

Evaluation of physical, mechanical and corrosion properties of BN reinforced Al7079 metal matrix composites

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Abstract— Metal matrix composites (MMCs) are regarded as viable alternatives to conventional materials such as metals, plastics, and ceramics in structural applications due to their properties, including lightweight, high specific stiffness, elevated elastic modulus, enhanced specific strength, and excellent wear resistance. Among the many metal composites, aluminum metal matrix composites (MMCs) have emerged as sophisticated engineering materials for several prospective applications in engineering industries due to their superior qualities compared to typical aluminum alloys. Ceramic particles are the most extensively utilized reinforcements in MMCs due to their superior wear resistance, thermal stability, and exceptional bonding with the matrix. This research work has been conducted to develop ceramic particle-reinforced aluminum matrix composites and to evaluate their physical and mechanical properties. Al7079 alloy and Boron Nitride (BN) are selected as the matrix and reinforcement for the study respectively. The stir casting technique was utilized to fabricate the composites. Al7079-BN composites are prepared by varying the percentage of BN reinforcement particles from 0 to 8% by volume, with an increment of 2%. Test specimens were machined from the produced composites for the evaluation of microstructural, physical, mechanical properties according to ASTM standards. The microstructural analysis of the produced samples was conducted using scanning electron microscopy (SEM). The density of the composite was assessed empirically using Archimedes' principle and theoretically through the rule of mixture. Microstructural analysis reveals a homogeneous distribution of BN particles throughout the matrix without any agglomeration, and it also demonstrates excellent bonding. The density of the composites decreased by approximately 4.6% with the incorporation of BN reinforcement up to 8%, attributed to the lower density of BN particles. Corrosion resistance of the composite found to be significantly with increase in reinforcement content.

Key words: Aluminium alloy, boron nitride (BN), Metal matrix composites (MMCs), mechanical property, corrosion property

I. INTRODUCTION

The 7xxx aluminum alloy possesses high strength, low density and excellent processing capabilities,

making it a crucial structural material in the aerospace sector, automobile and marine industry. As these sectors advances, high-strength aluminum alloys must possess exceptional overall qualities. In recent decades, some engineering materials including magnesium alloy, titanium alloy and composite materials, have exhibited significant advancement, presenting challenges to 7xxx aluminum alloy. Consequently, to maintain competitiveness in its primary sector and secure additional prospects in emerging industries, the 7xxx aluminum alloy necessitates continued enhancement of its performance. Micron and nano-scale ceramic particles such as alumina (Al_2O_3), silicon carbide (SiC), titanium oxide (TiO_2), titanium carbide (TiC), aluminium nitride (AlN) and boron carbide (B_4C) are extensively utilized as reinforcements in aluminum matrix composites (AMCs) for many industrial applications. BN particles are among the most commonly utilized reinforcement materials for Al matrix composites, owing to their availability and exceptional qualities, including high mechanical strength and excellent chemical stability at elevated temperatures. The process of liquid casting facilitates the production of composites featuring complex designs. It is preferable to produce lightweight bulk components composed of metal matrix composites that exhibit uniform reinforcing distribution and preserve structural integrity. The use of micro-sized ceramic particles poses difficulties owing to their elevated viscosity, poor wettability in metal matrices, and substantial surface area-to-volume ratio. Attaining a homogeneous distribution of these particles in liquid metals is challenging. To resolve this issue, pretreatment of the particles is essential to improve their bonding capacity with the metal matrix.

The primary drawback of aluminium alloys is their diminished resistance to elevated temperatures and wear characteristics. To address this issue, researchers commenced the fortification of aluminium alloys using ceramic nanoparticles such as

boron carbide, silicon carbide, and aluminum oxide. It is essential to develop advanced mechanical strength aluminum matrix composites for the aerospace and automotive sectors to ensure prolonged fatigue lifetimes in structural components [1]. The propensity of the metal to enhance corrosion resistance mostly relies on the cooling rate during solidification, which influences the redistribution of solid particles, the dendritic atomic size, and the electrochemical properties of the solution [2]. The density of the fabricated AMCs diminished by up to 9 wt% with additional reinforcement, whereas porosity escalated from 3.7% to 11% in the Al/10%SiC/15%RHA composite compared to pure Al alloy. The microstructural study of the composite demonstrated a homogeneous distribution of SiC and RHA particles, except for the 15% RHA composite, which displayed aggregation of RHA particles [3]. Investigated the corrosion resistance of powder metallurgy composite material composed of ENAW-2124 aluminum alloys enhanced with Al₂O₃ ceramic particles. They determined that Al₂O₃ particles diminish the corrosion resistance of the AMCs composite. This is attributable to the potential for selective corrosion at the interface between the ceramic particles and the matrix material phases [4]. Investigated the corrosion behavior of a metal matrix composite comprising aluminum alloy 7020 reinforced with Al₂O₃ particles at weight percentages of 5%, 7%, and 10%, with particle sizes ranging from 53 to 75 μm. The alloys were fabricated by the molten metal atomization method. The corrosion behavior of aluminum matrix composites (AMCs) in a 3.5% NaCl solution was analyzed by potentiodynamic polarization studies. He determined that the corrosion rate escalates with higher concentrations of Al₂O₃ particles in the specified atomized samples immersed in a 3.5% NaCl solution at a temperature of 30°C. This results from galvanic corrosion between the matrix and reinforcement, as well as the presence of secondary phases surrounding Al₂O₃ particles in the microstructure of AMCS [5]. Investigated the corrosion characteristics of aluminium 6061 alloy incorporating 15 volume percent silicon carbide particles in a 5 molar sodium hydroxide solution concerning its electrochemical behavior. The tests were conducted utilizing the ACM electrochemical workstation version 5. They conducted potentiodynamic polarization and impedance investigations. The results were deemed unsuitable for applicability. The matrix demonstrated a reduced corrosion rate relative to composite materials in

sodium hydroxide, despite an increase in reinforcement content. They conclude that the composite and matrix alloy do not exhibit passivation. [6]. Developed composite materials utilizing aluminium 6061 alloy infused with silicon carbide particles and evaluated their corrosion resistance in a salt chloride environment. The pitting potentials for the composites were nearly same, regardless of the varying quantities of SiC particles. The corrosion rate escalated with higher SiC p concentration, leading to the conclusion that the development of galvanic couples contributes to the enhanced corrosion rate [7]. Investigated the mechanical and corrosion-related characteristics of cobalt-reinforced aluminum 6061 composites. Their research led them to the conclusion that mechanical qualities improve and corrosion properties decrease with increasing cobalt percentages [8]. assessed the corrosion behavior of an aluminum 6061 alloy containing 15% SiC particles in three different potassium hydroxide concentrations at different temperatures. In addition, they looked at how adding 8-hydroxy quinolone inhibited the process. They draw the conclusion that corrosion rates for matrix and composite materials rise with increasing potassium hydroxide concentrations. According to their findings, the corrosion caused by potassium hydroxide actually increases as the temperature rises, regardless of the exact concentration [9]. A graphene-SnO₂ composite film is successfully fabricated to improve the corrosion of AA 6061 in a heavily acidic environment. The sample is firstly etched to attain hydroxyl groups on the surface of AA 6061 and is then immersed alternately in the positive charge of Poly (diallyl dimethyl ammonium chloride) (PDDA) aqueous solution and the negative charge of graphene oxide (GO) aqueous solution, respectively, to attain a (PDDA-GO)₁₀-modified substrate by a self-assembly method [10]. Some preparation methods, such as chemical vapour deposition and heat treatment, are relatively high in cost and their preparation conditions are very rigorous. Therefore, combining graphene and SnO₂ to protect aluminium alloy 6061 (AA 6061) from corrosion with a simple and low-cost method can achieve good results, including a high protection efficiency of 99.7% in a heavily acidic solution of 0.5 M H₂SO₄ and 2 ppm HF [11].

The motivation and interest behind the research work is to produce a lightweight and higher strength-to-weight ratio which should have good physical and mechanical properties for sustainable aerospace, automotive and marine applications. The addition of

BN improves the mechanical and corrosive properties of the composites. This investigation aims to study the effect of adding Boron Nitride (BN) to the Aluminium 7079 alloy (AA7079) matrix as a reinforcement processed through the stir casting route. Density, Brinell hardness and corrosion test are utilized to get the results and for further evaluation of the prepared composites.

II. MATERIAL SELECTION

A. Matrix

The aluminum alloy 7079 has been selected as the matrix material. The Al7079 alloy in its ingot state is depicted in Fig. 1. Zinc is the primary alloying element, added in quantities of 3.8 to 4.8%, and is combined with a lesser percentage of magnesium, 2.9 to 3.7%, resulting in a heat-treatable alloy. The chemical composition of the Al7079 alloy is presented in Table 1. These alloys are advantageous for medium to high-strength applications when copper and chromium are incorporated in minimal proportions. High-strength Al7079 alloy has reduced susceptibility to stress corrosion cracking and is frequently utilized in a slightly lower temper to provide an improved mix of strength, fracture toughness, and corrosion resistance.



Fig. 1 Al7079 in ingot form

Table 1 Composition of Al 7079

Element	Content (%)
Zn	3.8-4.8
Mg	2.9 – 3.7
Cu	0.40-0.8
Fe	0.40 max
Si	0.30 max
Mn	0.10 – 0.30
Cr	0.10 – 0.25
Ti	0.10 max
Al	Remainder

high temperatures in inert atmospheres and melts at 1300 °C, density of BN is 2.1 g/cc. BN is a ceramic compound that consists of boron and nitrogen atoms.

It possesses unique characteristics that make it suitable for reinforcement in various composite systems. With addition of BN it improves the mechanical properties, thermal conductivity and electrical resistivity.

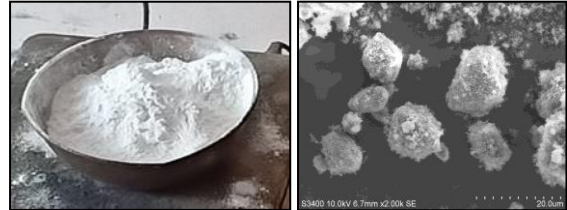


Fig.2 (a) BN powder sample (b) SEM image of BN particles

III. FABRICATION PROCESS

The fabrication of specimens with varying percentages of aluminium nitride was conducted via the stir casting technique at ambient temperature, utilizing optimal process conditions. The schematic diagram of stir casting and the actual setup utilized for the current study are illustrated in Fig. 3(a) and (b). This method entails the incorporation of particles into molten aluminium via stirring, followed by the solidification of the material in the mould under standard environmental conditions. The requisite quantity of Al7079 alloy in ingot form was initially melted at 700 – 750 °C utilizing an electric resistance furnace. The aluminum nitride particles and permanent mold were warmed to 400 °C to mitigate the chilling impact during solidification. Degassing of the molten metal was accomplished by using commercially available tablets of Hexachloroethane (C₂Cl₆). The primary limitation of the particle reinforced metal matrix composite is wettability, which can be enhanced by using a tiny proportion (<2%) of magnesium chips. Coverall (1%), a drossing flux with a melting temperature of 607 °C, is incorporated to diminish the surface tension between metals and to create a continuous layer over the molten metal, so safeguarding it against oxidation and the absorption of air hydrogen. The stainless steel stirrer, coated with zirconia and featuring a blade angle of 30°, is employed to create a vortex in the melt. The stirrer height is adjusted to ensure that two-thirds of its length is submerged in the melt. The preheated reinforcement was gradually introduced into the melt, with stirring maintained at 400 rpm for an additional 15 minutes following the complete incorporation of the reinforcement. The temperature was consistently maintained with an accuracy of ±5 °C via a digital temperature controller.

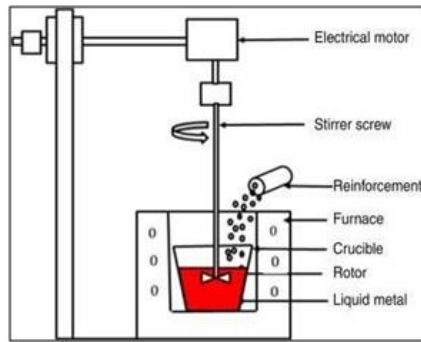


Fig. 3: Stir casting process

IV. SPECIMEN PREPARATION

Specimens of Al7079-BN composites were prepared for microstructural observation, density measurement, hardness and corrosion test in accordance with ASTM standards. The dimensions for the corrosion test specimen is illustrated in Figure 4.

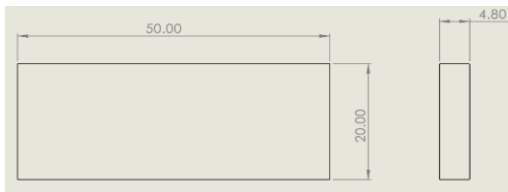


Fig. 4 corrosion test specimen geometry

V. EXPERIMENTAL WORK

A. Microstructural study

A metallographic study was done for the casted aluminium matrix composites using Scanning Electron Microscopy to ensure the homogeneity of distribution and interfacial bonding between matrix and particle.

B. Density measurement

The effect of BN reinforcement on the density of the developed composites are studied both experimentally by using Archimedes principle and theoretically by using the mass by volume ratio. The experimental density is determined by using mathematical equation is given below.

$$\rho_{ex} = \frac{m}{m - m_1} \times \rho_w$$

Where

m is the mass of the composite sample in air,
 m_1 is the mass of the same composite sample in distilled water.

ρ_w is the density of the distilled water.

C. Corrosion test

The test specimens were assigned a unique identity and measured to ascertain the area. All specimens were initially rinsed with acetone to eliminate any organic contaminants, followed by a wash with water. The specimens were subsequently rinsed with 0.1M hydrochloric acid to eliminate any scales or corrosion products, followed by a water wash and drying in a hot air oven at 60°C for 30 minutes. The precise weight of the cooled specimens was recorded.

All specimens were submerged in 0.5M sulfuric acid (acidic corrosion) and 0.5M sodium hydroxide (alkaline corrosion) to the designated level and incubated at 30°C for 72 hours. The specimens were subsequently extracted and rinsed with 0.1M hydrochloric acid to eliminate the corroded material, followed by scrubbing with Embry sheets to get a pristine surface. The specimens' final weight was recorded, and the corrosion penetration rate was determined using the formula.

$$CPR = \frac{k w}{d A t}$$

Where K = Corrosion penetration rate constant, W = weight loss observed, d = density of the specimen, A = area of specimen, t = time in hours





Fig. 5 corrosion test equipment and samples

VI. RESULTS AND DISCUSSIONS

A. Microstructural analysis

The microstructure and distribution of BN reinforcement particles in the developed composites were analysed using SEM. Fig. 6 (a) to (e) shows the SEM images of fabricated composites. It reveals the presence of BN particles in aluminium metal matrix and it is observed that the reinforcement particles are adequately dispersed in the matrix. The composites exhibits rich interface between the matrix and alloy, during solidification of composites the dendrites of aluminium solidify initially BN particles are precluded by solid-liquid interface resulting in segregation of BN particles at the inter dendrite region. The developed composites are also observed to be free from any kind of casting defects such as porosity, inclusion of slag and shrinkage, which may result from the poor bonding between the matrix and reinforcement at the time of casting and solidification [12]. The average spacing between the reinforcement particles is reduced with the increase in reinforcement content. The homogeneous distribution of the particles in the developed composites may be attributed to the parameters selected for the fabrication of these composites. The microstructure of the composites indicates that the stirring process was adequate to achieve a homogeneous structure. The distribution of reinforcement particles is actually depends on the density gradient between the molten alloy and particles [13].

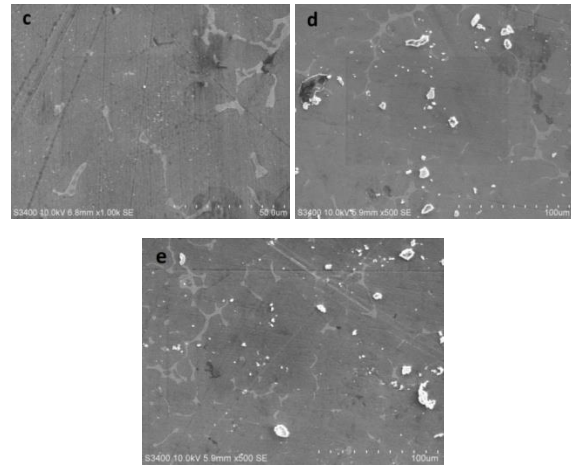
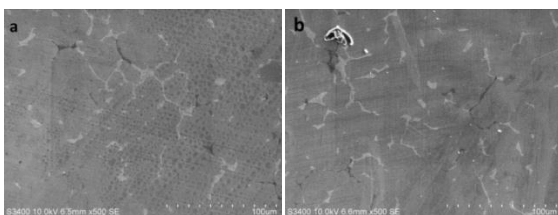


Fig 6: SEM images of (a) Al7079 (b) Al7079+2%BN (c) Al7079+4%BN (d) Al7079+6%BN (e) Al7079+8%BN

B. Density

The variation of density values with respect to increasing reinforcement percentage is illustrated in fig. 7. From the results it is observed that experimental density of Al7079 alloy was 2.56×10^{-3} g/mm³ and density of Al7079 -8% BN composite is found to be 2.68×10^{-3} g/mm³ and theoretical density of Al7079 alloy is 2.61×10^{-3} g/mm³ and density of Al7079 -8% BN composite is found to be 2.71×10^{-3} g/mm³. It is witnessed that both theoretical and experimental density of the samples decreases by 4.6 % and 3.8 % the addition of BN particles about 8 %. This decrease in density is attributed to lower density of reinforcement particles [15,16]. This decrease in density is attributed to the addition of slightly lower density BN particles (2.11 g/cm³) to higher density Al7079 alloy (2.72 g/cm³).

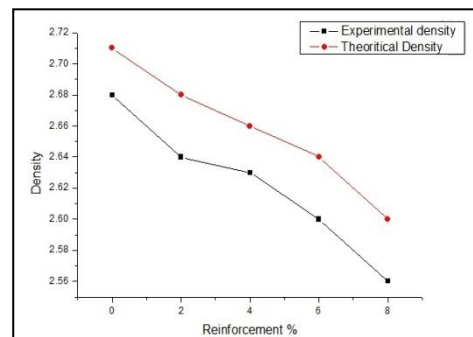


Fig. 7 Variation of density with various % of reinforcement

C. Hardness

It is observed that hardness for unreinforced Al7079 alloy is 76.9 BHN and for Al7079 -8% BN composite is 95.72 BHN. From the results it is

observed hardness of the composite increased by 24.4% for the addition of BN reinforcement about 8%. The variation of Brinell hardness with percent of reinforcement is shown in Fig. 8.

This increase in hardness of the samples can be ascribed to the particle strengthening and capacity to bear the load due to increased content of the comparatively harder reinforcement in the matrix [17]. The addition of BN particles in the continuous matrix increases its surface area and it also reduces the grain size of aluminium matrix, the presence of BN particles offers large confrontation to plastic deformation which fall out into rise of the hardness of the developed composites [18,19].

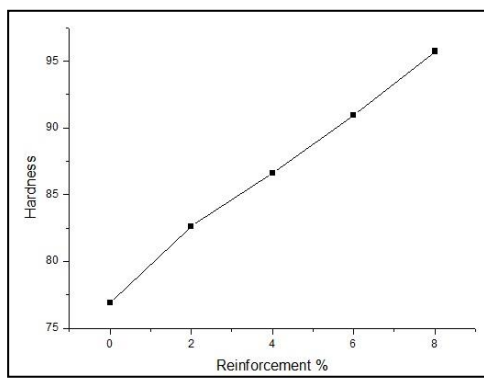


Fig. 8 Variation of hardness value with various % of reinforcement

D. Corrosion property

The corrosion behavior is evaluated for the prepared composites were carried out at room temperature by the means of sodium hydroxide (NaOH) solution. The samples are dipped into the solution at 1cm³. The samples are kept observation upto 72 hours. Then the samples are washed, cleaned and weight loss is measured.

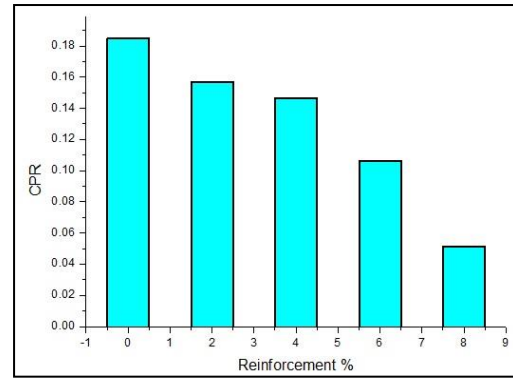
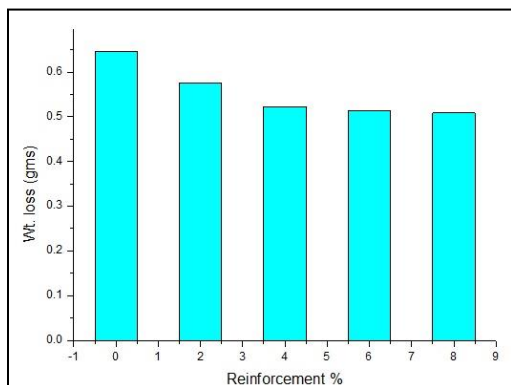


Fig. 9 Weight loss and CPR of the composite for different wt% of reinforcement

As the weight percentage of BN particles increased the corrosion rate dropped and the Al7079-8% BN composite outperformed the unreinforced composites in a NaOH solution. The results show that when the percentage of BN reinforcement increases from 2% to 8% the weight loss due to corrosion falls by 78%.

The results indicate a steady reduction in the corrosion rate, suggesting that passivation inside the metal matrix alloy leads to the formation of a stable layer that influences the corrosion process [20]. The Al7079 particulates reduce the corrosion rate as the weight % of BN particles increases. The corrosion rate for unreinforced Al7079 alloy is 0.18 CPR but with Al7079-8%BN it is 0.051 CPR. The composite's overall corrosion rate has dropped by 22%. The stability of the generated inhibitory layer is influenced by the applied elevated potential. The chloride ion present in the corrosive electrolyte is adsorbed onto the passive layer, thereby initiating corrosion. This adsorption facilitates the dissolution of magnesium by disrupting the established passivation layer, thus leading to the initiation and proliferation of pits. Metals undergo cathodic and anodic reactions during corrosion. In the anodic reaction, metal either dissolves or alters its ionic state. The cathodic process also leads to the formation of a passive layer or the evolution of hydrogen [21,22].

VII. CONCLUSION

Al7079-BN composites were successfully fabricated using stir casting process. Microstructural study of composites shows the even distribution of reinforcement particles throughout the matrix without agglomeration and tough bonding were perceived which is due to the addition of K2TiF6 and preheating of reinforcement

particles before adding which increases the wettability of the particles. Density of the composites increased nearly by 4.6% as the content of BN particle reinforcement increased upto 8%. Hardness of the composite enhanced by 24.4% for the addition of BN particles of 8%. The weight loss of the composites due to corrosion were found to be decreased by 27% as the BN reinforcement is increased from 2% to 8%. Corrosion resistance of the composite found to be significantly with increase in reinforcement content.

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