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Development and Characterization of Nano Banana Peel Ash Reinforced Al7075-T6 advanced Composites: Wear, Impact, and Corrosion Performance

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ABSTRACT

The growing demand for sustainable and high-performance engineering materials has promoted the utilization of agricultural waste-derived reinforcements in aluminium matrix composites. In this study, nanoscale Banana Peel Ash (BPA), synthesized via dehydration, calcination, and high-energy ball milling, was employed as an eco-friendly reinforcement in Al7075-T6 composites fabricated by the stir-casting process. The synthesized BPA was characterized using Scanning Electron Microscopy (SEM), Energy Dispersive X-ray Spectroscopy (EDS), particle size analysis, and thermogravimetric analysis, which confirmed the formation of thermally stable nano-sized particles enriched with oxide-forming elements such as potassium, oxygen, calcium, magnesium, and silicon. The wear behaviour of the fabricated composites was investigated under dry sliding conditions, revealing a significant reduction in wear rate with increasing BPA content. SEM examination of worn surfaces indicated a transition from severe adhesive wear in the base alloy to mild abrasive wear in reinforced composites, characterized by shallow grooves, reduced delamination, and limited wear debris formation. Impact testing demonstrated enhanced energy absorption capability and improved resistance to crack initiation and propagation with BPA addition. SEM analysis of impact-fractured specimens revealed ductile fracture features, including dimples, tear ridges, and microvoid coalescence. Furthermore, immersion corrosion studies showed improved

corrosion resistance due to the formation of stable protective oxide layers and uniform reinforcement distribution. The results confirm that nanoscale BPA is an effective, low-cost, and sustainable reinforcement for enhancing the wear, impact, and corrosion performance of Al7075 composites. The enhanced mechanical, tribological, and corrosion properties of the developed composites are potential candidates for applications in aerospace structural components, automotive parts, marine equipment, defence systems, lightweight machinery components, and other engineering sectors.

Keywords

Al7075-T6, Banana Peel Ash, Dry Sliding Wear, Impact Behaviour, Immersion Corrosion, SEM - EDS Characterization.

1. Introduction

Metal matrix composites (MMCs) have emerged as advanced engineering materials due to their unique combination of low density, high strength, superior wear resistance, and enhanced thermal stability. The growing demand for lightweight, high-performance, and environmentally sustainable materials has accelerated the development of aluminium-based MMCs, which offer improved specific strength and overall mechanical performance compared with conventional monolithic alloys, making them suitable for a wide range of industrial applications [1]. Among the various aluminium alloys used as matrix materials, Al7075 has emerged as one of the most important high-strength alloys owing to its excellent strength-to-weight ratio, fatigue resistance, fracture toughness, and corrosion performance. These characteristics have resulted in its widespread use in aerospace, defence, marine, and automotive structural components, where weight reduction and mechanical reliability are critical requirements [2]. Numerous investigations have demonstrated that the incorporation of suitable reinforcements into Al7075 matrices can significantly improve mechanical, tribological, and corrosion-related properties beyond those achievable by the base alloy alone [3]. The performance enhancement achieved through reinforcement addition is primarily attributed to load transfer mechanisms, grain refinement, dislocation strengthening, and improved resistance to surface degradation processes. Traditional ceramic reinforcements such as silicon carbide, alumina, and boron carbide have been extensively utilized in Al7075 composites because of their ability to improve hardness, stiffness, and wear resistance. Age-hardened Al7075 composites reinforced with ceramic particulates have shown remarkable

improvements in tensile behaviour and microstructural stability, demonstrating the effectiveness of particulate reinforcement in high-strength aluminium alloys [4]. However, despite their technical advantages, conventional ceramic reinforcements often involve relatively high processing costs and significant energy consumption during production. To address these challenges, researchers have increasingly focused on the utilization of industrial and agricultural waste materials as sustainable reinforcement alternatives. Fly ash reinforced Al7075 composites have demonstrated improved physical, mechanical, and tribological properties while simultaneously promoting waste utilization and reducing environmental burdens associated with industrial waste disposal [5]. Similarly, bagasse ash has been successfully incorporated into aluminium-7075 composites, resulting in notable improvements in hardness and tensile strength through effective reinforcement-matrix interactions [6]. Recent reviews on sustainable MMC development have highlighted the growing importance of agro-waste and industrial waste reinforcements as environmentally responsible alternatives to conventional ceramic particles [7]. Agricultural waste materials are particularly attractive because they are abundantly available, inexpensive, renewable, and often contain naturally occurring mineral constituents capable of contributing to composite strengthening mechanisms [8]. Among the various agricultural residues investigated, sugarcane bagasse ash has received considerable attention due to its silica-rich composition and its ability to improve the performance of aluminium composites while supporting circular economy principles [9]. Likewise, date palm ash-reinforced AA7075 composites fabricated through stir-casting have exhibited enhanced microstructural uniformity and improved engineering properties, confirming the potential of agricultural ash particles as effective reinforcement materials [10]. The successful utilization of other agro-waste materials further supports this approach. Coconut shell-ash-reinforced AA7075 hybrid nanocomposites have demonstrated improved microstructural characteristics and enhanced quality parameters when fabricated through ultrasonic-assisted stir-casting techniques [11]. In addition, agro-bio-waste-reinforced aluminium-hybrid nanocomposites have shown significant improvements in physico-mechanical properties following appropriate thermal treatment and particle incorporation [12]. The combination of waste-derived particles with conventional reinforcements has also been reported to improve the mechanical performance of aluminium nanocomposites while simultaneously reducing production costs [13]. Impact resistance is an important consideration for aluminium matrix composites used in aerospace, automotive, and structural applications that are subjected to sudden loading conditions. The incorporation of reinforcements can improve energy absorption capability and resistance to crack initiation and

propagation. Previous studies have reported that particulate reinforcements enhance the fracture-related properties of Al7075 composites through grain refinement and improved interfacial bonding [4,12]. Furthermore, nanoscale reinforcements can effectively impede crack growth and promote uniform stress distribution, thereby contributing to improved impact performance [18].

Among the numerous agricultural wastes generated worldwide, banana peel waste has emerged as a particularly promising reinforcement precursor. Global banana production generates enormous quantities of peel residues that are frequently discarded as waste despite their valuable mineral composition. Recent studies have highlighted the significant potential of banana peel waste within circular bio economy frameworks due to its abundance and rich content of inorganic constituents [14]. Consequently, the valorisation of banana peel waste has attracted increasing scientific attention in fields ranging from renewable energy production to sustainable materials engineering [15]. Banana peel contains appreciable concentrations of potassium, calcium, magnesium, silica, phosphorus, and other mineral constituents. Following controlled thermal treatment, these constituents can be converted into ash particles containing oxide-forming compounds that may contribute to reinforcement strengthening mechanisms when incorporated into metallic matrices. The utilization of banana peel-derived fillers has already demonstrated promising results in polymer-based composite systems, where improvements in physical, thermal, mechanical, and tribological properties have been reported [16]. Further evidence supporting the effectiveness of peel-derived ash reinforcements can be observed in studies involving plantain peel ash. Plantain peel-ash-reinforced aluminium alloys have exhibited enhanced microstructural integrity, improved corrosion resistance, and superior mechanical behaviour compared with unreinforced alloys, indicating that peel-derived agricultural ashes can function as effective reinforcement materials for metallic systems [17]. In recent years, increasing attention has been directed toward the use of nanoscale reinforcements rather than conventional micron-sized particles. Nano-sized reinforcements offer significantly larger specific surface areas, improved interfacial bonding, enhanced load transfer efficiency, and greater grain refinement effects, all of which contribute to superior composite performance [18]. The development of nanoscale agricultural waste reinforcements, therefore, represents an attractive strategy for simultaneously improving composite properties and enhancing sustainability. A critical requirement in the development of such nanocomposites is the accurate characterization of reinforcement morphology, composition, and distribution. Advanced characterization techniques such as energy dispersive spectroscopy

(EDS) mapping have proven effective for quantifying elemental distribution and assessing phase assemblages in particulate-reinforced material systems [19]. Such techniques are essential for understanding reinforcement behaviour and ensuring uniform particle dispersion within aluminium matrices. Recent investigations into banana peel ash have revealed that thermally processed banana peel residues possess significant quantities of inorganic mineral constituents and exhibit favourable characteristics for advanced material applications [20]. Furthermore, emerging research has demonstrated that banana peel ash can serve as a valuable precursor for environmentally friendly technological processes owing to its unique chemical composition and reactive mineral content [21].

These findings suggest that banana peel ash possesses substantial potential as a sustainable reinforcement material for aluminium matrix composites. Despite the increasing number of studies on agro-waste-reinforced aluminium composites, research concerning the use of nanoscale banana peel ash (BPA) as reinforcement in Al7075-T6 aluminium matrix composites remains extremely limited. In particular, comprehensive investigations focusing simultaneously on wear behaviour, impact performance, and corrosion resistance of BPA-reinforced Al7075-T6 composites are scarce in the available literature. Furthermore, the influence of nanoscale BPA particles synthesized through controlled calcination and high-energy ball milling on the tribological and electrochemical performance of Al7075-T6 composites has not been adequately explored. Therefore, the present study aims to develop sustainable Al7075-T6 aluminium matrix composites reinforced with nanoscale banana peel ash produced through dehydration, calcination, and high-energy ball milling processes. The synthesized BPA particles were characterized using scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS), particle size analysis, and thermogravimetric analysis. Subsequently, BPA-reinforced composites were fabricated through the stir-casting route and evaluated with respect to wear behaviour, impact properties, and corrosion performance. The study seeks to establish the feasibility of utilizing banana peel ash as a low-cost, environmentally sustainable, and high-performance reinforcement for advanced aluminium matrix composite applications in aerospace structural components, automotive parts, marine equipment, defence systems, lightweight machinery components, and other engineering sectors.

2. Material and methods

2.1. Aluminium alloy

Al7075-T6 aluminium alloy was selected as the matrix material for the present investigation because of its excellent combination of high specific strength, superior fatigue resistance, good fracture toughness, and favourable corrosion performance, making it one of the most widely used high-strength aluminium alloys in aerospace, automotive, marine, and structural engineering applications [1,2]. The alloy possesses an outstanding strength-to-weight ratio and exhibits excellent mechanical reliability under both static and cyclic loading conditions, which makes it highly suitable for advanced aluminium matrix composite development [3].

The Al7075-T6 alloy was procured from Bharat Aerospace Metals, Maharashtra, India, in the form of cylindrical billets with a nominal diameter of 50 mm, as shown in Fig. 1. The alloy conformed to the standard chemical composition specifications of Al7075-T6, with zinc serving as the primary alloying element, while magnesium and copper contributed significantly to precipitation hardening, strength enhancement, and hardness improvement [2,4]. The detailed chemical composition of the matrix alloy is presented in Table 1.

Before composite fabrication, the billets were carefully inspected to ensure a defect-free surface condition and uniform material quality. The billets were then cleaned and sectioned into suitable sizes according to the stir-casting process requirements. Accurate weighing of the alloy charge was carried out before melting to maintain the desired matrix-to-reinforcement ratio during composite production. The prepared alloy charges were subsequently utilized for the fabrication of banana peel ash (BPA)-reinforced Al7075-T6 composites under controlled stir-casting conditions [5,6].



Fig.1. Aluminium 7075-T6 Ø50 mm billets

Table 1: Chemical Composition of Al7075-T6 Aluminium Alloy (wt.%)

Element	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
(%)	0.1	1.5	1.4	0.01	2.6	0.2	5.7	0.04	88.45

2.2. Synthesis and Processing of Nanoscale Banana Peel Ash (Nano-BPA)

Banana peel waste (BPW) collected from local sources was washed thoroughly and dried in an industrial dehydration machine (ECOTECH, Model ET-500H) at 60-65°C for 9-10 h. The dried peels were pulverized using a stainless-steel industrial pulverizer (2800 rpm, 3 HP) to obtain banana peel powder (BPP). The powder was then calcined in a muffle furnace at $500 \pm 5^\circ\text{C}$, producing mineral-rich banana peel ash (BPA) through the removal of organic constituents and volatile matter. Previous studies have shown that calcined banana peel waste contains valuable inorganic compounds suitable for sustainable material applications [14,15].

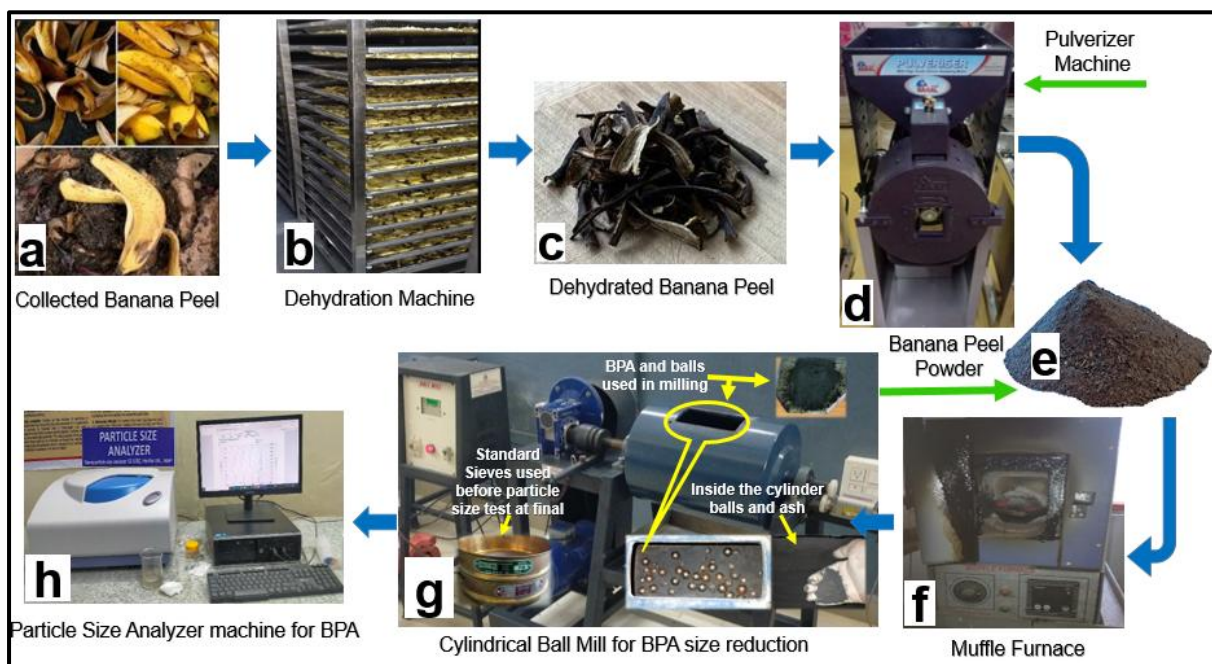


Fig.2. Schematic representation of the processing route adopted for the production of nanoscale banana peel ash (BPA) reinforcement from banana peel waste: (a) raw banana peels, (b) dehydration machine, (c) dehydrated peel, (d) pulverizer machine, (e) banana peel powder, (f) calcination in a muffle furnace, (g) ball milling for particle refinement, and (h) particle size analyzer machine.

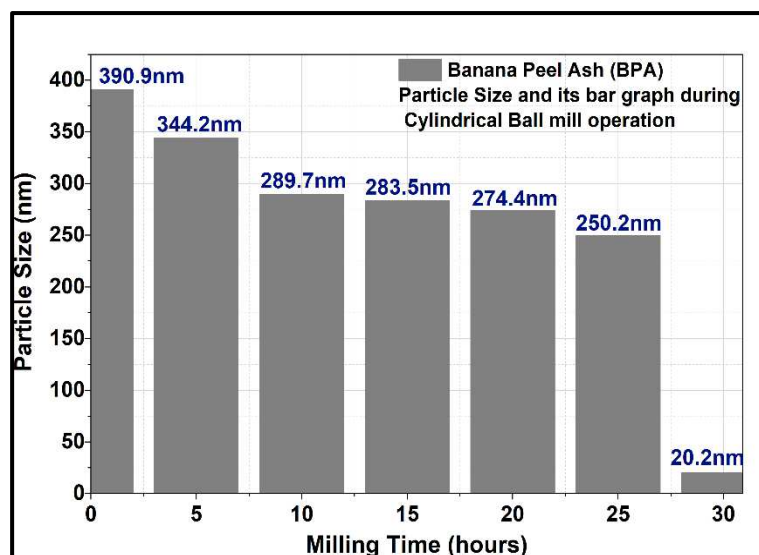


Fig.3. Bar graph of Cylindrical Ball Milling Time Vs Banana Peel Ash Particle Size

The obtained BPA was cooled to room temperature and stored in airtight containers before further processing. To achieve nanoscale particle size, the ash was milled using a KCMO-103A cylindrical ball mill for 30 1/2 h under controlled conditions. Particle size analysis using an SZ-100Z analyzer confirmed an average particle size of 20.2 nm Fig3. As of initial banana peel to final nano-size banana peel ash particle size formation is in Fig.2. Nano-sized agro-waste reinforcements are reported to improve particle dispersion and interfacial bonding in aluminium matrix composites, thereby enhancing composite performance [7,11].

2.2. Characterization of Nano-BPA

The thermal stability of Nano-BPA was evaluated using a thermogravimetric analyzer (STA7200) over the temperature range of 30-800°C. The TGA results indicated negligible mass loss up to approximately 300°C, demonstrating low moisture content and good thermal stability. Significant weight reduction was observed between 350°C and 550°C due to the decomposition of residual organic constituents, whereas a stable residual mass remained beyond 550°C, confirming the presence of thermally stable inorganic oxide phases. Such thermal characteristics make Nano-BPA a suitable reinforcement for aluminium matrix composites [14-17]. The morphology and elemental composition of Nano-BPA were characterized using scanning electron microscopy (SEM, TESCAN VEGA3) coupled with energy-dispersive spectroscopy (EDS). SEM analysis revealed fine particles with irregular morphology, while EDS confirmed the presence of oxide-forming elements predominantly consisting of potassium and oxygen, along with minor amounts of magnesium, silicon,

phosphorus, and calcium. The SEM image of the BPA particle and the size changes at a certain time during the operation of the ball mill as shown in Fig.4. The combined calcination and high-energy ball milling processes produced a mineral-rich and thermally stable Nano-BPA reinforcement capable of enhancing the microstructural integrity, wear resistance, impact performance, and corrosion behaviour of Al7075-based composites [10,11,17,19].

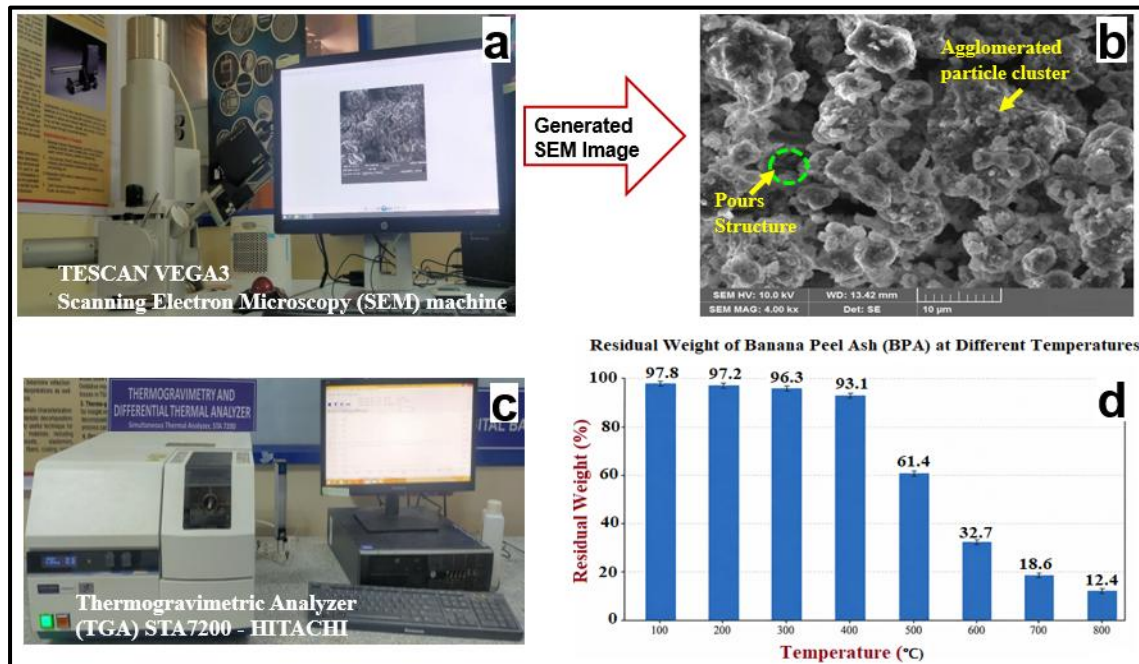


Fig.4. (a) TESCAN VEGA3 scanning electron microscopy (SEM) machine (b) Obtained SEM image of banana peel ash (BPA), (c) Thermogravimetric Analyzer (TGA) STA7200 - HITACHI, (d) bar graph of Residual Weight (%) vs Temperature (°C) of Banana Peel Ash (BPA).

2.2. Fabrication of base and Composite materials

Al7075-T6 alloy and its composites reinforced with 2 wt.% and 4 wt.% nano-sized banana peel ash (Nano-BPA) particles were fabricated using a Swam Equip stir casting machine (SCM), an economical and widely adopted technique for producing aluminium matrix composites with uniform reinforcement distribution [7]. Initially, Al7075 billets were charged into the furnace and melted at a temperature range of 700-800°C. The molten alloy was mechanically stirred at 400 rpm for 10 min to promote melt homogeneity before being poured through the bottom-pouring mechanism into a pre-prepared metallic mould. After solidification under ambient conditions, the cast Al7075-T6 block was removed from the mould and used as the reference material for subsequent characterization.

For composite fabrication, Nano-BPA particles were preheated to 400 °C prior to their addition into the molten alloy to eliminate residual moisture and enhance wettability with the aluminium

matrix. The preheated reinforcement was gradually introduced into the melt while maintaining a stirring speed of 400 rpm to facilitate uniform particle dispersion and minimize agglomeration. The composite slurry was then released into metallic moulds and allowed to solidify under atmospheric conditions, producing Al7075-2 wt.% Nano-BPA and Al7075-4 wt.% Nano-BPA composite castings. These cast blocks were subsequently machined into standard specimens for microstructural and mechanical characterization. An attempt was also made to fabricate a composite containing 6 wt.% Nano-BPA reinforcement using identical processing parameters. However, sound casting could not be achieved due to excessive porosity, poor melt flow characteristics, and inadequate cast ability associated with the higher reinforcement content Fig.4. Consequently, only the Al7075 - T6 alloy, Al7075 - 2 wt.% Nano-BPA, and Al7075 - 4 wt.% Nano-BPA composites were selected for further investigation. Experimental aspects are as Fig.5 from beginning to the end of operations along with system operative temperature settings and as magnitude/value of each process parameter of Fig.6.

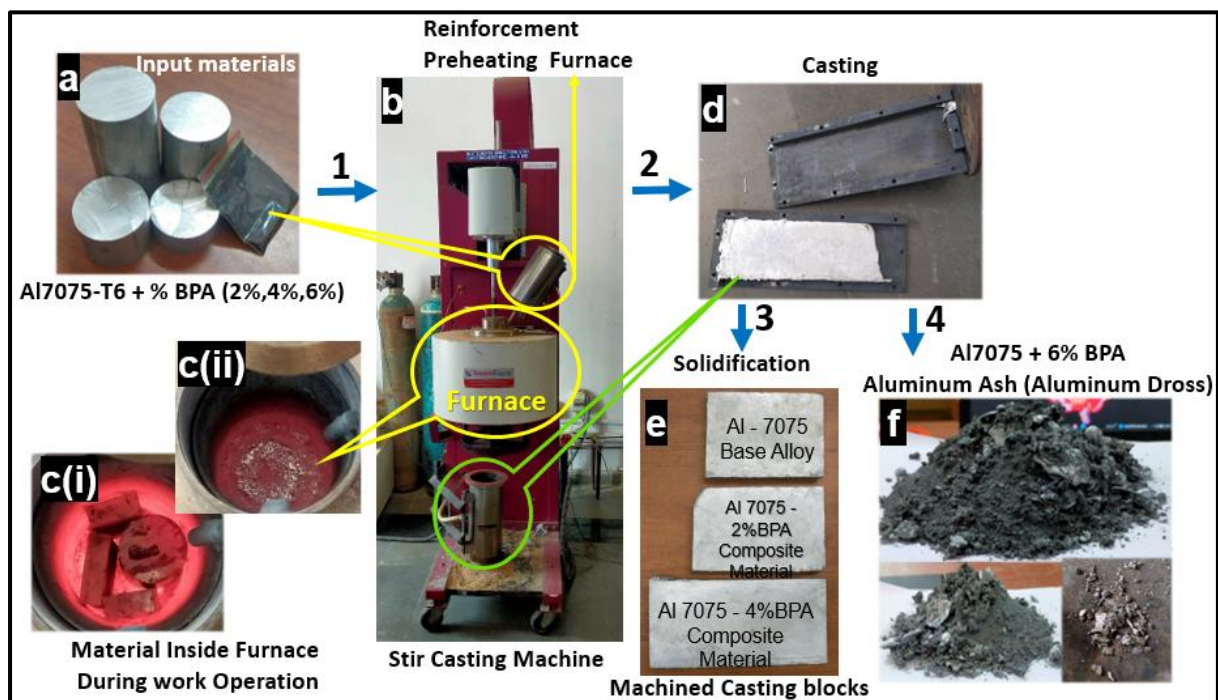


Fig.5. Experimental Workflow (1,2,3,4) for Al7075 - BPA Composite Preparation (a) Input material (b) Stir Casting machine (c-i) Material inside stir casting furnace before melting (c-ii) after melting (d) Casted material inside the die (e) casted blocks for test specimens (f) aluminium ash of Al7075-6% BPA.

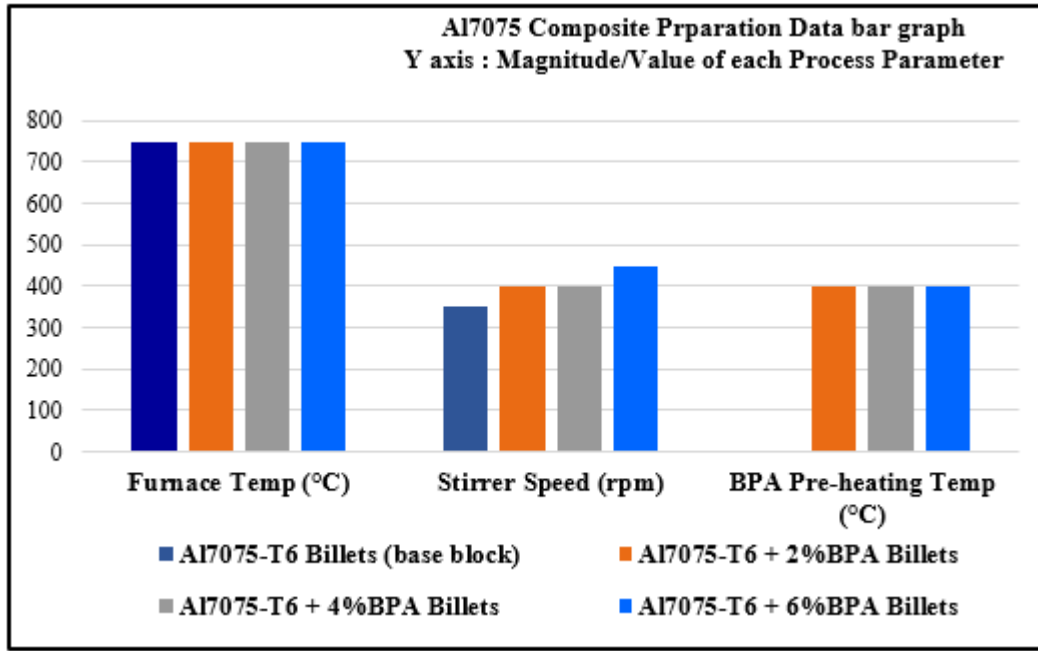


Fig.6. Experimental data of Al7075 T6 base and composites preparation

3. Mechanical property evaluation

Mechanical property evaluation is the process of assessing how a material responds to various service conditions, including mechanical loading, frictional wear, impact forces, and corrosive environments. In the present study, wear, impact, and immersion corrosion tests were conducted to evaluate the tribological behaviour, toughness, and corrosion resistance of the fabricated composites. These evaluations provide valuable insights into the material's durability, reliability, and suitability for engineering and structural applications.

3.1. Wear test

Dry sliding wear tests were carried out on Al7075 alloy and Al7075 - BPA composite specimens using a OUCOM Material Characterization System PIN ON DISC TRIBOMETER TR201 machine in accordance with ASTM G99 standards. Aluminium matrix composites are widely used in engineering applications due to their lightweight nature, high strength, and improved wear resistance. The specimens were machined to dimensions of 10mm x 10mm x 30mm and their contact surfaces were ground and polished to ensure uniform contact during testing. The wear experiments were performed under a constant load of 10 N, rotations speed of 400 rpm, and wear track radius of 80mm for a duration of 15min. Throughout the test, the frictional force was continuously monitored to evaluate the coefficient of friction, while the wear rate was determined from the mass loss of the specimens before and after testing Fig.7 (a, b, c). The investigation was conducted to evaluate the influence of BPA reinforcement on the

tribological behaviour and wear resistance of the fabricated composites under dry sliding conditions [3,5,16].

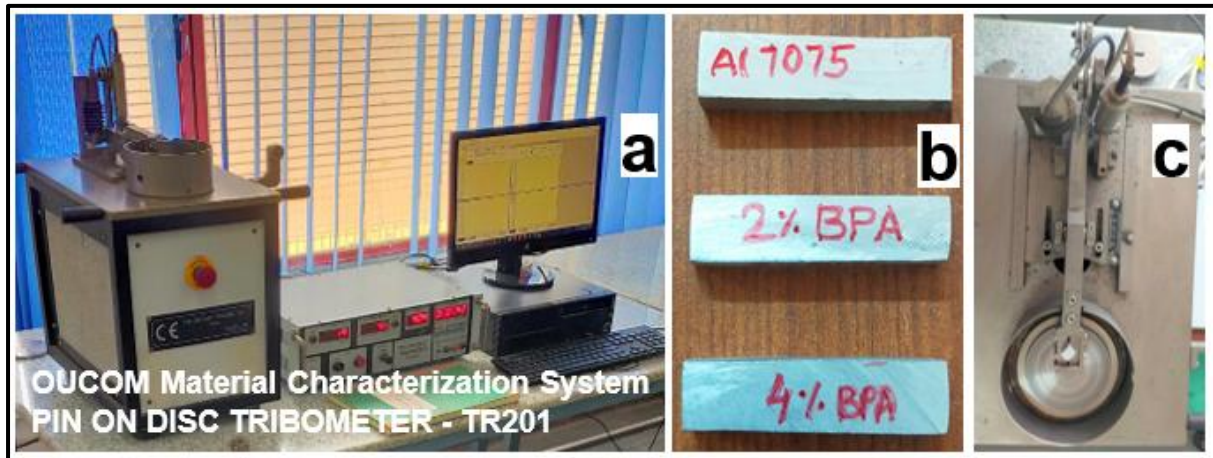


Fig.7. (a) Wear test machine (b) Wear test Specimens (c) Machine during operation for test

$$\text{Wear Rate} = (W) = \frac{\Delta m}{\rho \cdot D} \quad (1)$$

Here Wear rate (W) was determined from the mass loss experienced by the specimen during the wear test. The mass loss (Δm) was converted into volume loss using the density (ρ) of the material, and the wear rate was calculated by relating the volume loss to the total sliding distance (D).

$$\text{Specific Wear Rate} (K) = \frac{\Delta V}{F \cdot D} \quad (2)$$

Here the specific wear rate (K) was evaluated by dividing the volume loss (ΔV) by the product of the applied load (F) and sliding distance (D). The specific wear rate represents the material loss per unit load and sliding distance and serves as an indicator of the wear resistance of the material. Lower values of wear rate and specific wear rate indicate improved wear performance and higher resistance to material removal during sliding

3.2. Impact test

Charpy impact testing was performed on an Impact Testing machine IT-30, Fig.8 (a) in accordance with ASTM E23 to evaluate the impact toughness of unreinforced Al7075-T6 alloy base material and Al7075-T6 composites reinforced with 2 wt.% and 4 wt.% BPA. Impact toughness is an important mechanical property that indicates a material's ability to absorb

energy and resist sudden fracture under dynamic loading conditions. Standard V-notched specimens were prepared 3 specimens of each that is 3 specimens for base material Al7075 T6, 3 specimens for Al7075T6-2% BPA composite material and 3 specimens for Al7075T6-4% BPA composite material with precise dimensions 10mmx10mmx55mm and “V” notch geometry to ensure uniform testing conditions and reliable results Fig.8 (b). Three specimens were tested for each composition, and the average absorbed impact energy was calculated to minimize experimental variation Fig.8 (c). The measured impact energy values were utilized to assess the influence of BPA reinforcement on crack initiation and propagation resistance. The addition of reinforcement particles can alter the energy absorption capability of aluminium matrix composites by affecting the matrix–reinforcement interaction and fracture behaviour, thereby influencing the overall toughness of the material [3,11,13,18]. The test results provide valuable information regarding the suitability of the developed composites for applications subjected to impact and shock loading conditions.



Fig.8. (a) Impact Testing machine (b) Impact test Specimens (c) few specimens after testing

Table 2: Charpy Impact Test Parameters for Al7075-T6 and Composite materials

Material / Qty.(No's)	Temperature (°C)	Notch	Initial Energy (J)
Al7075 / 3	29	“V”	300
Al7075 +2% / 3	29	“V”	300
Al7075 +4% / 3	29	“V”	300

3.3. Immersion Corrosion Test

The Corrosion behaviour of Al7075-T6 and Nano - BPA refined composites (2 wt.% and 4 wt.%) was evaluated using an immersion weight - loss method based on ASTM G31 guidelines. Specimens measuring 40 x 20 x 5 mm³ were polished, cleaned, and dried. And weighed before immersion in 3.5 wt.% sodium chloride (NaCl) solution prepared by dissolving 3.5g NaCl in 100 ml. distilled water in each of 3 individual conical bakers. Each specimen was immersed separately in a conical flask and exposed under static laboratory conditions for 72 hours as shown in Fig.9 (a, b, c, & d). After testing, the specimens were removed, rinsed, dried and reweighed to determine mass loss. The corrosion resistance was assessed by comparing the weight loss of the base alloy and reinforced composites. The reduced mass loss observed in the Nano-BPA reinforced specimens indicated improved corrosion resistance, which may be attributed to the formation of a stable protective oxide layer and the uniform distribution of reinforcement particles that hinder corrosion attack [10,17]

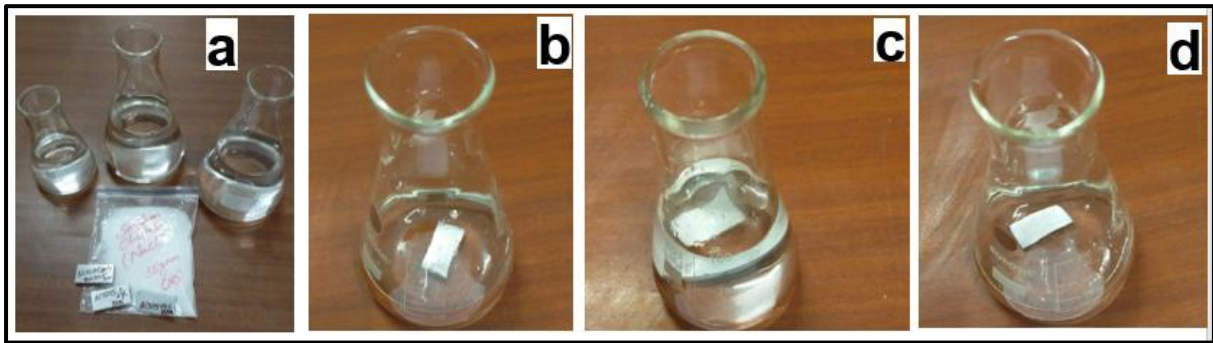


Fig.9. (a) Immersion corrosion Test Setup (b) Al7075T6 base alloy in 72hours test conical baker (c) Al7075T6+2% BPA composite specimen base alloy in 72hours test conical baker (d) Al7075T6+4% BPA composite specimen base alloy in 72hours test in conical baker.

The weight loss (ΔW) of each specimen was calculated using:

$$\Delta W = W_i - W_f \quad (1)$$

The weight loss (ΔW) of the specimen was determined by calculating the difference between the initial weight before immersion (W_i) and the final weight after immersion (W_f). The initial weight (W_i) represents the mass of the specimen measured prior to exposure to the corrosive medium, while the final weight (W_f) represents the mass after the completion of the immersion test and removal of corrosion products. The measured weight loss was used to evaluate the corrosion behaviour of the Al7075-T6 alloy and Nano-BPA reinforced composites. A lower weight loss indicates better corrosion resistance of the material.

The percentage weight loss was determined using:

$$\text{Weight Loss\%} = \frac{W_i - W_f}{W_i} \times 100 \quad (2)$$

The percentage weight loss was calculated by comparing the difference between the initial weight (W_i) and final weight (W_f) of the specimen after immersion with its initial weight. This parameter indicates the extent of material degradation due to corrosion. A lower percentage weight loss signifies better corrosion resistance of the material.

The corrosion rate was calculated according to ASTM G31 using:

$$\text{CR} = \frac{87.6 \times W}{D \times A \times T} \quad (3)$$

The corrosion rate (CR) was calculated in accordance with ASTM G31 using the measured weight loss (W), material density (D), exposed surface area (A), exposure time (T) and 88.76 is of Unit Conversion Constant. This parameter quantifies the rate of material degradation in the corrosive environment and is expressed in millimetres per year (mm/year). A lower corrosion rate indicates superior corrosion resistance and enhanced material performance.

4. Result & Discussion

4.1 Characterization and thermal stability of reinforcement

The characterization and TGA analysis of Nano-BPA demonstrated excellent thermal stability, with negligible weight loss up to 300 °C due to the removal of moisture and volatile compounds. A significant mass reduction occurred between 350 °C and 550 °C, attributed to the decomposition of residual organic constituents. Beyond 550 °C, the curve remained nearly stable, leaving a residual mass of 12.4% at 800 °C, which indicates the presence of thermally stable inorganic oxides and mineral phases Fig.10. These results confirm the suitability of Nano-BPA as a thermally stable reinforcement for Al7075-T6 aluminium matrix composites.

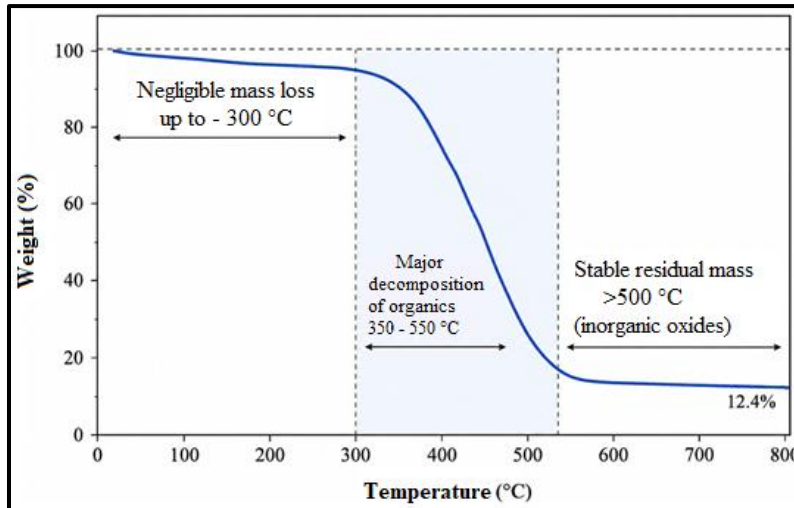


Fig.10. Thermogravimetric analysis (TGA) Curve of Nano-BPA

4.2 Energy Dispersive X-ray Spectroscopy (EDS)

The Energy Dispersive Spectroscopy (EDS) analysis of the banana peel ash (BPA) revealed the presence of several inorganic elements, confirming the mineral-rich nature of the calcined material. As shown in the spectrum and of Fig11, potassium (K) was the predominant element with a weight percentage of 46.1%, followed by oxygen (O) at 34.8%, indicating the formation of potassium-based oxides and mineral compounds during calcination. Minor amounts of calcium (Ca) (2.9%), silicon (Si) (1.8%), magnesium (Mg) (1.6%), phosphorus (P) (1.5%), sulphur (S) (1.0%), and chlorine (Cl) (0.4%) were also detected. The presence of these oxide-forming elements suggests that BPA contains hard ceramic-like constituents, which can contribute to improved hardness, wear resistance, and strengthening when used as a reinforcement in Al7075 composites. The EDS results therefore confirm the successful conversion of banana peel biomass into a mineral-rich ash suitable for reinforcement applications in aluminium matrix composites.

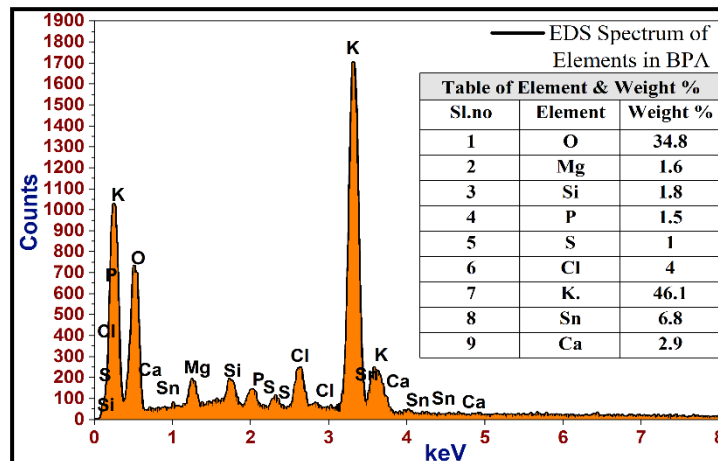


Fig.11. Energy Dispersive Spectroscopy (EDS) of nano banana peel ash (BPA)

4.3 Wear test

The wear test Fig.12(a) results revealed a significant improvement in the wear resistance of Al7075-T6 with the addition of BPA reinforcement. As of Fig.12 (b) the specific wear rate decreased from 3.5 mm³/m for the unreinforced alloy to 2.55 mm³/m and 1.0 mm³/m for the composites containing 2 wt.% and 4 wt.% BPA, respectively. This reduction indicates that the incorporation of BPA effectively enhanced the material's resistance to material loss during Sliding. The improved wear performance can be attributed to the presence of hard BPA particles, which increased the load-bearing capacity and reduced direct metal-to-metal contact. Among the tested materials, the Al7075 + 4 wt.% BPA composite exhibited the lowest wear rate, demonstrating superior tribological performance and confirming the beneficial effect of BPA reinforcement on wear resistance.

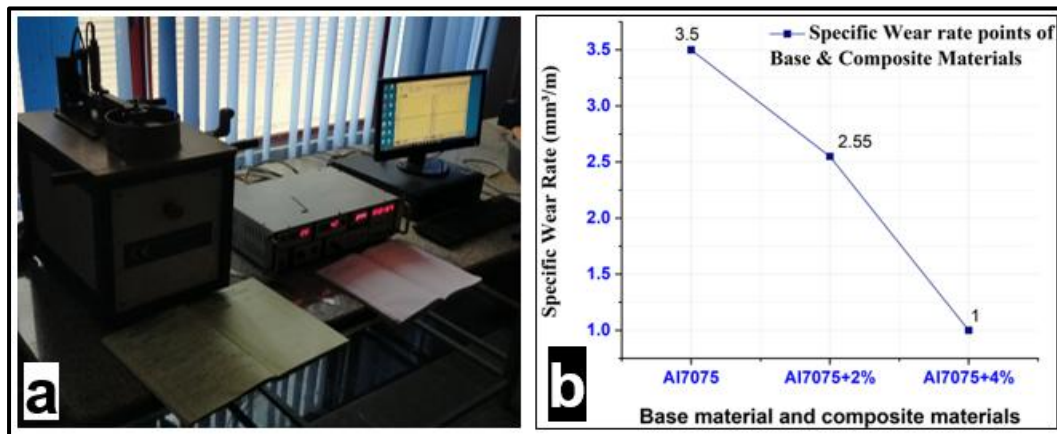


Fig.12. (a) Pin on Disc during testing, (b) Obtained calculation result graph of Wear Test

Table 3: Result tabulation of Wear Test on Pin on Disc Tribometer

Material	Weight (N)	Speed (rpm)	Time (min.)	Track Distance (mm)	Specific Wear Rate (mm ³ /m)
Al7075 (Base)	10	400	15	80	3.5
Al7075+2% BPA	10	400	15	80	2.55
Al7075+4% BPA	10	400	15	80	1

4.4 Wear test area's Scanning Electron Microscope (SEM) analysis

SEM micrographs Fig.13 (a, b, c) reveal progressive microstructural refinement with increasing Nano-BPA content in the Al7075-T6 matrix. The unreinforced alloy (Fig.13a) exhibits a relatively coarse morphology with surface grooves and localized micro-voids. The addition of 2 wt.% Nano-BPA (Fig.13b) results in improved particle dispersion and enhanced matrix–reinforcement bonding, leading to a more uniform microstructure.

Further reinforcement with 4 wt.% Nano-BPA (Fig.13c) produces a denser and more homogeneous structure with reduced defects and finely distributed particles. The observed refinement confirms the effective incorporation of Nano-BPA and is expected to contribute to improved mechanical, wear, and corrosion properties of the developed composites.

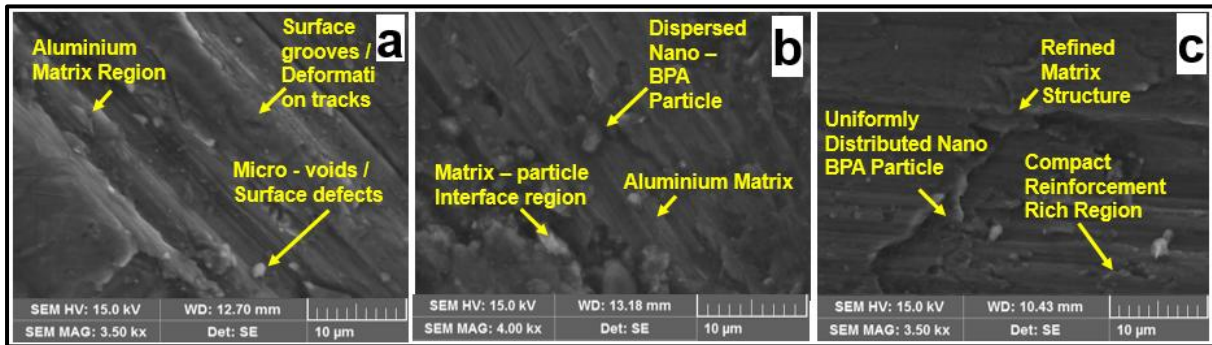
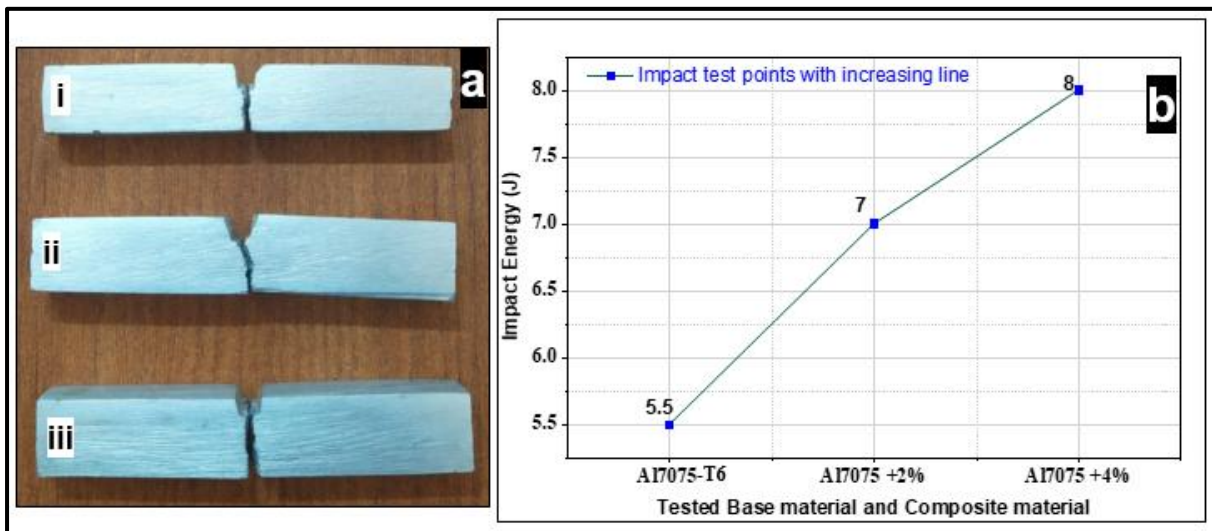


Fig.13.SEM image of (a) Al7075 (base alloy), (b)Al7075 +2%BPA, (c) Al7075 +4%BPA

4.5 Impact Test

The Charpy impact test results demonstrated that the impact toughness of Al7075-T6 improved with the addition of BPA reinforcement Fig14(a). The average absorbed impact energy increased from 5.5 J for the unreinforced Al7075 alloy to 7 J and 8 J for the composites containing 2 wt.% and 4 wt.% BPA, respectively. The enhanced impact strength is attributed to the effective dispersion of BPA particles within the aluminium matrix, which impeded crack



initiation and propagation during impact loading. Among the tested materials, the Al7075-T6+ 4 wt.% BPA composite exhibited the highest energy absorption, indicating superior toughness and improved resistance to sudden fracture Fig.14 (b). These results confirm that BPA reinforcement positively influences the impact performance of Al7075-T6 composites Table 4.

Fig.14. (a- i, ii, iii) one set of Tested Specimens, (b) Obtained average Final Energy (J) result of Tensile Test for the Specimens of Al7075-T6 (base alloy), Al7075+2% & Al7075+4% (Composite Materials)

Table 4. Charpy Impact Test Average Results on “V” notch nine test specimens

Material / Qty.(No's)	Temperature (°C)	Initial Energy (J)	Final Energy (J) Average Result
Al7075 / 3	29	300	5.5
Al7075 +2% / 3	29	300	7
Al7075 +4% / 3	29	300	8

4.5 Immersion Corrosion

The immersion corrosion test results revealed that the corrosion resistance of Al7075-T6 improved with the addition of Nano-BPA reinforcement Fig.11 (a). The unreinforced Al7075-T6 alloy exhibited the highest weight loss of 48 mg and a corrosion rate of 0.944 mm/year after 72 hours of exposure to a 3.5 wt.% NaCl solution. In comparison, the Al7075 composite reinforced with 2 wt.% Nano-BPA showed a reduced weight loss of 34 mg and a corrosion rate of 0.669 mm/year, while the 4 wt.% Nano-BPA composite exhibited the lowest weight loss of 15 mg and the lowest corrosion rate of 0.295 mm/year as shown in graph Fig11(b). These results indicate that increasing the Nano-BPA content significantly enhanced the corrosion resistance of the alloy as clearly given in the table 5. The improved performance may be attributed to the formation of a more stable protective oxide layer and the uniform distribution of Nano-BPA particles, which act as barriers to the penetration of corrosive ions and reduce the corrosion attack on the matrix material.

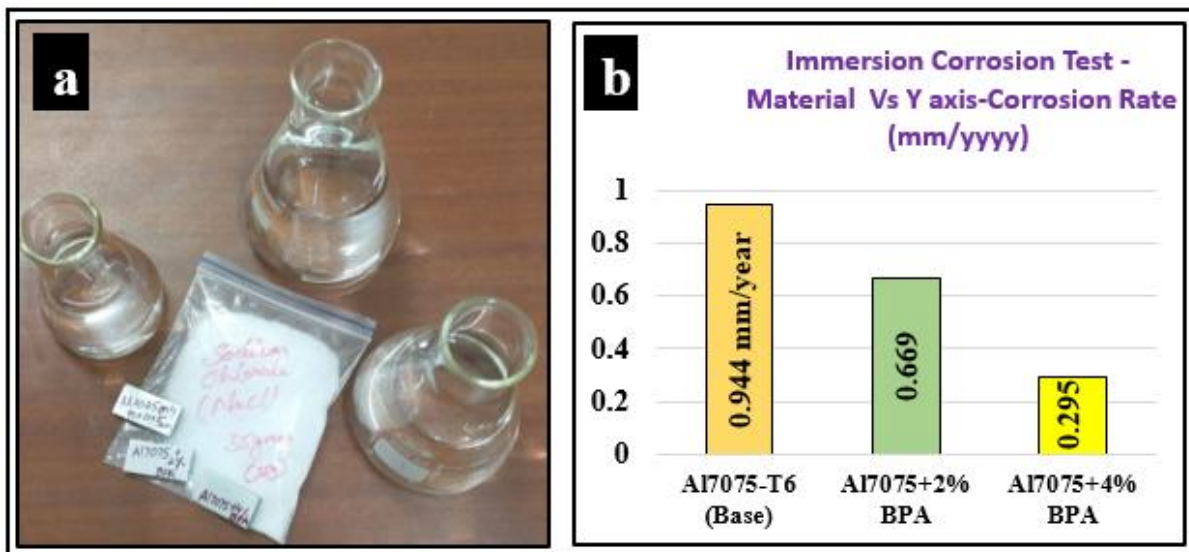


Fig.11. Immersion corrosion Test (a) Set of Test (b) immersion test result graph after 72 hours.

Table 5. Tabulation for the obtained result

Material	Specimen L x W x T (mm)	Corrosive Medium (%) NaCl	Initial Weight (g)	Time (h)	Final Weight (g)	Weight loss (mg)	Corrosion rate (mm/year)
Al7075-T6 (Base)	40x20x5	3.5 wt.%	25.860	72	25.812	48	0.944
Al7075+2% BPA	40x20x5	3.5 wt.%	25.920	72	25.886	34	0.669
Al7075+4% BPA	40x20x5	3.5 wt.%	26.010	72	25.995	15	0.295

5. Conclusion

In the present study, nanoscale Banana Peel Ash (Nano-BPA) was successfully synthesised from agricultural waste through dehydration, calcination, and high-energy ball milling, and was utilised as a sustainable reinforcement for Al7075-T6 aluminium matrix composites fabricated by stir casting. Characterisation studies confirmed the formation of thermally stable nano-sized particles with an average particle size of 20.2 nm and the presence of beneficial oxide-forming elements such as potassium, oxygen, calcium, magnesium, and silicon.

The experimental results demonstrated that incorporating Nano-BPA significantly improved the wear, impact, and corrosion performance of the Al7075-T6 alloy. Wear testing revealed a progressive reduction in specific wear rate from 3.5 mm³/m for the base alloy to 2.55 mm³/m and 1.0 mm³/m for the composites reinforced with 2 wt.% and 4 wt.% Nano-BPA, respectively. Charpy impact testing showed enhanced toughness, with the absorbed impact energy increasing from 5.5 J for the unreinforced alloy to 7 J and 8 J for the 2 wt.% and 4 wt.% reinforced composites. Immersion corrosion studies in 3.5 wt.% NaCl solution indicated improved corrosion resistance, as evidenced by the reduction in corrosion rate from 0.944 mm/year for the base alloy to 0.669 mm/year and 0.295 mm/year for the 2 wt.% and 4 wt.% Nano-BPA composites, respectively.

SEM observations further confirmed improved microstructural uniformity, better particle dispersion, and enhanced matrix–reinforcement bonding in the reinforced composites. Among all compositions investigated, the Al7075-T6 + 4 wt.% Nano-BPA composite exhibited the best overall performance. The study demonstrates that Nano-BPA is an effective, low-cost, and environmentally sustainable reinforcement capable of enhancing the tribological, impact, and corrosion properties of Al7075-T6 composites, making it a promising material for lightweight engineering and structural applications

6. Future Scope

Further research may focus on optimizing the Nano-BPA reinforcement content and investigating additional mechanical properties such as tensile strength, hardness, fatigue, and fracture toughness. Advanced characterization techniques can be employed to better understand the strengthening mechanisms and interfacial bonding. Moreover, the long-term corrosion performance and high-temperature behaviour of the composites can be evaluated for demanding service conditions. The development of hybrid composites and the exploration of aerospace, automotive, and marine applications will further enhance the industrial potential of Nano-BPA reinforced Al7075-T6 composites.

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