“Effect of Activated Carbon and Rice Husk Ash on the Mechanical and Microstructural Properties of Eco-Friendly Aluminum Hybrid Composites: An Experimental Study”

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A report submitted to the Department of Mechanical Engineering, Sonargaon University, in fulfilment of the requirements for the course ME-400.

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CERTIFICATE OF RESEARCH

This is to certify that the research work titled **“Effect of Activated Carbon and Rice Husk Ash on the Mechanical and Microstructural Properties of Eco-Friendly Aluminum Hybrid Composites: An Experimental Study”** has been carried out by “ (Atiqur Rahman, ID: ME2201026082, Safikul Alam, ID: ME2201026121, MD Ariful Islam, ID: ME2201026262, Sajidul Islam Sajid, ID: ME2201026060, Md. Rayhan Uddin Shovo, ID: ME2201026164, Tanjum Akter Mim, ID: ME2201026240,) ” under the supervision of **Md. Anash Mia**, Lecturer, Department of Mechanical Engineering, Sonargaon University, Dhaka, Bangladesh.

This thesis contains original work carried out by the author and does not include any material previously published or written by another individual, except where due acknowledgment has been made.

Any sources of information used in this study have been properly mentioned in accordance with academic standards.

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ABSTRACT

Aluminium hybrid composites are a new generation of metal matrix composites that can meet the demands of modern engineering applications. These demands are fulfilled through improved mechanical properties, compatibility with conventional processing methods, and the possibility of reducing production cost. The performance of such composites mainly depends on selecting the right reinforcement materials, since many processing steps are linked to the properties of the particulates. In this study, aluminium was used as the base matrix and reinforced with agricultural waste–based activated carbon (AC) and rice husk ash (RHA) to produce eco-friendly hybrid composites. The stir-casting method was applied with different reinforcement ratios. Samples were tested for tensile strength, hardness, and impact energy following ASTM standards. Results showed that balanced addition of AC and RHA increased both yield strength and ultimate strength. The A2 sample achieved the highest tensile strength (≈145 MPa), hardness (46.6 HRB), and impact strength (13.6 J). Excessive AC or RHA reduced ductility due to particle agglomeration and stress concentration. FESEM and EDX analysis confirmed that proper reinforcement ratios led to uniform particle distribution, grain refinement, and strong interfacial bonding. These features were directly related to the improvement in mechanical properties. This study proves that AC and RHA together can produce lightweight, strong, and eco-friendly aluminum composites. Such materials show promising applications in automobile, aerospace, and structural engineering.

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NOMENCLATURE

ASTM	American Society for Testing and Materials
AC	Activated Carbon
RHA	Rice Husk Ash
Nm	Newton-metre, Unit of Torque
gm	Gram, Unit of Mass
mm	Millimeter, Unit of Length
J/mm^2	Joule per square millimeter
J	Joule, Unit of Energy
kJ/m^2	kilojoule per square meter
ρ	Density

CHAPTER 1: INTRODUCTION

1.1 Overview

Eco-friendly aluminium hybrid composites are materials reinforced with agricultural waste products such as activated carbon (AC) and rice husk ash (RHA). These reinforcements improve strength and durability while keeping the material lightweight and sustainable.

Aluminium was chosen as the base matrix because it is light, corrosion-resistant, and widely used in engineering applications. However, its mechanical strength is limited, which makes reinforcement necessary. Activated carbon was selected due to its high porosity and large surface area. These properties enhance bonding with the aluminium matrix, improve load transfer, and increase wear resistance and thermal stability. Rice husk ash is considered effective because of its high silica content, which contributes to hardness, compressive strength, and thermal resistance. Being a by-product of rice milling, it is also eco-friendly and cost-effective.

The hybrid uses of AC and RHA is significant because it combines the strengths of both reinforcements. Together, they balance hardness, toughness, and ductility, offering better performance than using either material alone. In this study, aluminium hybrid composites were fabricated using the stir-casting method. Reinforcement powders were preheated and added to molten aluminum, then cast into Molds and machined to ASTM standards.

Reinforcement content strongly influenced mechanical properties. Moderate additions improved tensile strength, hardness, and impact energy, while excessive AC or RHA caused particle agglomeration and reduced ductility. Microstructural analysis showed grain refinement, uniform particle distribution, and strong interfacial bonding. These changes correlated directly with improved mechanical behaviour.

The study demonstrates that agricultural waste can be transformed into high-performance aluminium composites, offering sustainable materials for automotive, aerospace, and structural applications.

1.2. Objectives

The objectives of this project are**:**

I. To fabricate hybrid aluminium matrix composites reinforced with activated carbon and rice husk ash.
II. To investigate the mechanical properties tensile strength, hardness, and impact energy of the fabricated composites.
III. To analyse the morphology and elemental distribution of the composites using FESEM and EDX, focusing on reinforcement dispersion and interfacial bonding.

1.3 Literature Review

Over the last few years, aerospace to automobile industries have been drastically changed over to new, light, power-saving materials without any sacrifice in strength. Then the traditional metals (steel and copper) are not favoured as they tend to corrode and weaken easily. Among the light metals, aluminium is characterized as lightweight, highly corrosion resistant and easy Machinability [1,2]. Aluminium alloys are most suitable for applications in engineering to achieve higher strength-to-weight properties, but the inherent strength of the alloys is not adequate for uses. The process is utilized to manufacture Metal Matrix Composites (MMCs). When reinforcement is incorporated into the matrix of aluminium, they have better mechanical and thermal properties and they are most suitable for Applications [3,4]. This type of composite is better than unreinforced alloys due to their mechanical and Thermal properties. That’s why, it is considerable as structural application. Aluminium alloys widely utilize for their versatile significance such as Automobile, Aerospace, construction, electrical, household items, electronics and marine industry [5,12]. However, Pure Aluminium is lightweight but it’s poor in mechanical strength and limited wear resistance. It is not suitable under high stress Condition for their soft nature. So, removing this limitation researchers are focusing on metal matrix composite [MMCs]. Where utilize hard particle such as Sic, Al_2O_3, graphite, rice husk ash (RHA), activated carbon (AC), and charcoal. This reinforcement Increase composite tensile strength, hardness, wear resistance and absorption energy. [7-11] Uniform dispersion of reinforcement is required to avert particle agglomeration and to ensure even stress distribution at loading [21]. To enhance the mechanical strength of pure aluminium, my research entails reinforcement of rice husk ash (RHA) and activated carbon (AC), both of which are bioproducts of agricultural wastes. The reinforcements not only save costs but are also environmentally friendly. Activated carbon (AC) is a very porous material with very small, low-volume pores and high surface area (max. 1500 m^2/g). Its features include microporosity, high adsorptive capacity, and certain physicochemical features such as particle size, ash content, and ph. It is produced by carbonization and activation of carbonaceous feedstocks, usually bio-wastes, and AC finds extensive application in water/air adsorption purification, industrial processes, and medical treatments. Even it can be reactivated to restore its properties [13] – [16]. RHA, on the other hand, owing to high silica content, is the prime contributor to the hardness and compressive strength of the composite. It provides superior thermal resistance and prevents degradation when heated high, a property that is desirable in mechanical as well as chemical processing [27], [28]. It has been researched and proven that RHA has the property of improving hardness by over 20% when mixed with pure aluminium in proper amounts [29]

Rice husk ash (RHA), which is a by-product of waste rice milling, is said to be rich in high amorphous silica content and ceramic-like properties.[17] Silica-rich rice husk ash (RHA) has exhibited enhanced thermal stability and mechanical strength in construction applications justifying its potential as a good reinforcement in aluminium based MMCs. [18]. Compared to conventional reinforcements such as Sic or Al2O3, RHA possesses the benefit of occurring naturally, being eco-friendly, and of low weight [19]. Pure aluminium reinforcement also allows microstructural evolution such as grain refinement, which is responsible for increased yield strength and improved toughness [22]. Mechanisms of improvement that are attained for pure aluminium reinforced by AC and RHA include grain refinement, dislocation blocking, and load transfer mechanisms. Grain refinement is a result of heterogeneous nucleation at particle–matrix interface and results in finer microstructure and improved mechanical performance. Resistance to plastic deformation and yield strength are increased by dislocation movement being hindered by reinforcement particles [21] [23] Load transfer is when externally applied stress is partially transferred by rigid reinforcement particles rather than ductile aluminium matrix, reducing matrix strain and overall strength improvement [24] Specifically, activated carbon enhances wear resistance and thermal stability under cyclic conditions of temperature, and hence is well-adapted for parts exposed to friction or temperature variation [25]. Its relatively lower density also makes it desirable in application areas where weight saving is the case, i.e., the transport sector [26]. AC and RHA powders were, in this study, grinded into very small particles by a grinding machine. Particle size reduction improves surface area available, responsible for improving bonding strength with the aluminium matrix [20]

Several studies have investigated the use of carbon-based reinforcements, such as activated carbon, graphite, nanocarbon, and graphene, in aluminium matrices to enhance mechanical properties including tensile strength, hardness, ductility, and toughness. Venugopal et al. [4] examined aluminium alloys reinforced with carbon powder, finding improved ductility and toughness due to stable compound formation and enhanced slip mechanisms. Microstructural analysis confirmed effective carbon infiltration within the matrix. [8] fabricated graphite/6061 aluminium composites via ultra-high pressure and hot pressing. The formation of the Al4C3 phase and improved graphite dispersion increased tensile strength up to 183 MPa, along with enhanced hardness, density, and wear resistance. Nanocarbon reinforcements have also shown potential. Surface-oxidized Nano diamond (ND) additions avoided harmful Al4C3 formation while increasing yield strength by 19% at an optimal 3% loading, maintaining balanced grain size [30]. Similarly, adding graphene nanoplatelets and activated nanocarbon (0.5–2 vol.%) to 2024 aluminium raised yield strength by up to 56%, ultimate strength by 57%, and hardness by 33%. Heat treatment further improved these properties without compromising ductility [8]. AA7075 alloy reinforced with powdered activated carbon (PAC) through stir casting demonstrated uniform carbon particle dispersion, significant hardness increase, and improved elongation compared to the base alloy [1]. Research on spent activated carbon reactivation confirmed the durability of carbon materials in composites, preserving adsorptive and mechanical properties [3]. Nanocarbon-reinforced 6061 aluminium composites prepared by powder metallurgy exhibited graphene-like carbon ring structures, confirmed by DFT calculations. These composites showed increased hardness and strength but experienced some ductility loss due to fewer fracture dimples [30]. Aluminium LM25 alloy reinforced with carbon via casting also displayed mechanical and microstructural improvements suitable for automotive and aerospace applications [1]. In AA6061 composites with 2–8 wt.% activated carbon prepared by stir casting, thermal resistance and matrix-reinforcement bonding improved significantly up to 6%, although higher percentages led to void formation. Activated carbon derived from peanut shells mixed with aluminium increased hardness and elastic modulus by up to 3.4 times at 2% addition, but excessive carbon weakened the matrix due to poor interfacial bonding [6].

The existing literature demonstrates that reinforcement particles significantly influence the mechanical and microstructural properties of aluminium matrix composites. Extensive research has examined the effects of Sic, Al_2O_3, graphite, fly ash, waste glass, and nanocarbon materials on various aluminium alloys [8], [1], [6], [30], [9]. However, the combined use of activated carbon powder and rice husk ash (RHA) as reinforcements in pure aluminium has not been addressed in studies. Research on activated carbon has primarily explored its individual impact on AA6061, AA7075, and LM25 alloys [8], [1], [30], [9], [6] reporting notable improvements in hardness, wear resistance, and tensile strength—especially when particle dispersion is optimized. RHA, known for its ceramic characteristics, high amorphous silica content, and thermal stability, has also shown promise as a reinforcement material [31]. Yet, its use in combination with activated carbon has not been investigated. The potential combination of activated carbon and rice husk ash (RHA) has not yet been thoroughly studied, especially in pure aluminium. On the other hand, RHA, with its high silica content, enhances thermal stability and insulation. Mechanically, RHA improves compressive strength, hardness, and wear resistance, making it a promising addition for lightweight and durable aluminium alloys.[32] Since both materials are derived from agricultural waste, their combined use offers a sustainable and promising area for research. Studying this hybrid reinforcement could lead to the development of lightweight aluminium composites with improved mechanical properties, suitable for a wide range of engineering applications.

The primary objective of this study is to examine how activated carbon and rice husk ash (RHA) affect the mechanical properties of pure aluminium alloys. This will be assessed through tensile, impact, hardness, and wear tests. Microstructural characteristics will also be analysed using Field Emission Scanning Electron Microscopy (FESEM) and Energy Dispersive X-ray (EDX) mapping to evaluate particle distribution and the bonding between reinforcements and the aluminum matrix. The research's novelty stems from the combined use of activated carbon and RHA—both agricultural waste products—as hybrid reinforcements. This approach offers a sustainable, lightweight composite solution that remains underexplored, potentially advancing environmentally friendly materials with improved mechanical performance for engineering uses. Together, these studies demonstrate that activated carbon and other carbonaceous reinforcements can significantly enhance aluminum composite performance. Careful optimization of reinforcement content and ensuring uniform particle dispersion are essential to maximize strength and hardness while minimizing negative impacts on ductility and matrix integrity. Activated carbon improves mechanical properties by enhancing load transfer between the matrix and reinforcement, increasing hardness and tensile strength. Its high porosity ensures better bonding and dispersion of particles, which refines the microstructure and boosts toughness and resistance to deformation.[6]

CHAPTER 2: MATERIALS

2.1 Materials

In this experimental study, the following materials were used to investigate the effects of Activated Carbon and Rice Husk Ash (RHA) on the mechanical properties of an aluminium alloy: -

2.1.1 Aluminum

A commercially available aluminum was selected as the matrix material due to its light weight, corrosion resistance, and good mechanical properties. These properties make aluminum suitable for use in composite fabrication. The aluminum was procured in ingot form and used as the base metal for reinforcement, as shown in Fig. 1(b).

Aluminum Alloy was collected from Millennium scientific mart, Hatkhola Road, Dhaka - 1203.

Table 1: **-** Typical Chemical Composition of the Aluminum:

Element	**Mass %**
Aluminium (Al)	85.14 %
Carbon (C)	11.21 %
Oxygen	3.26 %
Others	0.39%

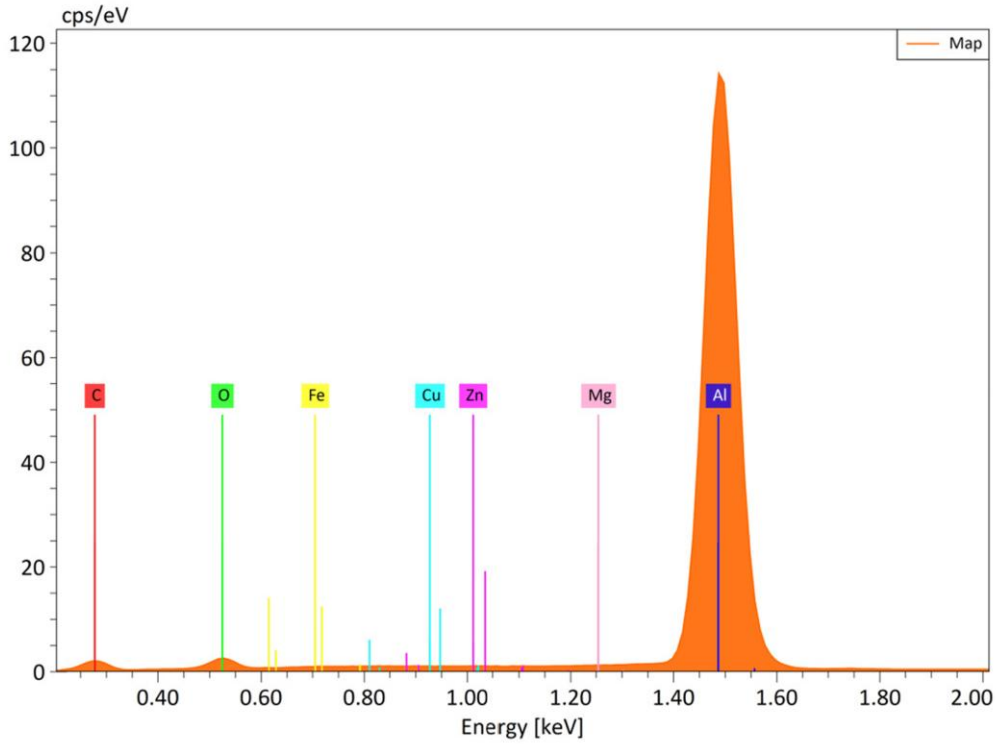


Fig .1(a): EDX map of the aluminum.

Fig .1(b): Aluminum ingot

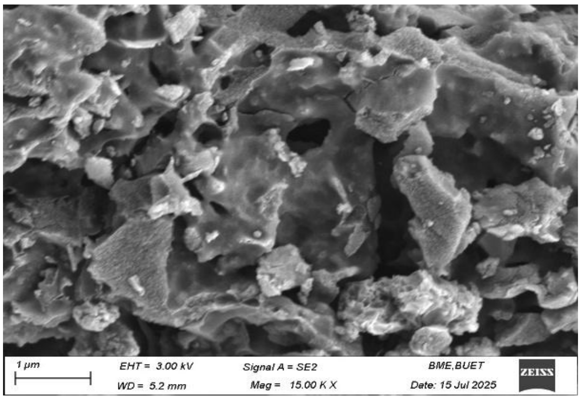
2.1.2 Activated Carbon (AC)

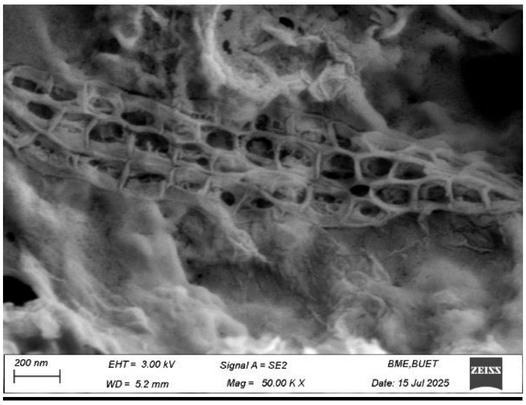
Activated carbon was used as one of the reinforcing agents. It was obtained from through carbonization and chemical activation. It is a highly porous form of carbon, made from materials like wood or coconut shell, that's processed to create millions of tiny pores, vastly increasing its surface area. The activated carbon particles were sieved to an average size of [mention particle size, e.g., 50 µm] to ensure uniform dispersion within the aluminium matrix, as shown in Fig. 4(b).

Activated Carbon was bought from an online platform which was "echem.com.bd", Kuril, Dhaka - 1229, Bangladesh.

<u>Table 2</u>: - Typical Chemical Composition of Activated Carbon:

Element	**Mass %**
Carbon (C)	69.61 %
Oxygen (O)	21.37 %
Calcium (Ca)	3.93 %
Silicon (Si)	3.24 %
Others	1.84 %





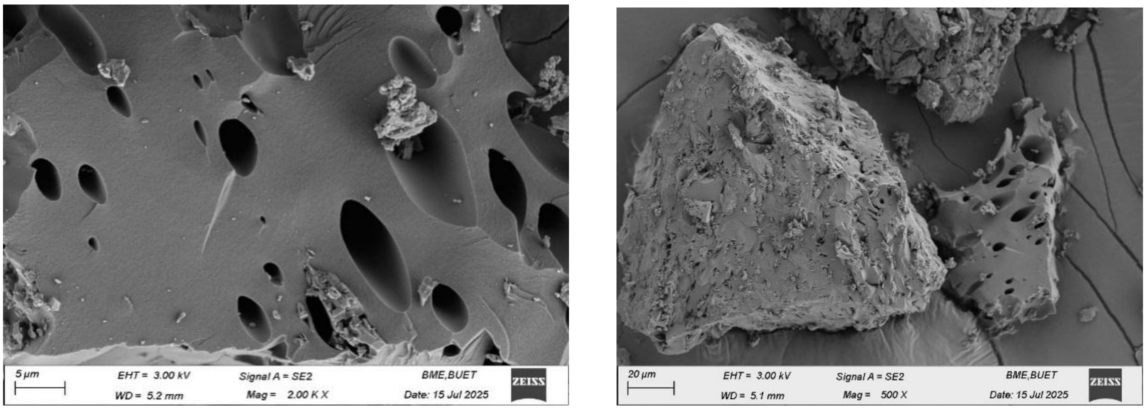


Fig .2(a): FESEM for activated carbon

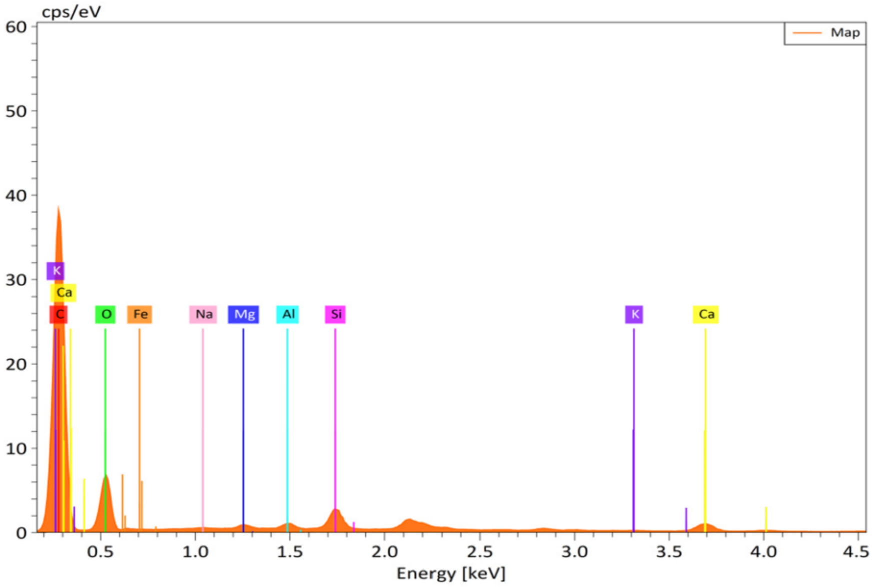


Fig .2(b): EDX map of the activated carbon

Fig .2(c): Activated Carbon

Fig. 2(d): grinding activated carbon

2.1.3 Rice Husk Ash (RHA)

Rice husk was used as a secondary reinforcing material, which was also collected from Jamuna Auto Rice Mill, Kushtia, Bangladesh as shown in Fig. 4(c); then it is washed with water and hydrochloric acid (HCl) to remove the dust and impurities. After washing the rice husk, we left it in the sun to dry for 3-4 days, then we put it in electric oven at 110°C temperature for 20 hours. It was made by burning rice husks inside a furnace at controlled temperatures (e.g., 400-465°C) for 30 minutes to produce fine rice husk ash containing silica. Then cooled it with air for 3-5 hours. The ash was then ground and sieved to a uniform particle size of approximately [e.g., 50 µm].

Table 3: - Typical Chemical Composition of the Rice Husk Ash:

Element	**Mass %**
Oxygen (O)	41.77 %
Silicon (Si)	32.32 %
Carbon (C)	25.36 %
Others	0.55 %

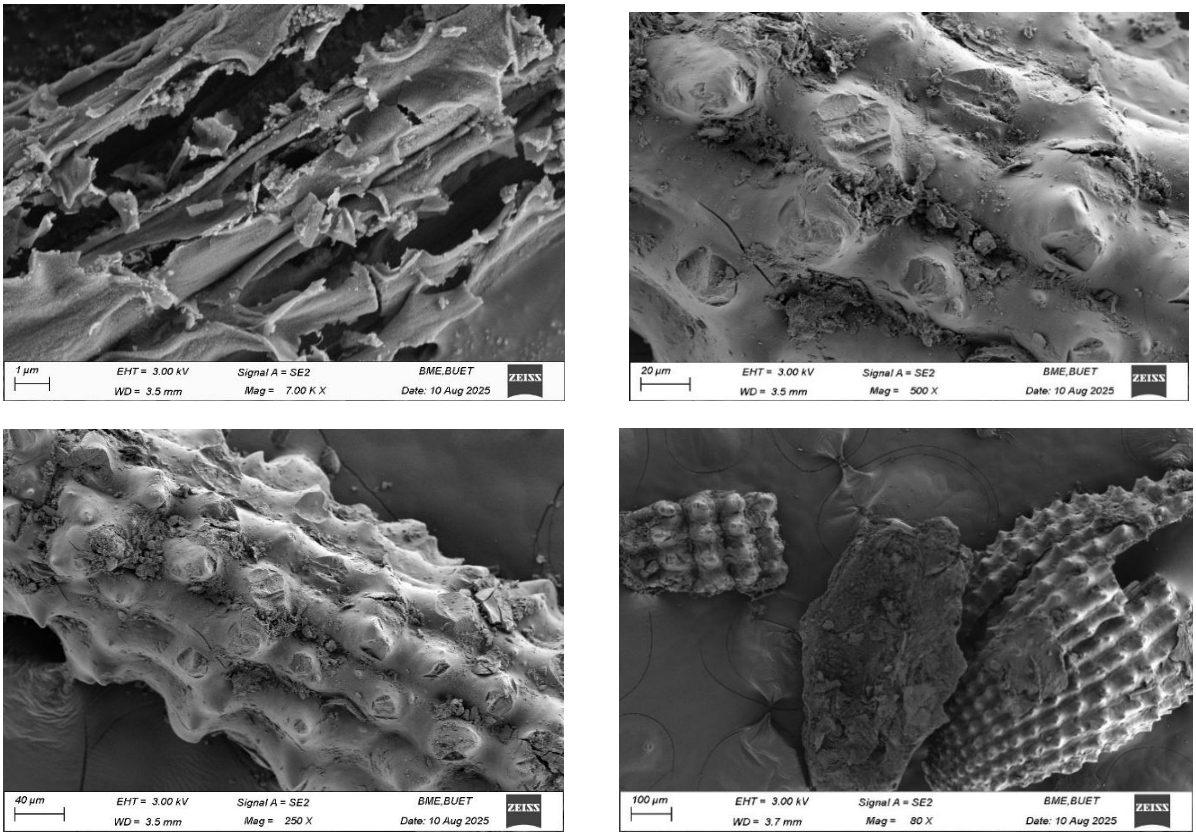


Fig. 3(a): FESEM for rice husk ash

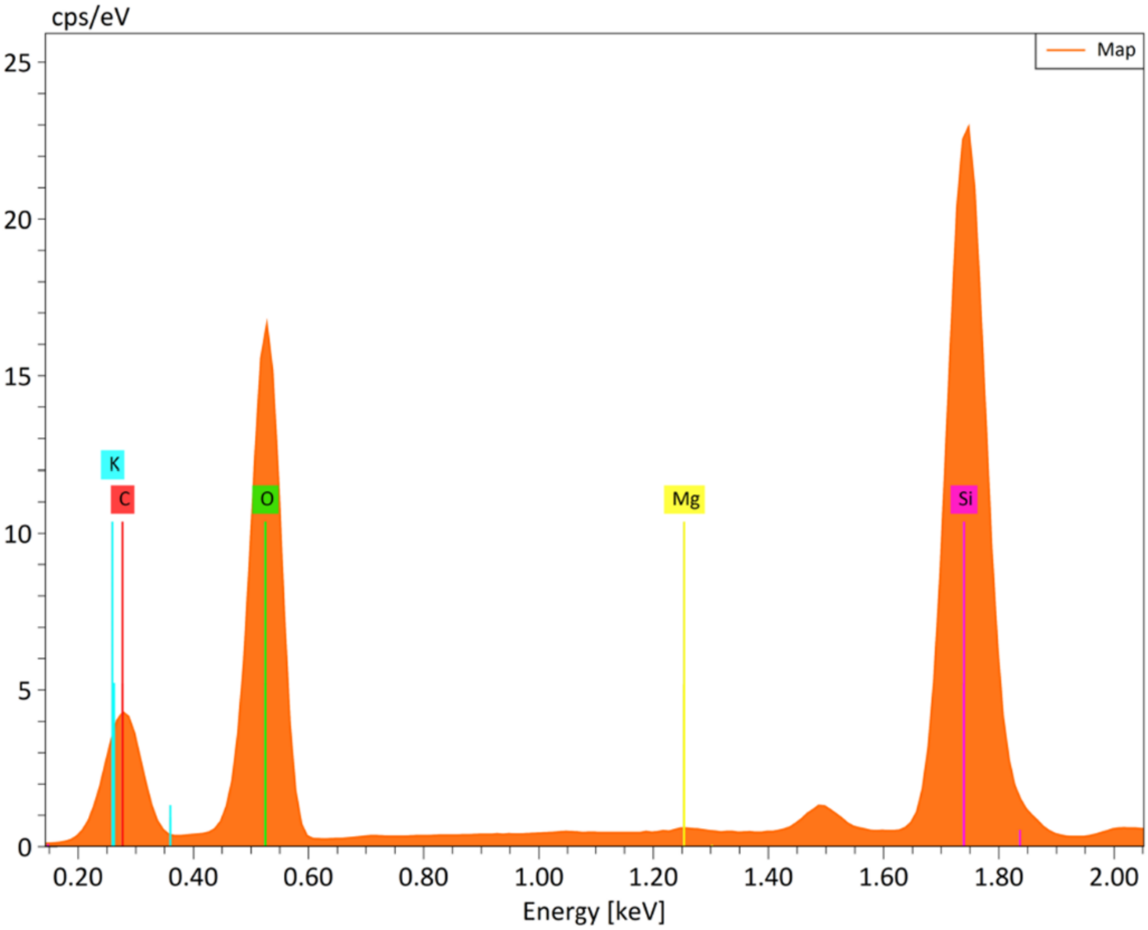


Fig. 3(b): EDX map of the rice husk ash.

Fig .3(c): Rice Husk

CHAPTER 3: METHODOLOGY

3.1.1 Preparation of rice husk ash (RHA)

The collected husk was first sieved to remove dust, stones, and other visible impurities. It was then washed with a 1% hydrochloric acid (HCl) solution to remove mineral contaminants, followed by thorough rinsing with distilled water. The cleaned husk was dried in a two-step process: initially under direct sunlight for 3–4 days, and then in an electric oven at 110 °C for 20 hours to ensure complete moisture removal.

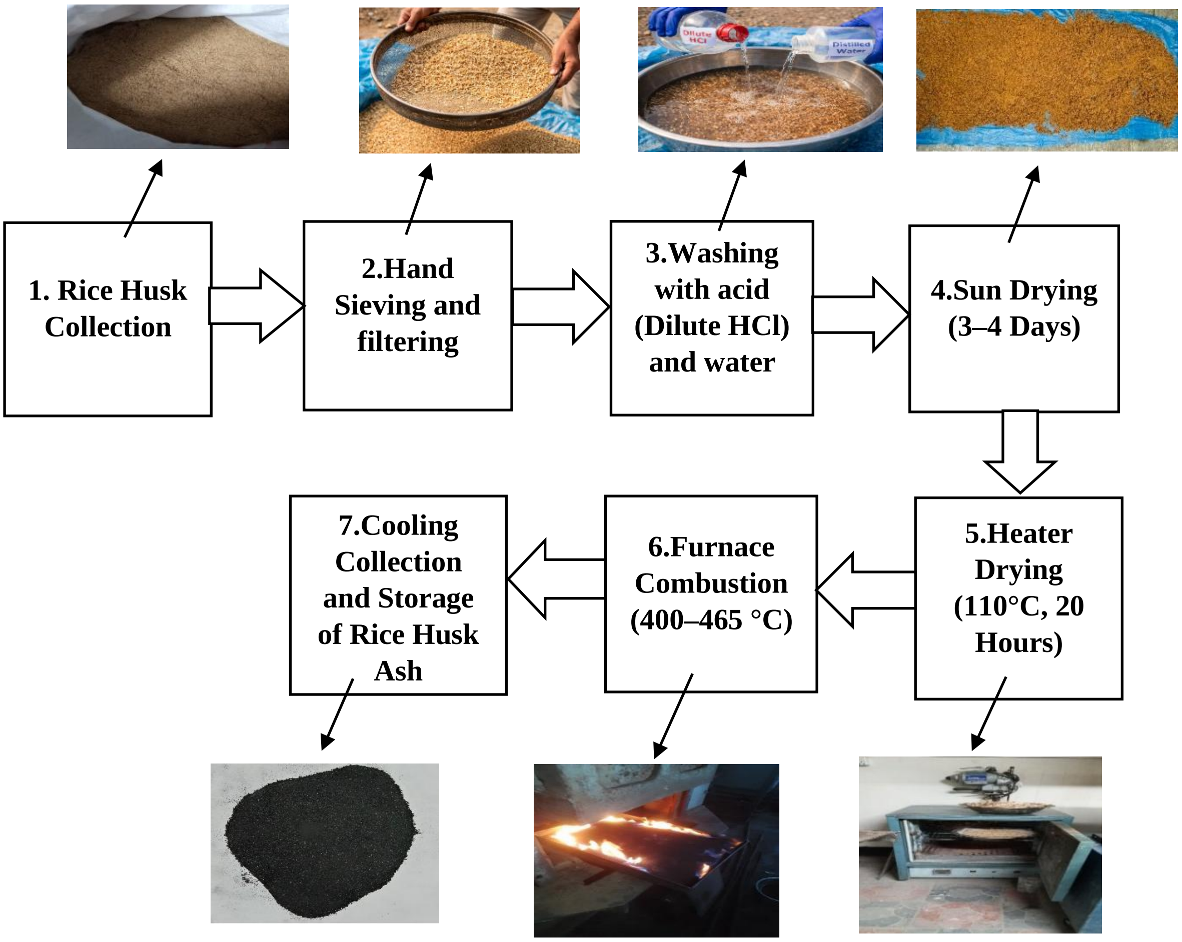


Fig. 4: Flowchart of Rice Husk Ash Preparation.

The fully dried rice husk was combusted in a furnace at a controlled temperature of 400–465 °C to obtain rice husk ash. This controlled combustion ensured maximum preservation of silica content. After combustion, the ash was allowed to cool, collected, and stored in airtight containers for further experimental use.

3.1.2. Stir casting method

Although stir-casting has some limitations regarding the wettability of some particles [33], this study chose this method over others due to the facility's availability. Moreover, this liquid metallurgy method is economical and offers simplicity and flexibility while mixing the particles [34]. Aluminum matrix composites have been developed using stir casting in a recent research project. Each batch used about 1.9 kg of aluminum. A total of 12 melting cycles were carried out in the experiment. The aluminum alloy cleaning with acetone before melting to remove surface oil, grease and moisture. After that, aluminium alloy melted at 660°C thorough coal-based furnace. Mechanical stirring was performed at 100 rpm for 2 minutes using a drill machine fitted with a coated steel impeller. This preheated reinforcement powders Activated carbon (AC) and rice husk ash (RHA) were added into the molten aluminum. potassium chloride (KCl) was added to enhance interfacial bonding between the aluminum matrix and reinforcement particles. After stirring, the molten metal poured into pre-prepared molds. Steel molds with a diameter of 28 mm and a length of 195 mm were used for tensile, hardness specimens, while wooden molds measuring 55 × 10 × 10 mm were used for impact testing. This cast samples were allowed to cool naturally at room temperature and were subsequently machined to the required dimensions according to relevant standards before mechanical testing.

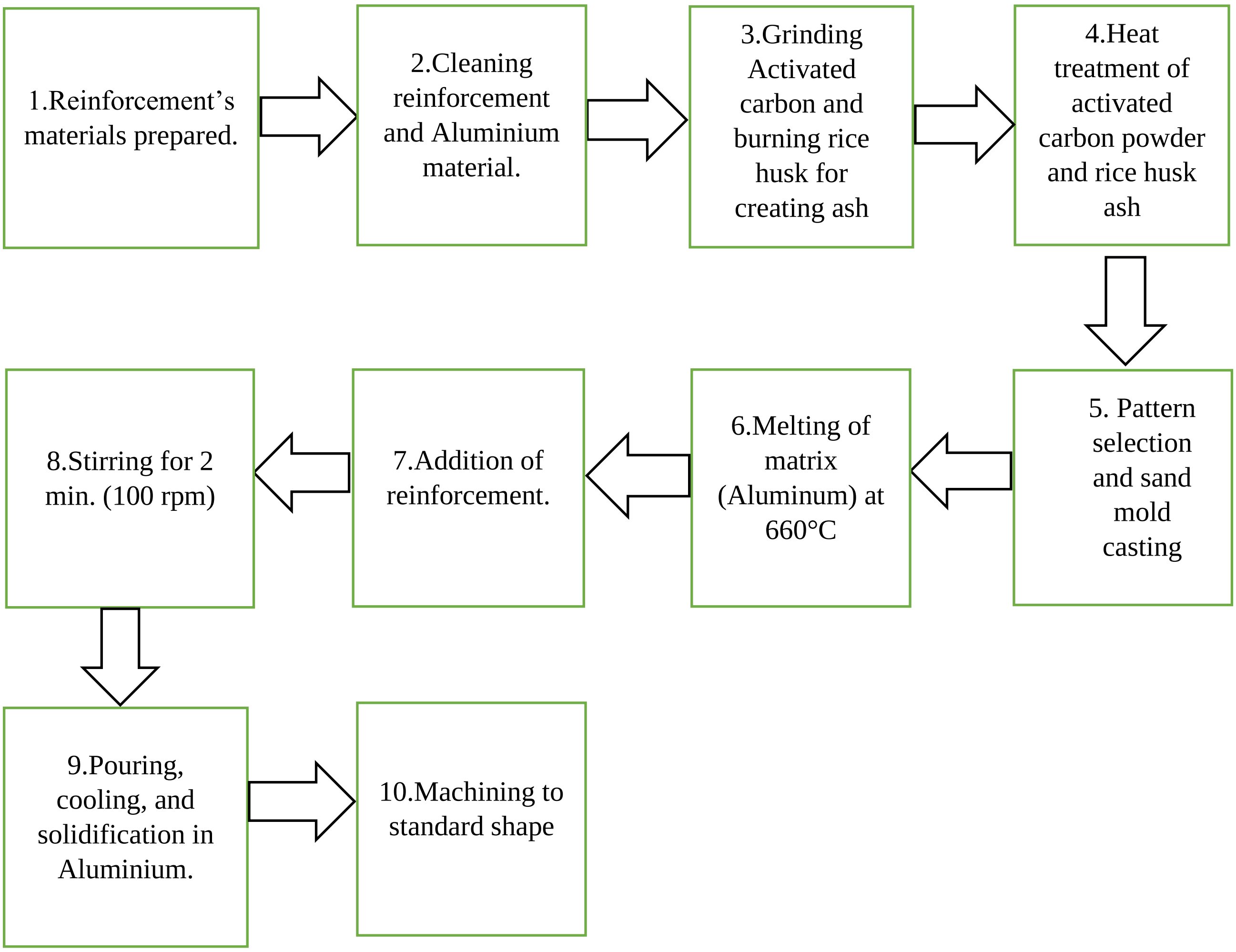


Fig. 5: Schematic of the composite fabrication process

3.1.3 Machining

After being cast and solidified, the composite specimens were carefully machined into the standard ASTM sizes for mechanical testing.

The shape, dimension and other requirements of each specimen are first design with computer model (CAD). Then, CNC lathes and milling machines are used to create the desired shape of the sample, obtained a smooth surface and accurate dimensions. Each specimen was machined in a such a way that test standard requires, to maintain its dimension and surface finish. Although the tensile, impact, wear and Rockwell hardness samples did vary in their size and shape, all other preparatory procedures were identical (i.e., finish on surface quality of each specimen provided was equivalent as well as proper labelling) to ensure consistent and reproducible test results.

Each specimen was carefully examined, measured, and marked before testing and after the last machining ensure that their sizes were consistent to be precise.

Figure shows the overview of the whole process and figure shows the CAD models of the desired specimen shapes.

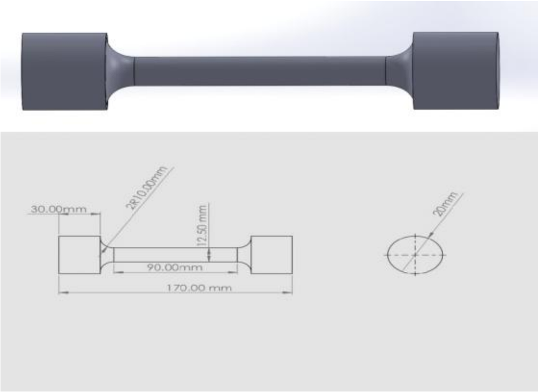


Fig. 6: CAD model of Tensile test

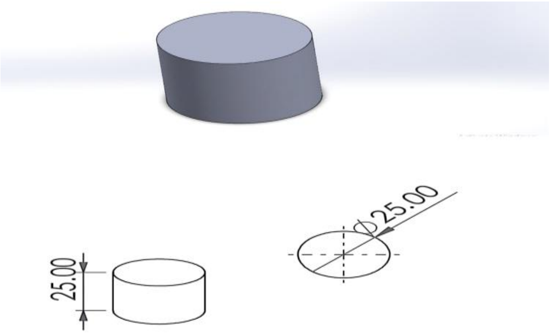


Fig. 7: CAD model of Rockwell Hardness test

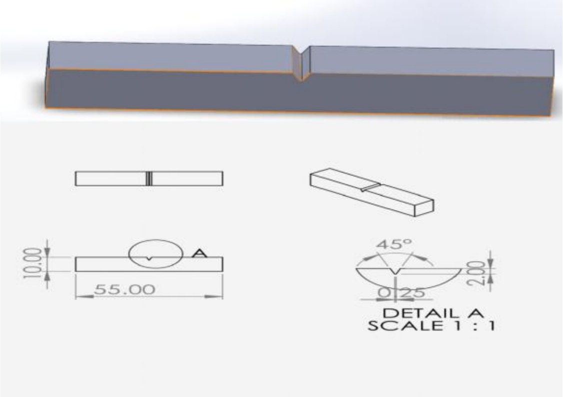


Fig. 8: CAD model of Impact test

3.1.4. Sample designation

A total of 48 specimens were produced as part of this experiment. They were divided into four distinct variations, with each variation consisting of 12 specimens.

All specimens were based on a matrix of 97.54 wt.% pure aluminium. The remaining 8 wt.% was distributed between activated carbon (AC) and rice husk ash (RHA), with the proportions varied across the four groups. The approach was designed to test how AC and RHA might work together to influence the properties of the composites. The precise weight percentages used in each variation are shown below:

Sample	Aluminium	RHA	AC
A1	97.54%	1.23%	1.23%
A2	97.54%	0.82%	1.64%
A3	97.54%	1.64%	0.82%
A4	97.54%	0.41%	2.05%

The design was guided by earlier studies. They showed that higher ash content can improve mechanical and tribological properties when paired with a fixed carbon source [include reference]. Small changes were made in the ratios of AC and RHA. These were introduced to test how slight adjustments could influence the composites. Focus was placed on wear resistance, hardness, and microstructural uniformity.

3.1.5 Mechanical testing

After the fabrication the 35 samples were shaped according to the ASTM standards: tensile test (ASTM E8/E8M-15a), Rockwell hardness (ASTM E18) and impact test (ASTM E23, Charpy V-notch). Strength, toughness and modulus were determined from the mechanical test using universal testing machine. strength YS (ultimate) of the was measured by a tensile test using standard specimens. Hardness was measured according to the Rockwell B-scale produced by various readings to ensure reliability. Impact test was performed with approved Charpy.

<u>Impact Test Energy Equation</u>

$$E = E_1 - E_2$$

Where,

E = Absorb Impact Energy

E_1 = Initial Potential Energy of the Pendulum (J)

E_2 = remaining Energy after Fracture

Impact Strength

$$K = \frac{E}{A}$$

Where,

K = Impact Strength (J/cm^2) or $ft.lb/in^2$

E = Absorbed Energy (J)

A = Cross sectional Area at the Notch $(mm)^2$

Rockwell Hardness (HRB)

$$HR = N-(h/S)$$

Where,

N is a Scale Constant, (like 100 or 130)

H permanent indention depth in mm

S is a scale factor (typically 0.002 mm for most scales)

Fig . 9: (a) Tensile test specimens **(b) Tensile test**

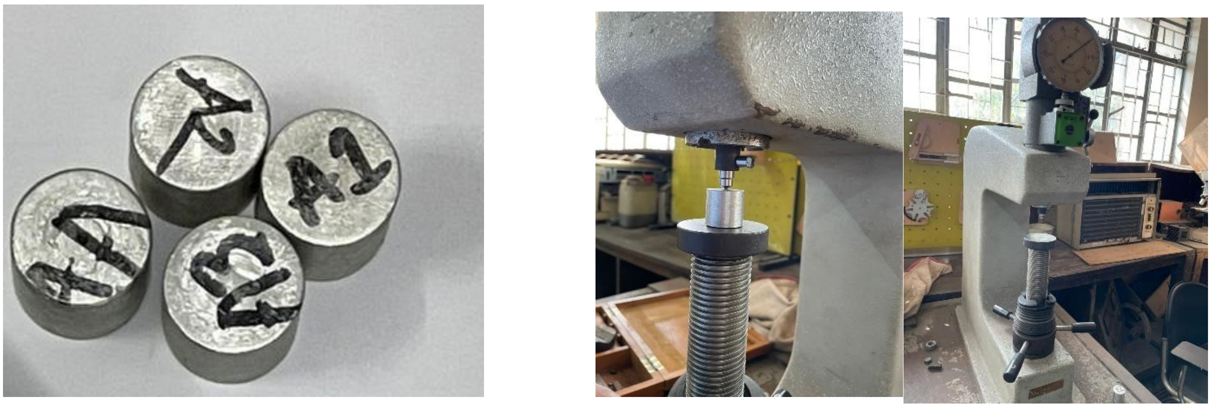


Fig. 10: (a) Rockwell hardness test specimens **(b) Rockwell hardness test**

Fig. 11: (a) Impact test specimens **(b) Impact test**

3.1.6 Porosity and density calculation

Porosity and Density Determination Porosity refers to the proportion of void spaces within a composite structure, which can significantly influence its mechanical performance. The porosity percentage of the fabricated specimens was determined using the following formula:

$$\text{Percent Porosity} = 1\text{- } (\rho\text{experimental} / \rho\text{theoretical}) \times 100\%$$

Where,

- ρExperimental is the density of the specimen measured using Archimedes' principle.
- ρtheoritical is the theoretical density, computed using the rule of mixtures as shown below:

$$\rho\text{theoritical} = (\rho\_\text{Al} \times \mathbf{X}\_\text{Al}) + (\rho\_\text{AC} \times \mathbf{X}\_\text{AC}) + (\rho\_\text{RHA} \times \mathbf{X}\_\text{RHA})$$

Here,

- ρ_Al = Density of pure aluminum = 2700 kg/m^3

- ρ_AC = Density of activated carbon powder= 450 kg/m^3 (Bulk density)
- ρ_RHA = Density of rice husk ash = 600 kg/m^3 (Bulk density)
- X = Corresponding weight fraction of each component in the composite

Both theoretical and experimental densities were calculated to assess the porosity level, which helps evaluate the internal compactness and potential mechanical integrity of the developed aluminum matrix composites.

CHAPTER 4: RESULT AND DISCUSSION

4.1 Result and Discussion

4.1.1 Density and porosity

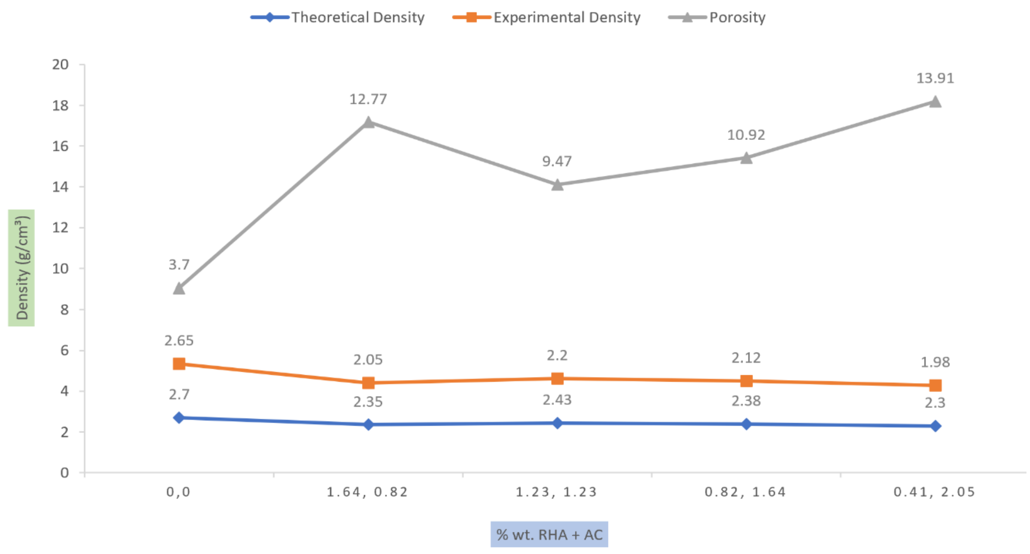


Fig. 12: Density and porosity of the samples

In Fig. 12 shows how theoretical density, experimental density, and porosity change with different RHA + AC weight percentages in aluminum composites. At 0,0 (pure aluminum), both theoretical density about 2.7 g/cm³ and experimental density about 2.65 g/cm³ are highest, while porosity is the lowest about 3.7%. When RHA and AC are added, the theoretical density gradually decreases from 2.7 g/cm³ to about 2.3 g/cm³, and the experimental density also generally decreases from 2.65 g/cm³ to about 1.98 g/cm³, showing that adding RHA and AC makes the material lighter. On the other hand, porosity increases overall with the addition of RHA and AC. It increases sharply from 3.7% at (0,0) to 12.77% at (1.64, 0.82). Then it slightly decreases to 9.47% at (1.23, 1.23), and after that increases again to 10.92% at (0.82,1.64) and reaches the highest value of 13.91% at (0.41, 2.05). So, density decreases as RHA + AC increases, while porosity increases, especially at higher AC content.

4.1.2 Tensile test

The base sample S (0,0) (aluminum) exhibits moderate tensile strength and ductility, reaching a peak stress of about 120 MPa, followed by a sharp drop indicating fracture. The A2a (0.82% RHA + 1.64% AC) sample shows the highest tensile strength, reaching approximately 145 MPa, and sustains higher strain before failure, indicating improved strength and ductility compared to the base metal. A1 (1.23% RHA + 1.23% AC) also performs well, with a peak stress around 135 MPa, slightly lower than A2a but higher than the base alloy. A2b (0.82% RHA + 1.64% AC) shows moderate improvement over pure aluminum, reaching about 110 MPa, but fails earlier than A2a, suggesting processing or microstructural variation. A4 (0.41% RHA + 2.05% AC) exhibits lower tensile strength (≈ 80 MPa) and reduced ductility, indicating excess AC negatively affects load transfer. A3a and A3b (1.64% RHA + 0.82% AC) show the lowest tensile strengths (≈ 60–70 MPa) with early fracture, suggesting that higher RHA content reduces tensile performance due to particle agglomeration and stress concentration

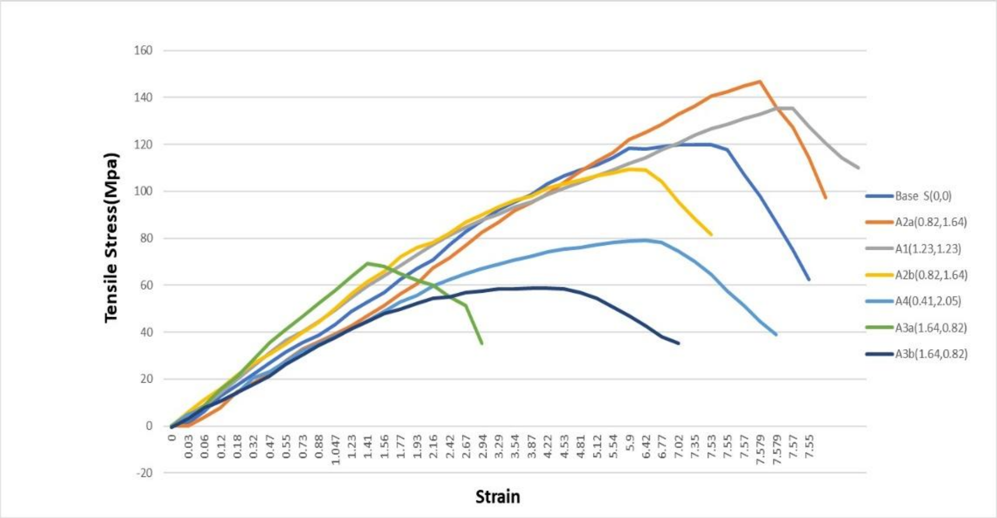


Fig. 13: Stress vs Strain of tensile test

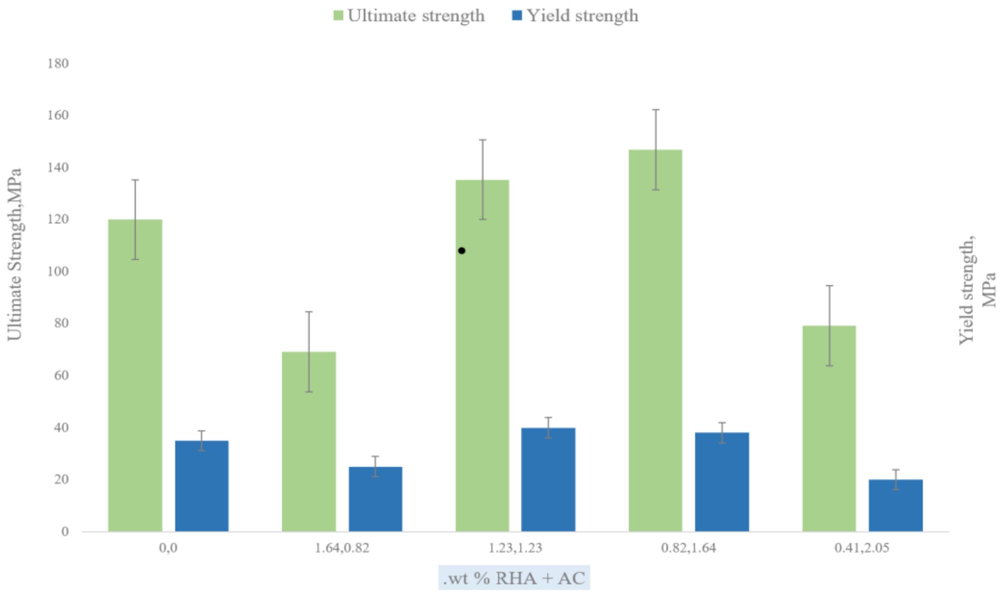


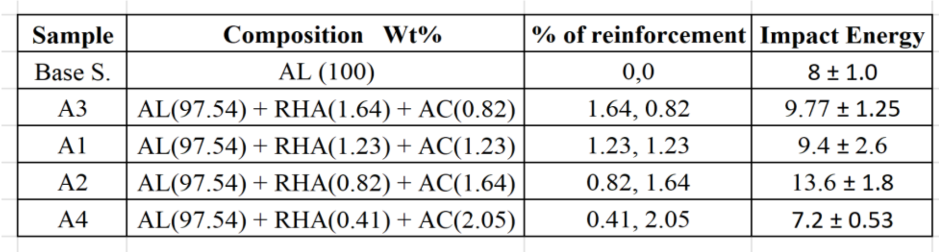
Fig. 14: Tensile and ultimate stress variation with wt.%

- **X-axis:** Composition of samples (RHA %, AC %)
- **Left Y-axis:** Ultimate strength (MPa)
- **Right Y-axis:** Yield strength (MPa)

The base sample (0,0) shows an ultimate strength of about 120 MPa and a yield strength of approximately 35 MPa. The 1.64% RHA + 0.82% AC composite exhibits a significant reduction in strength, with UTS around 70 MPa and yield strength near 25 MPa, indicating poor load transfer at higher RHA content. The 1.23% RHA + 1.23% AC sample shows improved mechanical performance, achieving a UTS of about 135 MPa and the highest yield strength (~40 MPa) among all samples. The 0.82% RHA + 1.64% AC composition records the highest ultimate tensile strength, approximately 145 MPa, along with a high yield strength (~38 MPa), representing the optimal reinforcement ratio. The 0.41% RHA + 2.05% AC sample shows moderate performance, with UTS around 80 MPa and the lowest yield strength (~20 MPa), suggesting excessive AC content adversely affects strength.

4.1.3 Impact test

Table 4: Properties table of materials (Impact Energy)



Sample	Composition Wt%	% of reinforcement	Impact Energy
Base S.	AL (100)	0,0	8 ± 1.0
A3	AL(97.54) + RHA(1.64) + AC(0.82)	1.64, 0.82	9.77 ± 1.25
A1	AL(97.54) + RHA(1.23) + AC(1.23)	1.23, 1.23	9.4 ± 2.6
A2	AL(97.54) + RHA(0.82) + AC(1.64)	0.82, 1.64	13.6 ± 1.8
A4	AL(97.54) + RHA(0.41) + AC(2.05)	0.41, 2.05	7.2 ± 0.53

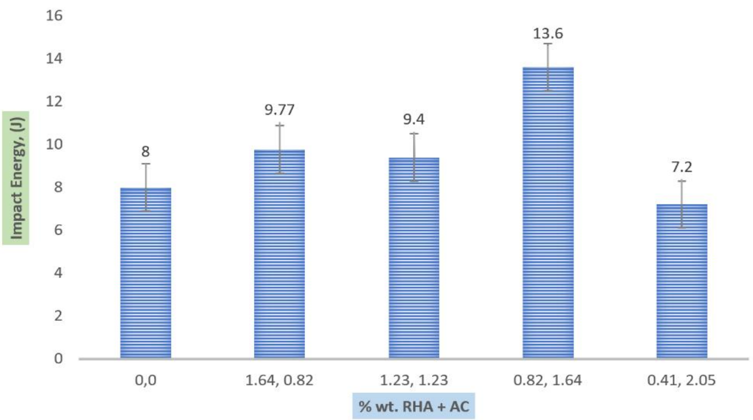
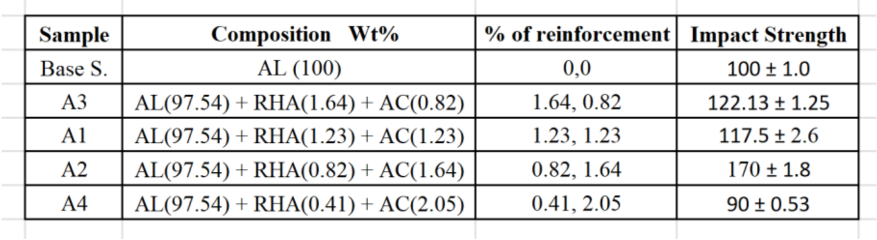


Fig. 15: Impact Energy vs % wt. RHA+AC

In Fig. 15 shows the Impact energy (J) for different rice husk ash (RHA) and activated carbon (AC) weight percentages. For the sample without reinforcement (0% RHA+ 0% AC), the impact energy is 8 J. When RHA and AC are added, the impact energy increases, indicating improved energy absorption capability of the material. At 1.64% RHA + 0.82% AC, the impact strength rises to 9.77 J, and at 1.23% RHA + 1.23% AC, it is slightly decreases to 9.4 J, showing a moderate improvement compared to the base material. The maximum impact energy of 13.6 J is obtained at 0.82% RHA + 1.64% AC, which is indicates the highest composition for impact performance. However, further increases in AC content to 0.41% RHA + 2.05% AC leads to a decrease in impact energy to 7.2 J. Overall, this graph clearly shows that impact energy increases up to the highest RHA, AC combination and then decreases beyond that point.

4.1.4 Impact strength

Table 5: Properties table of materials (Impact Strength)



Sample	Composition Wt%	% of reinforcement	Impact Strength
Base S.	AL (100)	0,0	100 ± 1.0
A3	AL(97.54) + RHA(1.64) + AC(0.82)	1.64, 0.82	122.13 ± 1.25
A1	AL(97.54) + RHA(1.23) + AC(1.23)	1.23, 1.23	117.5 ± 2.6
A2	AL(97.54) + RHA(0.82) + AC(1.64)	0.82, 1.64	170 ± 1.8
A4	AL(97.54) + RHA(0.41) + AC(2.05)	0.41, 2.05	90 ± 0.53

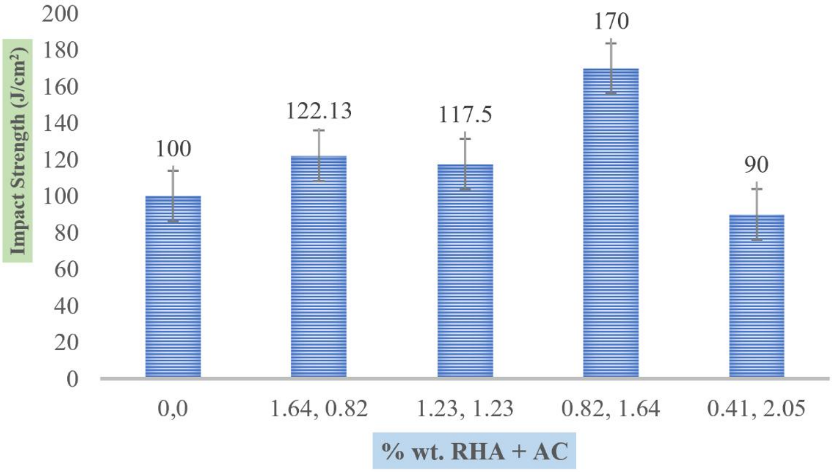
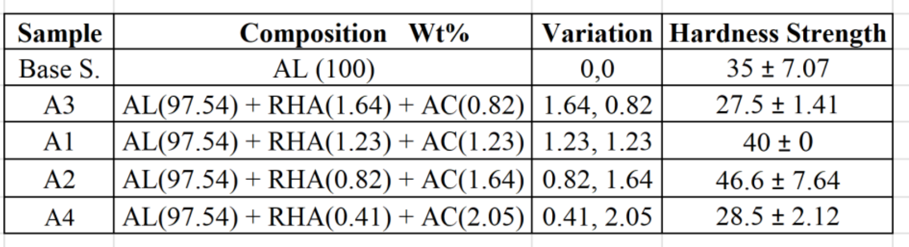


Fig. 16: Impact Strength vs % wt. RHA+AC

In Fig. 16 shows the Impact strength (J/cm²) for different rice husk ash (RHA) and activated carbon (AC) weight percentages. For the sample without reinforcement (0% RHA+ 0% AC), the impact strength is 100 J/cm². When RHA and AC are added, the impact strength increases, indicating improved energy absorption capability of the material. At 1.64% RHA + 0.82% AC, the impact strength rises to 122.13 J/cm², and at 1.23% RHA + 1.23% AC, it is slightly decreases to 117.5 J/cm², showing a moderate improvement compared to the base material. The maximum impact strength of 170 J/cm² is obtained at 0.82% RHA + 1.64% AC, which is indicates the highest composition for impact performance. However, further increases in AC content to 0.41% RHA + 2.05% AC leads to a decrease in impact strength to 90 J/cm². Overall, this graph clearly shows that impact strength increases up to the highest RHA, AC combination and then decreases beyond that point.

4.1.5 Hardness test

Table 6: Properties table of materials (Rockwell Hardness)



Sample	Composition Wt%	Variation	Hardness Strength
Base S.	AL (100)	0,0	35 ± 7.07
A3	AL(97.54) + RHA(1.64) + AC(0.82)	1.64, 0.82	27.5 ± 1.41
A1	AL(97.54) + RHA(1.23) + AC(1.23)	1.23, 1.23	40 ± 0
A2	AL(97.54) + RHA(0.82) + AC(1.64)	0.82, 1.64	46.6 ± 7.64
A4	AL(97.54) + RHA(0.41) + AC(2.05)	0.41, 2.05	28.5 ± 2.12

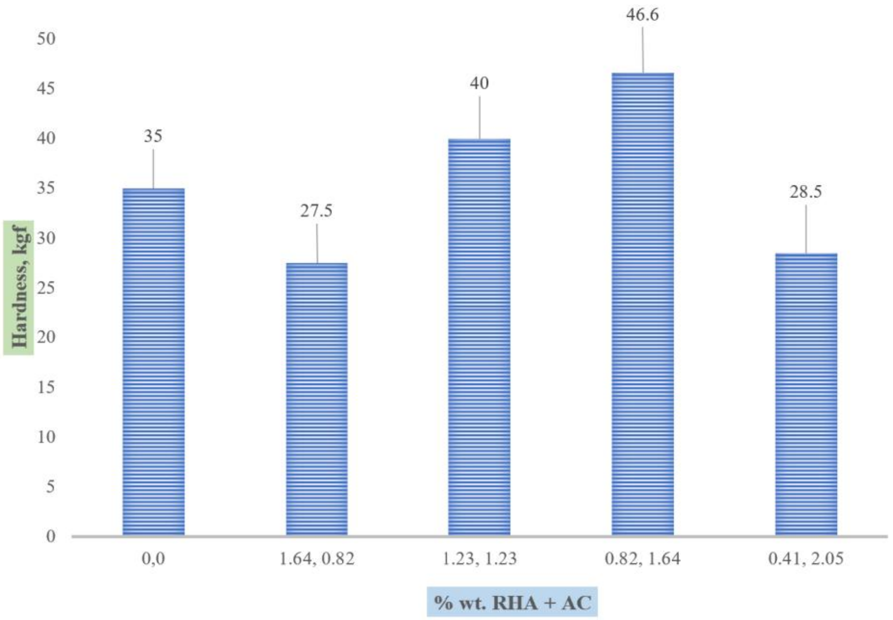


Fig. 17: Rockwell Hardness vs % wt. RHA + AC

Fig. 17 shows the Rockwell hardness number (HRB) of aluminium composites reinforced with rice husk ash (RHA) and activated carbon (AC). The maximum HRB of 46.6 is sample (0.82, 1.64), representing a 33.14% improvement of the base. The base sample (0,0) shows an HRB value of 35 and is taken as the reference. The second-highest hardness is recorded for the composite (1.23, 1.23), where the HRB reaches 40, indicating a 14.28% improvement compared to the base. In contrast, certain compositions show a reduction in hardness. The composite (0.41, 2.05) records an HRB of 28.5, corresponding to an - 18.57% decrease, while the composite (1.64, 0.82) exhibits an HRB of 27.5, reflecting a - 21.42% decrease relative to the base. Another notable observation is that when the AC content remains nearly constant, an increase in RHA content leads to a clear enhancement in hardness, which aligns with previous findings for aluminium–RHA composites [35]. The increased hardness is attributed to the presence of harder RHA and AC particles, which are more resistant to plastic deformation and surface indentation. This results in an overall improvement in the hardness of the composite.

4.1.6 Microstructure analysis

The element composition of pure aluminum was analysed using EDX, The EDX spectrum of pure aluminum presented in Fig.1(a) shows a pure aluminum (Al) peak with negligible impurities, confirming the high purity of the matrix material used in this study. The surface morphology of activated carbon was observed using FESEM, as presented in Fig. 2(a). The images show an irregular and porous surface with many small pores and rough edges. This type of structure helps the activated carbon particles to bond well with aluminum matrix. The corresponding EDX spectrum shown in Fig. 2(b) confirms that activated carbon is the main element, with amount of oxygen and other elements due to activation process. The FESEM micrographs of rice husk ash shown in Fig. 3(a) display angular and uneven particles with rough surfaces. These rough and porous particles can improve the bonding between the rice husk ash and the aluminum matrix. The EDX spectrum presented in Fig. 3(b) shows the presence of oxygen and silica as the major elements, confirming of the rice husk ash.

The FESEM micrographs of the tensile fractured specimens, shown in Fig. 18, reveal important features related to the fracture behaviour of the aluminum hybrid composites. The fractured surfaces show the presence of dimples and micro-voids, which indicate a predominantly ductile mode of facture. In some regions, broken and pulled out reinforcement particles are observed, suggesting effective load transfer between the aluminum matrix and the reinforcements before failure. The rough and uneven fracture surface further confirms strong interfacial bonding between activated carbon, rice husk ash, and the aluminum matrix. Additionally, the presence of small cracks and localized brittle zones around reinforcement particles indicates stress concentration during tensile loading. Overall, the fracture morphology demonstrates a combined ductile-brittle fracture behaviour, which contributes to the improved tensile strength of the hybrid composites.

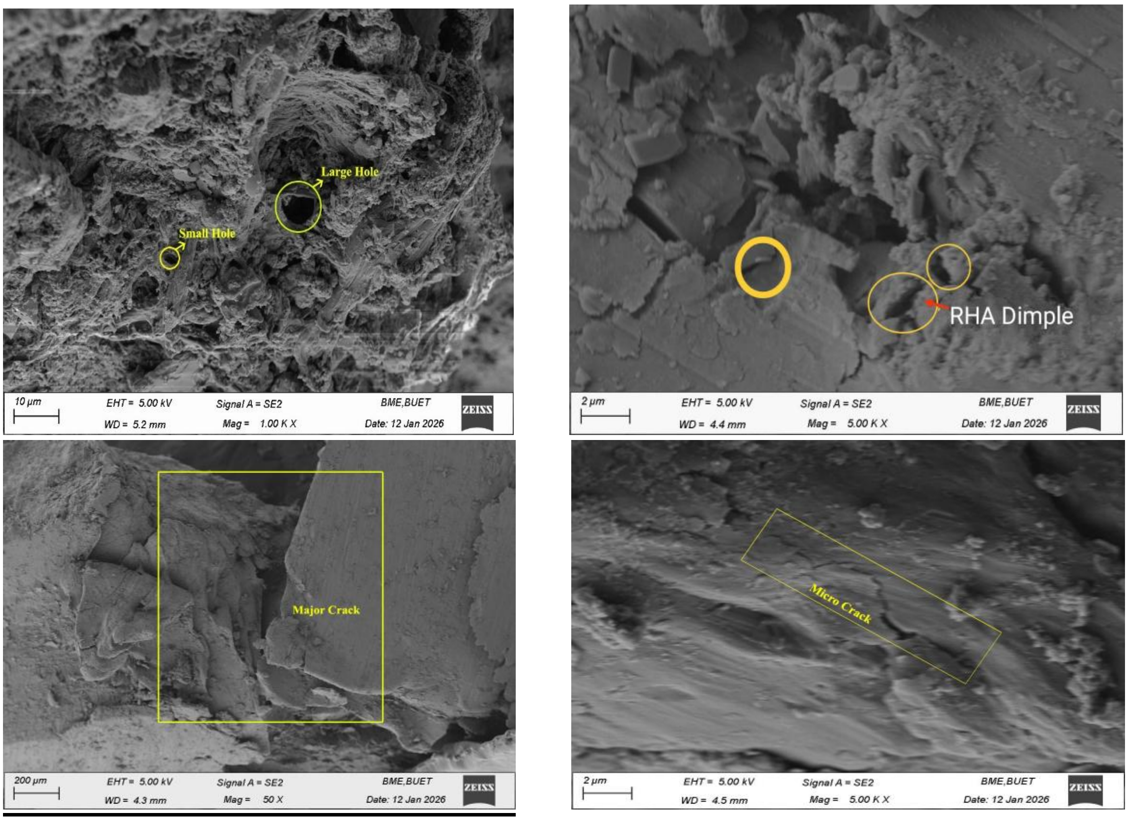


Fig. 18: FESEM for tensile specimens

CHAPTER 5: CONCLUSION AND FUTURE RECOMMENDATIONS

5.1.1: Conclusion

This study fabricated aluminum hybrid composites reinforced with activated carbon (AC) and rice husk ash (RHA) using the stir-casting method. Mechanical and microstructural properties were evaluated through tensile, hardness, and impact tests, along with FESEM and EDX analysis. Porosity remained within acceptable limits, but reinforcement ratio strongly influenced performance. The base aluminum sample S (0,0) showed moderate strength at ≈120 MPa with early fracture. A2a (0.82,1.64) achieved the highest tensile strength of ≈145 MPa, improved ductility, hardness of 46.6 HRB, and impact strength of 13.6 Nm. A1 (1.23,1.23) also performed well at ≈135 MPa, while A2b (0.82,1.64) reached ≈110 MPa but failed earlier, indicating microstructural variation. Excess AC in A4 (0.41,2.05) reduced strength to ≈80 MPa, and higher RHA in A3a/b (1.64,0.82) caused agglomeration, lowering strength to ≈60–70 MPa.

Microstructural observations confirmed grain refinement, uniform particle distribution, and strong interfacial bonding in optimized samples. Overall, balanced AC and RHA reinforcement enhanced yield and ultimate strength, proving these agro-waste additives can produce lightweight, strong, and eco-friendly aluminum composites suitable for automotive, aerospace, structural and engineering application.

5.1.2 Future recommendations

- A wider range of activated carbon (AC) and rice husk ash (RHA) weight percentages should be studied to identify the optimum hybrid composition.
- The influence of different particle sizes and shapes of AC and RHA on mechanical, wear, and impact properties should be investigated.
- Heat treatment processes such as solution treatment and aging may be applied to further improve hardness and strength.
- Long-term performance tests, including wear, fatigue, corrosion, and high-temperature behaviour, should be carried out.
- Alternative fabrication techniques such as squeeze casting and powder metallurgy can be compared with stir casting to reduce porosity and improve particle distribution.
- Advanced microstructural analysis using XRD and TEM is recommended to study phase formation and interfacial bonding.
- Scale-up studies and cost analysis should be conducted to evaluate industrial feasibility.
- Environmental impact and life-cycle assessment are recommended to confirm the sustainability benefits of using agricultural waste-based reinforcements.

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