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Microstructural and Tensile Characterisation of Si_3N_4 Reinforced Al2219 Alloy Composites

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Abstract

The current exploration focuses on the preparation of Al2219 with micron-sized Si_3N_4 composite using a liquid metallurgy technique. Al2219 alloy was used to make composites with 3 and 6 wt. % of Si_3N_4. Microstructural analysis was performed on the produced composites using a Scanning Electron Microscope (SEM). Under the American Society for Testing and Materials (ASTM) guidelines, measurements of ultimate and yield strength, hardness and ductility were carried out. Micrographs taken using a SEM showed that the boron carbide particles were evenly dispersed throughout the Al2219. Al2219 alloy's hardness and tensile properties were improved by adding Si_3N_4 particles. Further, Al2219 with 3 and 6 wt.% of Si_3N_4 composites showed lesser ductility in comparison with Al2219 material. Thus, developed composites exhibit higher tensile properties than Al alloy, hence these composites are proposed to be used in automotive applications.

Keywords: *Al2219 Alloy, Hardness, Microstructure, Si3N4 Particles, Tensile Behaviour*

1.0 Introduction

A variety of composite materials are already accessible and their number is growing due to ongoing breakthroughs and improved qualities. The need for high-performance materials has led to a resurgence in the use of combinations of different materials to achieve superior performance that cannot be achieved by any single constituent[1,2]. This approach allows for the creation of flexible and customised materials that meet specific user requirements[3]. Today, the progress of technology is heavily reliant on advancements in the realm of materials.

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To achieve this goal, a significant advancement in the efficient utilisation of continuously evolving materials is the use of composite material[4,5].

Composite materials are composed of a continuous matrix phase that binds and shapes a stronger, more rigid reinforcing phase[6,7]. This combination results in a material with superior structural qualities that surpass the individual properties of its constituent elements[8]. Composites are better than other building materials because they have a lot of great qualities, such as being able to bend without breaking, being resistant to wear and strain, possessing a high specific strength and specific modulus, and being able to handle thermal cycling and a certain amount of thermal expansion[9,10].

The possessions of combinations are determined by the relative amount and characteristics of the several phases present, in addition to the dispersed phase's geometry, which takes into account elements like particle size, shape and orientation inside the matrix[11,12]. Multiple fabrication techniques exist for processing composites[13,14]. The composites that have been created are typically assessed for improved characteristics by the implementation of experiments such as hardness, compression, tensile, fatigue and tribological tests, following the guidelines set by the ASTM standards[15,16].

The composite material is composed of a predominant matrix (binder) together with a more robust reinforcing substance[17,18]. The weight percentage of reinforcements is modified in relation to the matrix alloy's weight percentages and the resulting samples are evaluated to determine their characteristics[19-21].

Ceramic particle-reinforced Metal Matrix Composites (MMCs) have become very popular recently because they have a lot of good qualities[22]. MMC is the best material for the automobile, aerospace and biomedical industries[23,24] because it is very stiff, has a high strength-to-weight ratio and doesn't wear down easily. These materials frequently use SiC, TiC, Al_2O_3, B_4C and graphite particles as reinforcements[25-28].

Aluminium, titanium and magnesium are extensively utilised as matrix materials. Among them, Over the past few decades, aluminium composites have drawn attention because of their increased properties over other materials[29,30]. Aluminium alloys that contain zinc, copper and silicon as their main alloying elements are a significant group of materials that are processed by shaping and have a remarkable combination of mechanical properties, ability to be cast, resistance to wear and also exhibit good resistance to corrosion[31,32]. Al alloys are major materials for automotive components and aerospace industries[33]. Reinforcing elements are commonly added to matrix alloys to strengthen and improve the qualities of the final product, in comparison to the properties of the constituent components. Various reinforcing materials including carbides, oxides and different nitrides have been utilised in the development of composition materials[34-38].

Aluminium Metal Matrix Composites (AMMCs) can be manufactured using many established techniques, but there is no one standardised procedure. The production technique is contingent upon the matrix material and the specific forms of reinforcement employed[39]. Stir casting is well recognised as a potential method for making short-fibre metal matrix composites due to its simplicity, versatility and ability to produce large quantities of applications[40,41]. Due to the increasing need for lightweight materials in developing applications, the Al-Si_3N_4 composites have a crucial role to play. Based on the aforementioned observations, the plan is to create Al2219- Si_3N_4 composites with different wt.% of Si_3N_4 particles.

In the present study, Al2219 alloy with 3 and 6 wt.% of Si_3N_4 particles composites were synthesised by stir cast method. The prepared composites were studied for microstructural analysis, hardness and various tensile properties as per ASTM standard methods.

2.0 Experimental Details

2.1 Materials Used

The main alloying element in 2219 alloy is copper, turning it into an aluminium alloy that precipitates hardening.

Table 1. Chemistry of Al2219 alloy

Elements	Si	Fe	Cu	Mn	Mg	Zn	Zn	Ti	Al
Weight (%)	0.20	0.30	6.80	0.40	0.02	0.10	0.20	0.05	Bal



Figure 1. Tensile test specimens.

2219-O (annealed) and 2219-T6 (solutionized and artificially aged) are two popular pre-tempered grades along with 2219-T651 (stretched, artificially aged and stress-relieved). Table 1, shows the chemistry of Al2219 alloy.

The manufacturing procedure for Al2219 alloy with Si_3N_4 composites involves the use of liquid metallurgy method and stir technique. The Al2219 metal ingots are introduced into the furnace and subjected to heat until they reach a liquid state. The furnace temperature is maintained at 750˚C. The crucible's extremely hot liquid metal is purged of gases by using solid hexachloroethane (C_2Cl_6)[42,43] for around three minutes. A steel rotor with a fan-like design, mounted on a shaft, is used as a stirrer to agitate the liquid metal. For this aim, the rotor is covered with zirconium ceramic material. The stirrer is fully immersed in the molten metal, descending to a depth of approximately 65% within the crucible. By rotating the stirrer at approximately 300 revolutions per minute, the molten metal is violently agitated, resulting in the formation of a swirling vortex. While churning the molten metal, the B_4C particles, which constitute 3% of the weight of the charged Al2219 alloy, are heated individually in a heater until they reach a temperature of 500˚C. These heated particles are subsequently introduced in a controlled manner into the swirling flow of the liquid metal in stages. The stirring procedure is prolonged until the Al2219 alloy matrix and Si_3N_4 reinforce particles acquire optimal wettability. The molten metal mix, which is made up of Al2219 and Si_3N_4 reinforced particles, is poured into different-sized cast iron moulds. leading to the creation of the Al2219- Si_3N_4-6 wt. % composite. Figure 1 depicts the specimen of the tensile test.

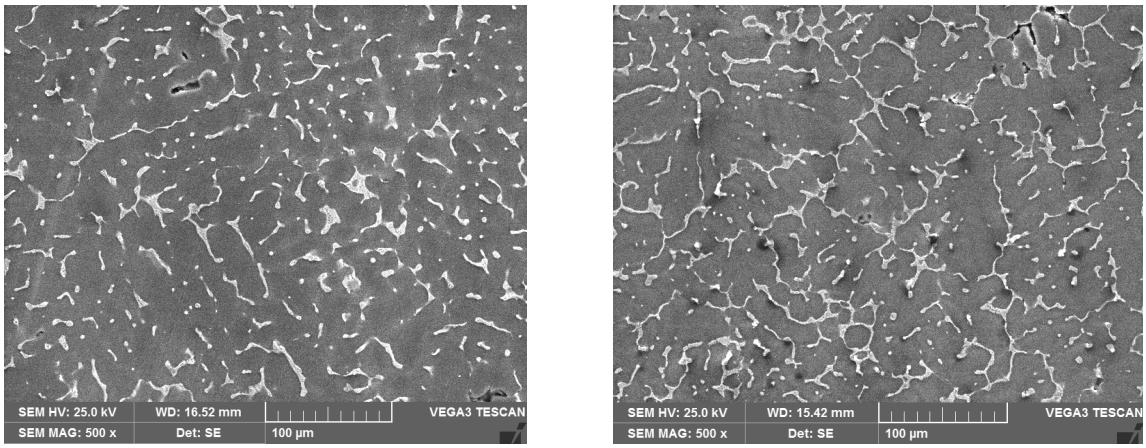
For characterisation, the synthesised micro composites were machined to ASTM standards. After confirming the presence of Si_3N_4 in the matrix using SEM, the mechanical performance of cast Al2219 and its nitride composites is evaluated using ASTM standards. Figure 1 shows the tensile test specimen used as per ASTM E8 standard[44,45].

3.0 Results and Discussion

3.1 Microstructural Studies

In this study, sections of a composite casting were cut into multiple pieces taken from various places and then polished using polishing materials containing abrasive particles smaller than 3 microns in size. The polishing process was carried out at a very low pace using a polishing machine. Polishing eliminates scratches on the surface of composite materials, resulting in a smooth surface. Polishing was carried out using films composed of SiC and Al_2O_3 abrasives. The achievement of a refined microstructure is contingent upon the superior quality of both polishing cloth and abrasive films. Kellar's reagent is used to etch the polished material[46,47] (a mixture of hydrochloric acid, hydrofluoric acid, nitric acid and water) as an etchant to improve the visibility of microstructural characteristics such as phase features and grain size. Use cotton swabs dipped in etchant to apply Kellar's reagent to the polished surface after making sure it is clean and clear of oil, grease and dirt. The reagent was applied in gentle rotating movements. Subsequently, the surface that had been etched was cleansed using alcohol and subsequently dried.

The specimens are analysed for microstructural characteristics using SEM. Figure 2 (A)-(B) shows the images of the Al2219 alloy and the composites reinforced with micro Si_3N_4. Figure 2 (A) shows the SEM image of the Al2219 alloy in its pure form. The SEM pictures of



(a) (b)

Figure 2. SEM of **(A)** Al2219 alloy **(B)** Al2219-6 wt.% Si_3N_4 composites.

Al2219-6 wt. % Si_3N_4 composites can be seen in Figure 2 (B). The analysis indicates that a significant portion of the micro Si_3N_4 particles are evenly distributed within the Al2219 alloy. Additionally, these statistics demonstrate the uniformity of the composites that were created. The microphotographs unambiguously demonstrate the heightened levels of reinforcement in the Al2219 alloy composites.

3.2 Hardness Measurements

From Figure 3, it can be noted that the hardness of Al2219 increased as the wt.% of Si_3N_4 particles increased from 3 wt. % to 6 wt. %. The as-cast Al2219 has a hardness of 68.5 BHN. Following the addition of 6 weight per cent of Si_3N_4, the hardness of the alloy increased to 20.72%. The reason for the increased hardness is because of the stiff Si_3N_4 particles, which prevent the dislocations within the Al2219 matrix from moving. Microparticles generally result in higher hardness in composites by increasing the strain energy at the periphery of Si_3N_4. Similar findings have been made by other researchers[48,49].

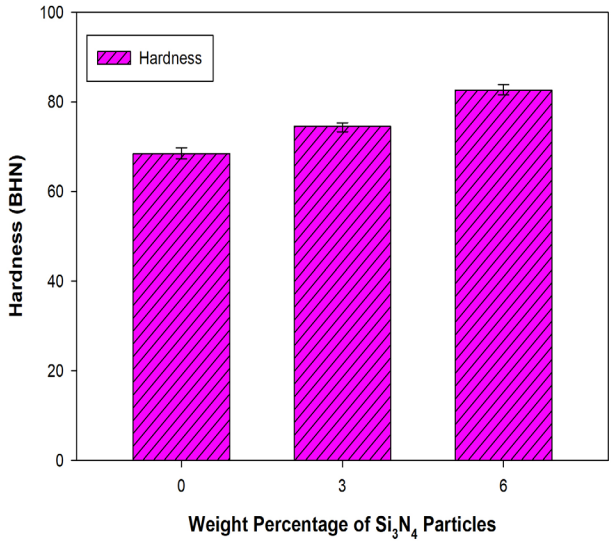


Figure 3. Hardness of Al2219-Si_3N_4 composites.

3.3 Tensile Properties

Based on Figure 4, it can be noted that the average Ultimate Tensile Strength (UTS) values are improved as the Si_3N_4 concentration in the Al2219 alloy increases. The inclusion of micro Si_3N_4 particles in the Al2219 matrix alloy serves as a safeguard for the more malleable matrix. The ultimate strength of the Al2219 in its as-cast state is 213 MPa. In addition, as the weight percentage of micro Si_3N_4 from 3 to 6 wt. % in increments of 3 wt. %, there was an observed rise in the ultimate values, as depicted in Figure 4. The ultimate strength of Al2219 with 3 wt. % of Si_3N_4 composites is measured to be 156.4 MPa. It is observed that in Al2219 alloy-4.5 wt. % of B_4C composite's UTS value is 228.3 MPa. An improvement was obtained in the ultimate strength of Al2219 after the addition of 6 wt. % of micro Si_3N_4 particles is 16.4%. An enhancement of the ultimate strength of Al2219 alloy after the incorporation of 3 and 6 wt. % of Si_3N_4 is due to the difference in the

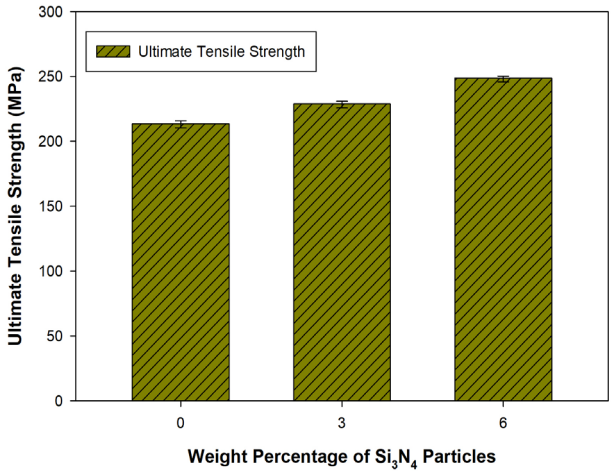


Figure 4. The ultimate strength of Al2219- Si_3N_4 composites.

thermal coefficient of expansion between Al2219 and the uniformly distributed micro Si_3N_4 [50,51].

The inclusion of Si_3N_4 enhances the yield strength of the Al2219 as seen in Figure 5. Increasing the wt.% of Si_3N_4 from 3 wt.% to 6 wt.% leads to a higher strength in the Al2219. The Yield Strength (YS) of the Al2219 in its as-cast state is 175.3MPa. This strength is enhanced to 193.6MPa and 212.7MPa, respectively, when the alloy is reinforced with 3 and 6 weight % of Si_3N_4 in composite form. Other authors[52,53] have also made similar observations when including hard particles into the Al alloy matrix. The strength of Al2219 – 6 wt.% Si_3N_4 reinforced composites is improved by 21.3%. The hard nitrides are responsible for the yield strength increase, which enhances the structural composition and hence provides improved mechanical stiffness. Throughout the cementing process, the enlargement of these rigid micro-particles may have resulted in significant and persistent compressive stress due to the variance in extension coefficients between the brittle particles and the flexible matrix[54]. The enhanced quality is also credited to the dense arrangement of the reinforcement, resulting in a minimal gap between particles in the lattice[55,56]. These hard nitride particles act as a barrier for plastic deformation, thus increasing the axial load-carrying capacity of composites.

Figure 6 illustrates the result of Si_3N_4 inclusion on the malleability of composites made of Al2219. When a specimen is under load in its axial direction, the substantial tends to elongate. Usually, a specimen's elongation expressed as a percentage is used as a measurement. The material has more ductility the higher the percentage of elongation. Figure 6 represents the percentage increase in length of the Al2219 in its as-cast state. Tensile testing was performed on the Al2219 alloy with the addition of 3 and 6 wt% of Si_3N_4 particle composites.

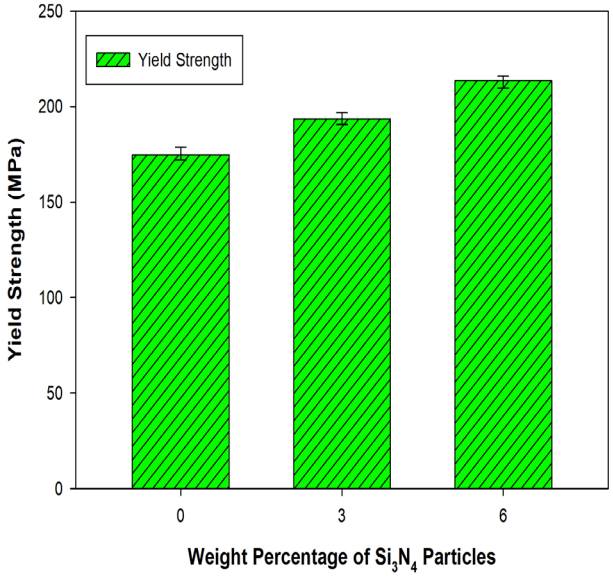


Figure 5. Yield strength of Al2219- Si_3N_4 composites.

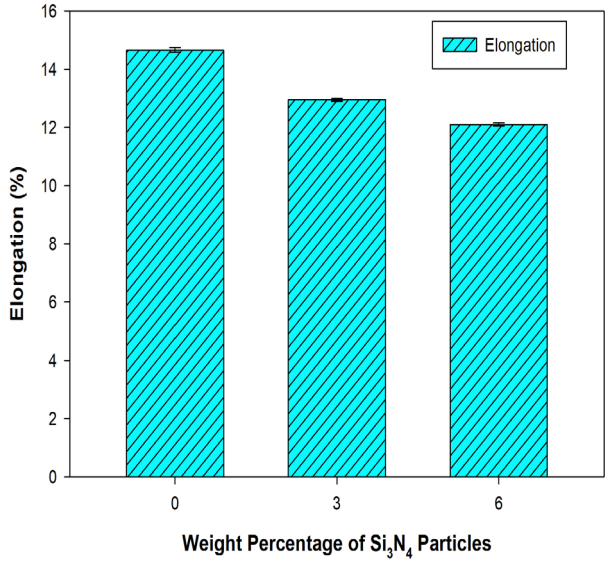


Figure 6. Elongation of Al2219- Si_3N_4 composites.

Figure 6. The addition of Si_3N_4 particles to the as cast Al2219 alloy results in a diminution in the ductility. Furthermore, the elongation is further reduced when the wt.% of reinforcement increases in the Al2219. The tensile strain of Al2219 is initially 14.6%. However, when 6 wt.% of Si_3N_4 particles are added, the tensile strain decreases to 12.1%. The reduction in elongation is mostly attributed to the inclusion of rigid ceramic particles inside the Al2219 alloy matrix.

4.0 Conclusions

This work investigated composite mechanical characteristics and microstructure constructed of Al2219 alloy with Si_3N_4 particles. Micro composites of Al2219 alloy with reinforcement of Si_3N_4 were made using the stir cast technique. Scanning electron microscope images revealed Si_3N_4 homogeneous dispersion over the Al2219. The hardness of Al2219 is improved by 20.7 % by adding 6 wt.% of Si_3N_4 in the Al2219 matrix. The ultimate and yield strengths of Al2219 were enhanced by the addition of silicon nitride particles. The UTS and YS of Al2219 have been improved by 16% and 21%, respectively, in the case of Al2219 with 6 wt.% of Si_3N_4 composites. The ductility of Al2219 alloy has been reduced due to the inclusion of hard nitride particles in the soft Al2219 matrix. The strength of Al2219 alloy with 3 and 6 wt. % of Si_3N_4 composites are superior to Al2219 alloy, these composites can be used in several aerospace applications like wing root fittings, bulkheads and fork hinges of aerospace vehicles.

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