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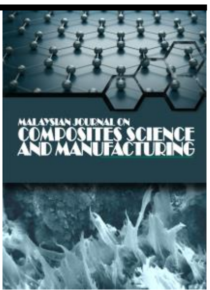

Fabrication and Characterization of Rice Husk Ash Reinforced Aluminium Matrix Composite

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ABSTRACT

Aluminium matrix composites (AMCs) are renowned for their exceptional properties, including low density, high specific strength, high thermal conductivity, and abrasion resistance, making them ideal for advanced structural, automotive, and aerospace applications. However, the challenge of finding cost-effective and environmentally friendly reinforcement materials remains. Rice Husk Ash (RHA), an often-discarded by-product of rice milling, presents a viable solution. Its utilization in AMCs repurposes waste, reduces environmental impact, and offers an economically viable alternative to conventional reinforcements. This paper explores the use of RHA as a reinforcement in aluminium matrix composites, with varying concentrations of 3%, 6%, and 9% by weight prepared through sand casting. Tensile, compressive, impact, and hardness tests were conducted, and it was found that increasing the RHA content enhances the mechanical properties of the composites. Specifically, tensile strength increases by 10.57%, 16.83%, and 46.26%, and compressive strength by 17.17%, 27.81%, and 40.45% for 3%, 6%, and 9% RHA reinforcement, respectively, compared to base samples (pure aluminium). Significant improvements in Rockwell hardness and impact energy absorption were observed, with a maximum increase of 55.26% and 70.63% for the 9% RHA reinforcement. This study demonstrates the potential of RHA-reinforced AMCs to surpass the mechanical properties of pure aluminium, contributing to the circular economy by transforming rice husk waste into a valuable composite material for diverse structural applications.

Keywords:
Aluminum matrix composites, Rice husk ash, Eco-friendly reinforcement

1. Introduction

Composite materials are widely used in engineering applications due to their high strength-to-weight ratio, versatile and tailorable mechanical properties [1,2]. Among different types of composite

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materials, metal matrix composites (MMCs) have attracted considerable interest as the potential replacements for conventional materials in a variety of engineering and industrial applications. Due to their high mechanical properties, cost-effectiveness, and low specific gravity, which make them ideal for lightweight applications, aluminum-based composites have become a widely discussed and widely employed option among MMCs [3]. Aluminum's efficacy has been improved by reinforcing it with materials such as silicon carbide (SiC), alumina (Alumina), or steel [4].

Bangladesh, leading an agriculture-based economy, has many challenges in utilizing waste, which can severely impact the environment. The burning of agricultural waste produces many greenhouse gees, including smog, which can cause serious health problems [5]. As the main crop of Bangladesh, the large amount of rice husk is a big burden for the country, but the amount of SiO_2 on it can be utilized in making effective composites with different metals [6]. The abundance and lost costs made rice husks competent for use in any reuse and sustainability projects [7]. Utilizing these waste products provides novel uses and financial and environmental advantages. Rice husk ash could be a good alternative if other materials are incorporated, reducing the percentage of comparatively expensive materials [8]. Automotive, aerospace, manufacturing, and electronic components are just some fields that benefit from metal-matrix composites. Thermal conductivity, shear strength, abrasion resistance, high-temperature operation, and resistance to fuels and organic solvents are only some of the many desired features displayed by aluminum matrix composites [9]. One of the many limitations is particle distribution, wettability, porosity and chemical reaction of the aluminum composites, making it less compatible with large-scale industrial production [10]. Though the inclusion of multiple materials like metals and organic substances, i.e., Al-Si-filled cobalt filling, creates good products with sufficient mechanical properties, the rapid use of this product creates major concern. This requires adding organic wastes or widely available and cost-efficient materials to create composite materials that can replace traditional metals [11].

The matrix is in charge of binding the reinforcement and influencing the overall qualities of the composite; it is found in both the matrix and the dispersion phase. Due to their low density, low cost, strong ductility, and great corrosion resistance, aluminum alloys are frequently utilized as the matrix in MMCs. Luecke [12] conducted research that delivered the mechanical properties of aluminum-based composites, which can be improved by adding some organic material. Reinforcements such as aloe vera, rice husk, sugar cane, and so on mainly consist of prominent reinforcement materials of MgO, SiC, MnO, and Al_2O_3.

Different types of composites exist depending on the reinforcing material used. The matrix particles in fiber-reinforced composites are much larger, while the dispersed fibres are much shorter and thinner. Strategically placed particles fortify the matrix in a particle composite. The mechanical properties of aluminium alloys have been considerably improved by modification, particularly to emphasize further their low weight and high strength-to-weight ratio [4]. International research efforts focus international research efforts on the optimal application and quality of aluminium alloys. Aluminium alloys are gradually replacing steel in the automotive and aerospace industries because of their same strength-to-weight ratio and less weight [13].

Reinforcing materials made of aluminium and rice husk ash (RHA/AMC) have been the subject of research due to their availability and affordability for processing. Materials with improved mechanical or thermal properties are achieved by incorporating reinforcements into the matrix. The composition of rice husk ash (RHA), which is mainly composed of silica (SiO_2) with extra metallic impurities, has garnered attention as a reinforcing component. Seikh et al. [14] investigated the effect of RHA reinforcement and found the Ultimate Tensile Strength (UTS) varies from 164.37 MPa at 0% RHA to 176.83 MPa with a maximum value of 10% RHA. Gladston et al. [15] researched 0%, 2%, 4%, 6% and 8% grains of RHA and found improved wear-resistant composites every time with more percentages of RHA. Kulkarni and Siddeswarappa [16] investigated the same percentage of RHA-reinforced composites and found significant improvement in increased hardness, compressive and tensile strength with increasing percentages of RHA. Significant enhancements in ultimate tensile strength, hardness, thermal stability, and corrosion resistance of the composites have been observed after optimizing RHA reinforcement and milling time. It has also been shown that RHA-reinforced AMCs perform better than composites reinforced with silicon carbide, at least in terms of mechanical properties [17].

From the review, it is evident that adding RHA to an aluminium matrix could enhance the mechanical properties of the composites. In this paper, RHA was added to the aluminium matrix at concentrations of 3%, 6%, and 9% by weight to prepare the composites. Subsequently, tensile, compressive, and impact tests were conducted on the specimens to investigate the influence of RHA on these properties.

2. Methodology

2.1 Materials

Aluminum 1350 was used for its superior conductivity and ductility. Rice husk ash, highly enriched with silica content and a phenomenal reinforcement material, has been locally sourced from Barishal, Bangladesh. These two materials were used to manufacture the specimen in 3%, 6%, and 9% by weight of RHA with the aluminum 1350 that is described in Section 2.2.

2.2 Composite Fabrication

Risk husks were washed and air-dried first, then at 650℃ in an electric heat treatment furnace for four hours till turning into a blackish color were done as shown in Figure 1(a), assuring silica enriched ash as the reinforcement in the composite. Afterwards, sand casting was done with the necessary shapes for preparing the composites at the necessary heat required to melt aluminum at 661℃, three categories of molds were prepared, and for different tests, various shapes and sizes of specimens were made, which are shown in Figure 1(b).

It was heated for 10-20 minutes after being included in titling to achieve homogeneity. Then, the floating slug was removed carefully, and the casting mold was made with PVC pipes filled with liquid metal, where flasks were built with a series of connected rings. The specimen was shaped into different forms using CNC milling, CNC lathe, conventional lathe, flat files, and hacksaws, following multiple ASTM recommendations for four different mechanical tests described in Section 2.3.

2.3 Testing

In this project, a comprehensive investigation was conducted on the mechanical properties of the manufactured composites. This was achieved by executing four distinct mechanical tests: tensile, compressive, hardness, and impact tests. Each test was meticulously performed, providing a robust understanding of the composite's behavior under different types of mechanical stress.

2.3.1 Tensile Test

The tensile test was performed according to ASTM E8 standard with 56±0.01 mm gauge length with 75 mm reduced section and 12.5±0.02 mm diameter of the specimen made for in 3%, 6%, 9% by weight of RHA with the aluminum 1350. The specimen was prepared dumble-shaped with the following standard, and the schematic diagram is shown in Figure 2(a). Samples tested in the Universal Testing Machine are shown in Figure 2(b).

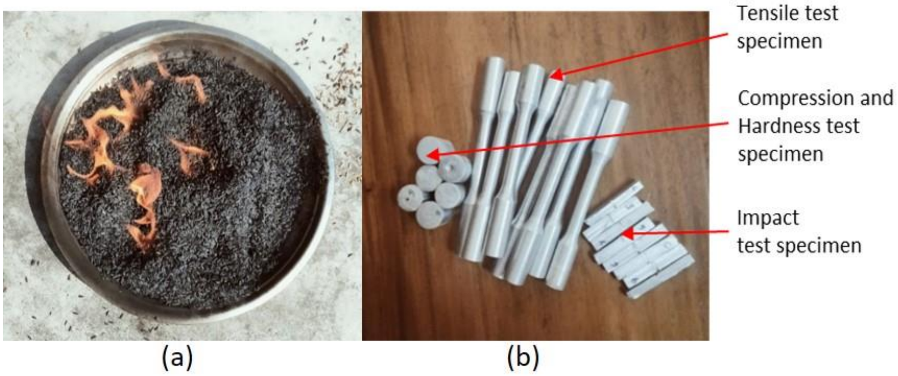


Fig. 1. (a) Rice husk ash (b) Sample for testing different mechanical properties

The modulus of elasticity was calculated by recording stress-strain responses. The modulus of elasticity was calculated using Eq. 1.

$$\mathrm{E} = \frac{\Delta\sigma}{\Delta\varepsilon} \tag{1}$$

Where E is the modulus of elasticity, $\Delta\sigma$ is the difference in the stress in two points of the linear portion of the stress-strain diagram, and $\Delta\varepsilon$ is the difference in strain.

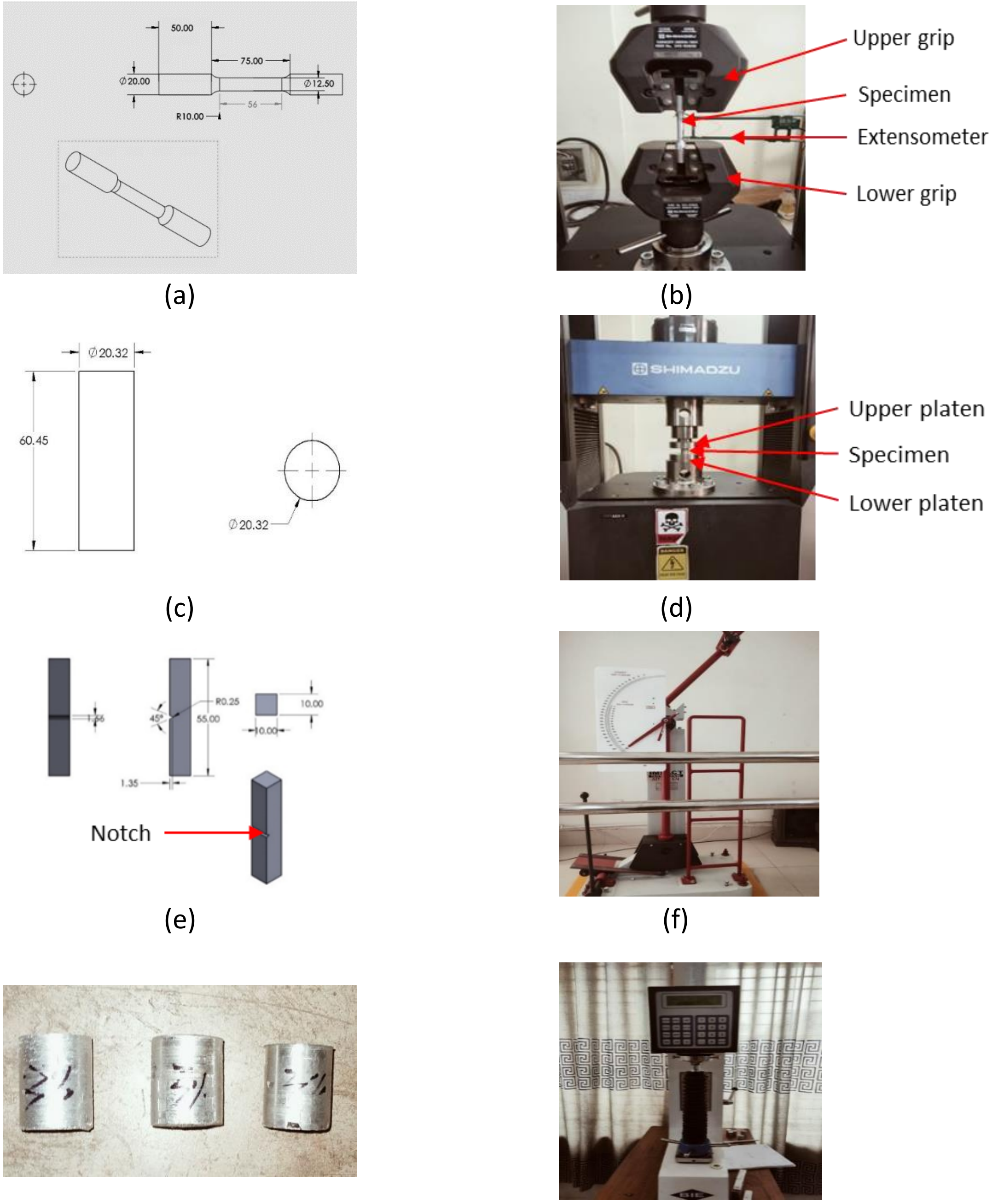
2.3.2 Compressive Test

The compression test was performed using a Shimadzu AGX-300KN universal testing machine (UTM) following ASTM E9 standard at a 2 mm/min crosshead speed. This test used cylindrical specimens of 60.45 mm in height and 20.32 mm in diameter. The schematic diagram of the specimen is shown in Figure 2(c), and the actual test setup on the UTM is shown in Figure 2(d). The load-displacement response was recorded, and the stress-strain was calculated.

2.3.3 Impact Test

In this project, the Charpy Impact Test was conducted following the ASTM A370 standard to measure the impact energy. The specimen absorbs the energy from the striker until it yields, initiating plastic deformation at the notch. The test specimen continued to deform plastically until it reached its limit, beyond which it could no longer absorb energy, resulting in a fracture. This method, one of the most cost-effective and straightforward, is commonly used to evaluate materials' relative or impact toughness.

Charpy test specimens typically have dimensions of 55×10×10 mm^3 with a notch machined across one of the larger sides, and the schematic diagram is shown in Figure 2(e), where the hammer mass was 20kg and drop height was 1.44 meters. Possible notches include V-notch – A notch in the form of a V, 2 mm deep, 45 degrees angle, and 0.25 mm in radius at its base; u-notches, also known as keyhole notches, have a 1 mm radius at the flat bottoms and are 5 mm deep. Hence, the impact energy is measured with the three types of specimens using the Charpy Impact Testing Machine shown in Figure 2(f).



(a) (b) (c) (d) (e) (f) (g) (h)

Fig. 2. (a) Schematic diagram of tensile test specimen, (b) performing the tensile test, (c) schematic diagram of compressive test specimen, (d) performing the compressive test, (e) schematic diagram of impact test specimen, (f) performing Charpy impact test, (g) specimen for Rockwell hardness test, and (h) performing Rockwell hardness test

2.3.4 Hardness Test

Rockwell hardness testing is the most prominent way to measure hardness, and it was used in this work following the ASTM E18 standard. The 25 mm×25 mm specimen shown in Figure 2(g) was used and mounted in the Rockwell testing machine, which is shown in Figure 2(h), ensuring that the test surface is perpendicular to the machine's base and the indenter is raised above the surface. First, the machine was set to the appropriate hardness scale, in this case, the Rockwell Hardness on the B scale (HRB). The indenter, a steel ball with a diameter of 1/16th inch, was prepared for the Rockwell test. Following this, the minor and major loads, typically 10 kgf and 100 kgf, respectively, were applied to the indenter following the HRB scale.

3. Results

3.1 Tensile Test Result

Testing was done on four different specimens, including pure aluminum, to determine their tensile strength and modulus of elasticity. Figure 3(a) shows that the resultant stress-strain curves offer important insights into the specimens' capacity to adjust to stress. The yield and ultimate strength improvements are also shown in Figure 3(b). However, it was noted that the specimens with larger weight percentages of rice husk ash (RHA) exhibited brittle fracture behavior after a certain level of elongation.

The integration of RHA improved stress adaptation, as the stress-strain curves showed. The specimens' yield strength and ultimate strength also increased, pointing to improved mechanical qualities. However, it is important to note that after a certain degree of extension, the specimens became more vulnerable to brittle fracture as the weight % of RHA increased. This shows that while RHA increases yield strength, it also causes the material to become more brittle. Raisi et al. [18] also observed that the compressive strength of concrete can be increased with the increasing percentage of RHA, but this also increases the brittleness of concrete.

The yield strength significantly increased with the addition of RHA, rising from 38.13 MPa for pure aluminum to 70.31 MPa. This discovery emphasizes the composite material's strengthening potential even further. However, a crucial issue to consider is the brittleness displayed by the specimens with larger RHA weight percentages. The increased brittleness could restrict the material's capacity to bend plastically under high stress, potentially compromising the integrity of its overall structure.

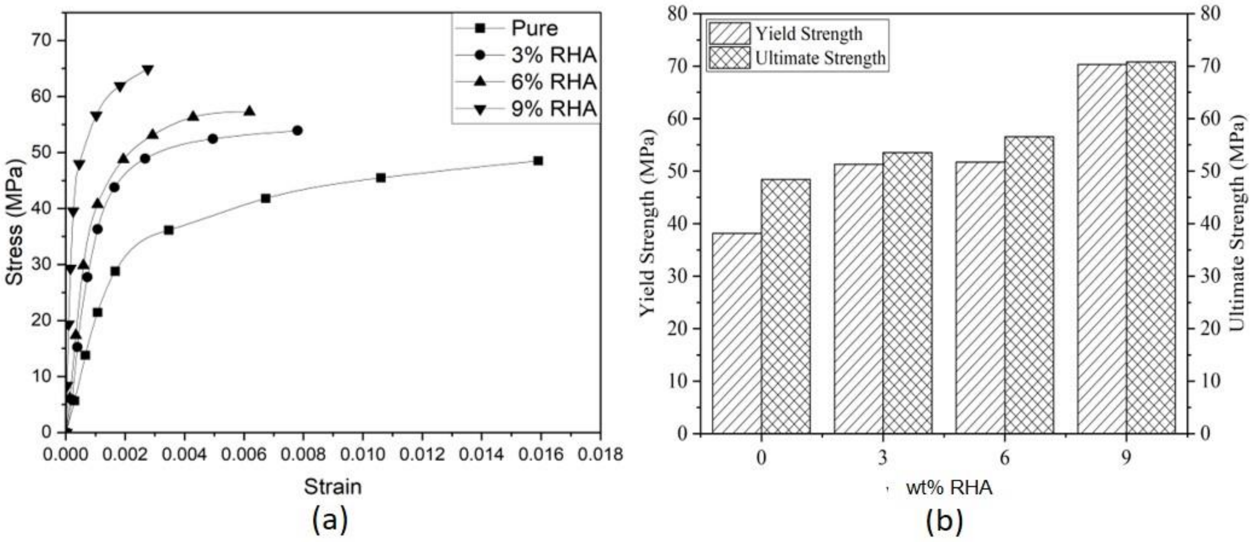


Fig. 3. (a) Stress (Tensile) vs Strain curve for different RHA-reinforced Al matrix composites, (b) Yield Strength and ultimate strength of different RHA-reinforced Al matrix composites

3.2 Compressive Test Result

A compressive test was performed to determine the material's strength after being deformed by 50%. The specimen was subjected to a strain equal to half its original length by being squeezed between two flat plates or platens in a universal testing machine (UTM).

The composite was discussed and analyzed in relation to the pure Aluminum 1350 specimen. This allowed for a thorough analysis of the differences between the composite and its base metal components. Figure 4(a) shows the stress-strain diagram, while Figure 4(b) shows the compressive strength with varying wt% of RHA. The results showed that the strength of the composite matrix strengthened with the increase in RHA. The ductility of the aluminum matrix was observed to be replaced by brittleness as the RHA level emerged. This indicates that while RHA added to the composite improved its strength, it reduced its ability to undergo plastic deformation when subjected to compressive stresses.

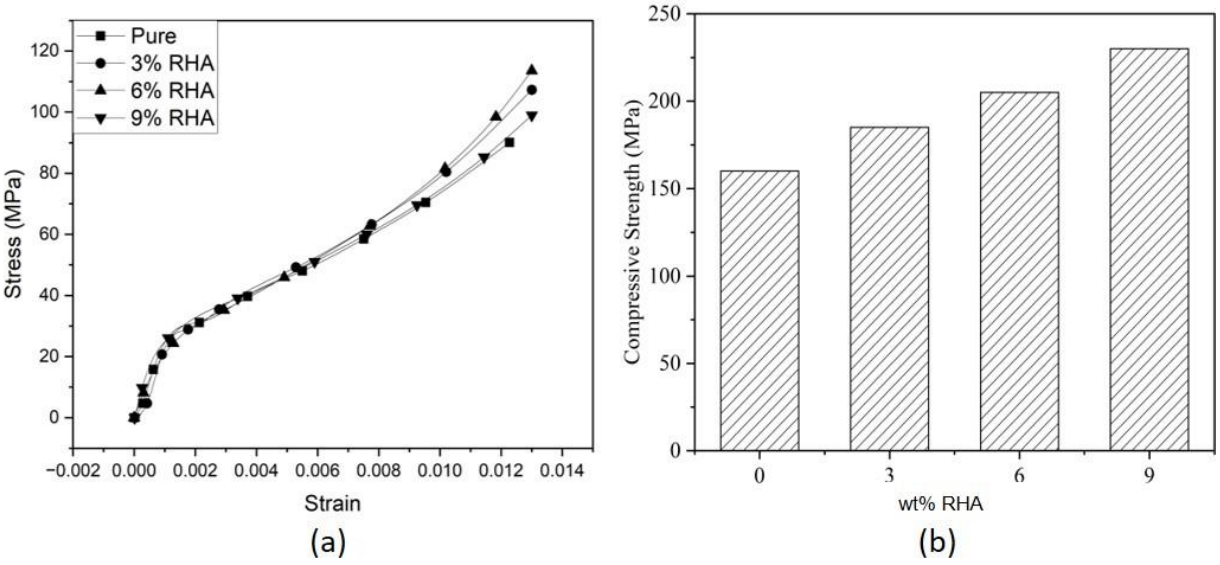


Fig. 4. (a)Stress (Compressive) vs Strain curve for different RHA reinforced Al matrix composites. (b) Change of compressive strength for different RHA-reinforced Al matrix composites with the increase in RHA weight percentage

3.3 Impact Test Result

Figure 5 shows the variation of impact strength with wt% of RHA. The experimental results unequivocally show that when the amount of RHA was raised, the composites gradually exceeded the pure aluminum in impact energy absorption. The data and associated graph, which show a noticeable increase in energy absorption with greater RHA percentages, make this clear.

A noticeable increase in impact energy absorption was seen when 9% RHA was added to the composite. Impact energy had become more significant in the composite, from 22.7 J in pure aluminum to 38.75 J. This improvement in hardness provides more evidence for the aluminum matrix-strengthening effects of RHA.

Interestingly, the base aluminum (Aluminum 1350) showed less energy absorption than the composites including RHA. The strength of RHA as a reinforcing material and its capacity to improve the mechanical properties of the composite are highlighted by this procedure of Charpy Impact testing of different specimens of different weight percentages of RHA-reinforced aluminum matrix composites.

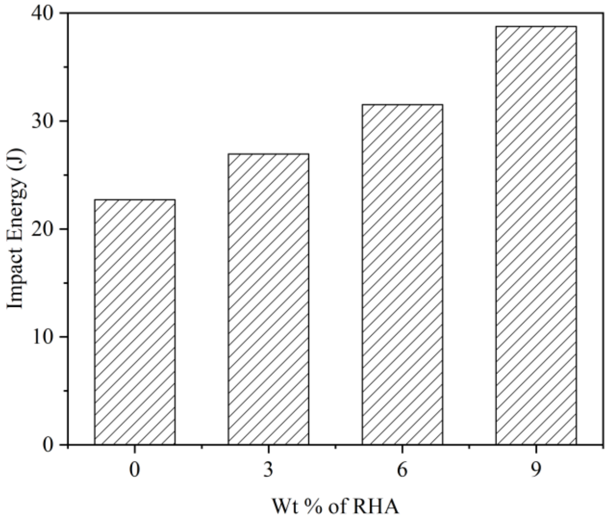


Fig. 5. Variation of Impact energy absorbed for different wt% RHA

3.4 Hardness Test Result

The variation of Rockwell hardness is shown in Figure 6. A clear relationship exists between the amount of rice husk ash (RHA) by weight percentage (wt%) in an aluminum matrix composite and the ensuing rise in hardness. The hardness increased linearly and significantly after RHA was added. This is explained by the fact that the RHA's reinforcing particles were stiffer than the matrix, which prevented plastic deformation. Notably, there was a big difference in hardness between pure aluminum 1350, which measured 38.4 HRB on the Rockwell scale, and a composite that contained 9% RHA by weight, which measured 62.9 HRB. The application of Rockwell hardness tests led to the discovery of these results.

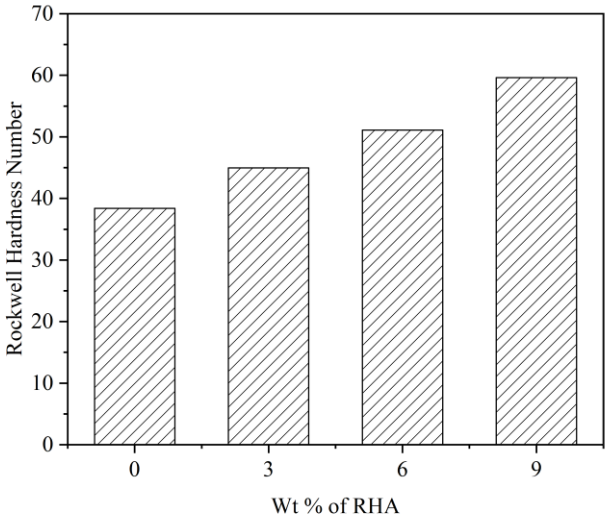


Fig. 6. Variation of hardness with the change of wt % of RHA

4. Conclusion

This paper investigates the effect of RHA content on the mechanical properties of aluminum matrix composites. Towards that, aluminum matrix composites with 3%, 6% and 9% RHA was manufactured by sand casting and tensile, compressive, impact and hardness tests were performed. The yield strength and ultimate tensile strength of the 9% RHA reinforced composite were found to be at their maximum, exhibiting an increase of 84.39% and 46.26% respectively, compared to pure aluminum. The compressive strength and impact strength of 9% RHA reinforced composite is 40.45% and 70.63% greater than pure aluminum. The Rockwell hardness of the 9% RHA reinforced composite was also improved by 55.26%. In this study, we capped the RHA content at 9%, which yielded observable improvements in the mechanical properties under investigation. However, there is potential for further enhancement by increasing the RHA content beyond this limit. Additionally, scanning electron microscopy analysis can provide a more detailed understanding of the matrix's failure modes and particle dispersion.

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