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Effect of Nano Composite Boron Carbide on the Mechanical and Corrosion Behaviour of Aluminium Matrix Composite

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ABSTRACT

This study examined the use of stir casting to create an aluminum-nanoscale boron carbide composite. Following the sample's solidification, mechanical and physical tests are carried out to determine the density and hardness. Tafel polarization in a 3.5% NaCl solution was utilized to determine the composite's corrosion behavior, and tensile strength and hardness characterization techniques were employed to determine its mechanical characteristics. After the stir casting process, the surface morphology of the metal and the dispersion of boron carbide particles on the matrix were examined using a field emission scanning electron microscope (SEM). The obtained powders and matrix samples were examined using X-ray diffraction (XRD) analysis to determine the phase and if reinforcement particles (B_4C) were present in the composite samples. The mechanical, microstructural, and corrosion investigations were used to evaluate the performance of the composites. The homogeneous distribution of the reinforcing particle was observed by the inspection of micrographs. The results showed that the corrosion rate of the aluminium matrix composite was lower than that of the base alloy in a 3.5% NaCl solution. Simultaneously, the composite's corrosion rates escalated as the B_4C concentration in the aluminum matrix grew. Hardness investigation has demonstrated that an increase of B_4C content in the aluminium matrix enhanced the hardness rating. In the tensile test, the composite containing 0.8 weight percent B_4C achieved a maximum strength of 149.95 MPa, which was roughly 48.64 MPa (32%) greater than the basic alloy.

Keywords: Aluminium matrix composite; nano size boron carbide; corrosion; hardness and tensile test

INTRODUCTION

Lightweight engineering makes use of aluminum alloy components, despite the material's poor resistance to corrosion, wear, and mechanical stresses. Aluminum matrix composites (AMCs) are created when hard reinforcing particles are incorporated into the aluminum matrix. Better specific stiffness, specific strength, corrosion resistance, elastic modulus, wear resistance, and lightweight qualities are among the qualities these composites offer (Kareem et al. 2021). AMCs are very advantageous over conventional alloys and can be used in a wide range of applications.

The automobile and aerospace sectors face growing technological obstacles in meeting customer demands. Manufacturers and designers predominantly favor materials that facilitate weight reduction in their projects. Decreasing the weight of aircraft holds the potential to decrease fuel consumption, enhance payload (Dursun & Soutis 2014), capacity, improve overall performance, and mitigate pollutants (Mangin et al. 1996). The primary concerns for both the aircraft and automotive sectors revolve around reducing costs and weight, particularly in the realm of electric cars. Therefore, it is essential to investigate cutting-edge materials that support these goals

(Manu et al. 2022; Suganeswaran et al. 2021). To develop innovative materials that meet client demands, researchers have dedicated significant attention to composite materials over the past few decades.

Aluminum matrix composites containing Al-B_4C are recognized as advanced materials, attributing to their exceptional thermal conductivity, high chemical stability, and impressive mechanical properties (Abdizadeh & Baghchesara 2017; Han et al. 2011; Hu et al. 2016; Hu et al. 2016; Li et al. 2016) . Consequently, these Al-B_4C composites find applications in diverse sectors, including the automobile and aerospace industries (Greim & Schwetz 2006; Hirota et al. 2017). Interestingly, the addition of B_4C particles causes changes in the aluminum matrix's corrosion behavior (Ding & Hihara 2011; Han et al. 2013; Han et al. 2011; Han & Chen 2015). Numerous studies have delved into investigating the corrosion and electrochemical characteristics of aluminum alloys reinforced with B_4C microparticles.

Han and Chen (2015) observed that the corrosion resistance of Al-B_4C composites is inferior to that of pure Al alloys. Furthermore, the electrochemical resistance of these composites diminishes as the volume fraction of B_4C micro-particles increases. Additionally, the galvanic corrosion of these composites in conjunction with stainless steel intensifies with higher B_4C content in the produced composites (Han et al. 2013). Another study suggests that increasing the boron carbide content in Al6061-B_4C micro size, by a little amount (less than 6 wt.%), results in a lower corrosion rate compared to the base alloy. Nevertheless, the rate of corrosion exceeded that of the base alloy when the boron carbide level exceeded 8 wt.% (Zaifol et al. 2023)

These composites comprised 16-30 vol% B_4C particles with a reinforcement particle size of approximately 20 μm. Previous findings indicated that Al-B_4C composites demonstrated reduced corrosion rates when subjected to a K_2SO_4 solution (Han et al. 2011). The galvanic corrosion of Al-B_4C composites was found to be constrained by the slow rate of oxygen reduction at the B_4C particles, mitigating the promotion of galvanic corrosion (Ding & Hihara 2011). Abbas Shafqat et al. (2019) investigated the electrochemical behavior of Al-B_4C composites with a particle content of 10 wt% in the aluminum matrix. Results from polarization tests indicated that the electrochemical resistance of the composites was more prominent in boric acid compared to NaCl solution. A. Fattah-Alhosseini (2016) explored the electrochemical properties of Al-SiC-B_4C hybrid composites in a 3.5% NaCl solution. These composites, produced through the ARB process, exhibited increased polarization resistance in both the hybrid composites and the matrix, as revealed by EIS tests.

Numerous investigations have focused on the corrosion and electrochemical characteristics of aluminum alloys reinforced with various nano-particles. In a 3.5 wt% NaCl solution, the corrosion rate of Al-6061 was found to be higher than that of the Al-ZrO_2 nanocomposite. Notably, an increase in ZrO_2 nanoparticle content from 2.5 to 7.5 wt% led to a significant decrease in the corrosion rate (Rashmi 2016). However, Chandrashekar et al. (Safarloo et al. 2018) contended that Al-Al_2O_3 nanocomposites demonstrated higher electrochemical resistance in a 0.1M NaCl solution compared to the aluminum matrix. Additionally, Loto et al. (Loto & Babalola 2018) demonstrated the excellent corrosion resistance of Al-Al_2O_3 nanocomposites in a 0.1M H_2SO_4 solution and a 1.78 wt% NaCl solution.

Kumar et al. (2016) investigated the corrosion characteristics of Al-TiB_2 nanocomposites in a 5% NaCl solution. Their findings indicated that forged alloys exhibited superior corrosion resistance when compared to cast specimens. In a study by Alaneme et al. (Kanayo Alaneme & Apata Olubambi 2013), the corrosion behavior of Al-Mg-Si alloy reinforced with alumina and rice husk ash (RHA) particles was explored. Results revealed an increase in the current density rate of composites with higher reinforcement content in the matrix in a 0.1M NaCl solution.

The mechanical properties of an aluminum matrix are improved by the addition of ceramic particles, according to numerous studies (Moustafa et al. 2005; Shen et al. 2014). Aluminum that has been strengthened with ceramic particles is hence a common class of MMCs.

For instance, a study on the mechanical behavior of Al 7075 matrix composites reinforced with silicon carbide and titanium carbide found that

the addition of these ceramic particles led to a substantial increase in the hardness, tensile strength, and impact strength of the composite material (Reddy et al. 2018). Similarly, a study on the mechanical properties of Al 7075 matrix composites reinforced with a combination of silicon carbide and boron carbide reported a significant enhancement in tensile strength and microhardness, with a simultaneous reduction in density and ductility (Sunil Kumar Reddy et al. 2021)

Salehi et al. (2015) developed Al/SiO_2 nano-composite foams by the ultrasonic technique and studied about the microstructural and mechanical properties. They added SiO_2 nano-particles in the pure aluminum matrix when the SiO_2 volume was less than 1 wt.%. They showed that when SiO_2 nano-particles content reached to 1 wt.%, nano-particles started to agglomerate and led to the decrease in the strength in comparison with other composites.

Stir casting is the most widely used and commercially preferred method in liquid-state processing due to its cost-effectiveness compared to other manufacturing techniques. This method also offers a relatively uniform dispersion of reinforcements within the matrix, improved wettability, and reduced porosity (Babu et al. 2021). For a variety of composites to be created successfully, wetting effects and chemical interactions between reinforcements and the matrix must be overcome (Li et al. 2016). It is crucial to tackle these obstacles to attain composite materials with customized characteristics and guarantee the overall effectiveness of the production process. Initially, aluminium foil was employed to enclose the boron carbide, to equally distribute it within the liquid metal and prevent its migration to the slag (Shirvanimoghaddam et al. 2016).

Totally due to the limited research on the mechanical and corrosion characteristics of Al-B_4C nanocomposites, the primary aim of this paper is to investigate the impact of nano-sized boron carbide content with diverse compositions on the mechanical properties and corrosion behavior of Al-B_4C nanocomposites within a 3.5% NaCl environment. In the current study, an Al6061 matrix composite with a homogeneous particle distribution was created using a two-step stir-casting approach

METHODOLOGY

CHEMICAL COMPOSITION OF MATERIAL

The Al6061 is typically applied in aircraft and automotive industries due to its resistance to corrosion and has high strength compared with others aluminium alloy. The chemical composition of base alloy material in wt% are following as Si (0.5), Fe (0.41), Cu (0.21), Mn (0.12), Mg (0.76), Cr (0.21 and balance of Al determined using Spark Emission spectroscopy (SES) (Model WAS Foundry-Master, Oxford Instruments)

REINFORCEMENT MATERIAL

The investigation selected nanosize B_4C with a purity of 99.99% supplied from Yemate Ind China as the reinforcing material due to its exceptional corrosion and wear resistance, as well as its enhanced mechanical properties such as tensile strength, hardness, and impact strength. The typical particle size of the B_4C reinforcement is around 50nm

STIR CASTING

The production of aluminum alloy 6061-based composites, which are strengthened by the addition of boron carbide nanoparticles, requires a careful two-step stir casting procedure.

The process begins with heating aluminum 6061 to its liquid state in an electric furnace. A specialized instrument exclusively designed for casting, features a stainless-steel impeller for stirring, while a temperature control system precisely manages heating and cooling rates. The aluminum is melted in a furnace with a temperature of 700°C for 10 min. Once all aluminum is molten, the resulting slurry is gradually cooled below the liquidus temperature to maintain a semi-solid form at the temperature of 600°C for 10 min.

Reinforcement particles, with varying compositions of 0.2 wt%, 0.4 wt%, 0.6 wt%, 0.8 wt%, and 1% wt% B_4C, are enclosed in aluminum foil and introduced into the molten metal. The foiled boron carbide is subjected to an independent preheating phase at 300°C to remove moisture and enhance its integration with the molten metal. During the initial phase of the semi-solid state at 600°C, foiled B_4C was introduced into the furnace, followed by manual stirring. Afterward, the combination of boron carbide and aluminum is subjected to reheating at a temperature of 700°C. The process involves ongoing mechanical agitation at a speed of 100 rpm for a duration of 30 minutes. The molten metal produced from the stirring process is put into molds, allowed to cool, and then undergoes sample cutting and analysis

DENSITY AND POROSITY

The Archimedes principle was used to determine the density of composite Al-B_4C nanocomposite samples. The porosity of Al composites was calculated as a percentage of the difference between theoretical and actual density.

METALLOGRAPHIC EXAMINATION

During the experiment, the test specimens, which were shaped into dimensions of 30 mm x 20 mm x 5 mm, were subjected to a mechanical grinding procedure using abrasive materials with grit sizes ranging from 120 to 640. Afterward, a polishing process was carried out using diamond pastes with particle sizes of 3 µm and 1 µm. An etching solution known as Keller's reagent was applied to the sample for a duration of 10 seconds. This was done to examine the microstructure of the material after a process of deep etching, which aimed to expose the interfacial microstructure between the aluminum base alloy matrix and B_4C. Subsequently, the sample was cleaned using acetone. The Zeiss GeminiSEM 500 model, a Field Emission Scanning Electron Microscope (FESEM), was used to do surface microscopic investigation. This imaging technique enabled a comprehensive analysis of the spatial distribution of B_4C particles, quantification of the percentage of surface area covered by these particles, and investigation of the interfaces between B_4C nanoparticles and Al 6061. The existence of nano particle B_4C particles and the type of the interaction were determined using Oxford Instrument's energy dispersive X-ray analysis (EDX) with the X-Max 80 model. The analytical methods used gave in-depth understanding of the structure and surface properties of the produced composites.

ELECTROCHEMICAL STUDY

The investigation involved conducting electrochemical experiments utilizing a Gamry Instruments Reference 600 electrochemical workstation in Warminster, PA, USA. The electrochemical performance analysis utilized a three-electrode compartment cell, with the working electrode consisting of either the produced aluminum composite or the base alloy under evaluation. The electrodes used were a silver/silver chloride electrode (Ag/AgCl) as the reference electrode and a graphite electrode as the counter electrode. The electrode potentials were measured using the silver/silver chloride electrode (Ag/AgCl) as the reference. The polarization experiment was carried out without any additional surface treatment just after an hour of corrosion potential running on the same electrode.

HARDNESS AND TENSILE TEST

Brinell hardness values of polished samples were measured using Brevetti Affri Model 206 RSD hardness tester according to ASTM E10-18 standard test method for Brinell hardness of metallic material. Hardness test was conducted using a 2.5mm diameter ball under a load of 62.5 kgf and a 10s dwell time. The tensile properties of the samples were assessed following the guidelines specified in ASTM E8 standard test methods for Tension Testing of metallic material. The experiment was conducted using samples in the Universal tensile testing machine (Simadzu brand, Autograph AG-X Plus model, maximum capacity 20KN) at a strain rate of 2 mm/min. Three specimens were examined for each composition to determine their tensile strength. The average value of the tensile strength was then plotted. Figure 1 depicts the specimen used for the tensile test.

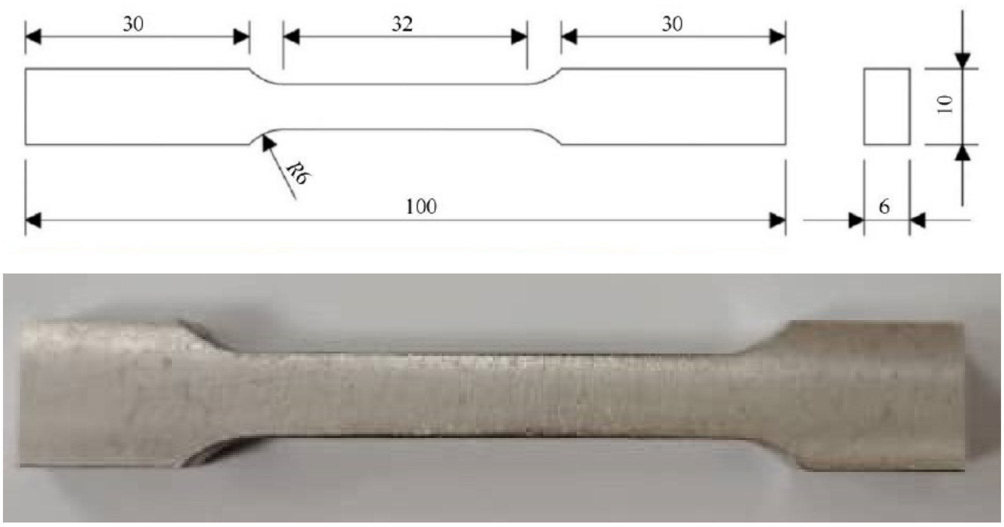

FIGURE 1. Typical specimen prepared for tensile tests

RESULTS AND DISCUSSION

MICROSTRUCTURAL CHARACTERIZATION OF COMPOSITE

The field emission -scanning electron microscope (FESEM) images of 0.2,0.6, 0.8 and 1.0 wt% nanocomposite B_4C in Al 6061 matrix fabricated by two steps of stir casting process are shown in Figure 2.

The distinct contrast zone in the micrograph is associated with boron carbide. The even dispersion of boron carbide throughout the aluminum matrix is the critical factor in the manufacturing of aluminum matrix composites. Figure 2(a) demonstrates that the second phase reinforcement is evenly distributed throughout the matrix, without any clustering or segregation. The addition of more boron carbide resulted in the clustering of reinforcement particles within the aluminum matrix. Increasing the volume proportion of reinforcement is known to result in a higher level of porosity and clustering in the reinforcement

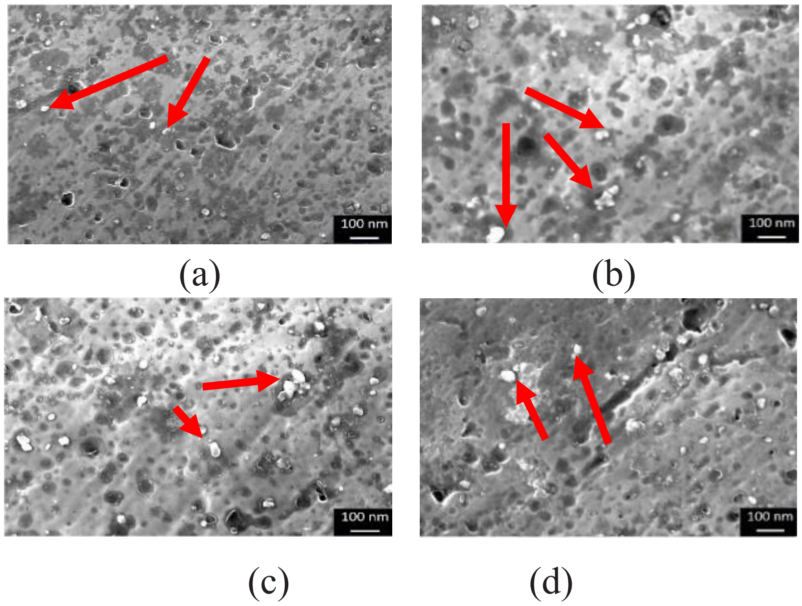

FIGURE 2. SEM micrographs showing etched surface of stir casting aluminium alloy (6061) matrix composite with (a) 0.2 wt%, (b) 0.6 wt% , (c) 0.8 wt% and (d) 1.0 wt% B_4C. Red arrow indicate B_4C position in the matrix Al

(Rao et al. 2010). Nevertheless, the high volume proportion of B_4C particles may be uniformly distributed in the aluminum matrix by employing the two-step stir casting procedure. Moreover, it has been found that the inclusion of magnesium in the AA6061 alloy enhances the capacity of the particles to spread by reducing the surface tension of the molten material. (Doel & Bowen 1996).

XRD ANALYSIS

In order to validate the presence of B_4C as reinforcement and identify other phases generated, the XRD studies were carried out on Al6061 based composites reinforced with 1.0wt% of B_4C particles, matrix aluminium of 6061 and reinforcement B_4C as shown in Fig.3. Bottom line of the Figure 3 displays the X-ray diffraction pattern and outcomes of the Al 6061 alloy with a 1.0 wt% B_4C aluminum matrix composite. In x ray diffraction pattern, seven peak have been obtained in the 2-span ranging from 20 to 80 and the peaks at 2ϴ of 23.50°, 34.92° and 37.69° belongs to B_4C and the peaks at 2ϴ of 38.51°, 44.82°, 65.18° and 78.28° belongs to pure Al and other remaining minor peaks attributed to impurity.

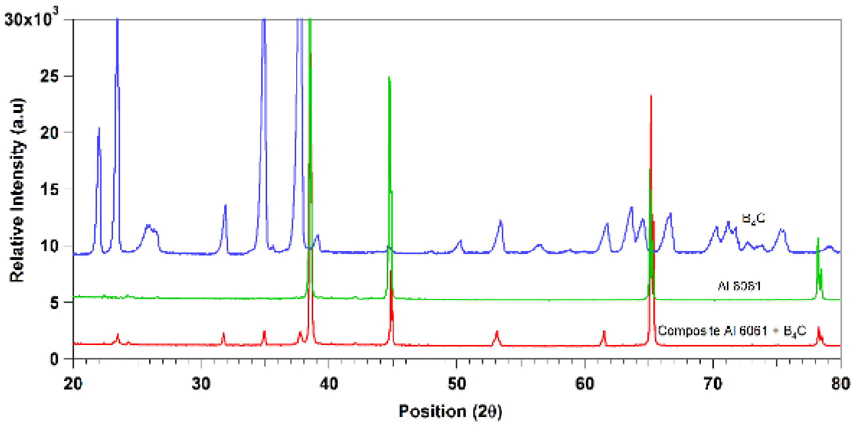

FIGURE 3. XRD analysis of B_4C particle, Al6061 and Al-1.0%B_4C composite

HARDNESS, DENSITY AND POROSITY OF COMPOSITE

The weight percentage of nanocomposite B_4C was increased, which improved the mechanical properties of matrix alloy AA6061. Figure 4 illustrates the correlation between the weight fraction, expressed as a weight percentage (%wt.) of B_4C reinforcing particulate matter in the nanocomposite, density and the hardness value of the produced aluminium matrix composite. It was discovered that when the quantity of reinforcement particles increased, the macrohardness of the aluminum matrix composite increased linearly. However, increasing the volume fraction of B_4C nanoparticles decreases the overall density of the composite. This is consistent with the material properties of B_4C and aluminum, where B_4C's lower density but high hardness contributes to these observed trends (Rajanish et al. 2024) .

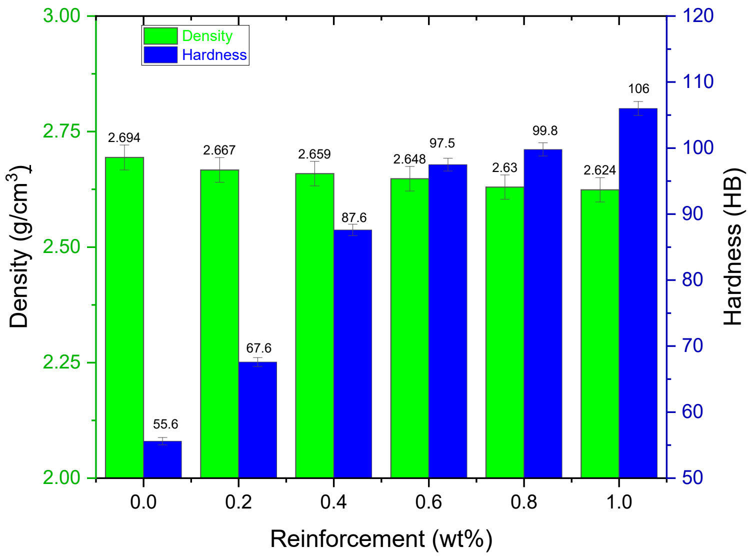

FIGURE 4. Bar chart of nano size B_4C particle wt% with brinell hardness and density of composite

The weight percentage of nanocomposite B_4C was increased, which improved the mechanical properties of matrix alloy AA6061. Figure 4 illustrates the correlation between the hardness value of the aluminum matrix composite and the weight fraction, expressed as %wt, of the B_4C nanocomposite reinforcing particles. It has been noted that when reinforcement particle concentration increases, the macrohardness of the aluminum matrix composite increases linearly.

The inclusion of solid surfaces in particles provides enhanced resistance to plastic deformation, leading to an elevation in the hardness of the composite material. The paper by (Ramesh et al. 2009) asserts that the inclusion of hard ceramic material into a soft and malleable matrix leads to a substantial increase in hardness, but at the expense of reduced ductility in the composites. Reinforcement particles significantly enhance the load-bearing capacity of the metal matrix composite, limit matrix deformation by limiting disruptive displacement, and ultimately raise the overall strength of the composites (Baradeswaran & Elaya Perumal 2014).

The results are represented in Table 1 and the respective for both experimental density and porosity. The theoretical density is decreasing with increasing B_4C reinforcement particles due to its low density. The experimental density by Archimedes Principle and theoretical density was calculated using rule of mixture. Further, measured density of composites is lesser than theoretical density, could be due to the presence of porosity. In the present study, it was noticed that the density is decrease with increasing reinforced ceramic particles while the (Rajanish et al. 2024)porosity is increases. Since the density of boron carbide (2.52 g/cm3) is less than the density of Al 6061 (2.70 g/cm3), the overall density of the Al-B_4C nanocomposites is reduced by increasing amount of boron carbide. Further addition of reinforcement particles decreases the density due to agglomerations that create voids. These results are also supported with the results already reported by (Gómez et al. 2009)

The addition of extra reinforcement during stir casting leads to an increase in the porosity of the composites. This is because pores are formed on the surfaces of the reinforcement particles. As a result, more gas bubbles are generated and the flow of liquid metal in the composites is reduced (Ponappa et al. 2013). According to Sambathkumar et al. (2017) porosity levels below 4% have been deemed acceptable in cast Aluminium matrix composites. Nevertheless, processing approaches have an impact.

Porosity, a prevalent imperfection in composites, can lead to an increase in density. Nanocomposites that are well-processed and have limited porosity will show a decrease in density as the B_4C content increases. Modifying the proportion of boron carbide results in a moderate alteration in the density and porosity of composites. The density of the composite varied depends on the amount of absorbed reinforcement by the matrix. However, it has been observed that some ceramic phases cannot be entirely absorbed by the aluminum matrix, leading to the formation of a slag-like material (Sunil Kumar Reddy et al. 2021). The presence of these unabsorbed ceramic phases can directly affect the overall density of the composite material

TABLE 1. showing the theoretical and measured densities of as cast Al 6061 and with 0.2,0.4, 0.6, 0.8 and 1.0 wt% of B_4Cp respectively

Composition	theoretical Density (g/cm^3)	Measured Density (g/cm^3)	Porosity	% Porosity
6061 Al	2.7000	2.6940	0.00222	0.22
6061 Al +0.2% nB_4C_p	2.6996	2.6670	0.01208	1.21
6061 Al +0.4% nB_4C_p	2.6992	2.6590	0.01490	1.49
6061 Al +0.6% nB_4C_p	2.6989	2.6480	0.01886	1.89
6061 Al +0.8% nB_4C_p	2.6985	2.6300	0.02538	2.54
6061 Al +1.0% nB_4C_p	2.6981	2.6240	0.02746	2.75

POTENTIODYNAMIC POLARIZATION TEST

To further confirm the polarization result, corrosion potential measurements were carried out for the composite and based alloy in 3.5% NaCl solution

Before the tafel polarization measurement, the variation of E_{ocp} as a function of time was measured, and the graph is shown in Figure 6. It is observed that the E_{ocp} is stable at 810±4mV, 778±2mV, 703±4mV, 680±3mV,702±4mV and 765±4mV for Al 6061, Al-0.2%B_4C, Al-0.2%B_4C, Al-0.4%B_4C, Al-0.6%B_4C, Al-0.8%B_4C and Al-1.0%B_4C respectively An investigation was conducted to analyze the impact of different compositions of nanocomposite B_4C particles on the polarization behavior of aluminum composites at room temperature. The corresponding tafel plot and kinetic

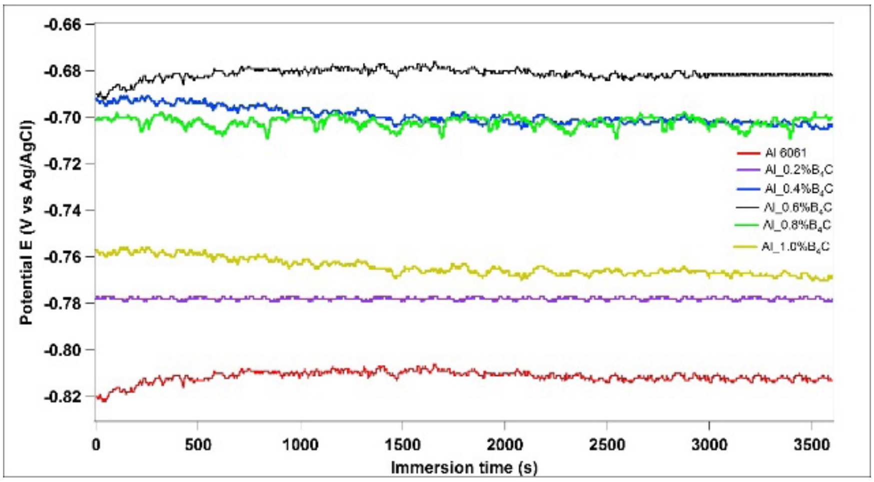

FIGURE 6. Variation of corrosion potential of aluminium alloy Al6061-B4C matrix composite material in 3.5% NaCl with time at 25±3 °C

parameter can be found in Table 3 and Fig. 7, respectively. Table 3 presents a concise overview of the corrosion potential, corrosion current density, and anodic-cathodic tafel slope.

The data demonstrates that the corrosion current (I_{corr}) rises from 3.004 to 10.0 µA/cm^2 when the B_4C composition increases from 0.2% to 1.0 wt.%.

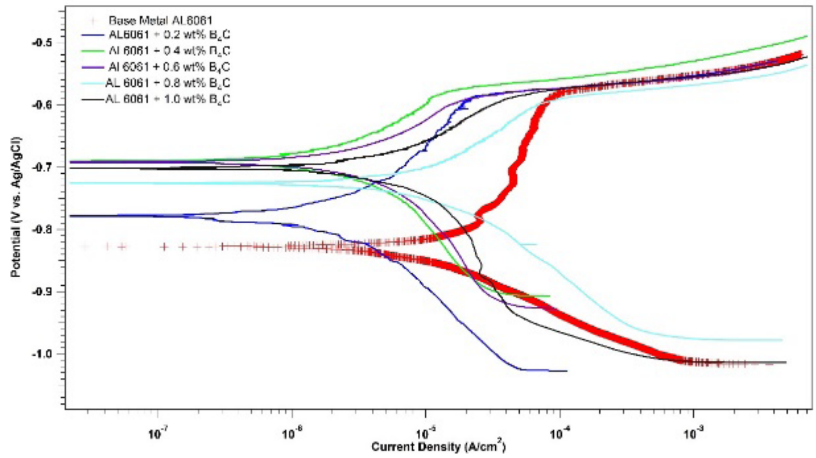

FIGURE 7. Tafel plot polarization curves comparing the behavior of aluminum 6061 and its B_4C composite in a 3.5% NaCl solution. The potential scanning rate is 1 mV/s at a temperature of 25 °C ±2 degrees

This indicates a substantial increase in the corrosion rate of the composite with higher boron carbide content. Adding a little amount (less than 1.0 wt.%) of boron carbide increases the corrosion resistance compared to the base alloy. Based on the data collected, the aluminum composite containing 0.2 wt.% of B_4C exhibits the lowest corrosion current density (I_{corr}) compared to the current density of alloy based. The corrosion rate of the composite undergoes a substantial rise following the addition of 0.8 and 1.0 wt.% B_4C. The high proportion of unevenly dispersed B_4C particles caused the B_4C to clump together in the aluminum matrix, leading to the disintegration of the passive layer.

TABLE 2. The electrochemical properties of the Al-B_4C composites in a 3.5% NaCl solution were determined by analyzing their polarization behavior

B_4C content (wt%)	E_{corr} (mV vs Ag/AgCl	I_{corr} (µA/cm^2)	βc (mV/dec)	βa (mV/dec)	Corrosion rate (µm/yr)
0	-827.6	5.684	130.8	316	62.57
0.2	-778.5	3.004	209.6	205.5	10.52
0.4	-690.7	3.420	218.4	160.4	11.97
0.6	-691.9	5.197	272.1	152.4	18.21
0.8	-701.3	7.036	257.7	133.9	24.65
1.0	-757.7	10.0	146.5	136.2	35.03

The agglomeration of B_4C will result in the formation of discontinuities in the passive layer of aluminum oxide, allowing hostile ions to penetrate through. The addition of 0.2 wt% of nanocomposite B_4C caused a shift in the corrosion potential from -827.6 mV to -778.5 mV in the composite. Unfortunately, the shift does not continue where the shift on the negative direction when content of B_4C up to 1.0 wt.%. According to the mixed potential hypothesis, an increase in the B_4C concentration in the composite material will cause the material's potential to shift towards a more noble direction. (Katkar et al. 2011). However, when the content of B_4C in the composite rises, the protective surface oxide layers become less continuous, leaving the Al-1.0 wt.% B_4C nanocomposite more susceptible to the chloride ions and producing a less noble potential.

TENSILE STRENGTH

Figure 8 illustrates the measurements of tensile strength for Al6061 metal matrix composites that have been reinforced with B_4C. Al6061 composites exhibit superior tensile strength compared to the base alloys. The enhanced strength of the composites is attributed to the existence of rigid reinforcing particles. The ceramic particles (B_4C) in the aluminium alloy matrix composite are evenly distributed, effectively obstructing the movement of dislocations in the matrix alloy. This leads to a reduction in fracture. The high strength of B_4C particles allows them to effectively carry a significant portion of the applied load, reducing the stress borne by the weaker aluminum matrix. B_4C particles act as obstacles to the movement of dislocations, which are responsible for plastic deformation in metals thereby enhancing the overall strength and stiffness of the composite (Kumar et al. 2021).

This impediment to dislocation motion requires higher stress to deform the material, thus increasing its strength The inclusion of ceramic particles primarily enhances the fracture and tensile strength of the composite material by facilitating the transmission of stress from the ductile aluminum matrix to the brittle reinforced particles (Adityawardhana et al. 2023)

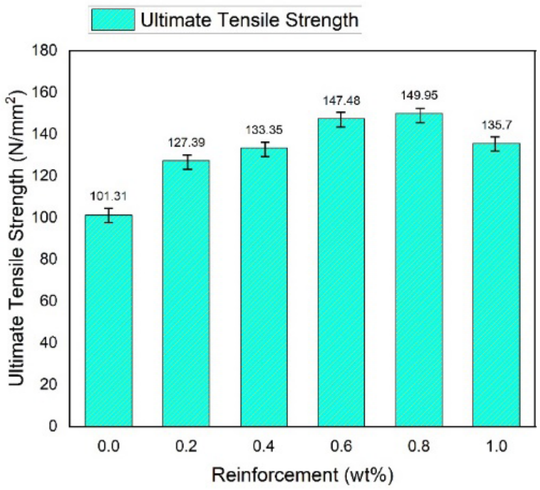

FIGURE 8. The tensile strength of composites made from aluminium 6061 reinforced with boron carbide

This impediment to dislocation motion requires higher stress to deform the material, thus increasing its strength. This mechanism of stress transfer and the impediment of dislocation movement has been shown to enhance the tensile strength of the material.

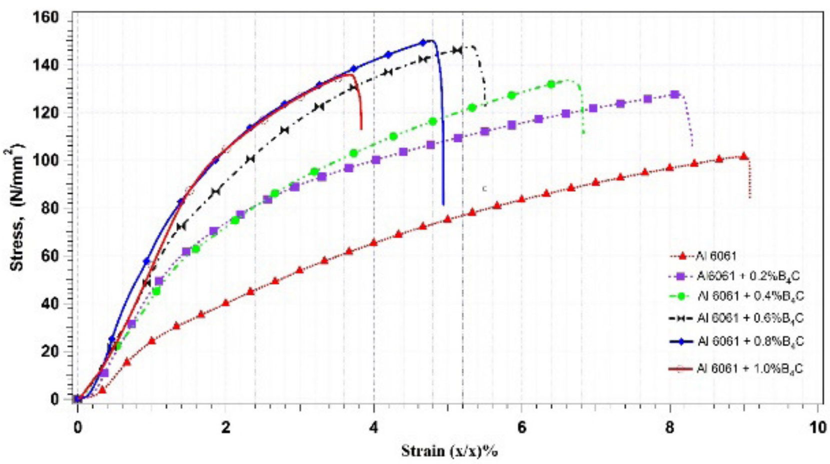

FIGURE 9. The stress-strain curve depicts the behavior of an aluminum matrix composite that has been reinforced with different amounts of boron carbide.

This phenomenon is attributed to the Orowan mechanism, where dislocations are able to bypass large obstacles, such as particles, that obstruct their movement (Murali et al. 2014). This results in an enhancement in the tensile strength. The strength of the 0.8wt% B_4C nanoparticle sample reached a maximum value of 149.95 MPa, which represents an increase of around 48.64 MPa (32%) compared to the base alloy. The decrease in strength in sample 1.0%B_4C is attributed to the presence of sharp edges on the hard ceramic particles, which serve as nucleation sites and cause particle agglomeration. Increasing the volume fraction of B_4C generally leads to an increase in tensile strength. However, there's often an optimal volume fraction beyond which the strengthening effect may plateau or even decrease due to factors like particle agglomeration. Fractures will occur as a result of the high concentration of stress at the nucleation location (Bhushan & Kumar 2011). Figure 9 illustrates the correlation between stress and strain in Al6061 matrix composites. The augmentation in the volume fraction of reinforcement from 0.2% to 0.8% resulted in a corresponding enhancement in both the tensile strength and yield strength. Increasing the volume percentage of reinforcing particles resulted in a decrease in the fracture strain. Figure 9 demonstrates a steady decline in the ductility of the composite materials due to the resistance of the reinforcing particles against the plastic flow of the matrix material. This is because B_4C particles are brittle and can act as stress concentrators, leading to early crack initiation and propagation under tensile loading (Clayton et al. 2019). As the content of nano composite B_4C within the aluminum matrix is increased, the composite increasingly inherits the high stiffness of the boron carbide, resulting in a corresponding enhancement in the overall modulus of elasticity of the composite

CONCLUSION

The findings of this investigation are highly significant and can be summed up as follows:

1. It was found that the two-step stir-casting process produced B_4C nanoparticles with a largely homogenous distribution across the microstructure. Nonetheless, there was a propensity for the B_4C nanoparticles to form tiny clusters.
2. The measured densities of composites are higher than those of their underlying matrix according to the Archimedes principle.
3. The Al6061-B_4C nanocomposite exhibited enhanced corrosion resistance in a 3.5% NaCl solution as compared to the base metal. However, the act of raising the weight fraction of nano-sized boron carbide resulted in the clustering of the reinforcement particles within the aluminum matrix. The agglomeration of B_4C particles resulted in a reduction in the continuity of the protective surface oxide layers. As a consequence, the Al-B_4C nano composite became more vulnerable to chloride ions and exhibited a lower noble potential. As a result, the corrosion rate was increased with increasing the content of nano size B_4C.
4. The Brinell hardness test results showed that the macrohardness was improved with the increase of reinforced B_4C nano composite particulates.
5. The composite containing 0.8 wt% B_4C had a maximum strength of 149.95 MPa in the tensile test, which was approximately 48.64 MPa (32%) higher than the basic alloy.

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DECLARATION OF COMPETING INTEREST

None.

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