Mechanical and tribological behaviour of nano scaled silicon carbide reinforced aluminium composites

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ABSTRACT
This work assesses the impact of the presence of Nano scaled silicon carbide on the Mechanical & Tribological behavior of aluminium matrix composites. Aluminium matrix composites containing 0, 0.5, 1, 1.5, 2 and 2.5 wt.%-nano scaled silicon carbide was set up by a mechanical stirrer. The trial comes about to demonstrate that the inclusion of Nano silicon carbide brings about materials with progressively high elastic modulus and likewise brings about expanded brittle behavior, fundamentally lessening failure strain. Shear modulus and flexural shear modulus likewise increases with silicon carbide increase. The presence of Nano scaled silicon carbide in the aluminium matrix diminishes subsurface fatigue wear and increases wear resistance, because of silicon carbide lubricant activity. Wear testing, microstructure & morphological, density & void testing, hardness, flexural and tensile test of the readied composites were investigated and outcomes were analyzed which demonstrated that including nano-SiC in aluminum (Al) matrix increased wear resistance, tensile strength, and 2 wt. % of nano scaled SiC for Al MMC indicated maximum wear resistance, tensile strength, and an optimum balanced mix of both Tribological and Mechanical properties. Microstructural observation uncovered uniform and homogeneous distribution of SiC particles in the Al matrix.

KEYWORDS
Aluminium; silicon carbide; mechanical properties; wear properties; composite

1. Introduction
There is rising interest in cutting-edge materials with enhanced properties, expecting to meet new necessities or to supplant available materials, for example, metal-based ones. This quest has altogether added to the appearance of new composite material matrix composite materials that permitted considerable design enhancements and discovered broad application in the manufacture of an assortment of items, including vehicle and airship parts, structural elements, sporting merchandise and biomedical gadgets [1]. Elite Performance of consistent fibre strengthened composite material matrix composites is altogether known & recorded. Nevertheless, these composites introduce disadvantages with respect to the matrix overwhelmed properties, which frequently restrict their relevance run [1,2]. The improvement of more up to date composite materials tending to these issues is hence
of incredible centrality for a few building applications, widening the scope of auxiliary utilization of composites.

Fibre reinforced aluminium matrix composites are a standout amongst the most utilized multi-stage materials, for the most part, because of their excellent strength-to-weight attributes [3]. Aluminium-matrix composites show incredible Mechanical and Tribological properties, satisfactory chemical and corrosion resistance, and phenomenal dimensional stability [4]. Nonetheless, matrix solidity, toughness & hardness, together with matrix ruled properties, for example, in-plane and interlaminar shear, have room for future change and improvement. A typical approach for enhancing properties comprises on the consolidation of filler particles in the aluminium [5]. Past investigation by different authors demonstrated that matrix dominated mechanical properties of material composites can be enhanced through the inclusion of ceramic fillers [6], for example, SiO₂, CaCO₃, mica, alumina trihydrate, glass beads, clay or fly ash. The achieved enhancements in this regard are increased hardness, heat distortion temperature, strength, stiffness, mold shrinkage, and at times additionally cost reduction of processing. The degree of improvement relies upon the preparing method and type [7], and on filler concentration [8,9], shape, size [10,11], and packing attributes, particle contents [12] and furthermore in the interfacial bonding with the matrix [13]. Of all the factors, particle size plays the most significant factor in improving properties of the MMCs, mostly when the particle size is reduced from micro to nanoscale [14].

Accomplishing synergies between the outstanding properties of host composite materials and distinctive potentialities originating from the included fillers is an energizing way to produce new composite matrix materials. In spite of the fact that the law of mixtures shows higher mechanical execution for the higher division of reinforcement stage, in proceedings, the inclusion of large particle concentrations comes about in handling challenges and conceivable property downside like brittle behavior, resistance to creep and fatigue, etc. [15,16]. Materials (counting silicon carbide, titanium oxide, and graphene) are evident reinforcement outcomes to create multifunctional designing parts consolidating high mechanical execution what’s more, reliability, bring downs friction, and enhanced seizure and wear conduct, and high thermal and electrical conductivity [17,18], e.g. silicon carbide, specifically, consolidates these attributes to an intriguing degree, and presents the more unassuming cost among said materials, optimizing the manufacturing cost [19].

Development of robust solutions with a combination of lightweight mechanical quality, low wear, low seizure propensity, and reduced electrical loss is of foremost significance to enterprises. Envisaged applications incorporate metal substitution in such varying applications as electro-mechanical management frameworks, electronic bundling, biosensors, or radar protecting [20,21]. In this setting, this work explores and looks at the Mechanical & Tribological properties of composites comprising of aluminium reinforced with silicon carbide. The general object is the advancement of another enhanced metal-ceramic composite material, consolidating mechanical and wear characteristics.

Prior investigations uncovered that as the percentage of nano Silicon Carbide is increased the properties gets better up to a certain level, or remains constant or gets decreased [22]. The goal of this study is to analyze the results of the different percentage of nano-SiC in Al matrix composites on Mechanical & Tribological properties, for example, tensile strength, modulus, deformation, wear and coefficient of friction. An attempt
has been made to find out the best percentage combination considering both Mechanical & Tribological properties.

2. Materials and methods

2.1. Materials used

In the present examination, aluminium AA2219 was chosen as a base matrix material with Nano silicon carbide as filler added to an extent of 0.5, 1, 1.5, 2 and 2.5 wt.%. Physical and mechanical properties of AA2219 along with silicon carbide(SiC) are displayed in Table 1. The ingots of Al 2219 were provided by Rohit Super Forge Private Limited, India and the ceramic Nano silicon carbide of size 50–70 nm was provided by Sigma Aldrich, India. Chemical distribution of Al 2219 alloy is tabulated in Table 2.

2.2. Sample preparation

In this work, ceramic reinforced metal network composite was utilized to acquire the coveted outcome. Nano silicon carbide powder was utilized as filler and aluminium as a base metal. Aluminium metal composite was readied utilizing metal casting technique. At first, aluminium is melted at 800 °C in the electric furnace and samples were collected for comparative study with siliconcarbide added composites. Preheated ceramic (Nano silicon carbide powder) were included then in the molten aluminium. Prior to the addition, froth from the molten Aluminium has to be removed, or else Silicon Carbide will get carried away with the froth. A little measure of magnesium is moreover required for legitimate dissemination of silicon carbide powder over the aluminium. A gentle steel stirrer is utilized to blend liquid metal for blending silicon carbide powder at speed of 400 rpm for 10 minutes. The blend of liquid aluminium and silicon carbide is filled into a mould and kept for 30 minutes in still air to solidify. The same process was rehashed for all concentrations of reinforced ceramic.

The step by step procedure followed for the fabrication of Al nano-SiC composite has been depicted in Figure 1.

2.3. Microstructural and morphological characterization

After the creation of Aluminium-silicon carbide composite, and before minuscule observation, samples were observed under scanning electron microscope (SEM) (JEOL, Model JSM 6390LV, Japan) (Figure 2) to study the morphology and to assess the filler dispersion and compatibility between the ceramic filler and metal matrix and moreover also to look at the silicon carbide/aluminium interface and the nearness of voids, before mechanical testing.

| Material       | Melting point (°C) | Thermal conductivity (W/mk) | Density (g/cm³) | Modulus of elasticity (GPa) | Co-efficient of thermal expansion (°C⁻¹) |
|----------------|--------------------|-----------------------------|----------------|----------------------------|-----------------------------------------|
| AA2219         | 550                | 170                         | 2.85           | 80                         | 22.1 × 10⁻⁶                           |
| SiC (50–70 nm) | 2730               | 120                         | 3.21           | 410                        | 4 × 10⁻⁶                              |
2.4. Density and void testing

The negative effect of the presence of manufacturing induced defect like voids makes it a critical issue in the applicability of composite material in engineering structures. The void assessment test is carried out according to ASTM D 2734-94. The density of the delivered Aluminium-Silicon carbide composites was resolved both geometrically and by the Archimedes technique (distilled water at 20 °C was utilized as the submersion liquid). The relative density of the sample was figured from the rule of mixture blends, utilizing bulk thickness theoretic values for aluminium and silicon carbide from Table 1. Porosity values were resolved from the distinction between figured and experimental values.

2.5. Mechanical testing

Flexural and tensile tests were embraced in an Instron 3369 (Figure 3) all universal test machine outfitted with 10 kN load cell. Tensile tests were led in adjustment to ASTM C1557-14 with a crosshead rate of 1 mm/min for all samples of Aluminium-Silicon carbide composites, and to 3-point bending flexural tests were done in agreement to ASTM.

| Table 2. Chemical compositions of AA2219 aluminium alloy (as said by supplier). |
|-----------------------------------------------------------|
| AA2219 | Si | Fe | Mn | Mg | Cu | V | Ti | Zr | Zn | Al |
|--------|----|----|----|----|----|---|----|----|----|----|
| 0.2 | 0.3 | 0.4 | 0.02 | 6.1 | 0.15 | 0.1 | 0.25 | 0.1 | Bal |

Figure 1. Flow chart showing steps involved in sample preparation.
C1161-02C with 5 mm/min crosshead speed, & span length of 100 mm. No less than three tests were completed for every type, for reproducibility evaluation and results with standard deviation were recorded.

2.6. Hardness

The analysis of Microhardness for the prepared composites was undertaken in a UHL microhardness tester (Model—VMHT MOT, Sl. No. 1002001, Technische Mikroskopie) (Figure 4) utilizing a Vickers diamond indenter. The load was applied for 15 s with indentation speed of 50 μm/s. The indentation image displayed by the attached computer was
processed through dedicated software to estimate Vickers hardness numbers. The test was repeated five times and the mean was recorded.

2.7. Wear testing

Aluminium-Silicon carbide composites were likewise portrayed by wear test, utilizing a multi-tribotester (TR25, Ducom, India) (Figure 5). Samples of size $20 \times 20 \times 8 \text{ mm}^3$ were pressed against EN8 steel with chromium coating rotating roller (Hardness 55 HRc). The test was done at room temperature under steady normal load of 20 kN even without
lubrication at 4 mm/s average linear velocity. The tests were attempted amid 5 min, relating to 600 cycles, comparable to an aggregate separation of 600 mm. Three wear tests were conveyed in each specimen for data reliability; all through the tests, the coefficient of friction was also checked.

3. Results and discussions

3.1. Effect of silicon carbide on composite microstructure and morphology

The methodology used to introduce silicon carbide platelets into the aluminium framework permitted the addition of a maximum of 2.5 wt.%-silicon carbide. The delivered materials display uniform microstructure (Figure 6), and they demonstrate uniform distribution in the aluminium. Presence of silicon carbide shows up to add significance to the decrease of surface roughness of the materials: while aluminium in the wake of polishing presents enough irregular grooves, the presence of increasing amount of silicon carbide brings about successively smoother aluminium surfaces. This is proposed to come about because of the self-lubricating up impact presented by silicon carbide.

Addition of increasingly high silicon carbide amount also influences surface roughness, however, the amount and kind of voids show in the produced materials [23]. For silicon carbide addition of 2.5 wt.%, the aluminium present voids visible between agglomerated silicon carbide platelets and aluminium (Figure 6). The expansion in the same is expected to come about for the most part from the more troublesome packing and increased the viscosity system in the presence of silicon carbide. For higher silicon carbide adds the viscosity step increments, & removal of bubbles amid blending moves toward becoming

![Figure 6. Microstructure of the produced materials: image of aluminium-silicon carbide, showing an overall uniform distribution of silicon-carbide (light grey regions) in the resin (dark matrix).](image-url)
significantly more troublesome. Under these conditions agglomerates de-cohesion effectively happens when the framework is submitted to mechanical load. Nonetheless, where great wetting is accomplished solid aluminium/silicon carbide holding is expected since the huge contact area and high surface roughness given by the platelets basal arrangement increments the range and number of contact sites with the matrix. This guarantees matrix/reinforcement attachment by mechanical anchorage.

### 3.2. Void content

The assessment of void content that built up due to the trapping of air bubbles during the casting process was accomplished and values are illustrated in Table 3. It can be revealed from the depicted data that as the filler loading increases the void content of the composite samples increases and becomes highest for filler loading of 2.5%. This behaviour can be attributed to the fact that bubbles formed during the stirring remain in the molten mixture due to increase in viscosity of the composite because of the presence of the SiC fillers. So with the increase in filler content, air bubble entrapment due to increased viscosity is greater. The increase in filler also increases the surface area for adhesion of the bubbles. The maximum void content value for the produced composite material was found to be less than 0.07% which is acceptable for industrial applications.

### 3.3. Hardness

The hardness of the reinforcement and hardness of the matrix phase dictates the hardness of a composite. As nano-SiC particles possess high hardness value, the hardness of the resultant composite should increase with the addition of the same. Vickers microhardness test yielded the values as provided in Figure 7. It indicates that hardness increases with increase in volume fraction of SiC reinforcement but gets stagnant beyond 2% addition. In case of composites, the depth of penetration is governed by the amount of increased reinforcement particles. The reinforcement particle provides support to developed contact stress which restricts deformation and abrasion between mating surfaces. Hence hardness increases with the volume fraction of reinforcement but due to agglomeration the value becomes less or gets almost constant.

### 3.4. Mechanical properties of the composites

Expanding silicon carbide filler sums in the composites inhibits microstructural changes that ponder mechanical properties. The determined tensile properties of pure aluminium

### Table 3. Density and void content of aluminium and aluminium SiC composite.

| Material of construction | Density (g/cm³) | Void fraction (%) |
|--------------------------|-----------------|------------------|
| Experimental             | Theoretical     |                  |
| Al                       | 2.848           | 2.85             | 0.021 |
| Al+0.5%SiC               | 2.851           | 2.852            | 0.028 |
| Al+1%SiC                 | 2.8527          | 2.854            | 0.032 |
| Al+1.5%SiC               | 2.8543          | 2.855            | 0.039 |
| Al+2%SiC                 | 2.856           | 2.857            | 0.042 |
| Al+2.5%SiC               | 2.8571          | 2.859            | 0.066 |
and silicon carbide reinforce aluminium network composites containing 0, 0.5, 1, 1.5, 2 and 2.5 wt.%-silicon carbide platelets are shown in various plots (Figure 8). All aluminium-silicon carbide composites demonstrate higher Young’s modulus than the pure aluminium matrix, giving a general increment with increasing silicon carbide substance [24]. Maximum estimation of 96.50 ± 0.42 GPa is accomplished for the aluminium-silicon carbide composition, which relates to a 20% increase contrasted with neat aluminium. The presence of silicon carbide is proposed to result in controlled matrix development in the area of individual platelets, increasing the general material rigidity nature. The strong silicon carbide-aluminium bonding required is relied upon to come about both from mechanical anchorage & chemical bonding [25]. Tensile strength, a general term indicating ultimate tensile strength (UTS), also behaves in a similar manner but tensile strain

Figure 7. Vicker’s hardness number for the aluminium and the composites with various % reinforcement.

Figure 8. Tensile properties: (a) modulus; (b) tensile strength; (c) deformation.
and deformation variation with silicon carbide concentration, on the other hand, gives a contradictory trend. Since an increasing concentration of platelets represses matrix distortion in their region, it can be expected that increasing silicon carbide fixation brings about progressively more rigid behaviour conduct when contrasted with the comparatively more flexible aluminium but at 2.5% addition change in properties is not much. This can be again related to the agglomeration phenomena. Presence of pores and voids are the likely an outcome of poorer blending capacity coming about because of the high viscosity in the exceptionally stacked composites [13] also affecting the results trend.

Flexural properties also show the same trend as for the tensile and the reasons for such behaviour can be explained in the same manner as in case of tensile properties.

3.5. Tribological properties of the composites

The Tribological properties of the neat aluminium matrix and of aluminium-silicon carbide composites containing 0.5, 1, 1.5, 2 and 2.5 wt.%-silicon carbide was analysed with a specific end goal to understand the impact of the silicon carbide substance on sliding wear resistance. The wear behaviour of Al-SiC metal matrix composite was studied. Wear results of Al-SiC metal matrix composites are depicted in Figure 9(a). The wear shows a non-monotonic nature. This can be attributed to resultant of the amalgamation of various factors. As the % age addition of SiC increases it increases the hardness and hence reduces the wear but beyond a limit (1.5%) and after certain time the particulate fillers starts getting detached from the matrix due to both high concentration and temperature developed between the surfaces. Moreover, there is also a reduction due to the lubricating nature of the filler i.e. SiC which rapidly polishes the worn out surface reducing the wear and hence the coefficient of friction.

Co-efficient of friction (COF) was also simultaneously taken from the multi tribo-tester via friction force sensor. The frictional force values were then divided by normal load to obtain the coefficient of friction values and plotted in Figure 9(b). The behavioral pattern was similar to the wear property and same explanation can also be provided for the same.

These outcomes demonstrate that the amount of silicon carbide present in the composite plays a noteworthy part on matrix wear and on the adhesion of delivered wear debris. It is expected that amid wear silicon carbide coats the discharged composite material wear particles, lessening agglomeration of composite material debris. This is in great agreement with presented results demonstrating a diminishment of the compacted wear debris layer

![Figure 9. Tribological properties: (a) wear; (b) coefficient of friction.](image-url)
shaped on the worn surface with increasing silicon carbide content. Moreover, it can also be observed that the coefficient of friction and wear decreases with increase in % SiC but after 1.5% addition becomes almost constant as the further increase in the reinforcement does not considerably change the properties.

4. Conclusions

The Mechanical and Tribological conduct of Aluminium-Silicon carbide composites were researched as a component of nano silicon carbide contents. The experimentation on void content showed less than 0.07% presence of the same. It supports the preparation technique adopted as the value is within the acceptance range and thus establishes a manufacturing process that could repeatedly yield low void samples. Moreover, the micrographs from the morphological study also highlighted the uniformity in the distribution of the nano fillers in the matrix which further indicates the uniform adhesion between the two. In various mechanical properties examined, hardness showed an enhancement to approximately 66% with 2.5% addition of nano-SiC filler. Similar observations were seen for the tensile and flexural properties where about 20% increment was observed. For tribological properties i.e. wear and coefficient of friction, although showed betterment by 10% approximately, but was not monotonic in nature and degraded with addition beyond 1.5% of SiC nano fillers by weight. But the addition surely improved the tribological behaviour as the worst value obtained was better than the virgin material. Therefore, the novel materials created in this study were of high mechanical strength and can be employed to manufacture highly critical and high-performance parts at the reduced self-weight, enhanced quality etc. But it can be observed that the increment or decrement in various properties with nano SiC addition between 2% and 2.5% does not provide many advantages. So looking at the various tests conducted it can be safely concluded that Al with 2% SiC (by wt.) addition would be the most optimal choice.

5. Future scope

In the present study, all mechanical testing was performed in the static condition but it is also required to investigate mechanical properties under dynamic and fatigue conditions. The tribological test was conducted under rotating conditions whereas most of the critical products undergo reciprocating situation. Hence a study would be essential for the same as well. Above all like every development, it is essential to optimize the product development taking into consideration all technical aspects along with economic factors. Hence further study on above aspects would be highly appropriate before utilization of the same.

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Disclosure statement

No potential conflict of interest was reported by the authors.
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