

“Experimental Study on the Mechanical and Microstructural Properties of Aluminium Hybrid Composites Reinforced with Graphite and Rice Husk Ash”

**A report submitted to the Department of Mechanical Engineering,
Sonargaon University in fulfilment of the requirements for the course**



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19th January 2026

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CERTIFICATE OF RESEARCH

This is to certify that the research work titled “**Experimental Study on the Mechanical and Microstructural Properties of Aluminium Hybrid Composites Reinforced with Graphite and Rice Husk Ash**” has been carried out by “ (Md.Kazi Rabbi, ID-ME 2201026081, Md. Rayhan Howalader, ID-ME 2201026185,Md. Akram Hossain, ID-ME 2201026024, Moksedul Hasan, ID-ME 2201026017,Sazal Kumer, ID-ME 2201026270) ” under the supervision of Md. Anash Mia, Lecturer, Department of Mechanical Engineering, Sonargaon University, Dhaka, Bangladesh.

The thesis does not include any work on the Aluminium Matrix Composites Reinforced with Rice Husk Ash and Graphite that has been previously published or authored by another individual, except where proper acknowledgment has been provided.

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CANDIDATES DECLARATION

This is to certify that the project and thesis work entitled “**Experimental Study on the Mechanical and Microstructural Properties of Aluminium Hybrid Composites Reinforced with Graphite and Rice Husk Ash**” has been carried out by “(Md.Kazi Rabbi, ID-ME 2201026081, Md. Rayhan Howalader, ID-ME 2201026185, Md. Akram Hossain, ID-ME 2201026024, Moksedul Hasan, ID-ME 2201026017, Sazal Kumer, ID-ME 2201026270) ” in the Department of Mechanical Engineering, Sonargaon University (SU), Dhaka, Bangladesh. The above thesis work or any part of this work has not been submitted anywhere for the award of any degree or diploma.

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ABSTRACT

This study investigates the mechanical properties of graphite powder (GP) and rice husk ash (RHA) reinforced aluminium matrix composites in comparison with pure aluminium. Tensile test specimens were fabricated with identical dimensions to ensure repeatability, having a total length of 170 mm, a gauge length of 90 mm, a gauge diameter of 12.5 mm, and a grip diameter of 20 mm. Hardness test samples were prepared with dimensions of $25 \times 25 \times 2$ mm, while Charpy V-notch impact specimens measured $55 \times 10 \times 10$ mm³. Pure aluminium exhibited an ultimate tensile strength of 90 MPa and a yield strength of 34.5 MPa. The incorporation of GP and RHA led to a gradual improvement in tensile properties, with the maximum values obtained for the composite containing 2.05% GP and 0.41% RHA. This composition achieved an ultimate tensile strength of 147.98 MPa and a yield strength of 55.85 MPa, corresponding to improvements of 64.42% and 61.88%, respectively. The improvement is attributed to effective load transfer and dispersion strengthening mechanisms. Rockwell hardness increased significantly from 20 HRB for pure aluminium to a maximum of 89 HRB for the highest reinforced composite due to the presence of hard silica-rich RHA particles and grain refinement. Impact test results showed a non-linear trend, with the highest impact energy of 15.3 J observed at the 1.23% GP–1.23% RHA composition due to crack-bridging and crack-deflection mechanisms, while higher reinforcement levels resulted in reduced toughness because of increased brittleness. Overall, the results demonstrate that GP–RHA hybrid reinforcement effectively enhances the mechanical performance of aluminium matrix composites, with an optimal balance of strength, hardness, and impact toughness achieved at intermediate reinforcement levels.

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NOMENCLATURE

ASTM E18	Standard Test Methods for Rockwell Hardness of Metallic Materials
ASTM E23	Standard Test Methods for Impact Testing of Metallic Materials
ASTM E8	Standard Test Methods for Tension Testing of Metallic Materials
ASTM	American Society for Testing and Materials
Kgf	Kgf stands for Kilogram-force, a non-SI unit of force equal to the weight of one kilogram of mass under standard Earth gravity (about 9.8 Newtons)
Nm	Newton-meter (Nm) for torque in physics/engineering
h	Hour, Unit of Time
gm	Gram, Unit of Mass
mm	Millimeters, Unit of Length
Mp	Megapixels (MP) measure digital image resolution, indicating one million pixels

CHAPTER 1: INTRODUCTION

1.1 Overview

Aluminium Composite Material (ACM) is a modern engineering material widely used in construction, transportation, and industrial applications due to its unique combination of light weight, strength, and versatility. ACM typically consists of two thin Aluminium sheets bonded to a lightweight core, which is often made of polyethylene (PE), fire-retardant polymers, or mineral-filled materials. This “sandwich” structure provides an excellent strength-to-weight ratio, making ACM an ideal choice for applications where structural performance and low weight are simultaneously required. One of the most significant advantages of ACM is its high stiffness and rigidity, which allows the material to resist bending and deformation while remaining lightweight. The Aluminium skins provide corrosion resistance and durability, while the core contributes to impact absorption, sound insulation, and thermal resistance. This combination of properties makes ACM not only strong and durable but also low-maintenance and long-lasting, which is particularly valuable in building and infrastructure projects. ACM also exhibits superior mechanical properties, such as high flexural strength, impact resistance, and vibration damping. Its thermal and acoustic insulation capabilities make it suitable for applications that require comfort and energy efficiency. Moreover, ACM’s smooth, flat surface and aesthetic versatility enable architects and designers to create visually appealing facades, partitions, ceilings, signage, and interior decorative elements. In practice, ACM has been widely adopted for building facades, cladding, partition walls, roofing panels, signage, and automotive body panels. Fire-retardant core materials have further expanded its use in high-rise buildings and industrial constructions where fire safety is critical. In addition, ACM is lightweight enough to reduce structural loads and transportation costs while maintaining high structural integrity. Overall, the combination of lightweight, high strength, durability, aesthetic appeal, and multi-functional performance makes Aluminium Composite Material a highly versatile and essential material in modern engineering and construction industries. Its continued adoption is driven by the need for innovative, energy-efficient, and aesthetically flexible solutions that meet both technical and economic demand

1.2 Objectives

The objectives of the project are:

- i. To develop a lightweight, strong, and durable aluminium composite by incorporating graphite and rice husk ash.
- ii. To investigate the changes in hardness and tensile strength of the composite with varying weight percentages of reinforcement.
- iii. To analyze the properties of the prepared composite for its potential applications in engineering and industrial sectors.

1.3 Literature Review

The composite materials are increasingly gaining popularity in engineering due to their strength, low weight, and versatility. Since the 1990s, there has been a drive for utilizing natural fibres such as rice husk and coir fibre because they are eco-friendly, renewable, biodegradable, and capable of absorbing carbon emissions [1]. Rice husk, which is a universal agricultural by-product, contains cellulose, hemicellulose, lignin, and high silica content. About 22% by weight of paddy is husk, and on burning, 85–90% amorphous silica is obtained [2,5]. Rice husk ash (RHA) has been successfully used as a pozzolanic material for partial replacement in cement, which enhances the durability and strength of concrete and minimizes environmental pollution... [3,4].

Studies from India, Thailand, and Colombia indicate that RHA can be used successfully in the construction sector. Apart from construction, RHA has found interest in engineering composites. High amorphous silica content offers enormous prospect for lightweight, strong, and eco-friendly aluminium-based composites [6]. RHA reinforced the aluminium matrix composites (AMCs) which have increased strength, hardness, and wear resistance. Heat treatment, in-situ reaction, and alloying enhance mechanical properties [7,8].

Poor particle distribution and weak bonding are however setbacks. The Techniques like friction stir processing (FSP) and stir casting which have been utilized to combat these issues, improving homogeneity, toughness, and strength [9–11]. At the same time, extensive studies which have explored the aluminium composites with graphite, graphene, SiC, B₄C, and other micro/nano-particles. For instance, Al–graphite and Al–graphene composites which have been studied for thermal management due to their excellent conductivity and self-lubricating properties [16–18].

Hybrid composites of aluminium alloys and reinforcements like SiC, graphite, and coconut shell ash have been prepared by stir casting, powder metallurgy, and hot press forging

methods [14,15,19–22]. These studies reveal improved hardness, wear resistance, thermal stability, and sustainability. Despite all these advances, utilization of agricultural waste such as rice husk ash in aluminium matrix composites is comparatively less explored compared to graphite or ceramic reinforcements. Therefore, this work has focused on the production of aluminium–RHA composites with enhanced mechanical properties (hardness, tensile strength, wear resistance) by low-cost and easy processing routes. The intention is to fabricate light-weight, high-strength, and eco-friendly materials for automobile, aerospace, and structural applications [12,

CHAPTER 2: MATERIALS

2.1 Materials

The raw materials that have been utilized for this investigation are described below. For this work, composite hybrid was mainly selected because it has very good electrical conductivity and is easy to deform without breaking. The rice husk ash and graphite are used here—rich in silica and carbon which is known for working well as a strengthening additive which was gathered from the Dhaka and Gazipur area in Bangladesh. By combining these two materials, samples were prepared with roughly RHA and graphite added by weight to the Aluminium.

2.2 Aluminium

In this study, a commercially Aluminium alloy, such as pure Aluminium, was selected as the matrix material. Aluminium was selected mainly for it is lightweight, resistant to corrosion, and good mechanical strength. These properties make Aluminium suitable for use as a base material in composite fabrication. The Aluminium alloy was collected in the form of ingots and used as the primary metal for adding different reinforcing materials. Figure 2(a) shows the Aluminium ingots used in this work. The Aluminium alloy was collected from a local commercial supplier and prepared properly before being used in the composite manufacturing process.

Applications:

Applications / Uses of Aluminium

Aircraft & aerospace – lightweight and strong ✈️

Automobiles – car bodies, engine parts 🚗

Construction – doors, windows, roofing, frames 🏠

Electrical – transmission cables and wires ⚡

Packaging – foil, cans, food containers 🥫

Household items – utensils, pressure cookers 🔪

Electronics – mobile phones, laptops, heat sinks 💻

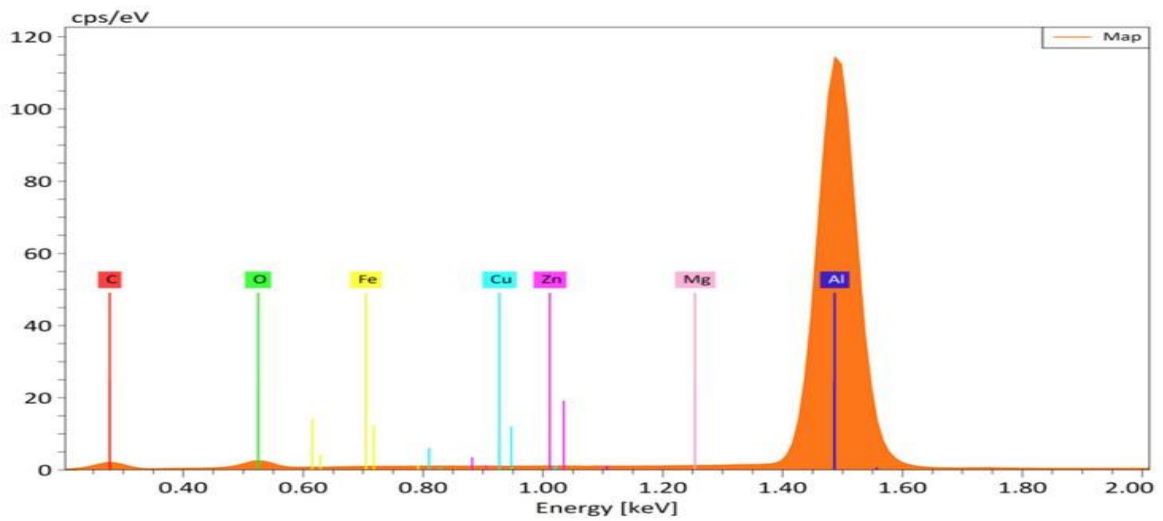
Marine industry – boats and ship parts 🚢



Fig 1: Raw Aluminium



Fig 2: Testing Specimen



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Fig 3: EDX mapping Aluminium

Figure:

1. Raw Aluminium
2. Specimen testing
3. EDX mapping Aluminium

Table 1: Prosperities Table of Aluminium

Element	At.No.	Netto	Mass [%]	Mass Norm [%]	Atom [%]	abs error [%]
C	6	23947	8.8	11.21	21.69	1.38
O	8	24233	2.56	3.26	4.73	0.31
Al	13	1814888	66.84	85.14	73.31	6.22
Cu	29	57	0	0.01	0	0.03
Zn	30	361	0.02	0.03	0.01	0.03
Fe	26	153	0.11	0.14	0.06	0.14
Mg	12	5038	0.17	0.21	0.2	0.03
sum			78.51	100	100	

2.3 Graphite

the present work, graphite powder (Gp) was utilized as the increasing reinforcing phase. The material was obtained from Millennium Scientific Mart situated at Hatkhola Road, Dhaka-1203, Bangladesh, as

depicted in Fig. 4(c). Several investigations on Aluminium matrix composite systems have demonstrated that graphite reinforcement plays a positive role in improving both mechanical properties and tribological behavior Morphological examination using Scanning Electron Microscopy (SEM) shows that the graphite particles are non-uniform in shape, Figure 3 presents the SEM microstructure together with the corresponding EDS elemental distribution of the graphite powder.

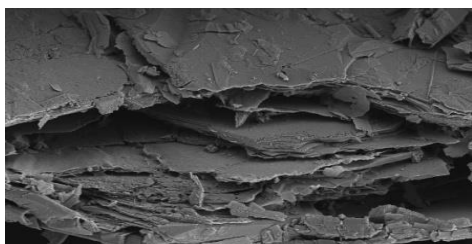


Fig 1: FESEM of Graphite

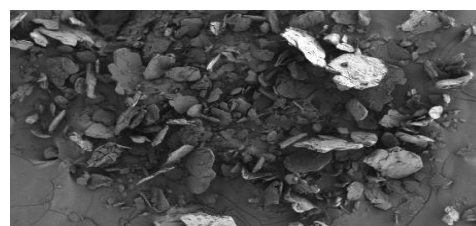


Fig 2: FESEM of Graphite

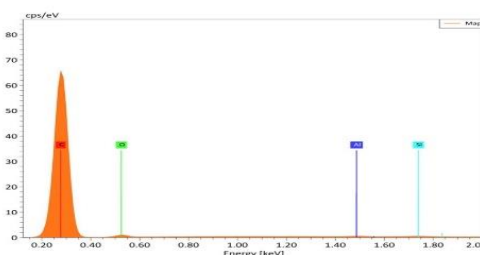


Fig 3: EDX Mapping of Graphite

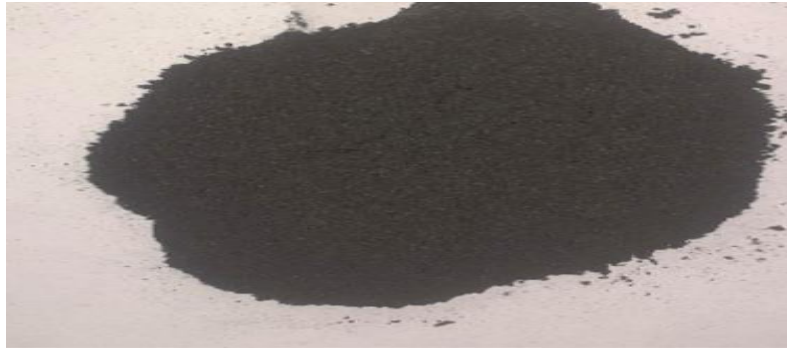


Fig 4: Graphite

Figure:

1. FESEM of Graphite
2. FESEM of Graphite
3. EDX mapping of Graphite
4. Graphite

Table 2: Properties Table of Graphite

Element	At.No.	Netto	Mass [%]	Mass Norm[%]	Atom [%]	abs. error [%]
C	6	1202477	96.09	96.09	97.19	9.26
O	8	14752	3.4	3.4	2.58	0.48
Al	13	3937	0.17	0.17	0.08	0.03
	14	5891	0.34	0.34	0.15	0.05
Sum			100	100	100	

2.4 Rice husk ash

Research, rice husk ash (RHA) was taken as a secondary reinforcing material. The rice husk was collected online from Jamuna Auto Rice Mill, Kushtia, Bangladesh, as shown in Fig. 2(c). At first, the rice husk was cleaned by washing it with water and hydrochloric acid (HCl) to remove dust and other unwanted materials. After cleaning rice husk ash, it was kept under sunlight for about six hours to dry. Then the dried rice husk was placed in an electric oven and heated at a fixed temperature for forty-eight hours. After drying, the rice husk was burned in a kiln at controlled temperatures between 400°C and 465°C to produce rice husk ash rich in silica. The ash was then allowed to cool naturally in air for nearly three hours. Finally, the cooled ash was ground and sieved to obtain particles of almost uniform size,

around 40 μm . Table 3 presents the thermal properties of activated carbon powder and rice husk ash particles.



Fig 1: Rice Husk Ash before Fire



Fig 2: Rice Husk Ash After Fire

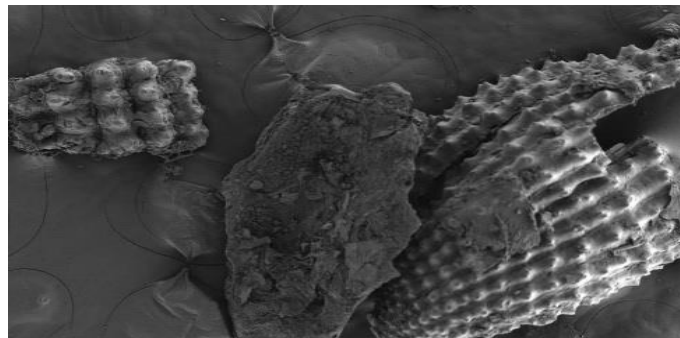


Fig 3: FESEM of Rice Husk Ash

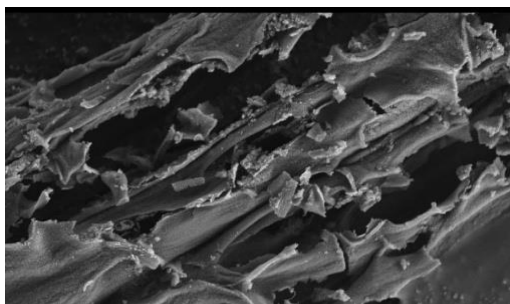


Fig 4: FESEM of Rice Husk Ash

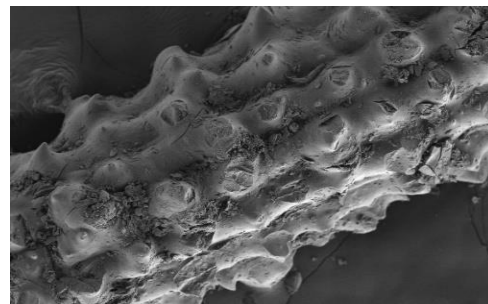


Fig 5: FESEM of Rice Husk Ash

Figure:

1. Rice husk ash before fire
2. Rice husk after fire
3. FESEM of RHA
4. FESEM of RHA
5. FESEM of RHA

Table 3: Properties Table of Rice Husk Ash

Element	At.No.	Netto	Mass [%]	Mass Norm[%]	Atom [%]	abs.error [%]
C	6	112858	21.54	25.36	35.85	3.1
O	8	368437	35.48	41.77	44.33	4.14
Si	14	681692	27.45	32.32	19.54	2.24
K	19	5209	0.36	0.42	0.18	0.04
Mg	12	3119	0.11	0.13	0.09	0.03
Sum		84.94		100	100	

CHAPTER 3: METHODOLOGY

3.1 Composite Fabrication

The rice husks were washed and dried first then. RHA AND graphite were heated in an electric furnace at 650 °C for four hours until they became dark. This made the ash rich in silica and high carbon which was used as the strengthening material in the composite After that, sand casting was done. Aluminium was melted at about 661 °C, and three types of molds were made. Different shapes and sizes of samples were prepared for the tests, To mix everything well, the molten metal was kept heated for another 10–20 minutes. The floating waste on top was removed carefully. Then the hot metal was poured into molds made from PVC pipes, and the flasks were built using connected rings. Later, the samples were shaped using shaper machine, CNC lathe, normal lathe, flat files, and hacksaws. Several ASTM guidelines were followed to make the samples for the four mechanical tests

3.2 Stir Casting Method

3.1 Composite fabrication:

The rice husks were washed and dried first then. RHA AND graphite were heated in an electric furnace at 650 °C for four hours until they became dark. This made the ash rich in silica and high carbon which was used as the strengthening material in the composite After that, sand casting was done. Aluminium was melted at about 661 °C, and three types of molds were made. Different shapes and sizes of samples were prepared for the tests, To mix everything well, the molten metal was kept heated for another 10–20 minutes. The floating waste on top was removed carefully. Then the hot metal was poured into molds made from PVC pipes, and the flasks were built using connected rings. Later, the samples were shaped using shaper machine, CNC lathe, normal lathe, flat files, and hacksaws. Several ASTM guidelines were followed to make the samples for the four mechanical tests

variation 1:	Aluminium 97.53%	–	Graphite powder 0.82%	RHA 1.64%
Variation 2:	Aluminium 97.53%	–	Graphite powder 1.64%	RHA 0.82%
Variation 3:	Aluminium 97.53%	–	Graphite powder 1.23%	RHA 1.23%
Variation 4:	Aluminium	–	Graphite powder 2.05%	RHA 0.41%

	97.53%		
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variation 1:

Aluminium 97.53%

Graphite powder 0.82%

RHA 1.64%

variation 2:

Aluminium 97.53%

Graphite powder 1.64%

RHA 0.82%

variation 3:

Aluminium 97.53%

Graphite powder 1.23%

RHA 1.23%

variation 4:

Aluminium 97.53%

Graphite powder 2.05%

RHA 0.41%

3.3 Machining part

The fabrication was finished, the solid sample which is shaped for testing specimens by machining. The dimensions of all specimens were selected according to ASTM standards so that different mechanical tests could be carried out correctly. These tests included tensile strength, compression strength, impact resistance, and hardness measurement. Using ASTM standard sizes helped to maintain consistency and accuracy in the test results. Before starting the machining work, the required shapes of the test specimens were first designed using CAD software. These digital designs clearly showed the size and shape of each specimen. Based on the CAD drawings, proper cutting paths were prepared for machining. The machining process was then carried out using CNC lathe machines and milling machines to ensure better accuracy, smooth surface finish, and repeatability. A figure presents an overall view of the complete machining process from design to final specimen. Another figure shows the CAD drawings of the different specimen shapes used for mechanical testing. To make the machining work easier and more flexible, the grip diameter of tensile, compression, and hardness test specimens was kept the same. This is common grip section, which is visible as

the extended part in the figure which is helped to reduce machining time, use of the same holding tools, and simplified the overall machining operation.

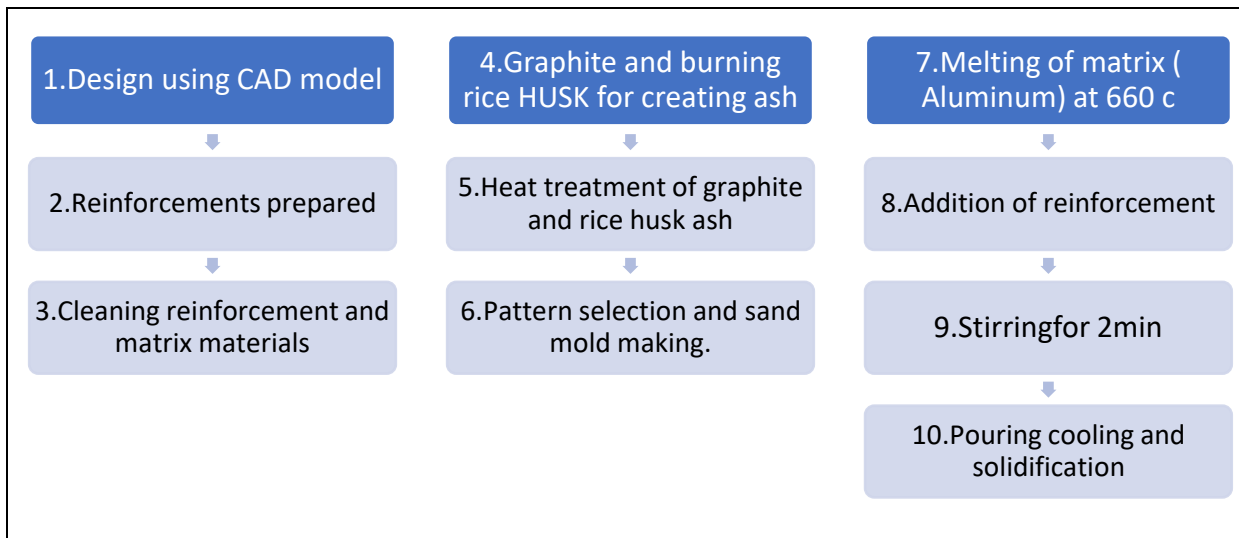
3.4 Sample Designation

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 92 wt% Aluminium. The remaining 8 wt% was distributed between Graphite and rice husk ash (RHA), with the proportions varied across the four groups. The approach was designed to test how Graphite and RHA might work together to influence the properties of the composites. The precise weight percentages used in each variation are shown below.

3.5 Table Chart

SL NO.	Aluminium(gm)	Aluminium%	RHA(gm)	RHA%	Graphite(gm)	Graphite%
1	1950 gm	97.53%	32 gm	1.64%	16 gm	0.82%
2	1950 gm	97.53%	16 gm	0.82%	32 gm	1.64%
3	1950 gm	97.53%	24 gm	1.23%	24 gm	1.23%
4	1950 gm	97.53%	8 gm	0.41%	40 gm	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 Graphite and RHA. These were introduced to test how slight adjustments could influence the composites. Focus was placed on wear resistance, hardness, and microstructural uniformity



3.6 Tensile Test

The tensile test was done to follow the ASTM E8 standard. The sample is used in the test which had a gauge length of about 90 mm, and a diameter of 12.5 ± 0.02 mm. Aluminium was mixed with rice husk ash (RHA) and graphite to prepare the specimens. The samples were made in a dumbbell shape as shown in Figure .Figure shows the samples placed in the Universal Testing Machine during the test. Figure shows the rice husk ash and Graphite and the samples used for different mechanical tests. To find the modulus of elasticity, the stress–strain data from the test were used. The following equation was applied: $E = \Delta\sigma / \Delta\varepsilon$ i

2.Reinforcemen ts prepared 3.Clearing reinforcement and matrix material. 4.Graphite and burning rice HUSK for creating ash 5.Heat treatment of graphite and rice husk ash 10.Pouring,cool ing,and solidification. 9.Stirring for 2 min. 8.Addition of reinforcement. 7.Melting of matrix (Aluminium) at 660 C 6.Pattern selection and sand mold making. 1.Design using CAD model. ` Here, E is the modulus of elasticity, $\Delta\sigma$ is the change in stress between two points in the linear part of the stress–strain curve, and $\Delta\varepsilon$ is the change in strain between those two points.

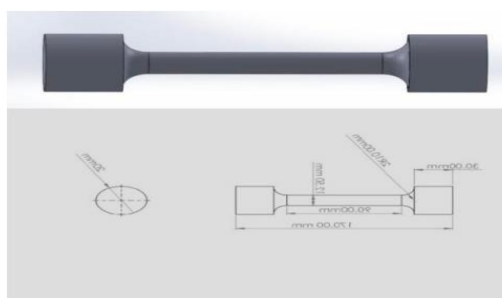


Fig: Tensile test Specimen(a)



Fig: Testing Figure(b)

3.7 Impact Test

In this work, the Charpy impact test was created based on the ASTM E23 to find out how much impact energy the specimen can absorb before breaking. When the pendulum hammer struck the sample, it starts to absorb the energy until the plastic deformation is started at the notched area. When the deformation is increased as a result the material gradually lost its strength and finally fractured when it can no longer take any additional energy. This test is widely used because it gives a clear idea about the relative toughness of different materials.

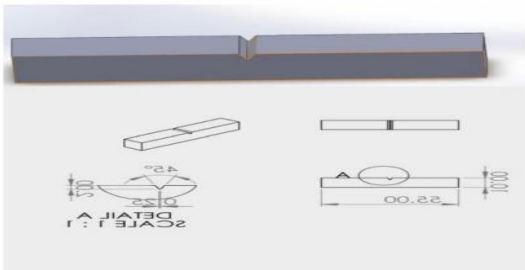


Fig: Impact test(a)



Fig: Testing figure(b)

Each Charpy specimen was prepared in the standard size of $55 \times 10 \times 10 \text{ mm}^3$, with a notch made across one of the larger faces. The testing setup, as shown in Figure 2(e), used a 20 kg hammer released from a height of 1.44 meters. Two kinds of notches were used: the V-notch, which was 2 mm deep, had a 45° angle and a 0.25 mm root radius; and the U-notch (also called a keyhole notch), which had a 1 mm radius at the base and was 5 mm deep. The amount of energy absorbed before fracture was recorded for each specimen using the Charpy Impact Testing Machine.

3.8 Rockwell Hardness

In this work, the sample was determined by the Rockwell hardness test which is used for evaluating the strength and surface resistance of materials. The test is maintained to follow the ASTM E18 guideline. A specimen measuring 25 mm by 25 mm, shown in Figure 2(g), was positioned properly for the Rockwell testing setup, as illustrated in Figure 2(h). During the process, care was taken to make sure the specimen's surface stayed flat and perpendicular to the machine base, and the indenter remained slightly above the surface before the test started. Afterward, the testing machine was set on the Rockwell B scale (HRB). A steel ball of 1/16-inch diameter was used as the indenter for this test. The procedure is included to apply two loads: first a light load of 10 kgf, and then a heavier load of 100 kgf, according to

the follow of HRB method. This step is helped to obtain a precise reading of the material's hardness.



Fig: Hardness Testing Machine (a)

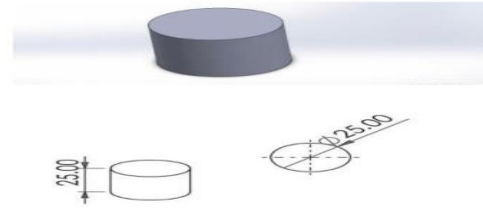


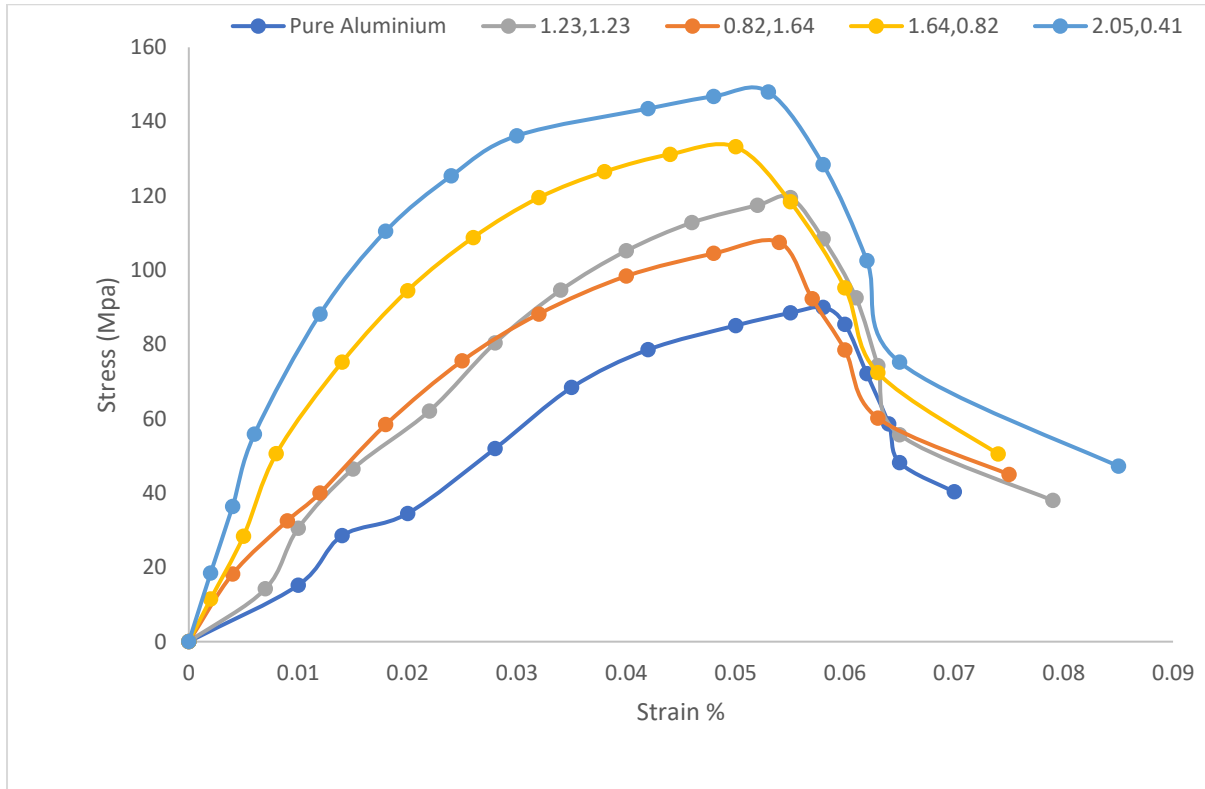
Fig: Hardness Testing Specimen (b)

3.9 Mechanical Testing

Testing Figure After making the composites, 35 samples were cut and shaped using CNC machining based on ASTM standards. Tensile tests were done following ASTM E8/E8M-15a. Hardness tests were carried out using the Rockwell method according to ASTM E18. The Impact tests were performed according to ASTM E23 by using the Charpy V-notch method. Mechanical properties such as strength, toughness, and modulus were measured using a universal testing machine. Yield strength and ultimate tensile strength were obtained from tensile tests using standard test samples. Hardness was measured on the Rockwell B scale, and several readings were taken to get reliable results. Impact tests were carried out using a standard Charpy impact testing machine

CHAPTER 4: RESULT AND DISCUSSION

4.1 Stress vs Strain Curve.



Fig, Stress vs Strain Curve

Stress vs Strain Curve Result:

Tensile tests were conducted on pure aluminium and graphite–RHA reinforced aluminium matrix composite specimens. All specimens were fabricated with identical dimensions to maintain uniform testing conditions. The total length of each specimen was 170 mm with a gauge length of 90 mm. The gauge section diameter was 12.5 mm, while the grip section diameter was maintained at 20 mm. These dimensions were kept constant for all compositions to ensure repeatability and accuracy of the tensile test results. The pure aluminium specimen exhibited an ultimate tensile strength of 90 MPa and a yield strength of 34.5 MPa. Upon the addition of graphite powder and rice husk ash (RHA), a significant improvement in mechanical properties was observed. In the first variation containing 0.84% graphite and 1.64% RHA, the ultimate tensile strength increased to 107.5 MPa and the yield strength to 40 MPa, representing improvements of approximately 19.44% and 15.94%, respectively, compared to pure aluminium. The second variation, with equal proportions of graphite and RHA (1.23% each), showed further enhancement, achieving an ultimate tensile

strength of 119.54 MPa and a yield strength of 46.5 MPa, corresponding to increases of about 32.82% and 34.78%. A more pronounced improvement was observed in the third variation containing 1.64% graphite and 0.84% RHA, where the ultimate tensile strength reached 133.2 MPa and the yield strength increased to 50.6 MPa. This represents an improvement of approximately 48% in ultimate tensile strength and 46.67% in yield strength. The maximum tensile properties were obtained in the fourth variation with 2.05% graphite and 0.41% RHA, where the ultimate tensile strength and yield strength reached 147.98 MPa and 55.85 MPa, respectively. These values indicate a significant enhancement of about 64.42% in ultimate tensile strength and 61.88% in yield strength compared to pure aluminium. The progressive increase in tensile properties can be attributed to effective load transfer between the aluminium matrix and reinforcement particles, improved stress distribution due to graphite addition, and the strengthening effect of RHA acting as a hard ceramic reinforcement. The combined effect resulted in enhanced resistance to plastic deformation and fracture, leading to superior mechanical performance of the composite materials.

4.2 Ultimate Strength vs Yield Strength Curve

Properties table of Ultimate Strength vs Yield Strength

Ultimate Strength (Mpa)	Yield strength (Mpa)	SD of Ultimate Strength	SD of Yield Strength	Variation
90	34.5	3.25528562	3.58694187	0
107.5	40	47.72970773	5.465728753	0.82,1.64
119.54	46.5	51.6470793	3.639534675	1.23,1.23
133.2	50.6	58.40702013	5.520396872	1.64,0.84
147.98	55.85	65.14574775	6.573086271	2.05,0.41

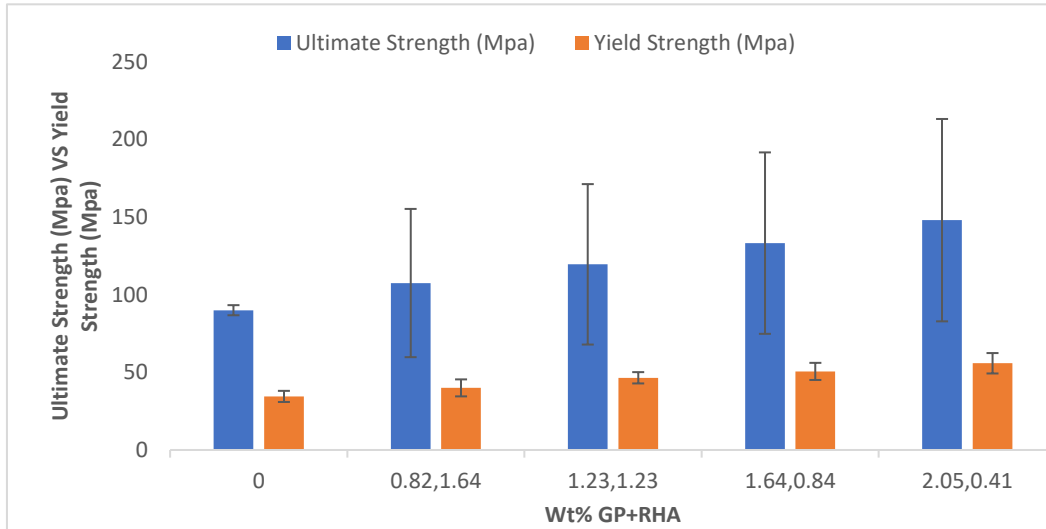


Fig: Ultimate Strength vs Yield Strength Curve

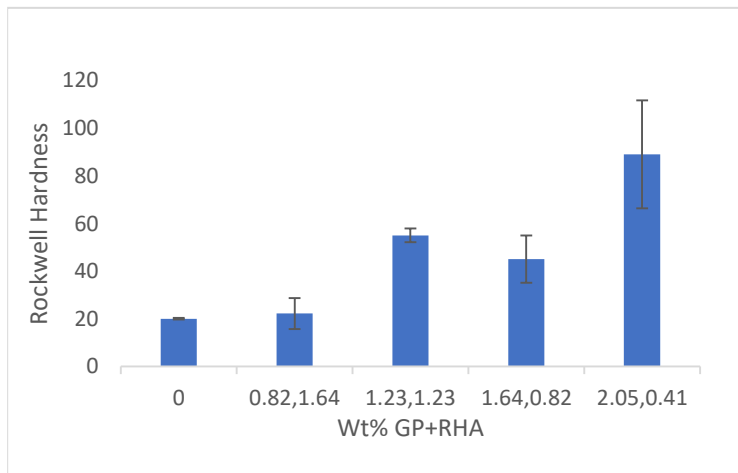
Ultimate strength vs Yield strength Curve Result:

The figure presents the variation of ultimate tensile strength (UTS) and yield strength (YS) of pure aluminium and GP–RHA reinforced aluminium matrix composites as a function of reinforcement content (wt%). The blue bars represent ultimate tensile strength, while the orange bars indicate yield strength. Error bars show the standard deviation, reflecting the consistency and repeatability of the tensile test results. For pure aluminium (0% reinforcement), the ultimate tensile strength and yield strength are recorded as 90 MPa and 34.5 MPa, respectively, which serve as the baseline values. Upon the addition of 0.82 wt% graphite and 1.64 wt% RHA, the UTS increases to 107.5 MPa and the YS to 40 MPa, indicating a noticeable improvement in tensile performance due to the introduction of reinforcement particles. A further increase in strength is observed for the 1.23 wt% GP–1.23 wt% RHA composition, where the ultimate tensile strength reaches 119.54 MPa and the yield strength rises to 46.5 MPa. This enhancement suggests improved load transfer efficiency and better stress distribution within the aluminium matrix. The composite containing 1.64 wt% GP and 0.84 wt% RHA shows continued improvement, achieving a UTS of 133.2 MPa and a YS of 50.6 MPa. The highest tensile properties are obtained for the composite reinforced with 2.05 wt% GP and 0.41 wt% RHA, where the ultimate tensile strength reaches 147.98 MPa and the yield strength attains 55.85 MPa. The overall trend clearly demonstrates a progressive increase in both UTS and YS with increasing reinforcement content. This behavior can be attributed to dispersion strengthening, effective interfacial bonding between the aluminium matrix and reinforcement particles, and the restriction of dislocation motion

by the hard RHA (SiO_2) and graphite particles. In summary, the figure confirms that GP–RHA hybrid reinforcement significantly enhances the tensile performance of aluminium matrix composites, with the maximum strength achieved at higher graphite content and optimized RHA distribution.

Properties Table of Rockwell hardness

Variation	Average	SD	Variation Code
0	20	0.337	Pure Aluminium(100%)
0.82,1.64	22.2	6.5053824	Al(97.53%)+GP(0.82%)+RHA(1.64%)
1.23,1.23	55	2.8284271	Al(97.53%)+GP(1.23%)+RHA(1.23%)
1.64,0.82	45	9.8994949	Al(97.53%)+GP(1.64%)+RHA(0.82%)
2.05,0.41	89	22.627417	Al(97.53%)+GP(2.05%)+RHA(0.41%)



Rock well hardness vs wt % GP+RHA

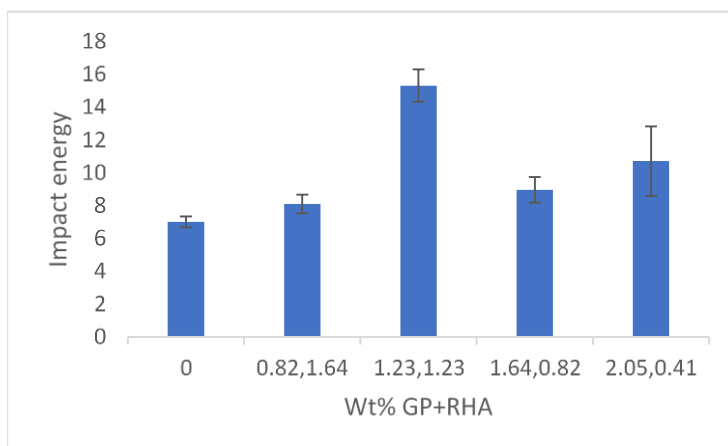
Rockwell hardness Result:

The Rockwell hardness of the pure aluminium and the developed composites was measured using a minor load of 10 kg and a major load of 100 kg on specimens with dimensions of 25 \times 25 \times 2 mm. The experimental results demonstrate a significant enhancement in the hardness properties upon the addition of Graphite Powder (GP) and Rice Husk Ash (RHA). Pure aluminium (0% reinforcement) exhibited a baseline hardness of approximately 20 HRB. With the initial addition of 0.82% GP and 1.64% RHA, the hardness increased to 22.2 HRB, marking an 11% improvement. A substantial rise was observed for the 1.23% GP and 1.23% RHA composition, where the hardness reached 55 HRB, representing a 175% increase over the base metal and a 147.7% increase from the preceding sample. However, a slight decline was

noted in the fourth sample (1.64% GP, 0.82% RHA), where the hardness dropped to 45 HRB. This reflects a 125% increase from the base metal but an 18% decrease compared to the third sample, which may be attributed to localized agglomeration of particles or internal porosity. The maximum hardness was recorded for the final composition containing 2.05% GP and 0.41% RHA, reaching approximately 89 HRB. This value indicates a remarkable 345% increase compared to pure aluminium and a 97.7% improvement over the fourth sample. The overall increase in hardness is primarily attributed to the dispersion strengthening mechanism, where the hard particles of RHA (SiO₂) and GP act as obstacles to dislocation motion within the aluminium matrix. The presence of silica from RHA provides high resistance to indentation, while the reinforcement particles promote grain refinement during the fabrication process. Effective load transfer from the ductile aluminium matrix to the hard reinforcement particles further enhances the composite's resistance to plastic deformation, resulting in the observed superior mechanical properties

4.3 Properties table of impact Energy

Variation	Average	SD	Variation Code
0	7	0.337	Pure Aluminium(100%)
0.82,1.64	8.1	0.5656854	Al(97.53%)+GP(0.82%)+RHA(1.64%)
1.23,1.23	15.3	0.9899495	Al(97.53%)+GP(1.23%)+RHA(1.23%)
1.64,0.82	8.95	0.7778175	Al(97.53%)+GP(1.64%)+RHA(0.82%)
2.05,0.41	10.7	2.1212203	Al(97.53%)+GP(2.05%)+RHA(0.41%)



Impact Energy vs Wt% GP+RHA

Impact Energy Result:

The impact energy of pure aluminium and the developed hybrid composites was evaluated using the Charpy V-Notch test with specimen dimensions of $55 \times 10 \times 10 \text{ mm}^3$. Based on the experimental data, pure aluminium (0% reinforcement) exhibited a baseline impact energy of approximately 7 J. The addition of Graphite Powder (GP) and Rice Husk Ash (RHA) reinforcements resulted in a significant but non-linear enhancement of energy absorption capacity. The second composition (0.82% GP, 1.64% RHA) showed an increase of 15.72% in impact energy, reaching 8.1 J. The maximum impact toughness was observed in the third specimen (1.23% GP, 1.23% RHA), which achieved a peak energy of 15.3 J, representing a substantial 118.58% increase compared to pure aluminium. However, the trend fluctuated in the subsequent samples. The fourth specimen (1.64% GP, 0.82% RHA) showed a decrease in energy to 8.95 J, though it still maintained a 27.86% increase over the base metal. The final composition (2.05% GP, 0.41% RHA) demonstrated a recovery in toughness with an impact energy of 10.7 J, resulting in a 52.86% increase relative to the 0% reinforcement baseline. The initial significant rise in impact energy (up to 118.58%) is primarily attributed to the crack-bridging and crack-deflection mechanisms provided by the RHA and GP particles. These reinforcements act as obstacles that force the crack to propagate along a more tortuous path, thereby consuming higher energy during fracture. Furthermore, the uniform distribution of particles at the 1.23% GP–1.23% RHA ratio likely optimized the load-sharing capability of the aluminium matrix. The subsequent decrease in impact energy observed in the fourth sample can be attributed to particle agglomeration and increased brittleness. As the concentration of harder reinforcement particles increases or their distribution becomes non-uniform, they act as localized stress concentrators, facilitating easier crack initiation and propagation at the matrix–reinforcement interface. Additionally, the reduction in the ductile aluminium phase in favor of brittle ceramic phases (RHA) may lead to a transition from ductile to semi-brittle fracture behavior, thereby reducing the total energy absorption capacity prior to failure.

4.4 Microstructure Analysis

The microstructures of the fractured surfaces of the tensile specimens are presented. Based on the characteristics of the stress-strain curves and the observed tensile performance, two fractured surfaces were selected for SEM analysis to investigate the fracture mechanisms. The fracture surfaces reveal the presence of dimples of various sizes, which are indicative of micro-void coalescence occurring during plastic deformation. This observation confirms the

ductile nature of the fracture in these samples. The gradual decrease in stress values observed in the stress-strain curves after reaching the ultimate tensile strength can be directly correlated to this ductile failure mechanism. During the fracture process, the material underwent nucleation, growth, and coalescence of micro-voids, ultimately leading to rupture. In addition, some regions show accumulation of Graphite and RHA particles. The uneven distribution of these Graphite and RHA reinforcements likely contributed to the relatively lower mechanical properties—such as tensile strength, compressive strength, and hardness—observed in these samples. the fracture surface exhibits a combination of dimple-dominated regions along with cleavage facets and micro-cracks, indicating a mixed-mode fracture with both ductile and brittle characteristics. It is noteworthy that increasing the RHA content at the same Graphite and RHA percentage appears to promote brittleness in the material. This trends the more uniform distribution of Graphite and RHA particles in this sample appears to reinforce the matrix more effectively, resulting in higher observed tensile strength compared to samples Overall, the SEM analysis demonstrates that the fracture behavior of the composites is strongly influenced by both the amount and the distribution of Graphite and RHA particles. Ductile fracture dominates in samples with lower RHA aggregation, while mixed-mode fracture with brittle features becomes more pronounced as Graphite content increases and particle distribution improves.

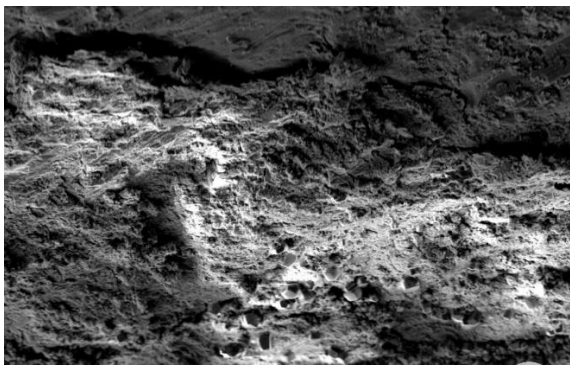


Fig: SEM of RHA



Fig: SEM of GP

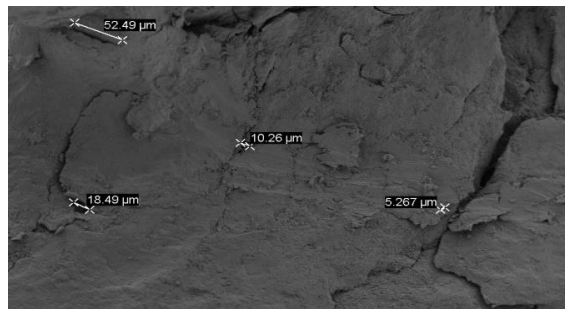


Fig: SEM of GP

Figure:

1. SEM RHA
2. SEM GP
3. SEM GP

CHAPTER 5: CONCLUSION AND FUTURE RECOMMENDATION

5.1 Conclusion

The study successfully demonstrates that the mechanical properties of pure aluminium can be substantially improved through the addition of Graphite and Rice Husk Ash (RHA) as reinforcements. Experimental results indicate that the maximum tensile strength and hardness were achieved with a composition of 2.05% GP and 0.41% RHA, resulting in a 64.42% increase in ultimate tensile strength and a 345% increase in hardness compared to pure aluminium. These enhancements are primarily driven by the dispersion strengthening of hard SiO₂ particles and effective load transfer within the matrix. Furthermore, the peak impact toughness was observed at a balanced 1.23% GP and 1.23% RHA ratio, highlighting the role of these reinforcements in optimizing crack deflection mechanisms. Although some variations showed slight property declines due to localized particle agglomeration, the overall development of these hybrid composites presents a highly effective method for producing lightweight, high-strength materials for advanced engineering applications.

5.2 Future Recommendation

Optimization of Reinforcement Content
Advanced Mechanical and Wear Studies
Detailed Microstructural and Interface Analysis
Improvement in Fabrication Techniques
Thermal and High-Temperature Performance Evaluation
Application and Sustainability Assessment
Numerical Modeling and Simulation
Application-Oriented Studies.

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