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Experimental Investigation of Nano Sic Reinforced AA6063 Composite by Vacuum-Assisted Stir Casting

Nagasrisaihari Sunkara[1], T. S. Krishna Kumar[2]*, Narendra Pothula[1], S. Anilkumar[3] and M. Prabu[4]

[1]Department of Mechanical Engineering, VNR Vignana Jyothi Institute of Engineering and Technology, Hyderabad - 500090, Telangana, India

[2]Department of Automobile Engineering, VNR Vignana Jyothi Institute of Engineering and Technology, Hyderabad - 500090, Telangana, India; krishnakumar_ts@vnrvjiet.in

[3]Department of Mechanical Engineering, T S Srinivasan Centre for Polytechnic College and Advanced Training, Chennai - 600095, Tamil Nadu, India

[4]Department of Safety and Fire Engineering, KSR College of Engineering, Thiruchengode - 637215, Tamil Nadu, India

Abstract

The present investigation is focused on the fabrication of nano Silicon Carbide (nSiC)-reinforced AA 6063 alloy composites through vacuum-assisted stir casting. The composites are subjected to varying SiC weight percentages (0%, 2%, 4%, and 6%). The specimen's mechanical behaviour and morphology were evaluated in accordance with ASTM standards (ASTM E8, E9, D790, and E23-07). In comparison to the base alloy, the mechanical parameters of ultimate tensile strength, compressive strength, and flexural strength are enhanced by 21.73%, 22.80%, and 22.88%, respectively, at 4% of the weight fraction of nano SiC. When nano SiC is incorporated into the base alloy, this phenomenon transpires. Furthermore, the impact strength is increased by 42.84 percent when 6% nano silicon carbide is applied in comparison to the base alloy. The specimen's morphology was investigated using a Scanning Electron Microscope (SEM) and an optical microscope. The material's microstructure indicates that it is a matrix alloy with consistently distributed reinforcing particles and non-existent residual pores. The morphology investigation of synthesised Aluminium alloy nanocomposites demonstrates that ceramic hard particles are unable to be distinguished and instead manifest as small cuboidal entities at elevated temperatures.

***Major Findings:** Mechanical characterization of 4wt% nanocomposites shows better properties compared to all other composites. The microstructural analysis shows uniform distribution of nanoparticles up to 4wt%.*

Keywords: *Impact Strength, SEM, SiC- Nanocomposites, Tensile Strength, Vacuum-assisted Stir Casting*

1.0 Introduction

The automotive and maritime industries have been the most prominent users of low-density materials for the past 10 years. Metal matrix composites are perfect for these applications due to their low cost and high strength-to-weight ratio[1]. Aluminium and its alloys find widespread application in engineering due to its low density and durability. The lack of hardness and wear resistance in these materials severely restricted their applicability[2]. Parent materials are enhanced by adding enough ceramic reinforcing particles to them. The existence of

*Author for correspondence

individual reinforcing particles on these alloys has been calculated in multiple experiments[3]. In certain cases, micron-sized ceramic reinforcement is incorporated into cast metal matrix composites. These particles are harder and less pliable. Tool wear reduces machining quality. This limitation is reduced by nanocomposites[4]. Nanocomposites excel in several applications due to their increased ductility and wear resistance. Hardness, fracture toughness, and tensile strength were all enhanced, regardless of the temperature[5]. Because of the increasing surface-to-volume ratio, particle aggregation became a major issue. Efficient process configuration and adaptable processing can fix this. Researchers have only recently begun to explore composites that incorporate nano-ceramic particles. A combination of mechanical properties, corrosion resistance, and wear resistance are all improved by adding certain ceramic particles. Considerations such as particle size, manufacturing processes, and uniform distribution of reinforcing particles with the base material should be top priorities[6]. Solid lubricants and hardening particles known as borides, carbides, and nitrides are prevalent in many common materials[7]. The use of stir casting to examine composites of aluminium and zinc with nano graphite (50 nm) ceramic particles was explored. As porosity increased synthetic composite densities decreased[8]. A comparison was made utilizing the liquid casting technique for aluminium alloy composites reinforced with Silicon Carbide (40nm)[9].

Aluminium composites with reinforcing particles of varied weights were made possible by liquid metallurgy. Composites reinforced with SiC/AA6063 have better physical properties than composites reinforced with SiC/AA6061[10]. There have been few literatures reporting nanoscale research on silicon carbide[11,12]. Stir casting of AA6063 with 5%, 10% and 15% of SiC was tested for hardness, tensile and impact strength. AA6063 with 15% SiC has a better performance compared with base alloy as well as other wt%[13]. Similarly, AA6063 with SiC in terms of 5%, 7.5%, 10%, 12.5% and 15% are prepared by stir casting. 12.5% shows better mechanical properties[14]. SiC nano reinforcement in AA7075 as composites with wt% of 1-4 % are prepared by stir casting. Hardness was improved for 4wt% of SiC whereas wear resistance is high for 2 wt% of SiC[15]. SiCnp 1 wt% /AA 6082 composites prepared squeeze casting combined stir casting, microstructural and mechanical properties are influenced by nanosized SiC. The grain size was reduced from 386.6µm to 268.5µm. However, the presence of nano SiC particles significantly increased UTS, % of elongation and yield strength[16]. From the above literature it is observed that manual stir casting needs higher concentration of nano particles and lower concentrations are desirable in advanced stir casting methods like ultrasonic or vacuum assisted stir casting.

In this research, vacuum-assisted stir casting is utilized to synthesize nano silicon carbide with varying weight proportions of 0, 2, 4 and 6 % reinforced with AA6063 alloy and investigate its microstructural and mechanical properties.

2.0 Experimental Procedures

2.1 Mixture of Matrix and Reinforcing Particles

Aluminium-magnesium-silicon alloy (AA6063) procured local shop in Hyderabad is used as the base material for making aluminium alloy nanocomposites using the vacuum-assisted stir casting method. Their chemical combinations are highlighted in Table 1. Reinforcement used in this work is nano-ceramic strengthening powder of SiC (2.71g/cm^3) with 30nm particle sizes purchased from Merck. The properties of SiC that make it more durable include higher hardness, flexural strength, elastic modulus, wear resistance, lower density, chemical and thermal stability[17].

2.2 Stir Casting

This study employed the vacuum-assisted stir casting technique to fabricate aluminium alloy composites is shown in Figure 1(a) and Figure 1(b). The solidification

Table 1. Chemical combinations of AA6063 wt%

Mg	Si	Fe	Mn	Cu	Ti	Al
0.50	0.40	0.15	0.30	0.01	0.01	Balance

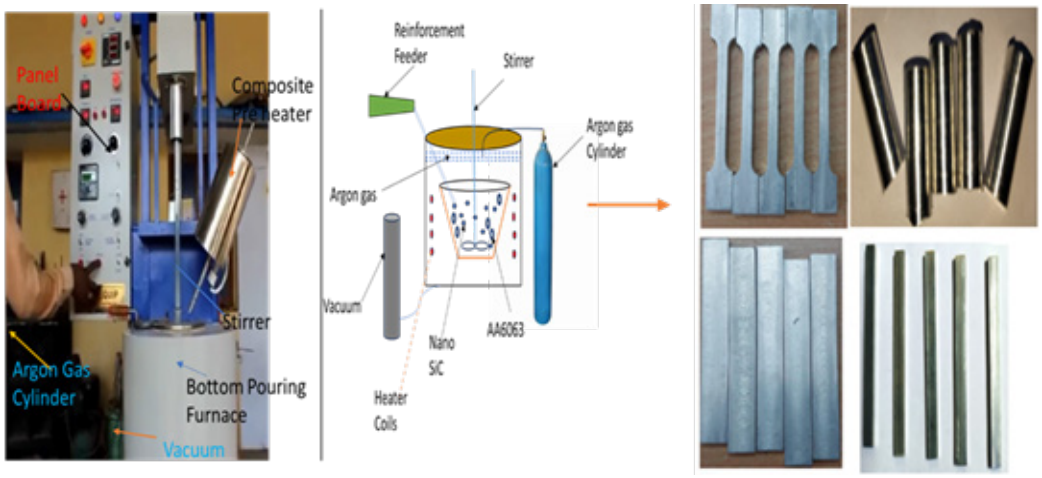


Figure 1. Experimental setup of vacuum-assisted stir casting.

process involves subjecting the molten slurry to increased pressure. A decline in temperature, particularly a sudden and significant decline, indicates the onset of nucleation. To enhance heat diffusion and grain refinement, it is necessary to prevent the movement of air between the mold and molten composites. Furthermore, it reduces the frequency of intermixture abnormalities[18]. A resistive heating electric furnace achieved a temperature of 720° C, resulting in the melting of AA6063 within duration of 10 minutes. To fully transform the alloy into a liquid state, vigorously stir it at a velocity of 250 revolutions per minute. Elevating the temperature of nano Silicon Carbide (nSiC) reinforcement particles (at 2%, 4% and 6%) to 200° C improves the matrix's capability to adhere to the reinforcement and reduces moisture content[19]. At 750℃, 2.5 kg of raw materials were melted in the crucible. After melting 6063 aluminium alloy materials at 730°C, degassing was done with argon gas bubbling for 5 min to refine and remove slag, and a slagging spoon was used to remove surface scum. Ceramic reinforcement particles were introduced into the system at a temperature of 770°C using an external sprue. To avoid the aggregation of particles, the liquid mixture is aggressively agitated at a rate of 500 rpm[20]. The interaction between the matrix and reinforcement particles leads to the disintegration of the particles, causing the formation of a vortex that obstructs the accumulation of nanoparticles. Consequently, this affects the even distribution of reinforcement in the molten slurry.

By elevating the temperature of the molten metal to 800°C, the viscosity of the composite slurry decreased, causing the ceramic reinforcement particles to ascend to the surface while being stirred[21]. Furthermore, the agitation rate was increased to 600 revolutions per minute (rpm) and the duration was prolonged to 15 minutes. Despite the utilization of efficient processing processes, the inclusion of nano silicon carbide (6wt%) results in the production of agglomerates within the ceramic particles. Therefore, 6 wt% was established as the upper limit. Before pouring the molten slurry into the EN 8 die cavity, the die was heated to eliminate any trapped gas and reduce the level of porosity in the matrix. The liquid combination in the die cavity underwent solidification at room temperature. The performance of the aluminium alloy composite was evaluated according to ASTM standards[22].

3.0 Morphological Analysis

The morphology of reinforcing particles in the matrix alloy was examined using an optical microscope and Scanning Electron Microscopy (SEM) model named Hitachi su3800. The microscopic behaviour of the nSiC particulates remains in contact with the matrix as a result of a strong particle-matrix interfacial bond, as evidenced by the microscopic images and SEM photographs.

3.1 Mechanical Properties Measurement

3.1.1 Tensile Test

A universal testing machine with a 10-ton load and a crosshead speed of 0.5mm/min was used to test the tensile properties of aluminium composites at room temperature as per ASTM E8 standard. The average values of tensile strength of AA6063, AA6063+2%nSiC, AA6063+4% nSiC and AA6063+6% nSiC exhibit180 Mpa, 205 Mpa, 230 Mpa and 212 Mpa respectively.

3.1.2 Compression Test

Five indentations of cylindrical samples have been prepared for conducting compression strength tests on aluminium nanocomposites, following the ASTM E9 test standard. The average compression strength values of AA6063, AA6063+2% nSiC, AA6063+4%nSiC, and AA6063+6%nSiC are 220 Mpa, 260 Mpa, 285 Mpa, and 255 Mpa, respectively.

3.1.3 Flexural Strength Test

The flexural properties of MMCs manufactured on AA6063-nSiC as per ASTM D790 standards. The average values of Flexural strength of AA6063, AA6063+2%nSiC, AA6063+4%nSiC and AA6063+6%nSiC exhibit 155 Mpa, 174 Mpa, 201 Mpa and 185 Mpa respectively.

3.1.4 Impact Test

Samples that have been prepared in accordance with the ASTM E23-07a test standard. The Impact test was carried out on impact testing equipment with the model number FIT 300N with a specification of Charpy with 300J with the least count of 2J and a drop angle of 140°. The impact energy of the manufactured sample surpasses that of the base 6063 aluminium alloy. The composite samples AA6063, AA6063 + 2%nSiC, AA6063 + 4%nSiC, and AA6063 + 6%nSiC exhibit impact strengths of 12 J, 16 J, 19 J, and 21 J, respectively.

4.0 Results and Discussions

4.1 Scanning Electron Microscope

The Scanning Electron Microscopy (SEM) image of the Aluminium composites (Figure 2a and Figure

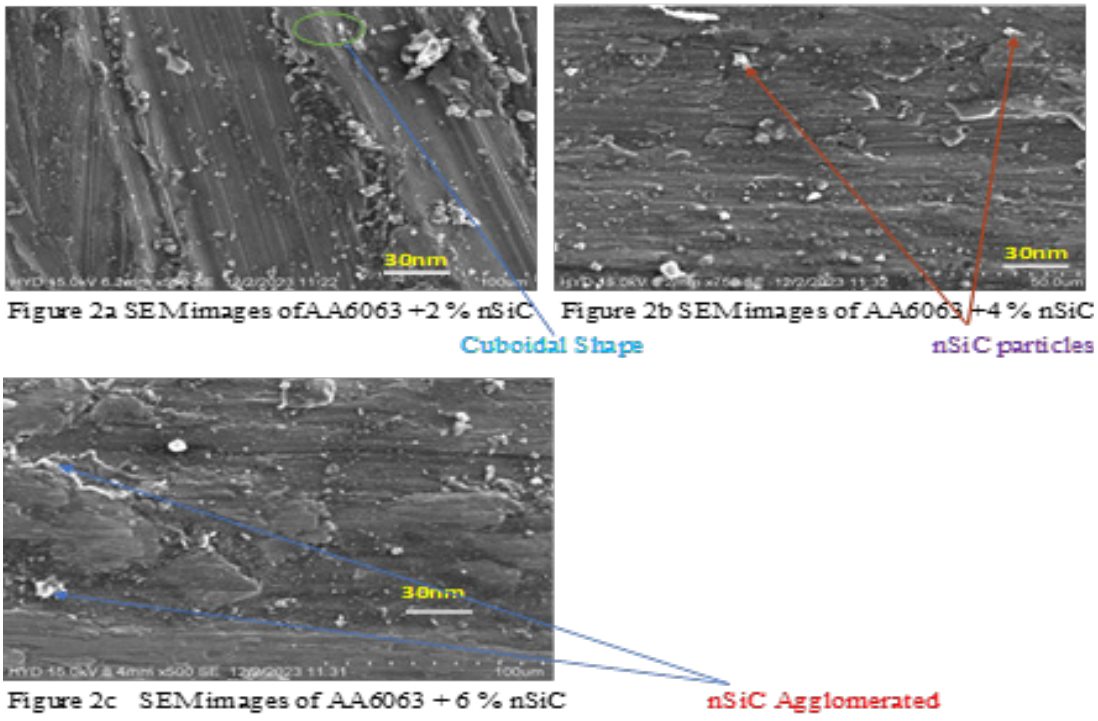


Figure 2. **(a)** SEM image of AA6063+2%nSIC **(b)** SEM images of AA6063+4%nSIC **(c)** SEM images of AA6063+6%nSIC.

2b) reveals that the strengthening particles are evenly distributed throughout the matrix and aggregate as the quantity of ceramic particulates rises (Figure 2c), regardless of any modifications made to the process conditions. Silicon carbide particles possess a cubic shape and demonstrate insolubility when exposed to high temperatures.

4.2 Tensile Strength

Figure 3a shows stir cast AA6063 and nanoSiC wt% tensile characteristics. With homogeneous reinforcement dispersion, AA6063 and its nano-based SiC-strengthened particles had higher tensile strength. Intermetallic bonding was enhanced in solid phases shielded by reinforced materials in AA6063 and nSiC[19]. Migrated load developed MMC characteristics well. SiC usually boosts strengthened MMCs intermetallic potency more than other strengthened ceramic particles. The results of this investigation are presented in Table 2.

MMCs treated at 4wt% nSiC with AA6063 exhibit higher tensile strength (230 MPa) compared to specimens with AA6063-0 (180 MPa), AA6063-2%nSiC (205 MPa), and AA6063-6%nSiC (212 MPa). nSiC at a certain

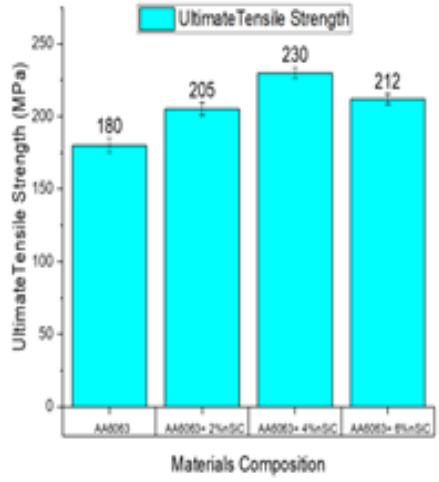


Figure 3a Ultimate Tensile strength of nanoSiC reinforced AA6063 composites

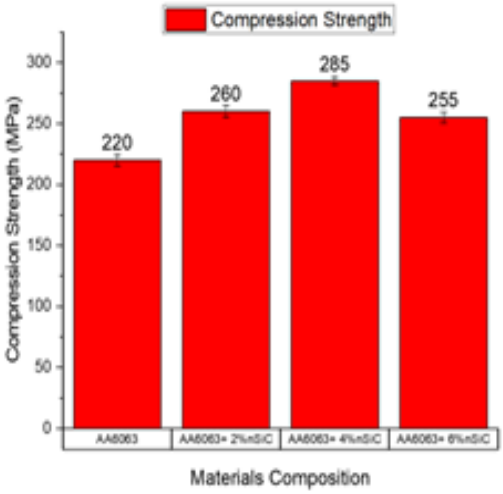


Figure 3b Compressive strength of nanoSiC + AA6063 composites

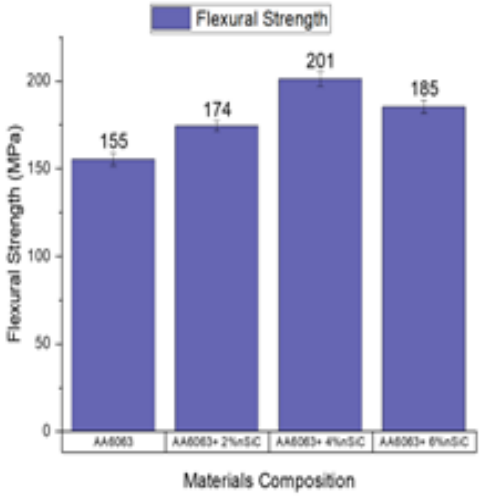


Figure 3c Flexural strength of nanoSiC + AA6063 composites

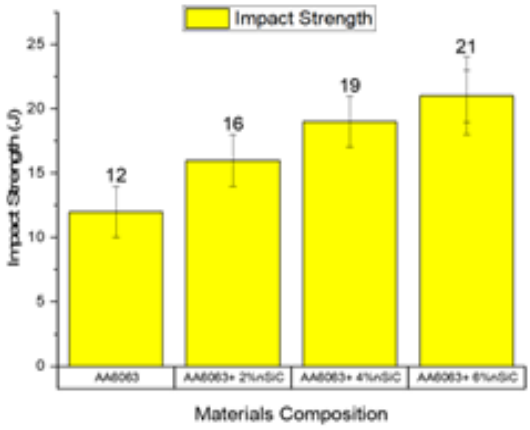


Figure 3d Impact strength of nanocomposites

Figure 3. **(a)** Ultimate tensile strength of nanoSiC reinforced AA6063 composites **(b)** Compressive strength of nano SiC+AA6063 composites **(c)** Flexural strength of nanoSiC+AA6063 composites **(d)** Impact strength of nanocomposites.

Table 2. Tensile strength

S. No	AA6063	AA6063+2%nSiC	AA6063+4%nSiC	AA6063+6%nSiC
1	180 MPa	205 MPa	230 MPa	212 MPa

Table 3. Compression strength

S. No	AA6063	AA6063+2%nSiC	AA6063+4%nSiC	AA6063+6%nSiC
1	220 MPa	260 MPa	285 MPa	255 MPa

weight percentage on the AA6063 improving tensile characteristics. Grain refining improves MMC tensile strength.

4.3 Compression Strength

Figure 3b shows AA6063 and nSiC processed MMC compressive strength contributions. Compared to base alloy, nanocomposites show improved compression strength, whereas 4% nSiC reveals a maximum compressive value of 285 MPa. SiC was evenly distributed on the foundation material to safeguard this processed specimen. nanoSiC specimens with 2%, 4% and 6 wt% yielded better results than base AA6063. Compression Strength of nano composites is shown in Table 3.

4.4 Flexural Strength

When compared to other sample sets, 4% nano Sic with AA6063 yields the highest flexural characteristics (201 MPa) as shown in Figure 3c.

The expanding weight ratio of SiC implicitly determines the flexural potency in the constructed MMCs. Compared to base AA6063, the findings obtained from nano SiC specimens with 2%, 4% and 6wt% were drastically improved. The Flexural strength values is shown in Table 4

4.5 Impact Strength

The impact test results for all created samples and the Al6063 matrix alloy are displayed in Figure 3d, indicating the impact energy values. The impact energy of the manufactured sample exceeds that of the base 6063 aluminium alloy. Aluminium alloys have high ductility and toughness, that is the reason impact strength improved even it agglomerates. The impact strength is shown in Table 5.

The impact strength of composite samples AA6063+2% nSiC, AA6063+4% nSiC and AA6063+6% nSiC exhibits 16J, 19J and 21J respectively.

Table 4. Flexural strength

S. No	AA6063	AA6063+2%nSiC	AA6063+4%nSiC	AA6063+6%nSiC
1	155 MPa	174 MPa	201 MPa	185 MPa

Table 5. Impact strength

S. No	AA6063	AA6063+2%nSiC	AA6063+4%nSiC	AA6063+6%nSiC
1	12 J	16 J	19 J	21 J

5.0 Conclusions

The following conclusions were made

1. Aluminium alloy composites (AA6063) and varying amounts (2%, 4% and 6% by weight) of nanoSiC have been effectively manufactured.

2. With no remaining porosity, nanoceramic reinforcing particles are evenly dispersed in base materials. However, agglomeration happens when the weight percentage of ceramic particles increases to 6%.

3. The SEM analysis reveals that the high-temperature properties of silicon carbide particles make them insoluble.

4. The 4wt % nSiC composites exhibit 21.73% increase in ultimate tensile strength in comparison to the original AA6063 alloy.

5. The compressive strength and flexural strength of nanocomposites are enhanced by 22.80 % and 22.88% in comparison to its basic materials at 4wt % nSiC.

6. The impact strength of 6wt% nSiC reinforced AA6063 composite materials reveals a 42.84% increase when compared to the base alloy.

6.0 Author Contribution

Conceptualization: Nagasrisaihari Sunkara, Methodology: T.S.Krishna Kumar, Writing-Original draft: T. S. Krishna Kumar, Writing - Review and Editing: M. Prabu, Formal analysis: S. Anilkumar, Investigation: Narendra Pothula, Resources: Nagasrisaihari Sunkara. All authors have read and agreed to the published version of the manuscript.

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