method were cylindrical in shape and had dimensions of 110 mm diameter and 30 mm height. Five samples of each cast were cut out and prepared in the machine shop for tensile testing. Tensile test samples having cross-sectional dimensions of 5 mm by 10 mm with a gauge length of 25 mm, were prepared for testing in an Instron Universal Testing Machine (IUTM) with 30 KN load. Five measurements (modulus) were taken for each sample and the average taken as the parameter value.

1.3 Micro-hardness Test

Micro-hardness measurements were carried out using a micro-hardness tester. The micro-hardness tester used was a LECO 700AT with a load of 492.3 mN and a dwell time of 10 seconds. Before testing, specimen surfaces were polished using emery papers down to 1000 mesh. At least 6 measurements were taken for each sample and the average was taken as the micro-hardness value.

1.4 Electrical Conductivity and Resistivity Test

Samples of each cast were cut out and prepared for electrical conductivity testing. Test samples, having cross-sectional dimensions of 5 mm by 10 mm with a length of 26 mm, were prepared for testing in a four point probe machine. The working voltage of 20 mV was used. Voltage, current, resistivity and conductivity were obtained from the Keithley instruments model 2400.

2 Results and Discussion

Table 3 presents the mechanical and electrical properties of AlSiC composites of the two grit sizes of 320 (29 μm) and 1200 (μm). The mechanical properties values were higher than the base metal aluminum. However, the electrical property values were marginally lower than the base metal. The results as indicated in Figs. 2, 3, 4 and 5, show the increasing trend of modulus, hardness and yield strength with the lowest particles size of 1200 (3 μm) in weight percentage of SiC up to 7.5 % weight fraction.

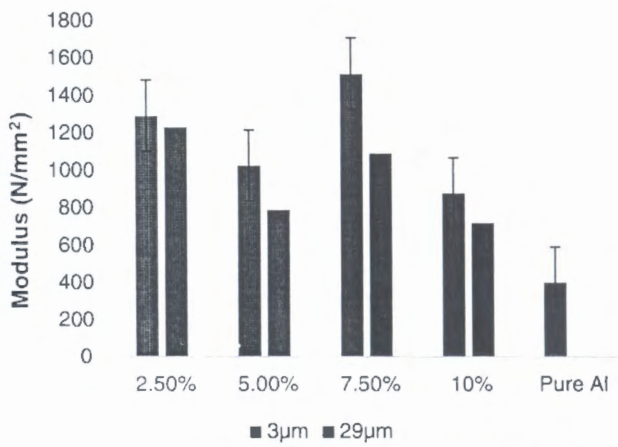

Fig. 2 Comparative chart of modulus of elasticity of two grit sizes of silicon carbide particles

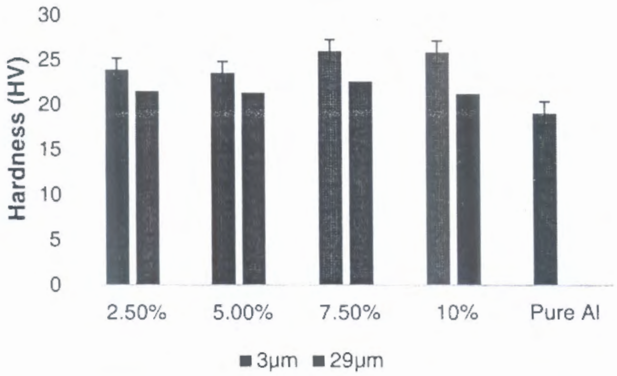

Fig. 3 Comparative chart of Hardness of the two grit sizes of silicon carbide

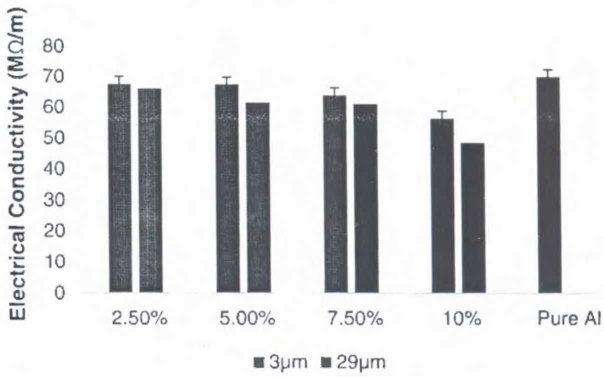

Fig. 5 Comparative chart of Electrical Conductivity properties of the two grit sizes of silicon carbide

The hardness of the composite was found to be considerably higher than that of the matrix alloy and increased with increasing particle content. The higher hardness of the composite samples relative to that of the matrix aluminum could be attributed to the existing hard particles (SiC) acting as obstacles to the motion of dislocation. The presence of small separate particles in the microstructure can impede the movement of dislocations provided that these particles are stronger than the matrix in which they are embedded [11, 12]. The degree of strengthening produced also depends on the size of particles, their distance apart and the tenacity of the bond between particles and matrix. Also the small grit size of silicon carbide influences the mechanical properties [13].

The two-step mixing, helps to disperse the particles, which results in the strengthening produced by the small size particles. When compared with the bigger particles, by pre-heating, the silicon carbide at 1200 °C for two hours before the mixing probably helped the tenacity of the bond between the particles and the matrix, which added to the strengthening effect. The particles of silicon carbide are stronger than the matrix, so the dislocation cannot pass through them, and the higher stress used during the tensile test might have activated the dislocation to by-pass them leaving a "dislocation loop" around each particle. This will make the passage of a second dislocation much more difficult, particularly since dislocations have greater difficulty in passing between particles which are near to each other resulting in a higher strength of the small particle more than the bigger one. The mechanical force by mixing mechanically and pre-treatment of silicon carbide before the automatic mixing was applied to overcome surface tension to improve wettability.

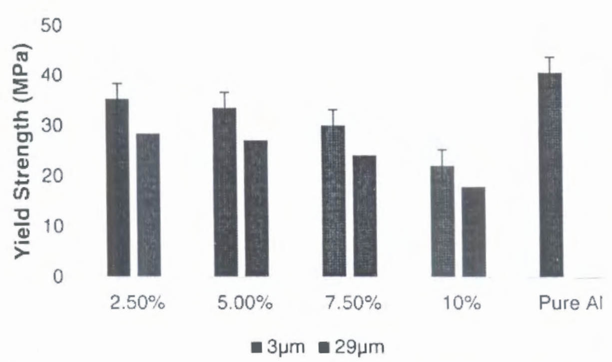

Fig. 4 Comparative chart of yield strength behavior of the two grit sizes of silicon carbide

The electrical conductivity of composite materials was observed to be invariably lower than that of the monolithic aluminum-base metal. The electrical conductivity of composite materials decreased with increase in particle sizes and the volume percent of the reinforcement phase during stir casting. However, the low material density of AlSiC (3 g/cm^3) made it ideal for weight sensitive applications such as portable devices over traditional thermal management materials like copper molybdenum, CuMo, (10 g/cm^3) and copper tungsten, CuW, (16 g/cm^3) [14].

Also, the addition of SiC molecules, a ceramic powder, improved the thermal stability of AlSiC material when compared to the monolithic aluminum. When this composite is attached as a heat sink to an IC device, stress failure would be avoided during service [14].

3 Conclusion

1. A simple designed conventional method of stir casting was used to produce an aluminum silicon carbide composite. The metal matrix composite (MMC) materials produced show that modulus and hardness had higher values than the unreinforced base metal aluminum.
2. At 7.5 % volume fraction weight of silicon carbide of 1200 (3 µm) grit size have impressive mechanical properties when compared with other grit sizes.

3. There was marginal reduction of electrical conductivity for composites when compared with the base metal aluminum.
4. The stir casting method seemed to disperse small grit of silicon carbide in the matrix better than the bigger grit, which resulted in the improvement of the strength and mechanical properties of the composite alloy. The small grit size of silicon carbide influences the strength of mechanical properties of the composites.

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