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Fabrication and Characterisation of Aluminium Alloy/Rice Husk Ash Composites for Lightweight Automobile Wheels

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Abstract
This study focuses on the development of an aluminium alloy composite reinforced with rice husk ash (RHA) for automobile wheel applications. Aluminium piston scrap was used as the base matrix, and RHA was introduced at 5%, 10%, and 15% weight fractions using the stir-casting method. The produced composites were subjected to hardness, tensile strength, impact energy, density, and wear tests to evaluate the influence of RHA on the aluminium alloy's mechanical and physical properties. Results revealed that the addition of RHA significantly affects the alloy's behaviour. At 5 wt% RHA, the hardness was increased by 12.7%, tensile strength by 5.9%, and impact energy by 8.3% when compared with the control sample. The density of the composite samples decreased by 1.2%, indicating an initial weight reduction. At 10 wt% RHA, the composite exhibited the highest performance, with hardness increasing by 18.2%, tensile strength by 16.7%, and impact energy by 25%, while density decreased by 2.8%, indicating an optimal strength-to-weight ratio. Furthermore, X-Ray Fluorescence (XRF) analysis of the raw materials confirmed that the rice husk ash contained 80.02% SiO_2, with minor quantities of Al_2O_3, Fe_2O_3, and CaO, making it an effective reinforcement material. The developed composite showed increased silicon content in the alloy from 19.6% to 21.2% after reinforcement, confirming the successful integration of silica-rich RHA into the aluminium matrix. Overall, the density consistently decreased as the RHA content increased, while mechanical properties improved up to the 10 wt% level before declining. The study concludes that 10 wt% RHA provides the best balance between lightweight characteristics and mechanical strength, making it a promising material for sustainable and high-performance automobile wheel production.

Keywords: Automobile Wheels, Rice Husk ash, Aluminium alloys.

1.0INTRODUCTION

The critical components that support the tyre, transmit loads to the suspension, and endure stresses from braking, road impacts, and rotating forces are automobile wheels. The construction of a wheel consists of the following parts. A rim, which is the outer edge of a tyre, is attached (Figures 1 and 2) and the centre cap, which provides a structural support, is fixed to the axle hub. The choice of material, geometry, and manufacturing process all significantly impact their performance, safety, and durability. Wheels are manufactured by either casting or forging. Forged components were more expensive and had lower mechanical properties than alloy-based cast wheels. Aluminium alloy-based cast wheels later came into focus due to their high-strength mechanical properties, light weight, and ease of repair compared to forged wheels. (Kumar and Reddy, 2015).

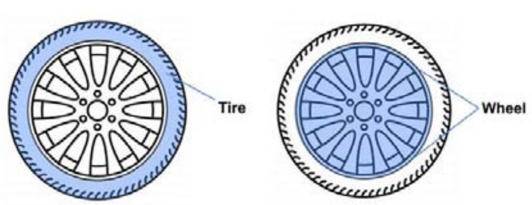

Figure 1: Automobile Rim (Hui *et-al.,* 2023)

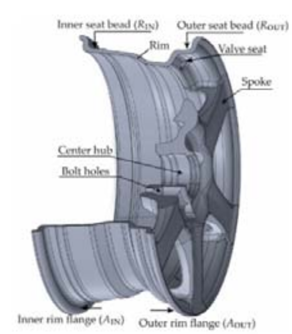

Figure 2: Layout of an Automobile Rim (Hui *et-al.,* 2023)

Cast Al-Si alloys, due to their silicon content, can be divided into three groups: sub-eutectic alloys with a content of 4-10 wt% Si, eutectic alloys with 10-12 wt% Si and alloys with a super-eutectic composition of about 17-30 wt% Si. These alloys have good mechanical properties, as measured by, among other things, specific stiffness (the ratio of Young's modulus to density) or specific strength (the ratio of tensile strength to density). These parameters are often a criterion for the selection of materials in terms of weight reduction, making it possible to reduce energy consumption during operation. For the production of Aluminium alloy wheels, the most commonly used are $AlSi_7Mg$, $AlSi_9Mg$ and $AlSi_{11}$ (Jaroslaw and Leszek, 2024).

A high strength-to-weight ratio and the ability to withstand high temperatures are typical requirements for the manufacture of various mechanical structures. Aluminium alloys possess a number of these distinctive properties that make them suitable for a wide range of applications, including the automotive, aerospace, and military industries. For example, engine blocks, piston heads, steering boxes, inlet manifolds, rocker covers, differential casings, brackets, and wheels are among the many components made from aluminium casting in the automotive industry (Sirata *et al.,* 2022).

Rice husk ash (RHA), an agricultural byproduct rich in silica (SiO_2), has gained attention as a reinforcing material in metal matrix composites (MMCs) due to its lightweight, high hardness, and thermal stability. When incorporated into aluminium alloys, RHA enhances mechanical properties such as wear resistance, strength, and thermal stability, making it suitable for aluminium alloy automobile wheel applications (Joseph et-al, 2023). Studies have shown that RHA-reinforced Al composites exhibit improved hardness, reduced wear rates, and better thermal conductivity compared to pure Al alloys, making them suitable for high-performance aluminium automobile wheels. However, challenges such as particle agglomeration, interfacial bonding, and optimal RHA content (typically 5–15 wt%) must be addressed to ensure uniform dispersion and mechanical integrity. (Kumar*et al.,* 2017).

Aluminium Alloy Reinforced with Rice Husk Ash (RHA) is a metal matrix composite (MMC) that combines the lightweight and strength of aluminium with the beneficial properties of rice husk ash, a natural, silica-rich agricultural byproduct. The resulting ash is rich in amorphous silica (Si_2O), which makes it a suitable reinforcing material. When RHA is added to an aluminium alloy, typically through stir casting or powder metallurgy, it acts as a ceramic reinforcement, improving properties like hardness, tensile strength, and wear resistance (Kusakabe*et al.*,2017).

Aluminium alloys are widely used in automotive and motorcycle wheels due to their light weight and excellent strength-to-weight ratio. However, they face significant challenges in terms of wear resistance; they can wear out faster when the car moves on rough roads, their hardness and strength may reduce under heavy load and high temperature from braking. These issues can affect the safety and lifetime of the wheel (Singh *et al*.,2020).

Therefore, there is a need to develop an alternative aluminium alloy wheel material with improved mechanical properties. This research focuses on the possibility of producing Aluminium alloy reinforced with silica source from rice husk ash to improve hardness, wear resistance and light weight.

The research developed a sustainable aluminium alloy composite for automotive wheels by reinforcing recycled aluminium piston scrap with silica-rich rice husk ash (RHA). A silica-rich RHA was first produced through thermal treatment. The composite was then fabricated using the stir casting technique. The chemical composition of both the raw materials and the final composites was investigated. Subsequently, the composite's mechanical and physical properties were evaluated through a series of tests, including assessments of hardness, tensile strength, impact resistance, wear resistance, and density.

Plate 2.1: Rice husk

Plate2.2: rice husk ash

2.0 MATERIALS AND METHODS

2.1 Materials

The primary materials employed in this study are rice husk, procured from a local rice mill situated in Samaru village, Kaduna State, Nigeria. Additionally, aluminium piston scrap was utilised, which was acquired from a commercial vendor. These materials served as the base matrix and reinforcement precursor, respectively, for the development of the composite samples.

2.2 Equipment

The equipment utilised throughout the research was primarily housed within the Department of Metallurgical and Materials Engineering at Ahmadu Bello University (ABU), Zaria, Nigeria, except for the X-ray fluorescence (XRF) analyser, which was located at DICON, Kaduna.

A custom stir casting setup, equipped with a variable-speed motor, was employed to mechanically agitate the molten metal, thereby facilitating the uniform dispersion of rice husk ash (RHA) particles within the aluminium matrix. Pre-heating of the RHA particles was conducted using an Sx-5-12 box-resistance furnace to eliminate moisture and enhance interfacial wettability between the reinforcement and the matrix.

Mechanical properties were evaluated using several specialised instruments. Impact strength assessments were performed on a Charpy impact testing machine (model 412-07-15269C). Hardness measurements were carried out with an Indentec universal hardness testing machine (model 8187.5LKV, Type B). Precise compositional control was achieved via an OHAUS digital weighing balance for measuring the masses of the aluminium alloy and RHA. Wear behaviour was quantified using a wear testing machine (model 8054, Graz).

Elemental analysis of the composites was conducted employing an Axiosm AXWDXRF X-ray fluorescence spectrometer. Finally, tensile strength evaluations were executed on a WDW-1000KN tensile testing machine.

2.3 Method

2.3.1 Production of rice husk ash (RHA) by thermal treatment

The rice husk was sourced from a local rice mill in Samaru Village, Kaduna State, Nigeria. It was thoroughly washed with water to remove impurities and subsequently sun-dried to eliminate excess moisture.

The dried rice husk was then subjected to controlled combustion in a ceramic container, resulting in the carbonisation of the organic matter. Following this, the carbonised material was placed in a furnace and heated to 650°C for a duration of 2 h to produce rice husk ash (RHA).

The resulting ash was sieved using a 150 µm mesh to obtain fine particles suitable for use as reinforcement in the composite (Olatunji et al., 2024).

2.3.2 Casting of Aluminium piston scrap and rice husk ash composite

The electric charcoal furnace was set into operation and the aluminium alloy was inserted into the furnace. The temperature of the furnace was then raised to 800 °C above the melting point of aluminium scrap (660°C). The aluminium alloy was left in the furnace for 30 min and stirred to achieve complete melting. The crucible containing the molten aluminium was let out of the furnace and the floating slag and other impurities were separated from the molten metal. After that, the appropriate quantity of rice husk ash reinforcement was introduced into the aluminium in percentage by weight and stirred thoroughly for 5 min.

The mixture was transferred back to the furnace and held for about 15 minutes, stirring it again and gently pouring it into the prepared sand mould shown in Plate 1.

The composites in the mould were left to air cool to room temperature for 40 min before being removed from the mould, as shown in Plate2 and taken for machining into the various standards required shape for the mechanical testing (Ahamad *et al*., 2016).

Plate 1: Sand mould

Plate 2: Cast sample

2.3.3Machining of the Sample to the standard dimension

The machining of the cast aluminium piston scrap and rice husk ash (RHA) composite was carried out to prepare a sample for mechanical and metallurgical characterisation. The composite castings were allowed to cool completely and were cut into standard dimensions (Plate 3) using a hacksaw in order to carry out some tests.

Plate 3: Sample for mechanical properties measurements.

2.3 Physical Characterisation of The Produced Sample

The theoretical density was calculated using the expression adopted from Kusakabe *et al* (2017) as stated in equation 1.

$$\rho = \frac{100}{\frac{\alpha_1}{d_1}+\frac{\alpha_2}{d_2}} \quad (1)$$

where:
α_1 and α_2 =wt% of the Al, RHA,
d_1 = density of aluminium piston scrap (2.81 g/cm³),
d_2= density of RHA (2.0-2.5 g/cm³)

2.4 Mechanical characterisation of the produced composite

2.4.1. Determination of hardness

The hardness test was conducted using an Indentec universal hardness testing machine (model 81875 LKV, model B, serial no. 053158) to assess the material hardness. The Rockwell hardness method was applied to measure the hardness of the samples following the ASTM E18 standard. The 25 mm×25 mm specimen shown in Plate 4 was used and mounted in the Rockwell testing machine, which is shown in Plate 5, ensuring that the test surface was perpendicular to the machine's base and the indenter was 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 (Hasan *et al*., 2024).

Plate 4: hardness testing sample

2.4.2 Compressive strength determination

The electronic universal testing machine, Model: WDW, 1000KN, was used for the tensile study and the study was carried out at the Department of Metallurgy and Material Engineering, Ahmadu Bello University, Zaria. Plate 5 shows the setup of the experiment. The procedure for conducting a tensile test using a Universal testing machine (UTM) involves a series of steps to determine the mechanical properties of the material (Hasan *et al*., 2024).

3.4.3Determination of wear

Wear tests of the produced sample were conducted using a tribometer (8054, Graz). The produce sample was fixed on the sample holder, and the normal load was applied against the sample in a way that ensured close contact between them. The weight of the produced sample was taken before and after the test for each produced sample, and the weight loss was determined. Finally, the wear rate will be determined using the expression by Wu *et al*. (2028) as stated in equation 2.

$$W=KD\left(\frac{M_1-M_2}{M_1}\right) \quad (2)$$

where W is the wear rate (%), K is the constant ($4.17 \times 10^{-4} mm$) D is the diameter of the sample, M_1 is the weight before test(g), and M_2 is the weight after test(g).

3.4.4 Chemical composition of the raw samples and the developed composite

Wavelength Dispersive X-Ray fluorescence (XRF) Spectrometer (model Axiosm AXWDXRF Spectrometer, PANalytical) was used to estimate the level of silica content and metallic impurities in RHA samples, The elemental oxide composition of the rice husk ash (RHA) was determined using X-ray fluorescence (XRF) spectroscopy, The XRF test was carried out using a wavelength-dispersive spectrometer to quantify the major oxides present in RHA, particularly silica (80.02%), alumina (2.02%) and trace metal oxides. The obtained chemical compositions were used to evaluate the suitability of RHA as reinforcement in aluminium piston scrap for wheel material development, as high silica content enhances hardness, strength–weight ratio and wear resistance in automotive applications (Ozor *et al*., 2022). A similar method was carried out for aluminium piston scrap and the reinforced composite.

3.0 RESULT AND DISCUSSION

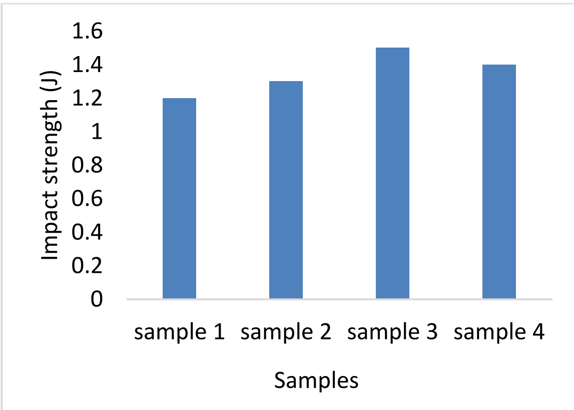

Figure 1: Impact energy of the samples.

Impact test is a measure of the energy (or work) required to fracture a specimen. The Impact Strength results shown in Figure 1 revealed that additions of the rice husk ash reinforcement to the aluminium alloy promote the Impact energy of the composite. The Impact energy increases from 1.2 J to 1.3 J when 5 wt% of rice husk ash was added to the aluminium alloy, the addition representing an increase of 8.3% over sample 1. At 10wt % addition of rice husk ash (sample 3), the Impact energy increases to 1.5 J, which is the peak value with 25% increase over sample 1. The impact force decreases at 15wt% addition. The increase in the impact force is due to the silica content, which acts as a hard reinforcement that increases the strength of aluminium. The value obtained falls within the range of impact strength of aluminium wheel material (1.53 - 2.75 joules) as reported by Sowrabh *et al*., (2025).

4.2 Density Test

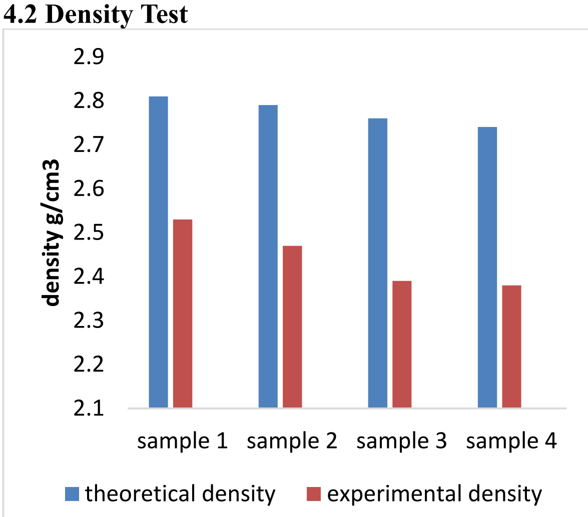

Figure 2: Density of samples.

The density results, as presented in Figure 2, show that the composite generally exhibited lower density as the aluminium alloy matrix. The density reduces as the percentage weight of the rice husk ash increases. The lowest density of $2.38\, g/cm^3$ was recorded at the highest wt% addition of the rice husk ash by 3.9% compared to the reinforced composite. Similar trends in the density behavior of the Aluminium matrix composite were equally reported by Olatunji *et al* (2024). The reduction in density of the composite results from the lower density of the rice husk ash when compared to that of the Aluminium alloy. The addition of the rice husk ash in wt % fraction reduces the overall weight of the composite and the mass-to-volume ratio and consequently lowers the density. The measured density of the developed rice husk ash reinforced with Aluminium alloy composite was compared with findings from previous research, which is approximately $2.46\, g/cm^3$,as reported by Abolusoro *et al*., (2024).

3.3 Hardness Test

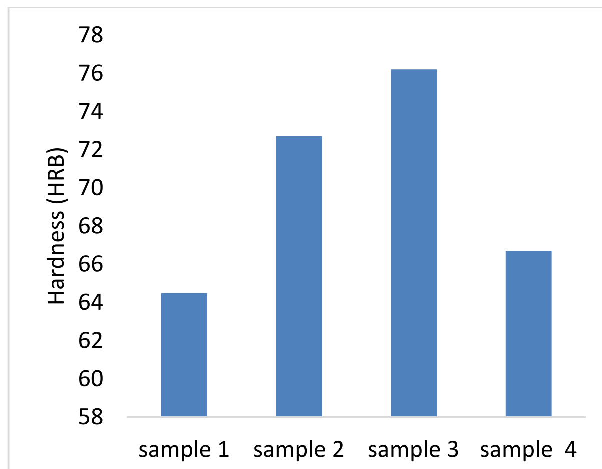

Figure 3: Hardness test of the sample.

The hardness value generally increases as the wt % addition of rice husk ash increases. At 5wt% reinforcement addition, the hardness value for sample 2 increases from 64.5HRB to 72.7HRB, with 12.7% over sample 1 and increases at 10wt% addition of rice husk ash, which is the peak value by 18.2% when compared with sample 1. At 15%w addition to the aluminium alloy there was a decrease noticed, which reduces the hardness. The maximum hardness value of 76.2HRB was obtained at the 10%w reinforcement addition. This result supports those of Saravan *et al.* (2019). The increase in the hardness of the composite is as a result of the presence of silica content in the rice husk ash, the silica particles serve as obstacles to dislocation movement during indentation, thereby improving resistance to plastic deformation. The developed composite of rice husk ash and aluminium alloy in this research exhibited a hardness range of

(64.5 - 76.2 HRB), which falls within the standard hardness range for Aluminium alloys used in automobile wheels. This indicates that the rice husk ash reinforcement enhanced the hardness, wear resistance and surface strength of the material (Joseph *et al*.,2023; Khan *et al*., 2022).

3.4 Tensile Test

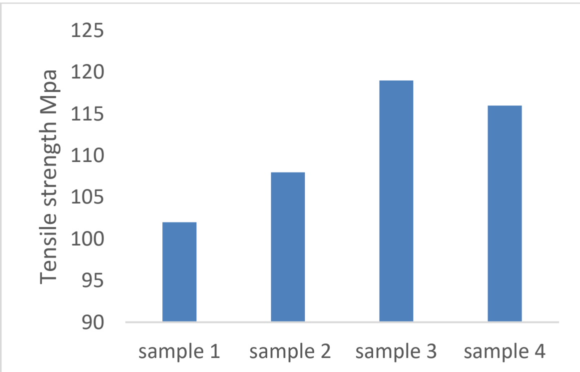

Figure 4: Tensile test of the sample.

The tensile strength as presented in Figure 4.4 indicated that the rice husk ash reinforcement improved the tensile strength of the composite. The tensile strength increases from 102MPa to 108MPa at 5wt% reinforcement addition of rice husk ash to the aluminium scrap over the sample 1 by 5.9%. The tensile strength value increases at 10wt% addition of the rice husk ash to 119MPa for sample 3 by 16.7 % over sample 1, at 15 wt% of rice husk ash, sample 4 decreases to 116 MPa. These findings agreed with the results reported by Neelima *et al.* ,(2023). The tensile strength improvement of the composite is connected to the high silica content of the rice husk ash, which impacts strength and improves the grain boundary dislocation of the composites during the tensile testing. The value of tensile strength falls within the tensile strength of automobile wheel material (116 MPa) as reported by Surasno and Tjahjohartoto (2020).

3.5Wear Test

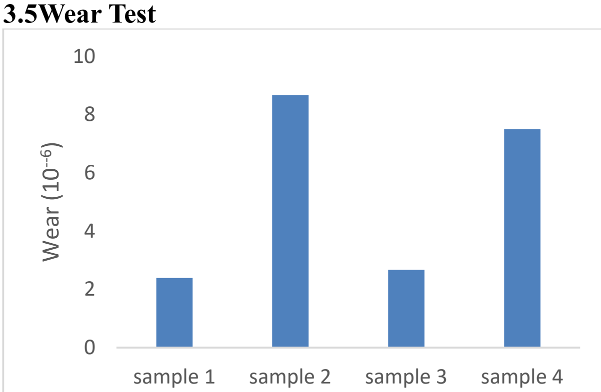

Figure 5: Wear test of the sample.

Figure 5 shows the wear rate of sample 2 increases as the percentage of rice husk ash is increased by 5 wt%. The addition represents an increase by 72.43% compared to sample 1.

At sample 3 the wear rate decreases with an increase of rice husk ash when 10%w was added and then further decreases when 15% w of rice husk ash was added by 64.4%. These findings agreed with the results reported by Sivasakthivel and Sudhakaran (2021).

The wear rate of Rice Husk Ash (RHA) reinforced Aluminium 7075 composite decreases significantly with increasing RHA content due to the presence of hard silica particles that improve surface hardness and resistance to abrasion.

Studies have shown that specific wear rate values fall within the range of (1×10^{-6}- 7×10^{-6}), which are within acceptable limits for automobile wheel applications.

4.6 Chemical Composition of the raw samples and the developed composite

Figures 6, 7 and 8 show the chemical composition of the aluminium piston scrap, rice husk ash and the developed composite.

The Result in Figure 6 vividly shows that the sample is a hyper-eutectic aluminium silicon cast alloy. This is due to the silicon composition being above the eutectic composition (Al 12.5 %)

Figure 7 XRF was done to identify the chemical composition and the silica purity obtained from the rice husk ash. It shows that the major component of RHA is silica (SiO_2), having the chemical composition of 80.02%. which also contains other smaller quantities of metallic contaminants.

Figure 8 shows that the percentage of aluminium decreases from the composite while the silica increases due to the addition of the rice husk ash. This is because rice husk ash is enriched with silica, which has good properties, e.g., wear resistance, corrosion resistance, hardness, toughness, and strength of the material.

Pure aluminium is light, soft and wears easily during use, but when reinforced with silica from rice husk ash, the aluminium becomes harder and more resistant to damage. This helps the automobile wheel last longer and perform better on rough roads.

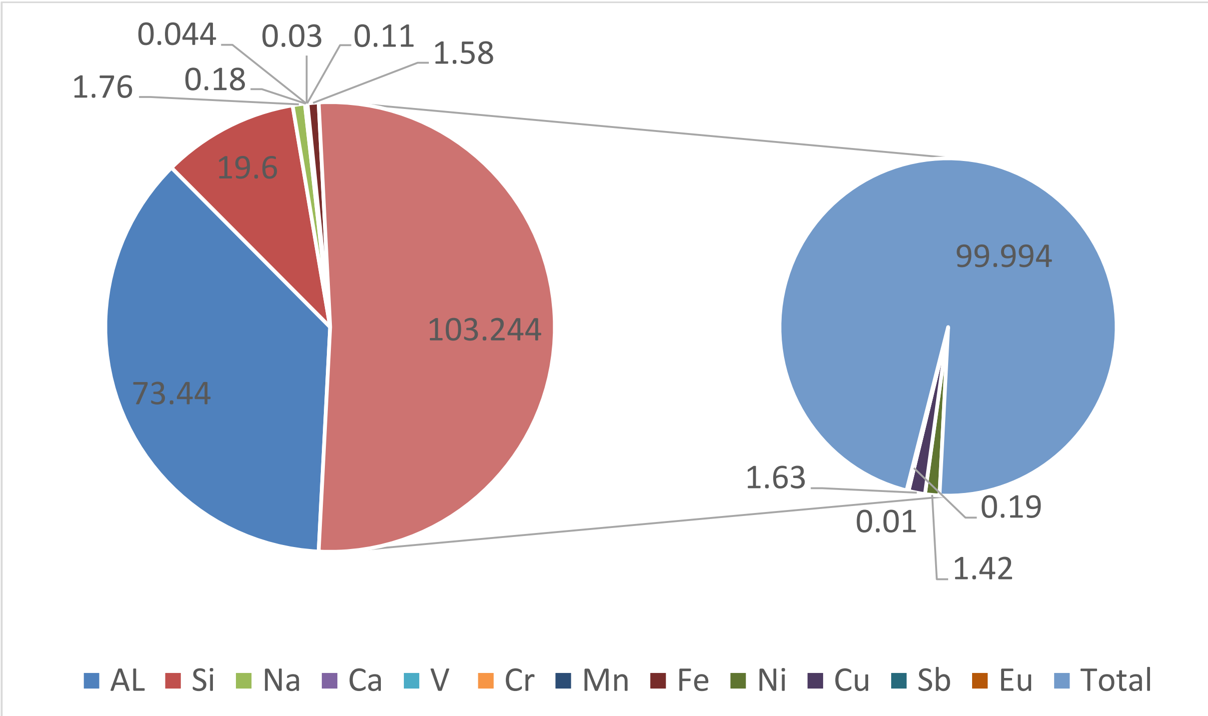

Fig. 6: Chemical Composition of Aluminium Scrap

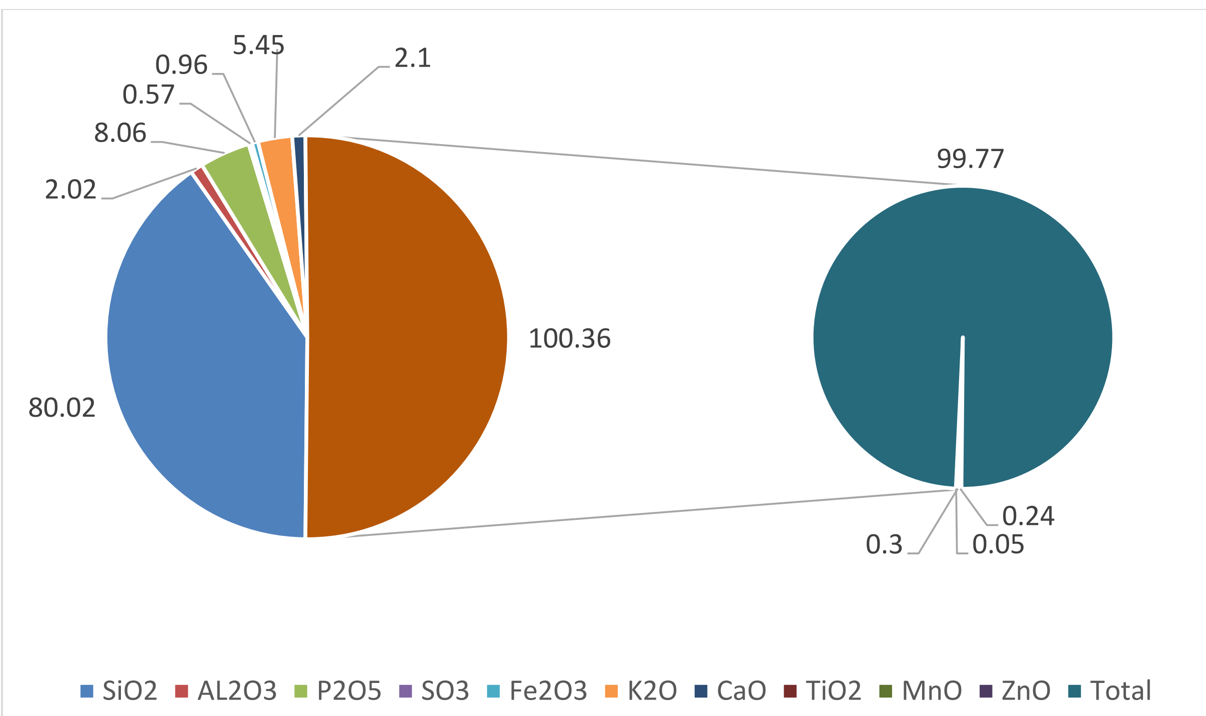

Fig. 7: Chemical Composition of RHA

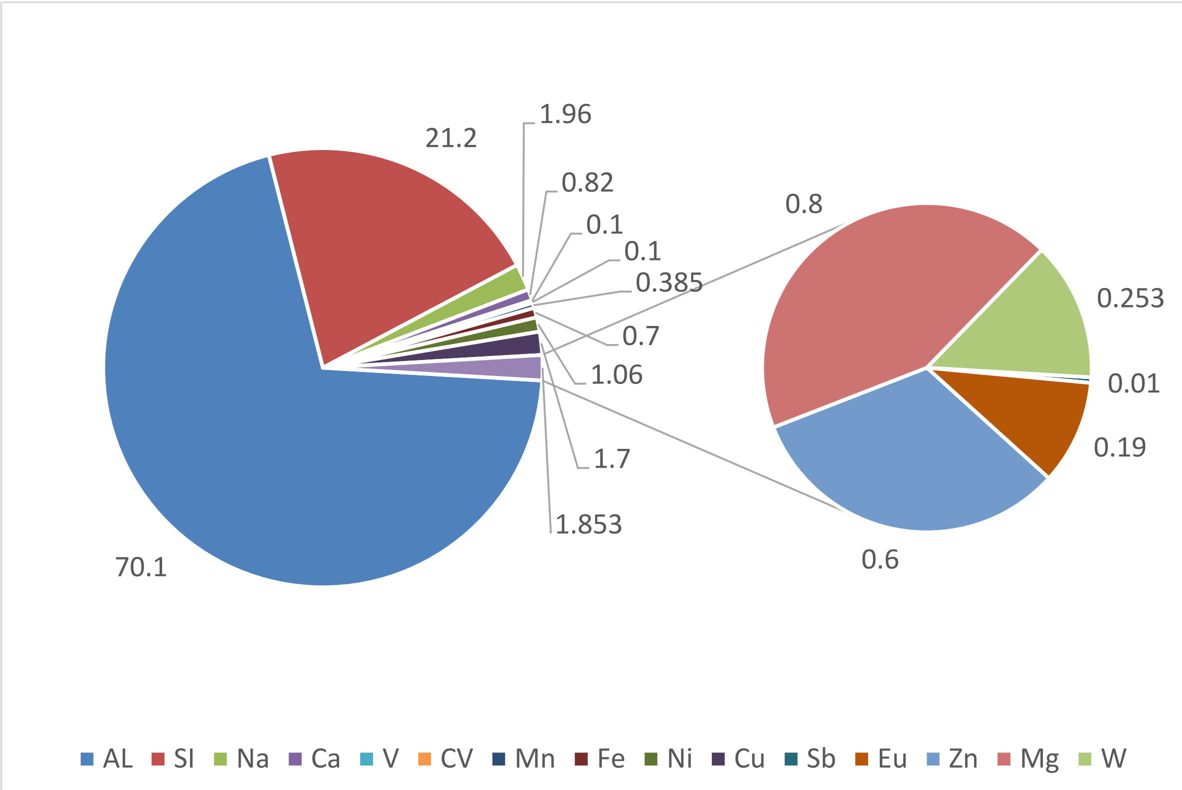

Fig. 8: Chemical Composition of Developed Composite

4.0 CONCLUSION

The study demonstrated that rice husk ash with high silica content can be effectively produced and used as a reinforcement in aluminium composites. Incorporating rice husk ash increased the silicon content of the alloy to acceptable levels for automotive wheel applications. Mechanical properties, specifically hardness, tensile strength, and impact strength, improved with increasing rice husk ash content, with the highest enhancements generally observed at 10 wt% reinforcement. Additionally, the composite's density decreased as more rice husk ash was added, indicating the potential for producing lightweight aluminium composites with good mechanical performance. Overall, moderate incorporation of rice husk ash yields an optimal balance of low density and enhanced mechanical properties.

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