



Evaluation of Mechanical and Microstructural Properties of Al-SiC/Gr Particulate Produced by Stir Casting Technique

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Stir casting is an economical process for the production of aluminum matrix composites. There are many parameters in this process, which affect the final microstructure and mechanical properties of the composites. In this study, micron-sized SiC and Gr particles were used as reinforcement to fabricate Al-SiC/Gr composites at holding temperature of 700 ± 5 °C for 5 min at 350 rev/min stirring speed. The evaluation of the mechanical properties of the composites show improvement compared with pure aluminum-matrix. The Scanning Electron Microscope (SEM) of the as-cast composites shows that the vortex formations within the melt eliminates the agglomeration of the particles and improve the wettability phenomenon.

Keywords: Stir casting; aluminum matrix composites; vortex formation; wettability.

1. INTRODUCTION

Aluminum alloys are widely used in many industrial engineering including transportation,

packaging, construction and domestic purposes due to their excellent properties, such as light weight, good heat and electrical conductor high corrosion resistance, high castability and

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machinability [1-4]. Among the most extensive used aluminum alloy, Al-356 alloy is widely used in pump components, flywheel castings, automotive transmission cases, oil pans, pump bodies because of its good forming processing performance, corrosion resistance, weldability and moderate intensity [5-7].

Moreover, Metallic Matrix Composites (MMCs) reinforced with ceramic particles are promising materials for structural applications due to excellent combination of physical and mechanical properties [8,5]. MMCs combine the properties of the metallic alloys (ductility and toughness) and the ceramic reinforcements (high strength-to weight ration and high modulus) leading to superior tribological properties, controlled coefficient of thermal expansion, higher fatigue resistance and better stability at elevated temperature [1,2]. It has been found that the use of aluminum metal matrix composites (AMMCs) in automobile and aerospace applications can reduce the overall weight, reduce fuel consumption and improve the performance of the engine or component as whole [4,9].

AMMCs reinforced with micro or nano-sizes ceramics such as silicon carbide, alumina, graphite, zirconium diboride particles have been well researched [4,9,10]. The strength of such composite materials depends upon composition and volume fraction of the reinforcement(s), grain size, microstructure and the fabrication process. Oh et al. [10] have proposed that morphology, type of reinforcements and distribution of reinforcing particles have significant contribution in the aggregate characteristics profile of the composites.

According to Ezatpour et al. [11], the variables that govern the distribution of particles are solidification rate and fluidity of the melt, type of reinforcements, the method of particle incorporation and wettability of particles in the melt.

Moreover, Auradi et al. [12] reported that the microstructures of the Al/SiC as-cast composites produced by melt stirring technique, exhibit a fairly uniform distribution of SiC particulates with some regional clusters and contain some porosity. Similarly, Boopathi et al. [13] have studied the microstructures of aluminum alloy (Al-2024) reinforced with different compositions of fly ash, SiC and their mixtures. They observed that the particles were uniformly distributed in the

matrix rather than using single reinforced composites where segregation of particles was clearly visible. They attributed the segregation of particles in a single reinforcement to the gravity-regulated of the particles in the melt.

Al6061/SiC/Gr hybrid composites containing 20 vol. % of SiC particles with average sizes of 19, 93 and 146 μm , along with 0–13 vol.% uncoated graphite particles was studied by Mahdavi and Akhlaghi [6]. Improved mechanical properties of these hybrid composites was obtained at 5 vol.% graphite along with increased size of SiC particles.

2. MATERIALS AND METHODS

Pure aluminum ingot 99.5 wt% commercial purity was used as a matrix. Table 1 present the chemical composition of the used ingot obtained using a 108M optical emission spectrometer. Micron-sized SiC particles with an average particle size of 25 μm , 99.9 % purity and Gr with an average particle size of 60 μm were obtained from Hunan Ketao Industry Co., Ltd, China, as the reinforcement. The properties of the SiC and Gr particles used in this study are shown in Table 2. In order to fabricate the composites, the Gr was further milled in a vibratory ball milling machine for 5 hours using ball/powder ratio (6/1 wt.), ball diameter 20 mm and at a speed of 550 rpm. After milling process, particle sizes of 45, 40, 30, 25 and 20 μm were obtained using Vibratory King Test Sieve Shaker following the ASTM standard.

These micro-sized particles were then used as reinforcement on pure Al-alloy. Table 3 present the variation of particle sizes used with pure Al for the melting operation. 10 wt.% of the mixed reinforcement each was added to 80 wt.%-Al to carry out the melting of each sample.

2.1 Stir Casting Process

Stir casting is a liquid state method for the fabrication of composite materials by mechanical stirrer in which a reinforcement phase is mixed with a molten matrix metal. Being the simplest and the most cost effective method of liquid state fabrication, it offers a lot of advantages in terms of uniform distribution of reinforcement; improve wettability between the reinforcement and the matrix. The stir casting set-up is shown in Fig. 1.

Each reinforced mixture powder was enfolded carefully in an aluminum foil packet for insertion into the molten aluminum metal and preheated at

350 °C for 2 hours before charging into the molten metal. This was done to remove the moisture content and impurities. Pure aluminum ingot was heated in a graphite crucible to 700 ± 5 °C in an electric resistance furnace. The preheated reinforced powder was feed into the molten metal and stirred vigorously for 3 minutes at a speed of 250 rev/min to achieve homogeneous mixture. The molten metal was cast in a prepared sand mold for analyzes.

Five specimens were prepared for metallographic examinations using 220, 320, 400 and 600 mesh emery papers, followed by polishing with 1- μ m sized diamond paste. The

structure of the as-cast samples were examined using scanning electron microscopes (JOEL JSM 5900LV-Model), equipped with energy-dispersive X-ray spectroscopy (EDX) analyzer for elemental composition. Vicker hardness tests of the were conducted according to ASTM-E384 using a ball indenter \varnothing 3.175 mm and an applied load of 100 gram for 15 s. Tensile specimens were also prepared from the as-cast composites. All of the tensile tests conducted were performed at room temperature using Instron testing machine (3369-Model) operating at a constant rate of cross head displacement, with an initial strain rate of $2 \times 10^{-3} \text{ s}^{-1}$.

Table 1. Chemical composition of used Al-alloy (wt %)

Al	Si	Cu	Mn	Fe	Zn	Ni	Pb	Sn
99.5	0.1	0.01	0.01	0.02	0.03	0.01	0.002	0.002

Table 2. Properties of silicon carbide and graphite particles

Reinforcements	Young Modulus (GPa)	Density (g/cm ³)	Hardness (VHN)	Poisson ratio	Thermal expansion
SiC	420	3.20	287	0.16	$3.7 \times 10^{-6}/\text{K}$
Gr	4.1	1.61	295	0.17	$2-5.8 \times 10^{-6} \text{ } ^\circ\text{C}$

Table 3. Mixing ratio of the reinforcement with Pure Al

Sample	A	B	C	D	E
Particle size(μ m)					
SiC/Gr	25/45	25/40	25/30	25/25	25/20

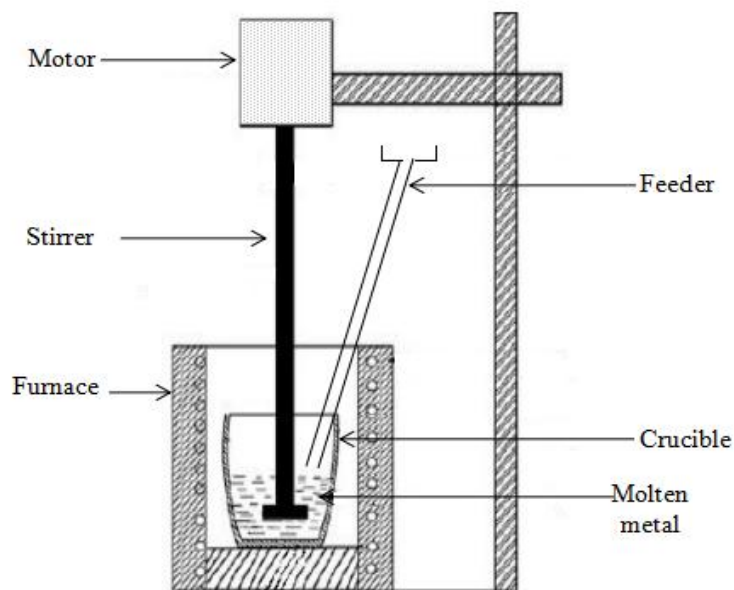


Fig. 1. Schematic of Stir Casting Setup

3. RESULTS AND DISCUSSION

3.1 Mechanical Properties of the Cast Composites

To evaluate the effects of these processing conditions on the as-cast aluminum composites, the mechanical properties tests were conducted. Fig. 2 shows the results of tensile strength, yield strength and modulus of elasticity of the material.

As seen from Fig. 2, there are significant difference properties among the samples. Sample B, C and D poses high mechanical properties with ultimate yield strength of 139.25, 140.00 and 138.51 MPa, respectively. From Fig. 3, the hardness values increase with the addition

of reinforcement. This can be attributed to hardnability properties of silicon carbide particulates compared with aluminum matrix alloy.

3.2 Metallographic Images of the Cast Composites

Presented in Fig. 4 are the SEM images of the particulate composites studied confirmed the uniform distribution of the reinforcements within the matrix. In the process of the mixing, the vorticity of the molten metal formed as a result of the rotation of the stirrer improve the wettability between the reinforcements and the matrix. Both the SiC and Gr reinforced aluminum composites are evenly distributed.

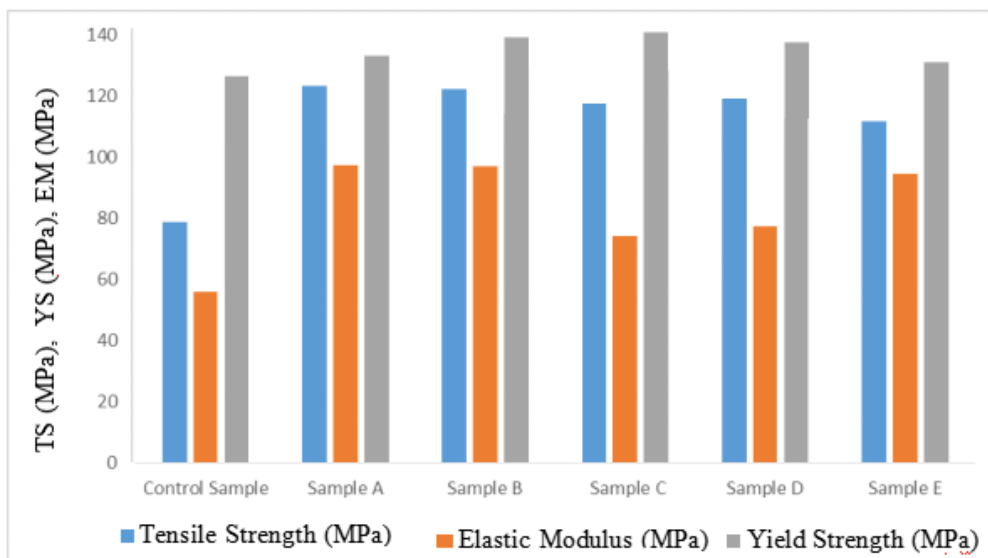


Fig. 2. Test properties of as-cast composites

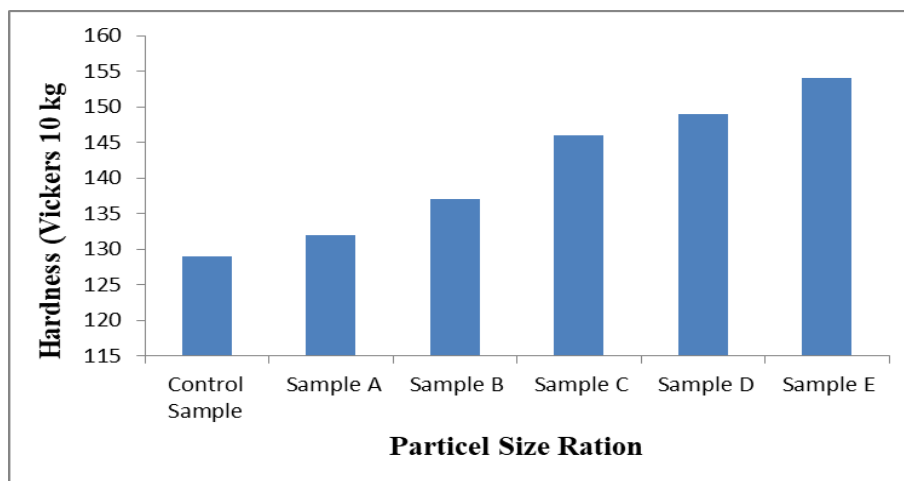


Fig. 3. Hardness test results of the as-cast composites measured by Vickers test (10 kg)

To determine the elemental composition of the Al-SiC/Gr composites produced, Energy-Dispersive X-ray (EDX) measurements are carried out. Fig. 5 describes the atom percentage of Si, Mg, Fe and Zn present in the pure Al-matrix. These outcomes specified that the chemical compositions of the cast composites are consistent. Varying degrees of intermetallic compounds can be observed. This may be due to the interaction between reinforcement and Fe present in the matrix which cannot be totally removed. From the EDX analysis (Fig. 5), the increase hardness of the material can be attributed to the formation Al(Zn)_x.

4. CONCLUSION

The effect of silicon carbide particulate and graphite addition on pure aluminum was studied. Hardness tests, tensile testing, SEM analysis were performed to complete the research. The tensile testing of the composites having weight ratio of 25µm-SiC wt.% to 30µm-Gr wt.% showed the maximum strength but the hardness values of the reinforced composites increased with the increase of SiC/Gr weight ratio addition.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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