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Research Article

Impact of AlN-SiC Nanoparticle Reinforcement on the Mechanical Behavior of Al 6061-Based Hybrid Composite Developed by the Stir Casting Route

S. Kaliappan,[1] A. Shanmugam,[2] Pradeep Johnson,[3] M. Karthick,[4] S. Sekar,[5] Pravin P. Patil,[6] M. K. S. Sai,[7] K. P. Yuvaraj,[8] and Venkatesan Govindaraajan[9]

[1]*Department of Mechanical Engineering, Velammal Institute of Technology, Chennai 601204, Tamil Nadu, India*
[2]*Mechanical Engineering, SAMS College of Engineering and Technology, Chennai, Tamil Nadu, India*
[3]*Department of Mechatronics Engineering, Hindustan College of Engineering and Technology, Coimbatore, India*
[4]*Department of Mechanical Engineering, Velammal Engineering College, Velammal New-Gen Park, Ambattur-Redhills Road, Chennai 600066, Tamil Nadu, India*
[5]*Department of Mechanical Engineering, Rajalakshmi Engineering College, Rajalakshmi Nagar Thandalam, Chennai 602105, Tamil Nadu, India*
[6]*Department of Mechanical Engineering, Graphic Era Deemed to be University, Bell Road, Clement Town, Dehradun 248002, Uttarakhand, India*
[7]*Department of Mechanical Engineering, Vignana Bharathi Institute of Technology, Hyderabad, Telangana, India*
[8]*Department of Mechanical Engineering, Sri Krishna College of Engineering and Technology, Coimbatore, Tamil Nadu, India*
[9]*Department of Mechanical Engineering, Haramaya Institute of Technology, Haramaya University, Dire Dawa, Ethiopia*

Correspondence should be addressed to Venkatesan Govindaraajan; venkatesanggg2011@gmail.com

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The enhancement of composites' mechanical characteristics (tensile, compressive, and hardness) is a constant demand for technological advancement. The stir casting process is used to make the hybrid aluminium alloy metal matrix composites Al 6061-SiC-AlN in our present study. To create mechanical qualities such as tensile, compressive, and hardness, silicon carbide and aluminium nitride (both 3% and 6%) were utilized as the reinforcement. The tensile strength, compressive strength, and hardness of the Al 6061-SiC-AlN hybrid composites samples were determined. The tensile, compressive, and hardness parameters of Al 6061-SiC-AlN hybrid composites are estimated and evaluated to those of the matrix Al 6061 alloy. With the inclusion of silicon carbide and AlN nanoparticles, the tensile strength, compressive strength, and hardness increased from 328 to 385 MPa, 145 to 178 Mpa, and 302 to 724 VHN, respectively.

1. Introduction

Aluminum and alloy hybrid nanocomposites (AAHNCs) are industrialized materials with desirable properties including strong tensile, compressive, hardness, and stiffness. In comparison to unreinforced alloys, these materials have a higher abrasion resistance. These materials are used in a variety of structural applications in a variety of sectors, including marine, aircraft, and automobiles [1, 2]. Rail coaches, towers, pylons, military and commercial bridges, aerospace applications, shipbuilding operations rivets, truck frames, and transportation are just a few of the heavy-duty structural uses for aluminium alloy 6061 [3]. Al 6061 is the repeatedly utilized matrix material owing to its low density and electrical resistance, high and good strength, superior corrosion resistance, and greater machinability [4].

Aluminium oxide (Al2O3), tungsten carbide (WC), titanium diboride (TiB2), silicon carbide (SiC), zirconium boride (ZrB2), titanium carbide (TiC), and boron carbide (B4C) are commonly utilized as nanoscale reinforcements in aluminium hybrid composites to improve mechanical properties like tensile, compressive, and hardness [5]. The current investigation used two reinforcements, one is SiC and another one AlN. Silicon carbide nanoparticles are possible a nano reinforcement for aluminium alloy 6061 matrix owing to its high hardness, low density, high wear, impact resistance, high melting point, and good chemical and thermal stability [6]. Aluminium alloy 6061 composites containing silicon carbide nanoparticles have improved toughness, machinability, and self-lubricating properties [7].

AlN is a high-hardness refractory compound with excellent corrosion and wear resistance, a low coefficient of thermal expansion, and high electrical resistivity. It has a wide range of applications in electrical and semiconductor devices, as well as corrosive and molten metal handling [8]. In recent years, the tribological and mechanical properties of nanoparticles and fiber-reinforced Al 6061 composites are greatly enhanced. Sun et al. investigated Al1060/Al6061-0.5SiC/Al1060 laminates with a hot roll bonding process and heat treatment. After heat treatment, the Goss and *R* components dominated the texture of the Al6061-0.5SiC composite. The tensile strength of the as-rolled laminates increased as the rolling reduction was lowered, but the elongation first increased and then decreased [9]. Using the powder metallurgy approach and the effect of SiC clusters, Mulugundam Siva Surya developed Al6061/SiC composites with high interfacial bonding between Al6061/SiC composites. It was discovered that diffusion-controlled grain formation had a detrimental influence on mechanical characteristics and resulted in improved features [10]. For the aerospace sector, Ishfaq et al. specified the Al6061-7.5% SiC composite. Although the SiC reinforcement in the Al-substrate greatly improves mechanical properties, it makes difficulties machining as the Al6061-7.5% SiC composite allows outstanding hardness and strength [11]. Halil et al. explored and improved the mechanical characteristics of Al6061-SiC-B4C hybrid composites made via powder metallurgy extrusion. Wear resistance, tensile strength, transverse rupture strength, hardness, and density of the Al6061-SiC-B4C hybrid composites were evaluated. Al6061-SiC-B4C hybrid composites with SiC particle reinforcement had the highest tensile strength [12]. Bhat and Kakandikar customized the Al6061-5% SiC-50 mm sized composite by the stir casting process and investigated hardness and wear characteristics of the new composite. The output of the new composite was obtained with a lower wear rate and superior hardness [13]. Veeresh Kumar et al. used particulate SiC with the Al6061 composite prepared by the liquid metallurgy route. The particulate SIC used in Al6061 enhanced the mechanical and tribological properties. Especially hardness, ultimate tensile strength, wear resistance, and density of the composites augment with the augmented SiC content [14].

The aluminium matrix with aluminium nitride particle composites is frequently employed in electrical and electronics equipment. Chemically, aluminium nitride is more stable than SiC, however, it has a poorer thermal conductivity. Aluminum does not react with aluminium nitride [15], but when Al interacts with SiC in Al–SiC composites, the Al4C3 phase forms, which affects the tensile, compression, and hardness properties of the aluminium silicon carbide composite [16, 17]. AlN has an excellent combination with aluminium alloys, outstanding heat treatment and physical properties, high thermal conductivity, high specific strength and stiffness, high electrical resistivity, low dielectric constant, a tailorable coefficient of thermal expansion [15]. As a result, the Al–AlNp composite is a fantastic material for electronic packaging [18, 19]. Ashok Kumar and Murugan developed the Al6061 (T6)-AlNp composite by the stir casting process and improved wettability, ultimate tensile strength, yield strength, microhardness, and macrohardness [20]. SiCp/Al composites were created by Xie et al., who also studied how the phase composition, densification behaviour, and mechanical characteristics of the composites were related. The findings showed that raising the laser power density improved the density, microhardness, and friction resistance of the SLM produced SiCp/Al composites. This improvement may be attributed to the higher molten pool temperature at higher laser power densities [21].

In generally aluminium alloy hybrid composites are prepared by stir casting [22, 23], squeeze casting [24, 25] and powder metallurgy [26, 27]. Stir casting has a number of advantages, including being trouble-free, supple, and affordable, as well as producing multifunctional, bulk-manufacturing, and contour composite components that are free of dangerous reinforcing particles. Due to these distinguishing characteristics of the stir casting technique, a slew of new efforts has been made to create a variety of composites using this method [28, 29]. The tensile, compression, and hardness properties of the stir cast Al-SiC-AlN hybrid composites with varied reinforcements have received only a cursory examination. This paper describes the mechanical properties of an Al-SiC-AlN hybrid composite made in a static ambiance utilizing a stir casting process.

2. Experimental Work

2.1. Materials. Nice Chemicals Limited, Telangana, India, provided the aluminium 6061 matrix alloy, and the reinforcements of aluminium nitride (50 nm) and silicon carbide (50 nm) nanoparticles used in this work. The SEM morphology of aluminium 6061, aluminium, and nitride silicon carbide powders is shown in Figures 1(a)–1(c). The chemical composition and mechanical characteristics of the matrix (Al6061 alloy) and reinforcements are shown in Tables 1 and 2. (AlN & SiC).

The distribution of aluminium nitride, silicon carbide, and aluminium 6061 matrix alloy is studied morphologically using a scanning electron microscope because this, in a sequence, resolves significantly to affect the mechanical characteristics of the composites and determination and also to verify their effective manufacturing. Aluminium nitride and silicon carbide nanoparticles have a stone-like shape and are 50 nm in size. The distribution of reinforcement and the matrix alloy is in uniform distribution. The distribution of aluminium nitride and silicon carbide in the aluminum 6061

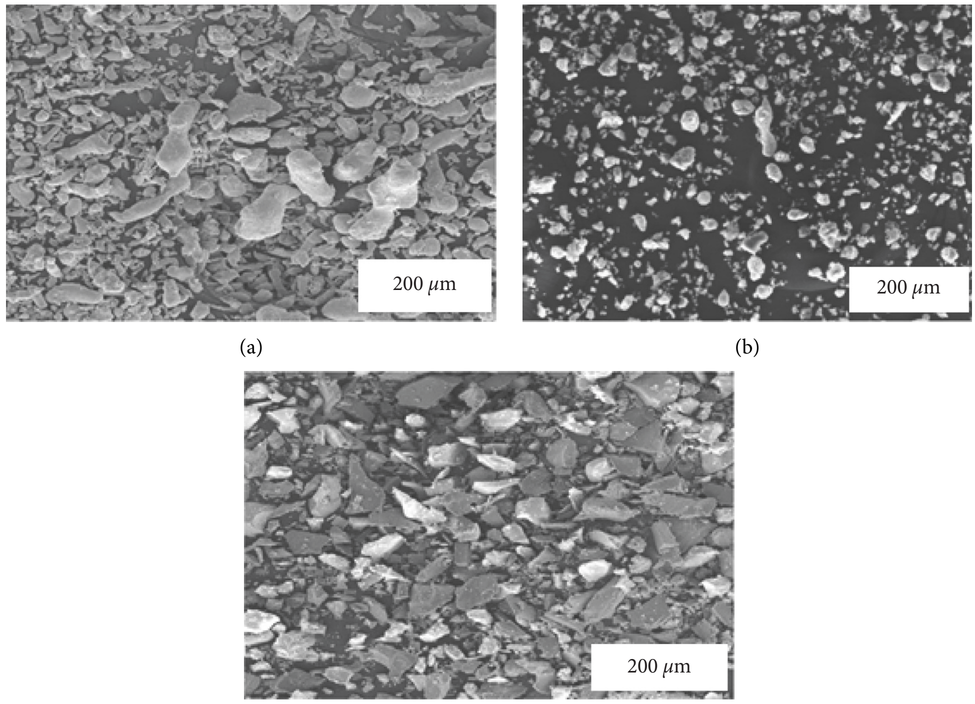

Figure 1: SEM morphology of (a) Al 6061, (b) AlN, (c) SiC.

Table 1: Chemical composition of the matrix (Al6061 alloy) [7, 9, 13].

Elements	Mg	Si	Fe	Mn	Cu	Cr	Zn	Ni	Ti	Al
Wt (%)	0.85	0.65	0.26	0.22	0.20	0.04	0.06	0.02	0.01	Balance

Table 2: Mechanical properties of the matrix (Al6061 alloy) and reinforcements (AlN & SiC) [3, 10, 20].

Properties	Ultimate tensile strength (Mpa)	Hardness (HRB)	Melting temperature (°C)	Modulus of elasticity (GPa)	Density (g/cm^3)
Al6061 alloy	320	80	650	70	2.7
AlN	270	1100	2,200	310	3.26
SiC	250	2800	2730	410	2.52

matrix alloy, which determines the substantial impact on the composites, and in addition, substantiate the victorious fabrication of composites.

2.2. Composite Preparations. The matrix AA6061 aluminium alloy was melted in a graphite clay crucible in a stir casting furnace and heated to a temperature of around 750°C. The nano particles of aluminium nitride (AlN) and silicon carbide (SiC), with a particle size of 50 nm were chosen as the reinforcement. The molten AA6061 was continually agitated at 500 rev/min to integrate the known amounts of preheated AlN and SiC filler components. The Al-AlN-SiC molten mixture was put into cast iron moulds when the procedure was completed. Castings were made using the Al 6061 alloy, with AlN and SiC filler percentages of 3% and 6%, respectively. Figure 2 shows experimental illustrations of a stir casting setup. The fashioned hybrid composites were cut and prepared into the desired forms. To prepare samples for FESEM and mechanical testing, they were machined. The prepared samples were polished and etched with Keller's reagent using normal metallographic procedures.

The casted samples, one matrix Al 6061 alloy sample, and two other samples with different wt. % SiC-AlN nano reinforcements were utilized to construct test specimens for tensile, compression, hardness, and FESEM examination analysis, and their dimensions are shown in Table 3.

3. Result and Discussion

3.1. Tensile Test. The tensile test was performed in accordance with the ASTM–E8 standard, using the tensile test. The digital tensometer setup is depicted in Figure 3. The specimen dimension was 14 mm diameter and 10 mm length as shown in Figure 4. The tensile test experiments were performed at the atmospheric temperature. The readings of Al 6061 alloy, 3% Al 6061-SiC-AlN hybrid composites, and 6% Al 6061-SiC-AlN hybrid composites sample were taken. The difference in tensile strength with an increase in SiC/AlN microparticle entitlement is shown in Figure 5. The

Figure 2: Experimental setup of the stir casting process.

Table 3: ASTM for tensile, compression, hardness, and FESEM.

S.No	ASTM	Test	Dimensions (in mm)
1	ASTM E8	Tensile test	Dia 14 × length 100
2	ASTM E9	Compression test	Dia 14 × length 20
3	ASTM: E384-10	Hardness test	Dia 14 × length 10
4	ASTM E3-11	FESEM	Dia 14 × length 10

Figure 3: Tensile test-digital tensometer setup.

tensile strength of the Al 6061-SiC-ALN hybrid composite material augments by a quantity of 90% as the substance of SiC/AlN nano particulates augment from 3 to 6 wt%. The SiC/AlN nano particulates reinforcement arrangement and properties regulate the mechanical characteristics of hybrid composites, resulting in a highly strong interface that transfers and relocates stress from the Al 6061 matrix to the SiC/AlN microparticle reinforcement, exhibiting improved strength and elastic modulus [30]. The elastic modulus, tensile strength, and fatigue strength of Al 6061-SiC-AlN

Figure 4: Tensile specimen.

hybrid composites reinforced by SiC/AlN nanoparticles are all greater than monolithic alloys [31]. By raising the volume proportion of the nano phase and lowering the size of the nano reinforcement at the price of concentrated ductility, the strength of SiC/AlN nanoparticles reinforced Al 6061-SiC-AlN hybrid composites is improved [32].

3.2. Compression Test. The compression test specimen samples were produced according to ASTM E9, as stated in Table 3. The compression testing machine was used to test the samples, as illustrated in Figure 6. It depicts the effects of varying compression strength with a weight percent of reinforcements. An Al 6061 alloy sample has a compressive strength of 145 MPa. The Al 6061-SiC-AlN hybrid composites sample with 3 percent SiC-AlN reinforcement and 6 percent SiC-AlN reinforcement has compressive strengths of 165 MPa and 178 MPa, respectively (Figure 7). When contrasted to the original matrix of the Al 6061 alloy, the organized Al 6061-SiC-AlN hybrid sample demonstrates an increase in compressive strength. This indicates that the aluminum ductile character has been gradually giving way to brittleness. This transformation was made possible through the absorption of hard nanoparticles into the soft and ductile aluminium metal matrix [33, 34].

3.3. Hardness. The microhardness of complicated samples of the Al 6061 alloy and its Al 6061-SiC-AlN hybrid composites (Figure 8) was examined using an ASTM-approved standard testing approach. The hardness of the Al 6061-SiC-AlN hybrid composites was determined using a Vickers microhardness tester in accordance with ASTM: E384-10. A weight of 1 kgf was applied on all of the samples for 15 seconds. The test was carried out at three different locations to avoid the indenter resting on the hard reinforcement particles. All ten measurements' averages were computed and reported. Figure 9 displays the hardness value in relation to the weight percent of nano reinforcements and summarizes the findings of the hardness tests.

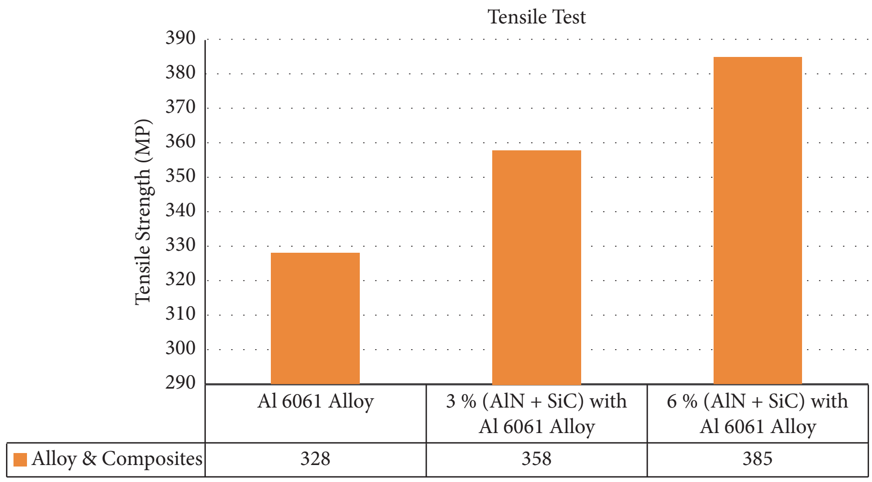

Figure 5: Tensile strength of the Al 6061 alloy and Al 6061 alloy-SiC-AlN hybrid composites.

Figure 6: Compression specimen.

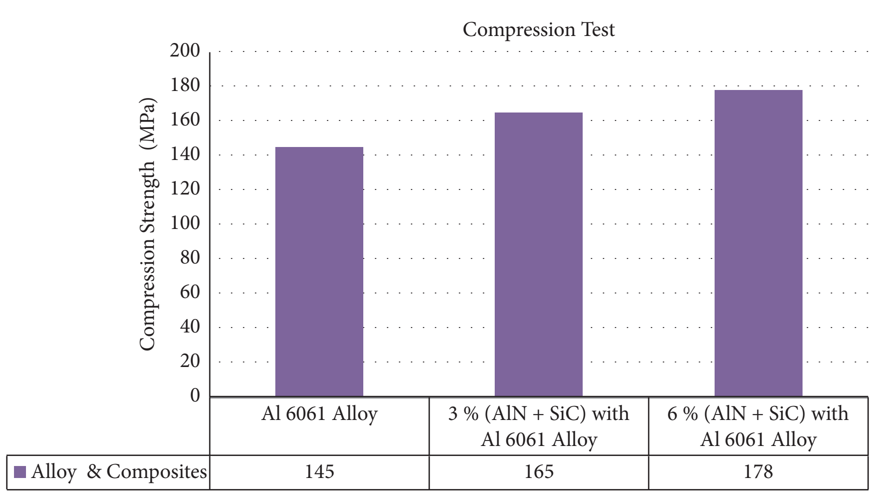

Figure 7: Compression test results.

In comparison to the Al 6061 matrix material, the hardness of composite specimen-2 was found to be higher than that of the Al 6061 matrix material. This might be due to a lack of nano reinforcement dispersion mixed with extra porosity. When compared to other test specimens, the hardness of composite specimen-3 was found to be larger than that of the matrix Al 6061 alloy[35], with a maximum hardness of 724 VHN. This might be due to the Al 6061 matrix material having the fewest holes and shrinkage cavities, as well as a better distribution of nano reinforcements. As a result, combining a hybrid composite of the Al 6061 alloy reinforced with 6% SiC-AlN proved to be the most effective way to achieve maximal hardness.

3.4. Fractured Surface Analysis. A FESEM is an electron microscope that uses a focused stream of electrons to create images of a substance. Electrons react with atoms in the

Figure 8: Hardness test specimen.

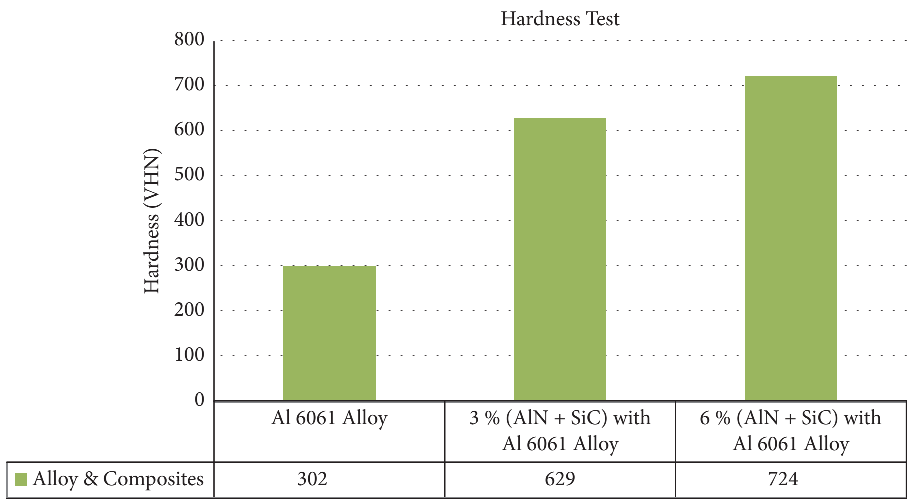

Figure 9: Hardness test results.

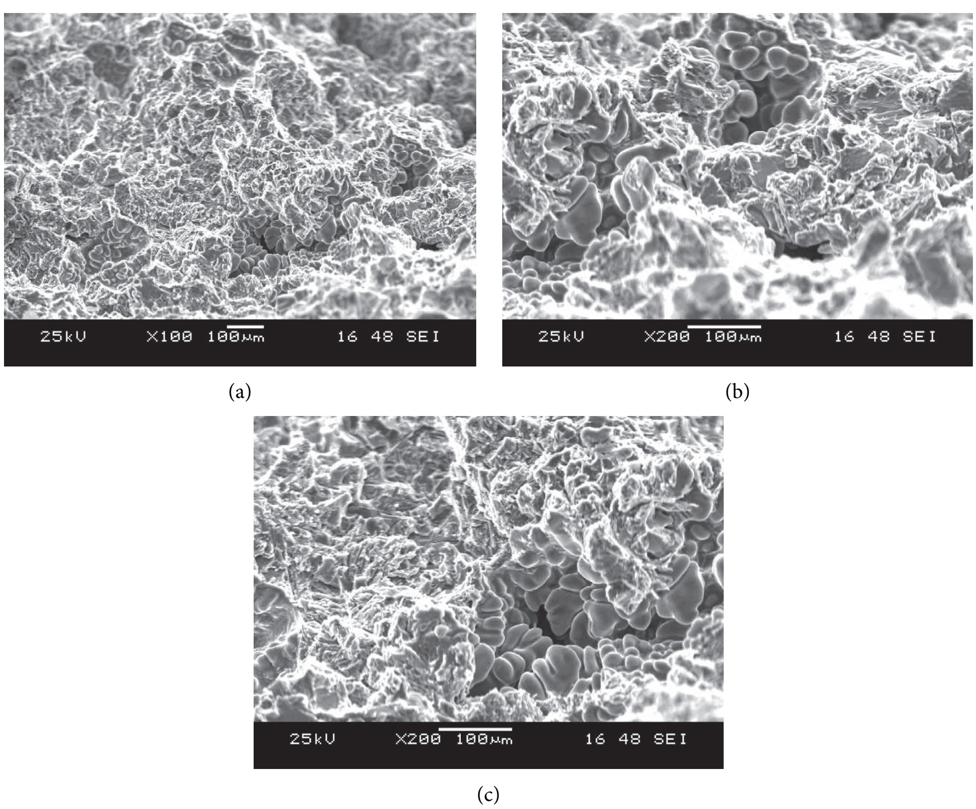

Figure 10: (a–c) FESEM of alloy and composites. (a) Al 6061 alloy; (b) 3% (AlN + SiC) with Al 6061 alloy; (c) 6% (AlN + SiC) with the Al 6061 alloy.

sample to produce a variety of signals that convey information about the sample's topography and composition. To create the image, the electron beam is scanned in a raster scan pattern and the location of the beam is combined with the signal received. FESEM has a resolution of over 1.5 nanometers.

Figure 10 shows the FESEM pictures of the aluminium composite. It is plain to see that the fracture is ductile. The grains are easily visible, and they are evenly scattered. As a result of this finding, it may be deduced that the fracture begins at the corroded area mentioned in the optical micrograph. The ductility of the material is marginally reduced as the amount of boron carbide increases, resulting in a considerable rise in hardness.

The dispersion of particles throughout the matrix was found to be very homogeneous as a black zone, as seen by these FESEM pictures. The uniform dispersion of AlN-SiC-reinforced particles with aluminium alloy can easily be seen in these pictures. The consistency of the cast composites can also be seen in these photos. The matrix particle and weight percentage, as well as the distribution of reinforcing particles and the particle-matrix interface bonding, determine the properties of aluminium MMCs [36, 39].

4. Conclusion

Stir casting was used to effectively cast Al 6061- AlN-SiC hybrid composites in this study. The impacts of aluminum nitride (AlN) and silicon carbide (SiC) on the composites tensile, compression, hardness, and FESEM characteristics were planned and reported. According to the tensile test, increasing the volume fraction of the nano phase and lowering the size of the nano reinforcement at the price of focused ductility improves the strength of SiC-AlN nanoparticles-reinforced Al 6061-SiC-AlN hybrid composites. The compression test, compressive strength of the Al 6061-SiC-AlN hybrid composite sample with 3% SiC-AlN reinforcement and 6% SiC-AlN reinforcement is 165 MPa and 178 MPa, respectively. When compared to the original matrix Al 6061 alloy, the organized Al 6061-SiC-AlN hybrid sample demonstrates an increase in the compressive strength. The hardness test combining a hybrid composite of Al 6061 alloy reinforced with 6% SiC-AlN proved to be the most effective way to achieve maximal hardness. The dispersion of particles throughout the matrix was found to be very homogeneous as a black zone, as seen by these FESEM pictures. The uniform dispersion of AlN-SiC reinforced particles with the aluminium alloy can easily be seen in these pictures.

Data Availability

The data used to support the findings of this study are included in the article. Should further data or information be required, these are available from the corresponding author and upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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