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https://doi.org/10.5109/2349295

出版情報：Evergreen. 6 (3), pp.200-206, 2019-09. 九州大学グリーンテクノロジー研究教育センター
バージョン：

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(Received June 5, 2019; accepted September 9, 2019).

Abstract: This study investigates the effect of addition of SiC particles on Al 6061 alloy. The composites are prepared with varied (0, 2, 4, 6 and 8) weight percent of SiC particles through electromagnetic stir casting technique. Scanning Electronic Microscope (SEM) is employed to examine the microstructure of the fabricated composite and results depict that SiC content were uniformly dispersed in the Al 6061 matrix. Density of the composite is increased due to high density of SiC particles in comparison to Al 6061 alloy. Hardness and tensile tests are performed to investigate the mechanical properties of composite. The hardness and tensile strength is significantly improved up to 8 wt % of SiC particles. The novelty of this archival work lie in fact that few experiments have been carried out for Al 6061/SiC composite and some significant insight for the electromagnetic stir casting is achieved in the performed experiment.

Keywords: Micro-structural analysis, Density, Hardness and Tensile strength.

1. Introduction

A composite material is a combination of two or more constituent materials with considerably different physical or chemical characteristics that, when combined, produces a material with properties different from the individual components[1]. Particulate reinforcement metal matrix composites (MMCs) have tremendous demand in present era due to enhanced mechanical and physical properties, enable them to replace conventional material. Several usage of composite material are found in aerospace, automobile, sports, marine and defence industries[2]. Composite possess isotropic mechanical characteristics in three orthogonal direction combined with quiet low cost accessibility of reinforcement and docility to fabricate. Superior mechanical characteristics and comparatively low cost make them as an appropriate opinion. Dissimilar metals and its alloys such as aluminium and magnesium has been considered and deliberated as metal matrix [1-4]. Among different matrix material present, the tradition of aluminium based MMCs had been increased. Different reinforcements used in aluminium matrix are SiC, B_4C, TiB_2, MgO, AlN, ZrO_2, E-glass graphite and Si_3N_4 [5-7].

Fabrication methodology of aluminium MMC can be categorized into (a) solid state processing such as powder metallurgy and friction stir processing (b) liquid state processing such as stir casting, squeeze casting and spray casting (c) liquid solid process such as compo casting or semi-solid forming[8-10]. Powder metallurgy is a dominant process to manufacture small composite parts in large scale but is not suitable to produce large components. Liquid state processing has got benefits such as easiness, comparatively less expensive and producing of complicated components. Several liquid state processing techniques available, stir casting process is an attractive method to manufacture the aluminum MMCs [11-14].

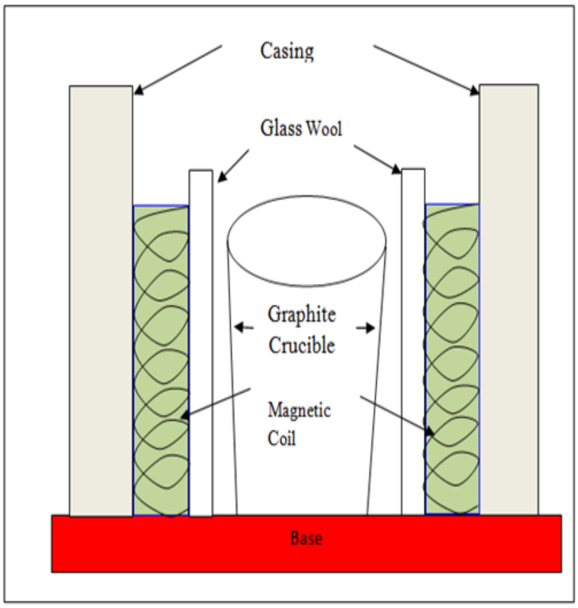
The main problem occurred in fabricating MMCs by traditional stir casting are porosity, uniform dispersal of reinforced particles, unwanted chemical reactions and poor wettability of reinforced particles[15]. Homogeneous dispersal of reinforced content in the melt has high impact on the mechanical properties of MMCs. Non uniform dispersal of reinforced particles causes the defects in the form of accumulated reinforced particles. These defects are responsible to reduce tensile strength, ductility, fatigue strength, hardness, and toughness of the composite[16].

Many researchers have incorporated SiC particles as reinforcement in Al metal matrix[17-20]. Silicon carbide reinforced aluminum MMCs have gained consideration since the cost of SiC powder is low, having good wettability between Al 6061/SiC composite. SiC particles having low density of 3.21 g/cm^3 had high hardness, strength, elastic modulus, thermal conductivity and superior chemical inertness with low thermal expansion [21].

The novelty of present investigation is to prepare Al 6061/SiC composite (by varying SiC particle from 2 to 8 wt % by weight) using electromagnetic stir casting technique. Uniform dispersal of reinforced particle in the matrix has been qualitatively examined by SEM to examine the microstructure of reinforced particles. Hardness test and tensile test of the fabricated composite have been used to evaluate the statistical characteristic of hardness distribution for the Al-SiC composites.

2. Design of Experiment

Electromagnetic stir casting set up was prepared to fabricate Al 6061 alloy matrix composite constituting 2, 4, 6 and 8 wt % of SiC particles[22]. The line diagram of electromagnetic stir casting setup and melting of Al 6061 alloy in muffle furnace is shown in Fig. 1 (a) and (b).



(a)

(b)

Fig. 1: (a) Line diagram of stir casting setup (b) Melting of Al 6061 alloy in muffle furnace.

Chemical composition of commercially available Al 6061 alloy is given in Table 1. The mechanical properties of Al 6061 alloy and SiC contents are shown in Table 2 and Table 3. Cut ingots of Al 6061 alloy having 600 gm weight were kept in a graphite crucible. The crucible was kept above the muffle furnace having temperature range of 400˚C to 1200˚C with temperature increment of 10˚C. The muffle furnace was used to melt the material. It was equipped with heating coil of power 3KW working at 230 V and 5 A. The Al 6061 alloy was melted at 660˚C with 1 wt % magnesium to improve the wettability [23]. The silicon particles were preheated at 200˚C to remove moisture content and absorbed gas. SiC particles of 2, 4, 6 and 8 wt % having average size 30 µm, kept in aluminum foil were incorporated (6 to 8 gm/min) in the melt into two steps to avoid clusters of reinforced particles. Electromagnetic stirring was performed for 10 minutes at 450 rpm. The melt slurry was poured in the preheated permanents steel mold at 300˚C for 2 hours having 34 mm diameter and 78 mm length. The melt was permitted to cool in atmospheric air.

Table 1: Chemical Composition of Al 6061.

Elem-ents	Mn	Cr	Ti	Si	Mg	Fe	Cu	Zn	Al
Cont-ents	0. 24	0. 8	0. 15	0. 43	0. 14	0. 7	0. 24	0. 25	Bala-nce

Table 2: Mechanical characteristics of alloy Al 6061.

Properties	Metric
Ultimate Tensile Strength (MPa)	310
Tensile Yield Strength (MPa)	276
Hardness (HRB)	40
Melting Temperature (°C)	585-692
Modulus of Elasticity (GPa)	68.9
Density (g/cc)	2.7

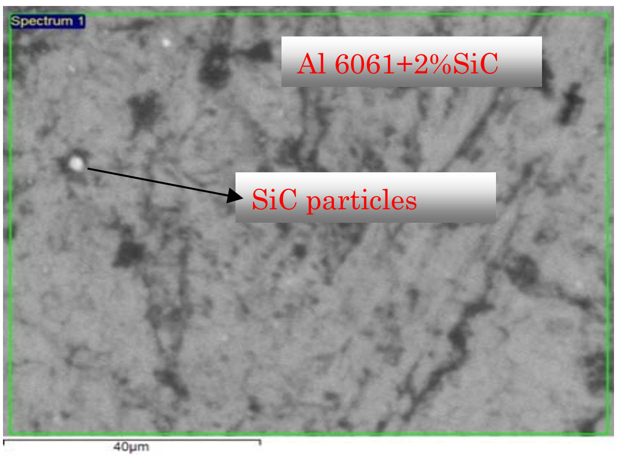
Table 3: Properties of Silicon Carbide.

Properties	Silicon carbide
Melting point temperature (°C)	2973
Thermal conductivity(W/Mk)	126
Density (g/cm^3)	3.2
Crystal structure	Hexagonal

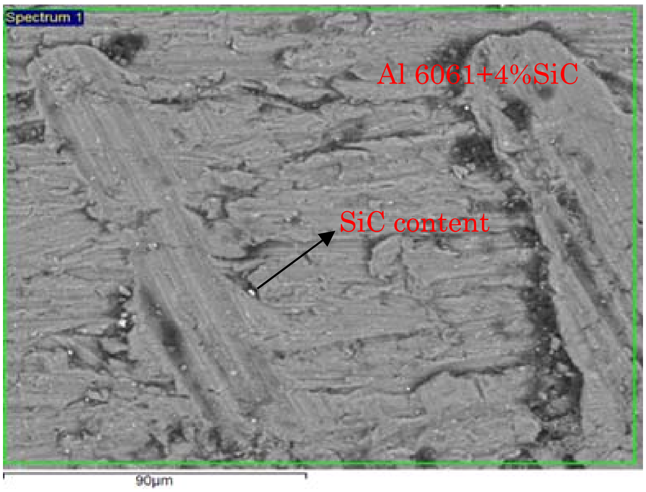
3. Results and Discussion

3.1 Microstructural Analysis

Metallographic sample of MMC was fabricated as per ASTM E3-95 standard to conduct SEM test. Configuration of the scattering of reinforcement in the matrix alloy was found by scanning electronic microscope. Uniform dispersal of SiC content was observed through the micrographs obtained from SEM in Fig. 2. The dark indendrite interstice shows the formation of Mg_2Si. In some portion small clusters of SiC contents was observed due to local accumulation of reinforced particles. This might be possible due to improper mixing of reinforced particles in the Al 6061 alloy.



(a)



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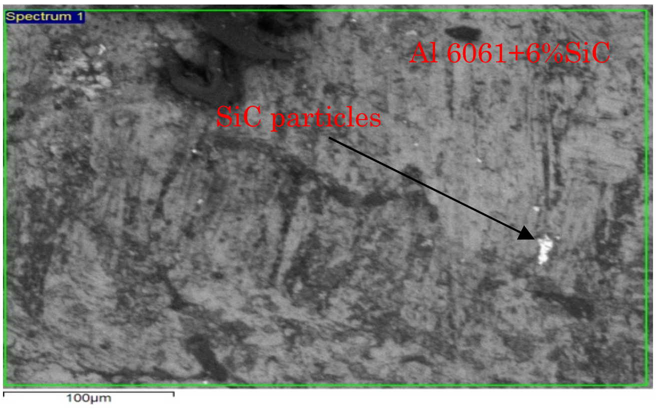

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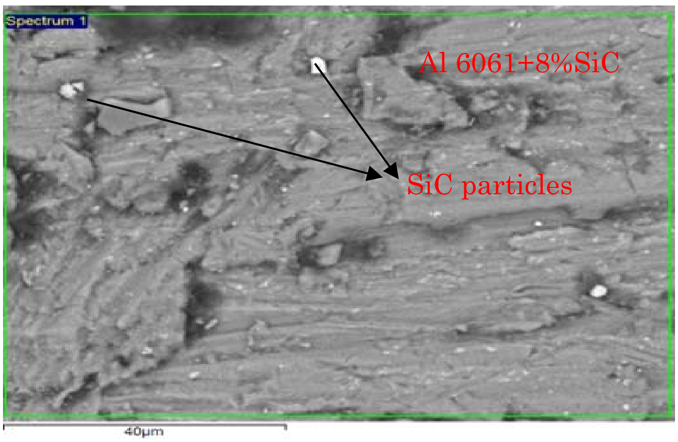

(d)

Fig. 2: SEM images of (a) Al 6061+2wt %SiC, (b) Al 6061+4wt%SiC, (c) Al 6061+6wt% SiC, (d) Al 6061+8wt% SiC at 100X.

3.2 Influence of SiC particles on density

The deviation in density with the increase of SiC particles is shown in Table 4. It was observed that with the increase of SiC content, the density of the composite was increased. The average increase in density was 0.44% while encapsulating SiC particles. Theoretical density was calculated by the rule of mixture. Composite's density was enhanced to maximum of 1.11% compared to base alloy Al 6061 with reinforcing 8wt% SiC particles. The cause of increase in density was due to high density of SiC particles (3.2 g/cm^3) in comparison to density of Al 6061 alloy (2.6 g/cm^3). A similar result of increased density was obtained by Kumar et al[24]. Fig. 3 shows the variation of increased density.

Table 4: Theoretical and experimental density of fabricated composite.

Material	Density	SiC Wt %				
		0	2	4	6	8
Al 6061/SiC	Theoretical Density	2.7	2.71	2.72	2.73	2.74
	Experimental Density	2.68	2.69	2.71	2.72	2.73

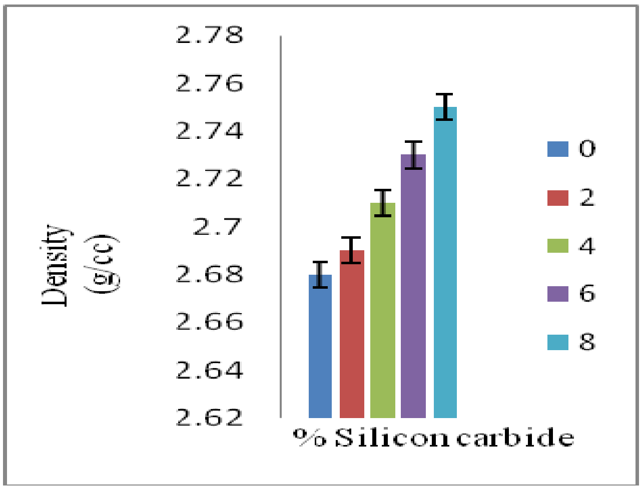

Fig. 3: Variation of density with increased wt% of SiC particles.

3.3 Effect of SiC particles on hardness

Rockwell hardness test was performed to find the influence of SiC particles on the matrix hardness. 100 kg of load was applied and indenter used was 1/16'. Composite having greater hardness has greater resistance to deform.

Samples were prepared as per ASTM E18-12 to measure the hardness [25]. It was found that with the increase of SiC content, the hardness of the Al 6061/SiC composite was increased. Improved hardness was observed due to resistance exhibited to indentation by silicon particles. Hardness of the composite was increased due to the reason that silicon particles bear the major load transferred by Al 6061. Table 5 shows the hardness of composites with varied SiC wt%. The maximum hardness was achieved 51 HRB with incorporating 8 wt% SiC particles. Fig. 4 shows the variation of hardness with the increased wt% of the reinforcement. The hardness of Al 6061/8wt%SiC composite was maximum and enhanced to 27.5 % in comparison to base alloy Al 6061.

Table 5: Hardness of the composites with varied SiC wt%.

Sample No.	% of SiC	Hardness (HRB)
1	0	40
2	2	42
3	4	43
4	6	46
5	8	51

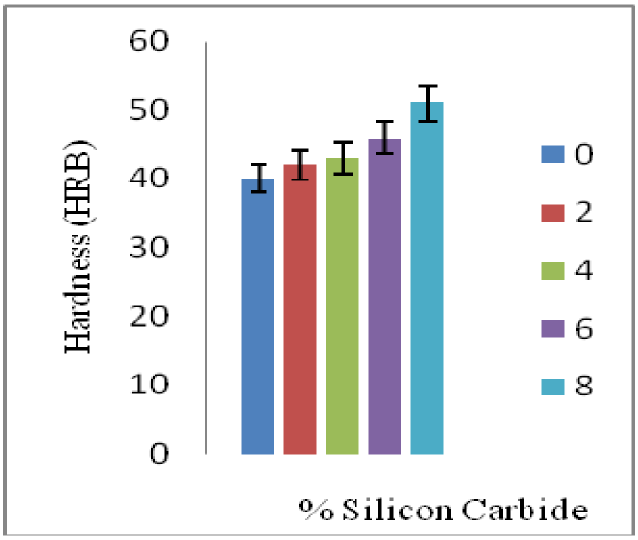

Fig. 4: Variation of hardness in the composites with varied SiC wt%.

3.4 Influence of SiC particles on tensile strength

The tensile test samples were prepared as per ASTM E8-04 standard [25]. The w/B ratio was 6.4, which does not satisfy the suggested value in the range of 2<w/B<4, yet it was an acceptable value due to small thickness of the specimen. Tensile test sample is shown in Fig. 5.

Machining scratches and surface defects were reduced by polishing the surface and rubbing emery paper. Tensile test was conducted on UTM (FIE/UTN-40). The tensile strength was assessed at cross head speed of 1 mm/min. The ultimate tensile strength was increased with the increase of SiC wt%. Table 6 shows the tensile strength of the Al 6061/SiC composite with varied SiC content. The maximum ultimate tensile strength was found to be 158 MPa for Al 6061/8wt%SiC composite. The variation of tensile strength is shown in Fig. 6. The improvement in tensile strength was due to embedded hard SiC particles in Al 6061 alloy. SiC particles resist the plastic flow of composites when subjected to strain [4].

Fig. 5: Specimen for tensile test.

Table 6: Ultimate tensile strength of the Al 2021/SiC composites with varied SiC wt %.

Sample No.	SiC wt%	Ultimate Tensile Strength (MPa)
1	0	276
2	2	281
3	4	287
4	6	291
5	8	298

The UTS was enhanced with the increased SiC content. Fig. 7 clearly demonstrates the increased UTS. Al 6061/8wt%SiC composite had maximum UTS of 324.7 MPa. With the improved UTS, percentage elongation of the SiC reinforced composite was reduced. High strength of SiC composite had reduced the ductility of the prepared composite. Beyond 8 wt% of SiC content, the ductility was significantly decreased. The reduction of percent elongation is given in Fig. 8. Al 6061/8wt%SiC composite had maximum reduced elongation.

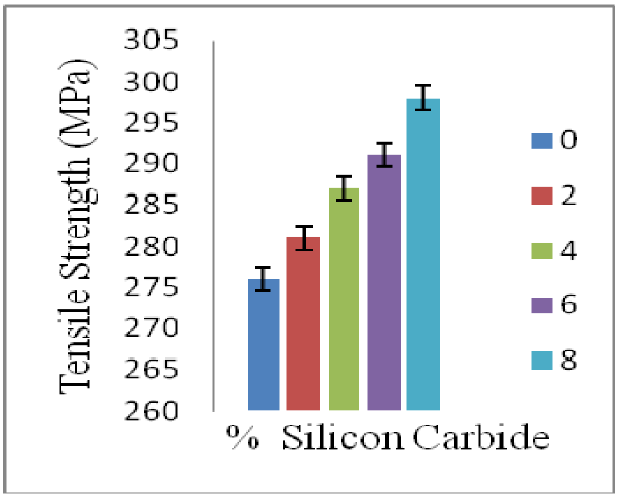

Fig. 6: Tensile strength of SiC reinforced composite.

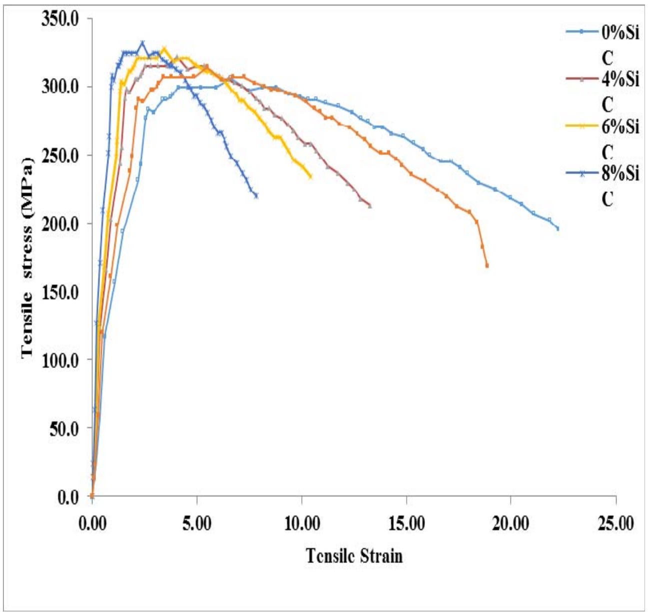

Fig. 7: Stress v/s strain diagram of Al 6061 composite with varying wt% of SiC

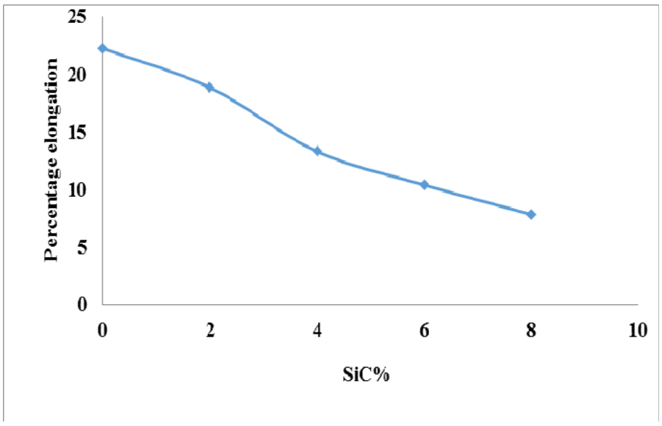

Fig. 8: Percentage elongation of Al 6061 v/s addition of SiC%.

Conclusion

In this present work, series of Al 6061 alloy matrix composite containing 2, 4, 6, and 8 wt% SiC content were casted using electromagnetic stir casting technique. The following inferences were concluded;

- Homogeneous and uniform dispersion of SiC particles was observed in the aluminum matrix.
- The density of the composite was increased with the increase of silicon carbide content. 1.11% density of the composite was increased with incorporating 8 wt% of silicon carbide.
- Considering the result of Rockwell hardness test, the maximum hardness was 51 HRB. 27.5% hardness was enhanced to Al6061/8wt%SiC in comparison to base alloy Al 6061.
- The maximum tensile strength was enhanced to 298 MPa for Al 6061/8wt%SiC composite in reference to Al 6061 alloy, having 276 MPa. Embedded hard SiC particles had improved the

tensile strength of fabricated composite.

- The UTS was improved with the addition of SiC particles. Al 6061/8wt%SiC composite had maximum UTS of 324.7 MPa in context to base alloy, having 299.3 MPa. With the enhanced UTS, the ductility of the composite was reduced.

Declaration of conflicting interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Acknowledgement

The author(s) received no financial support for the research, authorship, and/or publication of this article.

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