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Research Article

The Study on Mechanical and Electrical Properties of AA6061/Snail Shell Composites

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Metal matrix composites are in high demand for various applications in the industrial sector and engineering firms. Therefore, new materials with enhanced mechanical and ecologically favourable characteristics must be designed and produced. This study focuses on the possibility of developing an aluminium matrix composite using agro-waste materials as reinforcement in preference to other industrial chemicals and materials. The morphological analysis carried out on the AA6061 + 15% snail shell at 100 μm showed the formation of homogenous particle size with stepped crystals. The micrographs of the developed composite were obtained using XRD (X-ray diffraction analysis), which indicated the presence of calcium and hydroxyapatite from the snail shell on the aluminium composite. Electrical analysis performed on the developed composite showed an increase in the conductivity from 32.03 Ωm^{-1} to 34.59 Ωm^{-1} as the snail shell reinforcements were increased, thus improving the capability of the developed MMC to transfer electricity due to the occurrence of the snail shell particulate within the composite.

1. Introduction

The growing requirement for materials with higher mechanical properties and reduced weight has driven research interest in current times in the further production of aluminium-based composites [1, 2]. It was confirmed that the inadequate mechanical properties of aluminium and its alloys unfavourably affect its utilization in automobile and aerospace industries [3]. Hence, enormous attention is directed toward using an aluminium-based metal matrix with better mechanical properties, especially in the building and servicing industries where component weight reduction, improved tenacity, and overall efficiency are key objectives [4]. The purpose of developing metal matrix composites is to blend the advantageous properties of metals and other organic composites. The importance of composites is seen here as it helps improve some of the less desirable properties of aluminium, including low welding ability, low strength, and partial brittleness [5]. Introducing agricultural waste in a particle form as a reinforcing agent for MMCs minimizes environmental pollution. The engineering firm also needs it because of its accessibility and minimal cost of converting agro-products into valuable raw materials for engineering applications [6]. Several methods are used to produce the aluminium matrix composites, such as powder blending, squeeze casting, and stir casting. Snail shells were used as the composite reinforcement material, and aluminium (AA6061) was used as the base material. This will give it additional strength and better resistance to extreme temperature, corrosion, and elasticity. Studies have shown that snail shells can be utilized as a cheaper fortifying agent to manufacture aluminium metal matrix composites for numerous industrial uses [7]. The chemical compositions of snail shells are 97.5 wt% calcium carbonate ($CaCO_3$), calcium phosphate, and calcium silicate making the material attractive for reinforcement. The available research proves that aluminium-based composite fortified with snail shells is a good alternative for composite production due to their availability, effectiveness, and mechanical properties [8].

2. Other Agricultural Waste Applications

2.1. Snail Shell. Several studies revealed through literature reviews had identified snail shells as an agricultural by-product and as one of the world's most serious agricultural waste and pollutants, particularly in countries where snails are more prevalent [9]. They have thrown light on the need to utilize them for more advanced purposes, including reinforcement. The effective utilization of snail shells can result in thrilling economic advancement [10]. As a reinforcement to metallic matrix composites, agricultural waste in a particular form has increased its significance not only because it is available and cheap but also because it decreases pollution by recycling waste from agricultural activities into useable raw materials in engineering [11]. Moreover, the major constituents within the snail shell are Ca and Si, which can be applied as ceramic reinforcing agent MMCs [12, 13]. Peter et al. (2020) researched ceramic/bio-based hybrid reinforced ALMMCs and discovered that the density of Al alloy is constantly enhanced when the inclusion of a reinforcing agent is improved, and an increment in reinforcement particles boosts the strength of aluminium matrix composites. The existence of snail shell particles within polyethylene increased the mechanical properties. In [14, 15], the effect of the snail shell powder on the mechanical characteristics of low-density polyethylene was studied. The LDPE carried out the range of other snail shell powders of 83 μm in particle size at different rates of 0%, 2%, 6%, and 10% and carried out various mechanical experiments on bending and tensile strength. Bending strength was carried out on the newly formed composites. The findings revealed a beneficial effect on the mechanical property of the polymer by increasing the tensile strength by 9.27 MPa, bending resistance by 25.42 MPa, and hardness by 31 kN. A snail shell is utilized to treat water, and the work in [16] studied the introduction of the snail shell as an effective means in the treatment of wastewater. The analyses carried out on the wastewater were PH analysis, electrical conductivity, turbidity, and phosphate analysis. The result exhibited a change in the colour concentration from dark brown before treatment to light brown following therapy. Also, turbidity has been reduced, and phosphates have been eliminated. The results revealed that snail shells are efficient in wastewater treatment.

2.2. Rick Husk Ash (RHA). RHA is a substance that is used to generate electricity. RHA can be used to reduce greenhouse gas emissions because trees ingest CO_2 as they develop, and this carbon is released when renewable energy from animals and plants is burned. In [17, 18], the synthesis and mechanical characteristics of aluminium reinforced composites with RHA were investigated by the stir casting method. Mechanical testing was performed on both the monolithic metal alloy and the composite material. Density decreased with an increase in reinforcing particles, and durability output and ultimate tensile capacity were improved.

Figure 1: Reinforced aluminium 6061 composite.

2.3. Coconut Shell. Coconut shell is an essential agro-based waste for tropical countries used internationally as another strategy for energy-biofuel. It was scorched as a strategy for strong waste dispersal which was added monstrously to CO_2 and methane discharges [19]. It is recognized as a fuel source as opposed to removal at the expense of fuel oil and flammable gas; furthermore, the power supply has soared immensely. At present, the Nigeria coconut shell is utilized as a fuel for the boilers; lingering coconut shell is released as gravel for appropriate street reconstruction [20].

3. Methodology

3.1. Metal Matrix. The designated materials for this research are AA6061 and snail shell particles.

3.2. Preparation of the Aluminium Composite Material. The aluminium metal matrix composite was produced using the process of stir casting. 98 g of aluminium 6061 was initially placed in a graphite crucible and heated to molten state at 810°C using a pit furnace. During the melting of aluminium, the surface tension of the molten metal was strong and the wetting ability of the molten metal was poor. Therefore, we added about 3 g of magnesium to improve the wettability of the molten metal. The previously ground snail shell was filtered to obtain a particular particulate size and was used as the reinforcement, which was incorporated into the molten metal using the graphite stirrer for unvarying circulation under proper stirring parameters. Then, the aluminium alloy melt was degassed for removal of impurities. The preheated matrix was stirred using a mechanical stirrer for the consistent distribution of the particles. Then, we transferred them into a preheated die, and the casting was allowed to solidify at room temperature; after that, we ejected and machined them for testing. Figure 1 shows the pictures of cast aluminium matrix composites.

3.3. Proportion of Reinforcing Particulates. The reinforcing particulates used in this research experiment are snail shells (achatinidae). It is a product from agro-based waste. Upon acquiring fresh snail shells, they were broken into small pieces with the aid of a hammer, which were later dried in the sun to remove any excess moisture and water on the sample and later pulverized locally into a finer powdery substance. This fine powder is then sieved to a particulate size of 100 μm.

3.4. X-Ray Diffraction Analysis. The XRD assessment is based on the X-ray beam travelling through a snail shell sample. The X-ray identifies the underlying layers that depend on the shell's d spacing. The d spacing is the exact location of the stakes of the crystal pattern (matrix) that specifies the total atom composition of the mineral. The X-ray, which passes through the shell samples, produces peaks which distinguish each type of diffraction on a series of planes and how they are divided, reflecting the arrangement of the atoms within the mineral. The XRD makes it easier to recognize the mixing of particles in the enhanced composite. It provides crucial information to determine the deposits obtained by further reinforcement. This increases the knowledge of the property structure behaviour by different techniques of characterization, such as optical/light microscopy and electron scanning. Figure 2 shows the XRD analysis of the pure aluminium alloy control sample.

3.5. Microhardness. The Rockwell hardness scale was utilized to calculate the endurance ratings of Rockwell for this project. The Rockwell hardness tester is used to test materials that are rough or not adequately polished to be tested using standard sample testing methodologies. This test technique usually involves large test loads of around 3000 kgf and 10 cm diameter. This is performed to ensure that the result is greater than most of the surface and subsurface incompatibilities. When indentation occurs, it resists plastic deformation. It is hydraulic operating equipment. Hardness was measured at 100 g for 15 seconds, and the Rockwell microscope across a minimum of two diameters is used to quantify depression, often at a straight angle. The results are estimated.

3.6. Tensile Testing Machine. The SM1000 UTM was used in this research to evaluate the tensile property and material strengths of the developed composites. It may be used to carry out a multitude of compressive and tensile tests on many kinds of materials, from metals to rubber, alluding to its name. The loading capacity of this machine is between 5 kN and 2000 kN. This device operates when the test material is fixed amid the machine's clamps. Once the test sample is tested, the machine records the force, which occurs when the load is applied to the test sample. The difference in length is also measured for each sample. Its maximum limit is 100 kN.

4. Results and Discussion

4.1. X-Ray Diffraction Analysis. Figure 3 shows the XRD analysis of the AA6061 crystalline phase at different peaks. The phases were obtained from the XRD pattern at the Bragg angle of 28^{o} at 3000 intensity counts. The phase shows the presence of the highest peak of aluminium, with trace elements of calcium oxide, calcium carbonate, calcium hydroxide, silicon IV oxide, and iron III oxide. It comprises a single crystalline phase with a single peak, except the aluminium has four extra peaks. Figures 3–6 show an elemental rise in the numeral of phases existing with peak discrepancies. It validates the occurrence of particles of industrial-based materials used in the study. The XRD patterns showed a crystalline phase of $Ca_2Al_3SIO_4$, Ca_2SIO_4, and $Ca(OH)_2$ at triple peaks resulting from snail composition used during analysis.

4.2. Microhardness Analysis. Figure 7 shows the effect of the varying mass fractions of snail shell particles on the microhardness property of the AA 6061/snail shell alloy matrix composite. The Rockwell hardness test was performed by applying a force of 100 N on an indenter ball of 3.175 mm for 15 seconds, and the surface of the material was broken down to an extent, thereby affecting the surface finish.

4.3. Ultimate Tensile Strength for Snail Shell Reinforced AA6061. Figure 8 shows the plot of a tensile specimen. The result of the reinforcement with a snail shell is shown in Figure 9. It was discernible that the tensile strength of the produced composite was improved by the inclusion of a snail shell as a reinforcing agent to the base aluminium alloy.

4.4. SEM/EDS Analysis. The SEM was used to investigate the physical and mechanical structure, and the quality of the grain of the reinforcing particle was injected. Figure 10 depicts the SEM of AA6061 and EDS, revealing the constituents of the control AA6061. Figure 11 shows the SEM images that the snail shell particles were completely dispersed in the matrix for 5 wt% reinforcement. There is a significant presence of voids of smaller sizes and a coarse surface in the specimen image because of the reinforcement. The images show the scanning electron microscope visualization of the AA6061 + 5 wt% snail shell particle. The EDS inferred the elemental constituents of the developed composites in which calcium had the highest concentration and showed uniformity with the images from the micrographs. In Figure 12, it was observed from the SEM images that there was a methodical distribution of the snail shell particulates in the reinforced sample because of the finer grain particles which brought about a better surface finish. The surface morphology shows the dispersal of the particles in the grain boundary and the existence of composition from the snail shell in the aluminium matrix. The SEM study also shows the existence of reinforcement alignment in the material due to the stirring technique used. As observed from the EDS analysis, the constituent elements of the AA6061 + 10 wt% snail shell sample revealed the existence of aluminium, silicates, oxygen, carbon, magnesium, and iron at different peaks because of an increase in the percentage of reinforcement. From Figure 13, we can observe the presence of arbitrarily stepped crystals in the cross section of the specimen. The EDS in Figure 13 shows the constituent elements of the AA6061 + 15 wt% snail shell sample. The peaks of the constituent elements are also observed. C, Ca, and O peaks are noticed, which are the primary constituents of the

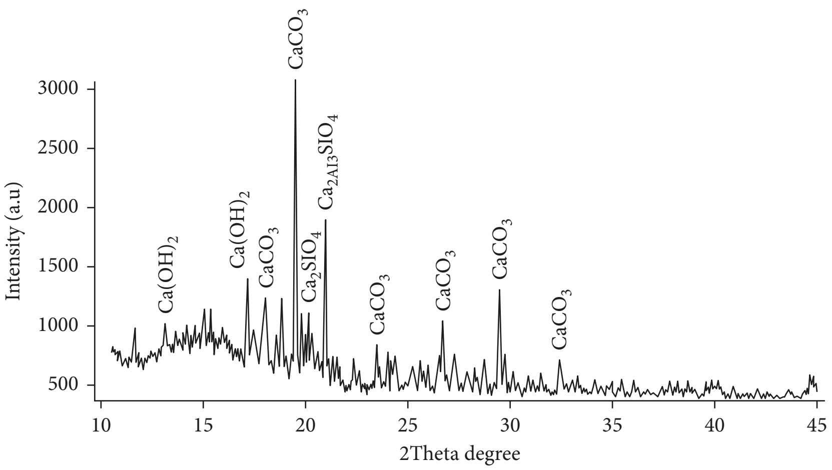


Figure 2: XRD of the aluminium alloy control sample.

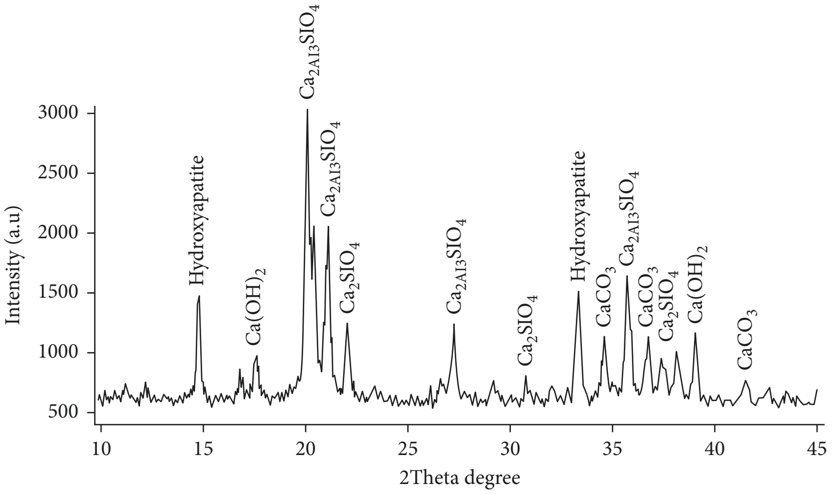


Figure 3: XRD of AA6061 + 5 wt% snail shell.

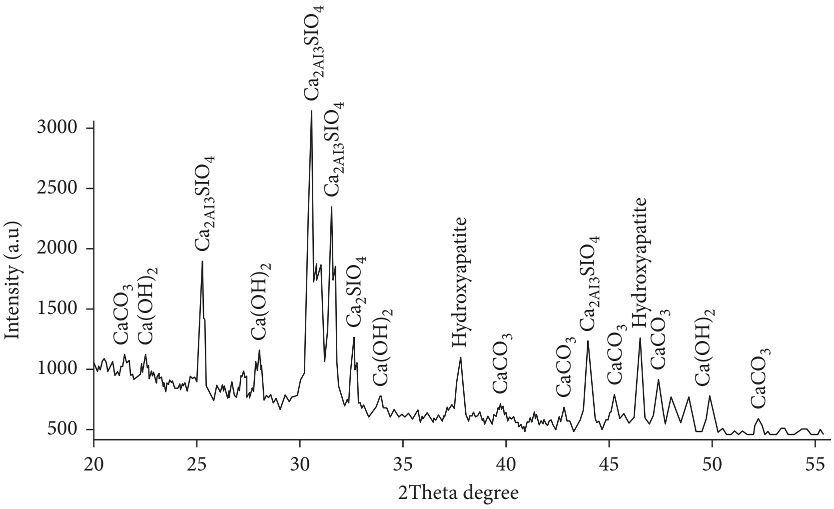


Figure 4: XRD of AA6061 + 10 wt% snail shell.

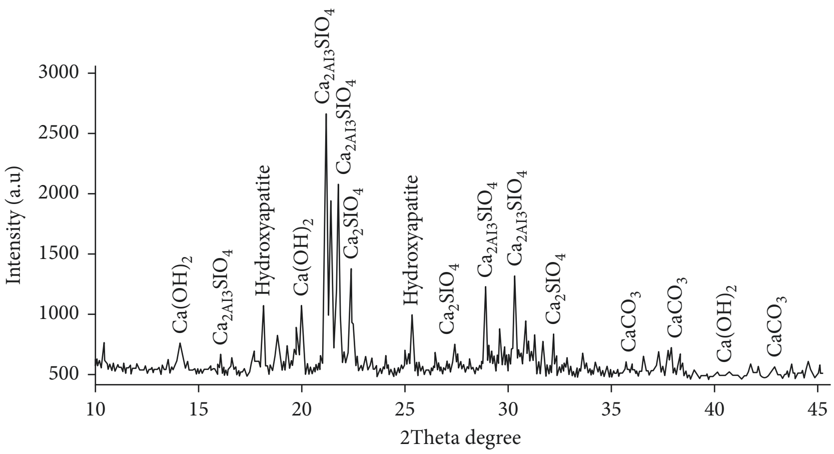


Figure 5: XRD of AA6061 + 15 wt% snail shell.

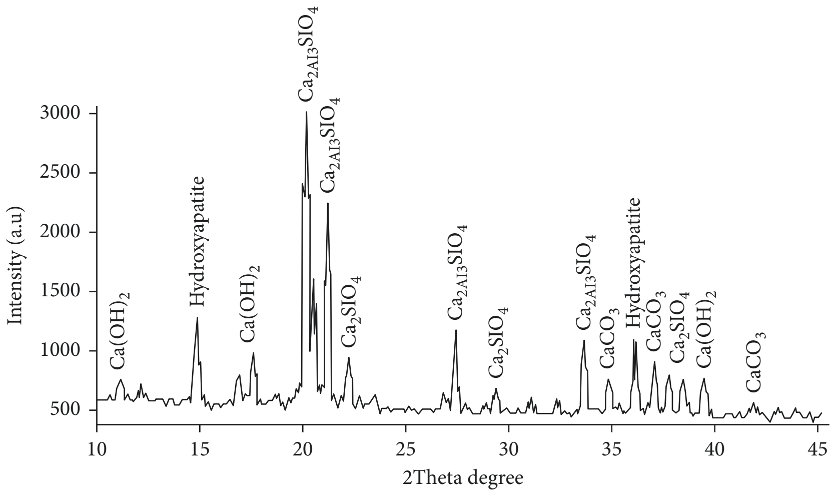


Figure 6: XRD of AA6061 + 20 wt% snail shell.

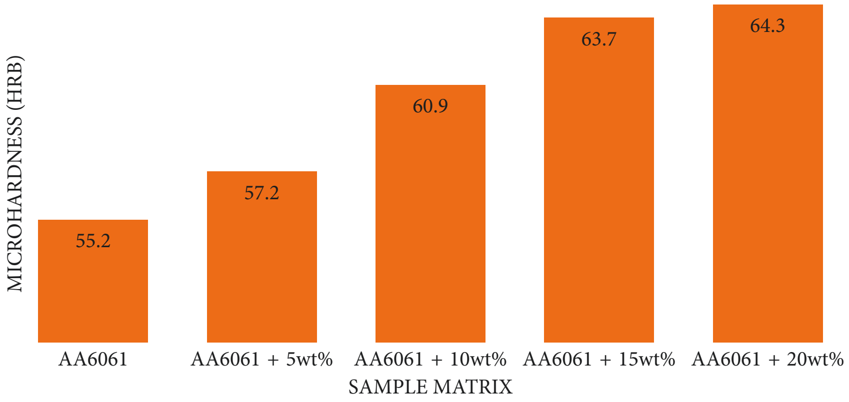


Figure 7: Effect of snail shells on the hardness of the reinforced aluminium composite.

reinforcements being considered. In Figure 14, it was observed from the SEM images that there was a spurious distribution of the snail shell particulates in the sample. At the grain boundary, it is evident that the introduction of snail shell particles into the aluminium alloy. The EDS shows the constituent elements of the AA6061 + 20 wt% snail sample. The peaks of the constituent elements are also observed. Al, Si, Ca, and O peaks are noticed, which are the

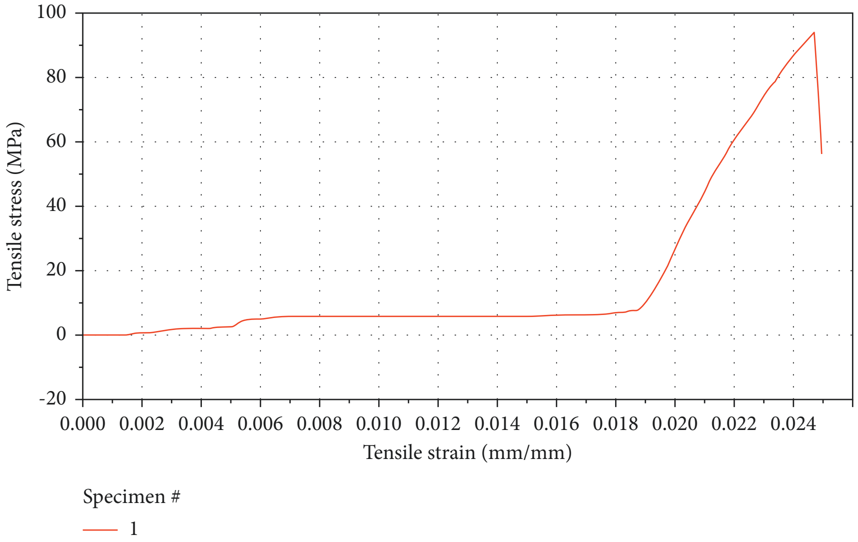


Figure 8: Tensile strength of the unreinforced AA6061 alloy.

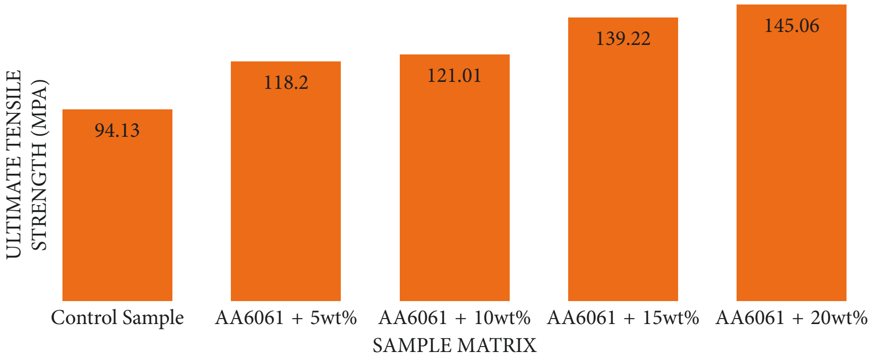
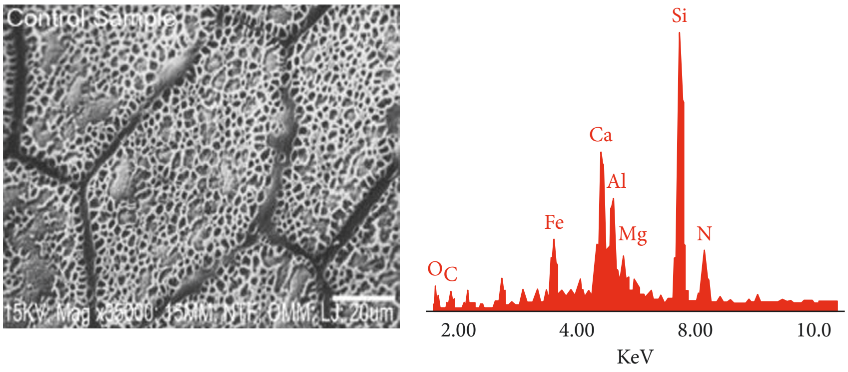


Figure 9: Tensile strength of the reinforced AA6061 alloy matrix composites.

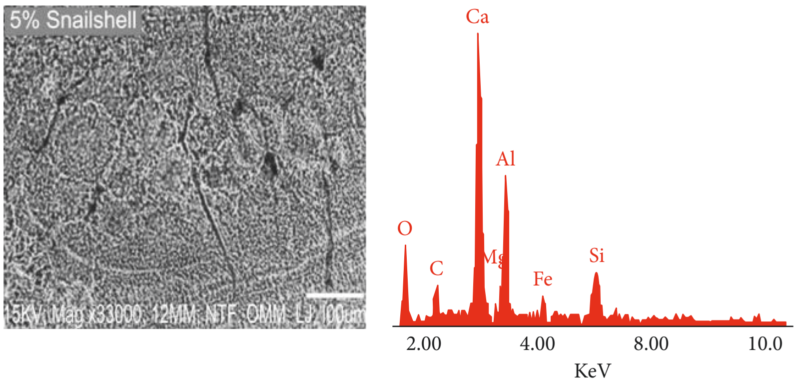


(a) (b)

Figure 10: (a) SEM image of AA6061; (b) EDS of AA6061.

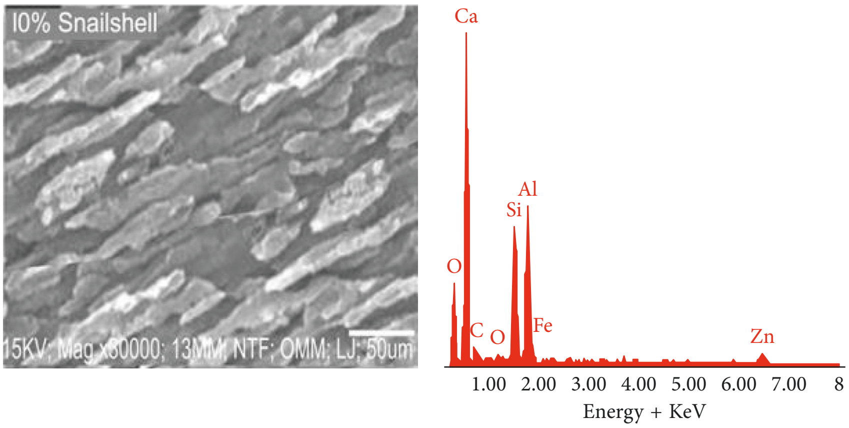
primary constituents of the reinforcements being considered. Elevated calcium is a result of the higher snail shell reinforcement.

4.5. Electrical Test. The electrical characteristics of the produced matrix were studied using the ammeter-voltmeter method. Figures 15 and 16 show the relationship between



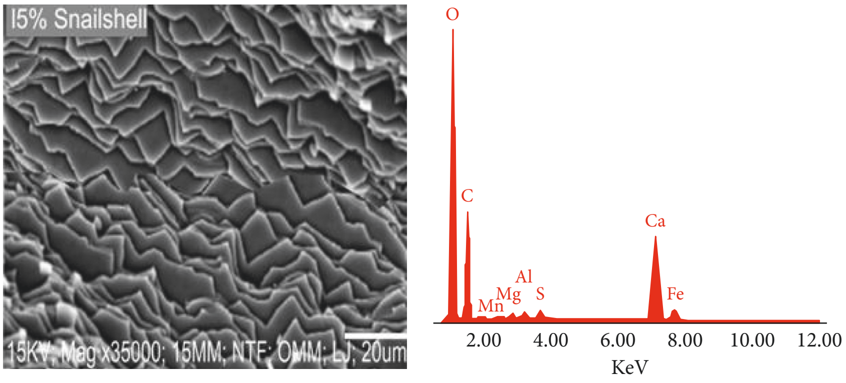
(a) (b)

Figure 11: (a) SEM image of AA6061 + 5 wt% snail shells; (b) EDS of AA6061 + 5 wt%.



(a) (b)

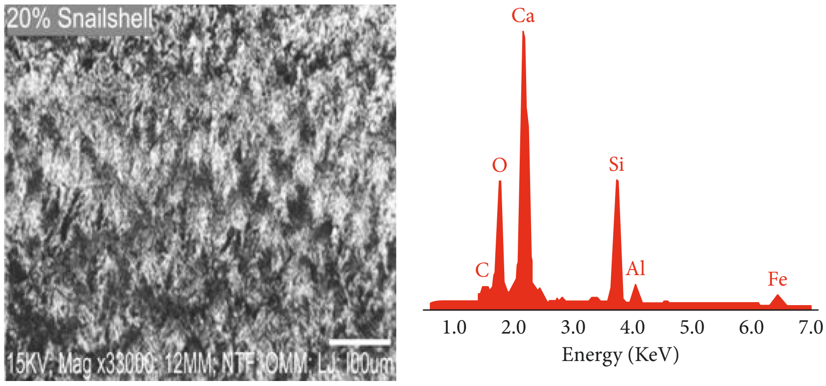
Figure 12: (a) SEM image of AA6061 + 10 wt% snail shells; (b) EDS of AA6061 + 10 wt%.



(a) (b)

Figure 13: (a) SEM image of AA6061 + 15 wt% snail shell; (b) EDS of AA6061 + 15 wt%.

the composite and its respective conductivity and resistivity. The snail shell improved the conductivity of AA6061 from 32.03 Ωm^{-1} to 34.59 Ωm^{-1}. The conductivity was attributed to the existence of calcium in the matrix. The resistivity of the alloy reduced from 0.031 Ωm to 0.029 Ωm, indicating the grade of performance of the produced composites. It was noticed that the electrical conduction of all fortified aluminium alloys was higher than that of the control sample.



(a)

(b)

Figure 14: (a) SEM image of AA6061 + 20 wt% snail shell; (b) EDS of AA6061 + 20 wt%.

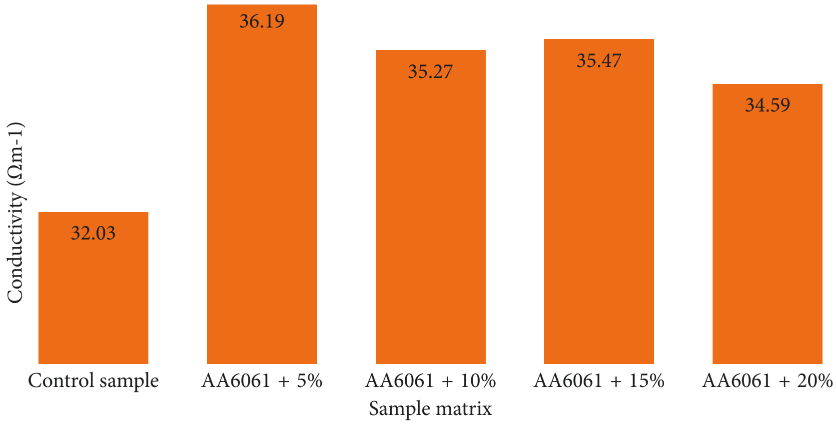


Figure 15: Effect of snail shells on the conductivity of the reinforced aluminium composite.

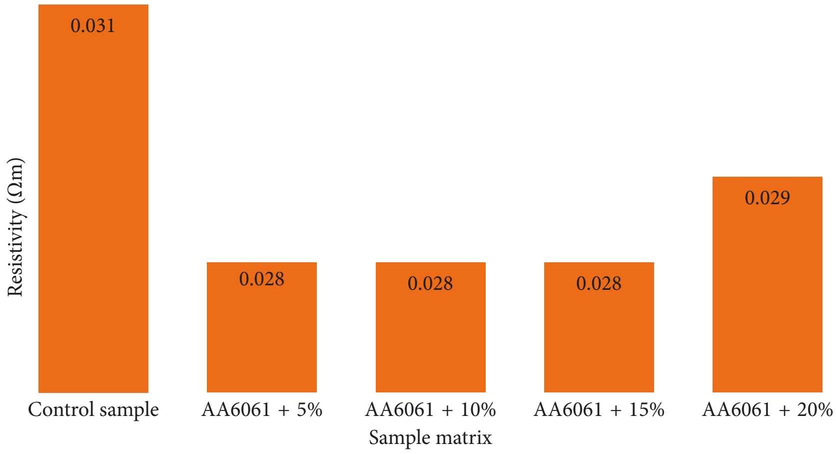


Figure 16: Effect of snail shells on the resistivity of the reinforced aluminium composite.

5. Conclusion

The following conclusions have been discovered from this research:

- (i) The use of agro-waste as reinforcements is possible as the snail shell was effectively infused into the pure matrix for composites to be constructed, converting waste to wealth
- (ii) The tensile strength was highest at the addition of 15 wt % of the snail shell particle with an increment of 16.49% with a reference to the control sample
- (iii) Rockwell's hardness test showed an increase in value with an increase in the mass fraction of snail shells with the highest value at 20 wt%
- (iv) The electrical conductivity test showed its highest conductivity at 5 wt% of a snail shell, and the resistivity of the material showed a gradual decrement in value
- (v) The stir casting method is the best operation for adding reinforcement to avoid porosity and agglomerations and does not damage the reinforcement when stirring occurs

Data Availability

The data used to support the findings of this study are included within the article.

Disclosure

This work was supported by the study based on research conducted at the Mechanical Engineering Department in Covenant University, Ota, Ogun State, Nigeria.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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