

EFFECT OF ADDITION OF SiC PARTICLES ON THE MICROSTRUCTURE AND HARDNESS OF Al-SiC COMPOSITE

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Abstract

This work aims to investigate the effect of the addition of silicon carbide particles on the microstructure and the hardness of the Al-SiC metal matrix composites. The said composite is prepared using the stir casting technique for different weight percentages of the SiC particles. The higher composition of the reinforcement causes the clustering of the particles in the matrix. Thus, research has to be carried out on the aluminum-silicon carbide composites with the reinforcement 3 wt%, 6 wt%, 9 wt%, and 12 wt% of SiC particles to obtain the optimized composition. In order to study the microstructure and the reinforcement distribution in the matrix, a scanning electron microscope is utilized. The hardness testing has been carried out using the Vickers' indentation technique for the as-cast and age hardening conditions. From the microstructural study, it is observed that the microstructure of the said composite exhibits the uniform distribution of the reinforcement. The EDX results show the presence of the reinforcing elements in the Al-SiC composite. From the results obtained from the hardness testing, it is observed that the presence of the carbide element in the composite increases the hardness of the Al-SiC particulate composites.

Keywords: Al-Si composite; stir casting technique; age hardening; Vickers hardness; microstructure.

Introduction

Metal matrix composites consist of a matrix, particularly an alloy or a metal, and a reinforcement such as the particles, short fiber or whisker, and/or long fiber.

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Discontinuously or particle reinforced MMCs have turned out to be extremely mainstream since they are more affordable, less expensive to fabricate than long fiber fortified composite, and it generally has isotropic properties contrasted with fiber reinforced composite [1,2], whereas the properties of aligned fiber reinforcement composites are highly anisotropic. Some common reinforcements for aluminum matrices are SiC, Al₂O₃, B₄C, and graphite.

Various authors have studied the mechanical properties of the as-cast aluminum graphite composites [3-7] for various reinforcement compositions. The results show that mechanical properties like hardness and tensile properties increase with the increment in the graphite. Research has also been carried out on the hybrid aluminum-SiC/Al₂O₃ composites [8-9]. From the outcomes, it is identified that the addition of the reinforcement increases the mechanical properties. The stir casting method used enhances the properties, which in turn obtained from the improved bonding between the matrix and reinforcement. However, the higher percentage of reinforcement causes the clustering of particles, thus decreases the properties.

Powder metallurgy, stir casting method [3-10], accumulative roll bonding (ARB) method [11-18] were utilized to prepare the aluminum matrix with different reinforced composite. From the results, it is identified that the mechanical properties obtained from both methods exhibit the improved properties of the composites. However, most of the authors preferred the stir casting method due to its various advantages like easiness, low cost, availability etc. Also, authors [19] use the alumina as the reinforcement in the copper matrix and studied the hardness and wear behavior of the composite.

From the literature, it is identified that aluminum matrix with silicon carbide reinforcement composites has a broad scope for the development of better material for automobile and aerospace applications. Many authors studied the aluminum-silicon carbide materials for various compositions like 5wt% to 30wt% of reinforcement in incremental steps of 5%. However, from the literature, it is observed that higher percentages or above the 10% of reinforcement clustering and grouping of particles are started. Thus research has to be carried out on the aluminum-silicon carbide composites with the reinforcement 3wt%, 6wt%, 9wt%, and 12wt% of SiC particles to obtain the optimized composition. Also, the heat treatment of the MMC increases the mechanical properties. Thus for the said compositions, heat treatment has been carried out to determine and compare the hardness of the composite. The main aim of this work is to study the microstructure of the Al6061-SiC composite and the effect of the addition of the different weight fraction of reinforcements on the hardness of the composite on as-cast and age-hardened conditions.

Materials and Processing

In the present work aluminum 6061 is utilized as a matrix, and silicon carbide particles are used as reinforcement. A precipitation-hardened aluminum (Al6061) alloy has its main alloying elements as magnesium (0.81 wt%) and silicon (0.70 wt%). The hardness of 95 BHN, $E=68.9$ GPa, $\sigma_y = 275$ MPa, $\sigma_{ut} = 315$ MPa and elongation 17% were some of its mechanical properties.

Silicon carbide, in short, called SiC is an abrasive material also called carborundum. The particles of the silicon and carbide are bonded using a sintering technique that forms the hard ceramic. The application of the silicon carbide can be found when it requires high endurance, as like in brakes, clutches, bulletproof vest

plates etc. Some of the properties of the SiC are Density = 3.1g/cc, melting point – 2730°C, Appearance –Black in color, Hardness = 45.8 GPa [9].

The aluminum-silicon carbide particulate (Al-SiC_p) composites demonstrate isotropic properties as well as an exceptional combination of structural and physical properties. The particle size of the silicon carbide, among many factors, is the most significant variable considered, which will influence the microstructure of the composite. The particle sizes of silicon carbide utilized in this work are 44 μm. The compositions used in this work are mentioned in Table 1.

Table 1. Different compositions of aluminum and silicon carbide with superheated temperature and speed.

Sample	Al6061	SiC	Composite	Temperature	Stirring speed
1	1000 gm	30gm	Al6061-3wt% SiC	720 °C	500rpm
2	1000 gm	60gm	Al6061-6wt% SiC	720 °C	500rpm
3	1000 gm	90gm	Al6061-9wt% SiC	720 °C	500rpm
4	1000 gm	120gm	Al6061-12wt% SiC	720 °C	500rpm

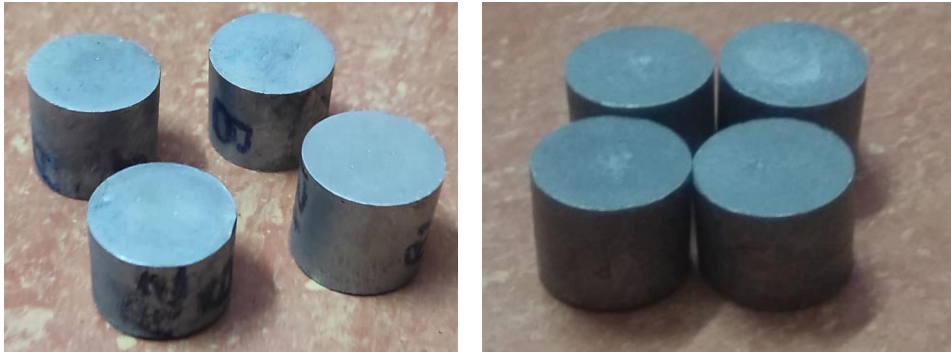
The stir casting method is used to cast the Al-SiC_p MMCs at 3, 6, 9, and 12% weight fractions of SiC. The aluminum superheated above its melting point (i.e.720 °C), and a predetermined quantity of reinforcement particles and degassifiers are added while stirring at a speed of 500 rpm. The molten Al-SiC is poured into the graphite mold, and it is allowed to solidify.

The block took from the mold were machined to the required size of the specimen. The prepared specimen size for the hardness test is Ø25X30mm. The samples are turned to the required size using the lathe machine. The indentation surface is machined using the surface grinding machine. The specimens are also prepared, using a lathe and surface grinding machine for the size Ø10X10mm, to study the microstructure using a scanning electron microscope (SEM).

The specimens of the Al6061-SiC composite with 3, 6, 9, and 12 wt% of SiC have been heated to a temperature of 460 ± 5 °C which is just lower than the early melting point of the matrix for 2 hours followed by quenching in water. In this way, all the solute molecules are permitted to dissolve to form a single-phase solid solution. Artificial aging was done at 120°C, for a period of 4 hrs and consequently cooled in the air.

Experimentation

The Vickers' hardness is the quotient gained by separating the kgf load by the square mm indentation area. Experimentation has been conducted on the Al6061-SiC composites for the 3, 6, 9, and 12 wt% of the reinforcement for both as-cast and age-hardened conditions. The prepared specimens are shown in Fig 1.



(a) As-cast specimens

(b) Heat-treated specimens

Fig. 1. Al6061-SiC composite specimens for the hardness test.

The Vickers' indentation hardness measurement technique comprises of diamond indenter used to indent the test specimen. The parameters observed in the Vickers' indentation hardness are given in Table 2.

Table 2. Vickers' hardness test parameters.

Indenter	Angle	Applied load	Holding time	No of trails
A diamond with a square base with a pyramid shape	136 °	30 kgf	10 sec	03

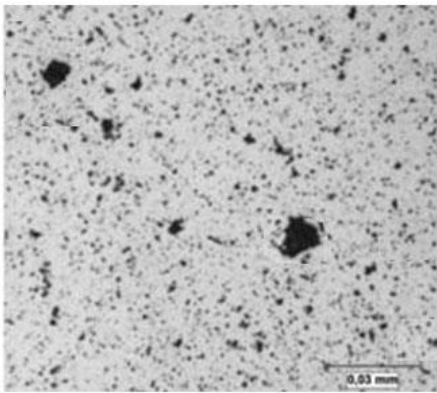
After removing the applied load, indentation applied on the specimen has been measured for both the diagonals on the surface utilizing a microscope, and the average value has been considered. The diagonal area of slant surfaces is determined to calculate the hardness of the Al6061-SiC particulate composites, for various weight fractions of the SiC, for both as-cast and heat-treated conditions. The result of the experimentation is listed in Table 3.

Table 3: Vickers' hardness values for the Al6061-SiC composites.

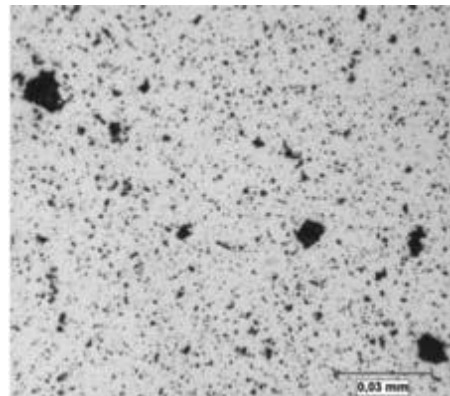
Sample	Composition	Vickers Hardness Number	
		As-cast	Age Hardened
1	Al6061-3wt% SiC	76	89
2	Al6061-6wt% SiC	84	103
3	Al6061-9wt% SiC	86	110
4	Al6061-12wt% SiC	79	101

Results and Discussions

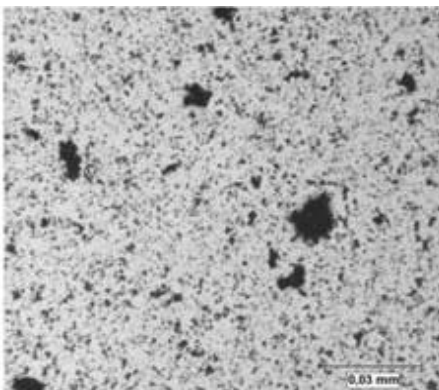
Fig 2 shows the microstructure of the Al6061-SiC particulate composite which reveals the distribution of the reinforcement is uniform. During the mixing of the matrix and the reinforcement in the stir casting process, the revolving stirrer forms the spinning of the liquid material which causes the particles of the SiC to drain into the dissolve. Due to the poor wettability of the SiC particles, the force applied by the mechanical stirrer will shear the surface strength of the molten material. The flow transitions will certainly influence the distribution of the silicon carbide particles in the molten aluminum. The lifting of the SiC particles takes place in the molten aluminum and also the prevention of particle settling in the matrix are due to the momentum transfer and the outspread flow of the melt. For the moment, the grouping of silicon carbide particles was subjected to the local hydrodynamic forces, which were able to break up the grouping of the SiC particles in the matrix. This causes the formation of the homogeneous microstructure throughout the cast.



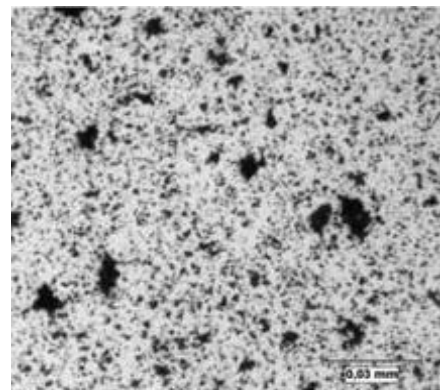
(a) Al6061-3wt% SiC



(b) Al6061-6wt% SiC



(c) Al6061-9wt% SiC



(d) Al6061-12wt% SiC

Fig. 2. SEM images showing the uniform distribution of SiC particles.

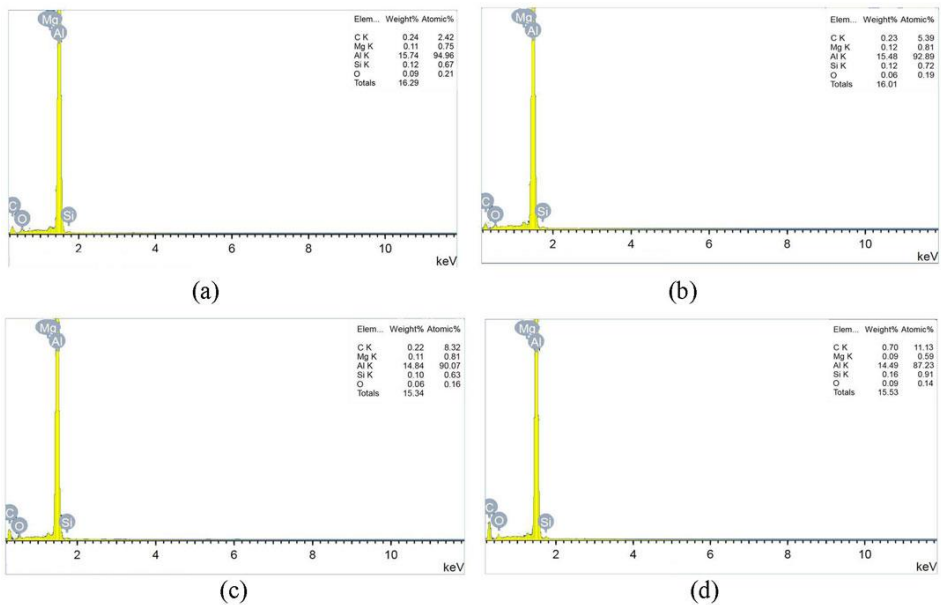


Fig. 3. EDX profile analysis for the surfaces (a) 3% (b) 6% (c) 9% (d) 12 wt% of SiC.

Fig. 3 displays the atomic percentage of elements available in the Al6061-SiC composites through the energy-dispersive x-ray spectroscopy (EDX) profile analysis. The EDX analysis is conducted for the elements like aluminum, silicon, magnesium, carbide etc. However, in all the compositions, additional element oxygen (O) has been obtained. The element 'O' is because of the formation of the alumina on the upper layer of the composite. The presence of carbon might have come from the reinforcement SiC in the aluminum matrix. The indication of elements Silicon (0.63 to 0.91) and Magnesium (0.59 to 0.81) is because of the elements present in the Al6061. The element 'C' varies from 2.42 to 11.13, indicates the increment in the reinforcement SiC in the aluminum matrix.

Thus, from the EDX analysis, it is observed that the elements obtained in the Al6061-SiC confirm the presence of alloying elements. The presence of these elements validates the experimental preparation of the composite using the stir casting method. To verify the bonding and the interface between the matrix and reinforcement has to be analyzed using the SEM. The interface between Al6061 and SiC particle has been tested using SEM and the resulting micrograph has been displayed in Fig.4.

From Fig. 4 it is observed that the bonding between the matrix and reinforcement is strong homogeneous structure, which will help in the transfer of load from SiC to the aluminum matrix. Hence the crack propagation occurs in the composites via SiC and not along with the matrix and reinforcement interface. The stir casting process also influences the interfacial relationship between the matrix and the reinforcement during the solidification process. The strong solid particle/matrix interface helps the SiC particles to logically set themselves up into the aluminum matrix. This increases the overall strength of the Al6061-SiC composite.

From Fig. 4 it is also noted that there is no formation of the void or extensive segregation at the aluminum and SiC interface. This enhanced interface, bonding, and homogeneous distribution of the reinforcement in the matrix will strongly influence the mechanical characterization of the Al6061-SiC composite.

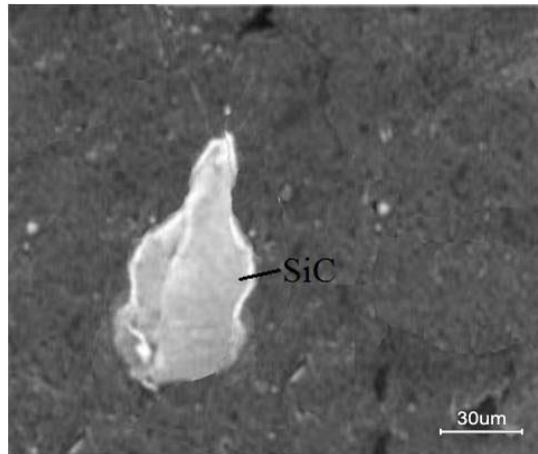


Fig. 4. SEM of an Al6061-SiC composite demonstrating interface between the aluminum matrix and silicon carbide particle.

The outcome of hardness testing, it is seen that the Vickers' hardness of Al6061-SiC is increasing with an increment in weight percent of silicon carbide. The increase of Vickers' hardness is due to the result of increased silicon carbide particles, which hold the matrix and the reinforcement together with the good bonding, which acts as the barricade to debonding of both. The decrease of Vickers' hardness at 12wt% is might be due to the increased particles of silicon carbide, which causes the grouping of particles in the aluminum matrix. Due to the good bonding and uniform distribution of silicon carbide particles in the aluminum matrix, Al6061-SiC particulate composites have greater mechanical properties, improved hardness.

Conclusions

The stir cast process has been utilized, which influences the uniform distribution of the SiC particles in the aluminum matrix. Quantitative investigation using EDX uncovered enhanced particle distribution in the Al6061-SiC particulate composites. The quantitative examination of the reinforcement distribution and mechanical properties affirmed the benefits of the stir casting processes. Enhanced Vickers' hardness is accomplished because of structural consistency, good bonding and uniform distribution, and strong interfacial bonding of silicon carbide particles in the matrix. From the enhanced properties, we can consider the Al6061-SiC particulate composites as a potential material for aerospace and automobile applications etc.

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