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The Study on Electrical and Mechanical Impact of Snail Shell Reinforced AA6061 Matrix Composites

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Abstract: There is a demand for lightweight and low-cost engineering materials with enhanced strength especially in automotive, aerospace, and structural applications in this modern age'. This study focused on developing an aluminium matrix composite using the stir casting method with snail shells of particulate size 75µm with varying proportions (4%, 8%, 12%, 16%) in order to enhance the properties of the composite such as tensile strength, hardness etc. The aluminium composites were studied and analyzed using the Brinell hardness tester for microhardness properties, UTM SM1000 for ultimate tensile strength behavior, scanning electron microscope equipped with energy dispersive spectrometer were used in studying the surface morphology and the elemental identification of the composite, X-ray diffraction was also used to categorize the crystalline phase of the composite. The results showed the XRD micrographs of the produced composite revealed the presence of calcium and hydroxyapatite derived from the snail shell on the aluminium composite. The diffractive pattern revealed a large number of reinforcements with stable intermediate phase $Ca_{10}(PO_4)_6(OH)_2$, $Ca_2Al_3SIO_4$, and Ca_2SIO_4 and so on. The electrical properties increased in conductivity due to the presence of the snail shell particulate within the composite from $31.9693\Omega m^{-1}$ to $34.6500\Omega m^{-1}$, thus increasing the capacity of the composite to conduct electricity. Furthermore, the ultimate tensile strength showed a significant change of 35.8% with the maximum tensile strength of 98.89MPa, achieved at 8% wt. snail shell. The hardness increased proportionally from 55.2HRB to 63.5HRB. Based on the outcome of experiments, this research has shown the possibility of using snail shell particulates as reinforcement in aluminium metal matrix composite and will help to improve the productivity and reliability of component made of AA6061 + 8% snail shell at 75µm.

Keywords: AA6061, Snail Shell, SEM/EDS, XRD, MMCs, Mechanical Properties

1. Introduction

The use of composite in pursuing new materials is considered advantageous because new materials can be favoured in several ways compared to common materials [1]. Aluminium matrix composites are important and capable of replacing conventional monolithic materials, which are rarely used [2, 3]. Factors that limit the variety of engineering applications for conventional materials include the high cost of fabricating synthetic components and the unavailability of resources. Al-MMC is widely utilized in the aerospace, marine, electronic, and car sectors due to its density, hardness, strength, fatigue resistance, and corrosion resistance [4, 5]. The usage of composites is rising rapidly now and is projected to continue in the future; aluminium and alloy-based composites are critical in the advancement of science and engineering [6]. Aluminium is a soft, non-magnetic, and ductile material. Its ore is bauxite, it is a silvery-white metal with the atomic number 13 and is commonly known as Al [7]. Aluminium is primarily strengthened by alloying it with elements such as copper (Cu), zinc (Zn), magnesium (Mg), silicon (Si), and lithium (Li) and processing the alloys. Despite its drawbacks, the world has begun to explore the use of aluminium matrices more frequently [8, 9]. Reinforcement will strengthen some of aluminium's present qualities while also creating new ones that will be useful in their respective sectors [10, 11]. Aluminium metal matrix composites have favourable physical and mechanical qualities that make them useful in a variety of industries, including automotive, aerospace, and marine [12, 13]. Reinforcement is carried out to improve the base metal's characteristics such as strength, conductivity, density, heat resistance, etc. [14, 15]. Some properties of the metallic matrix are heat treatment response and mechanical and corrosion behaviour, which offers flexibility in terms of these aspects [16]. Therefore, aluminium and its alloys are extensively researched in modern engineering for research and technological application, with their known characteristics of lightweight, non-magnetic, ductile at low temperature, corrosion-resistant, low density, non-toxic, thermal conductivity for their uses in automobile, aerospace, and structural industries [17]. Stir casting, spray deposition, powder metallurgy, vapour-state processing, and other methods are used to make metal matric composites [18]. Stir casting is a more suitable fabrication process due to it being less expensive, applied in large production, and no damage to reinforcement [19, 20]. Due to the restricted availability and high cost of synthetic materials, the use of synthetic materials as Reinforcement in metal matric composite (MMC) has hampered large-scale industrial manufacturing [21, 22]. For decades industrial wastes and agricultural wastes have been used as Reinforcement because of their low cost and availability [23, 24]. Snail shells are regarded as aquacultural waste having low economic value, exploiting them can bring tremendous economic wealth [25]. Snail belongs to the class gastropods, which is the largest class of the phylum Mollusca. The family members include achatina achatina, achatina maginata, and achatina fulica, and linicolarial species. Its main constituent is calcium carbonate [26]. The study is to investigate the mechanical characterization of aluminium alloy (AA6061) reinforced with a snail shell.

2. Material and Methods

2.1. Sectioning

In this project, the matrix under review is aluminium 6061, contracted by a metallurgical seller in Ota. The aluminium 6061 slabs were cut using an automated cutting machine and lubricant and coolant were sprinkled with soluble oils to alleviate the distortion of heat and metal. The aluminium 6061 was divided into four weights: 97.5%, 95%, 92.5%, and 90%.

2.2. Proportion of Reinforcing Particulate

A snail shell was used as a reinforcing particle in this experiment. It is a waste product derived from agriculture, it was broken into small pieces with the help of a hammer and then dried in the sun to remove any moisture before being ground locally into finer powdery powder. After that, the fine powder is sieved to a particle size of 75µm, then later separated into wt% values of 0%-16% with 4% increment.

2.3. Preparation of Reinforced Aluminium Composite

The composite aluminium metal matrix was manufactured employing the stir casting method. A pit furnace was used to melt 98g of aluminium 6061 that had been placed in a graphite crucible and heated to 810°C. The surface tension of the liquid metal was high during the melting of aluminium, and the molten metal's wetting ability was poor. Therefore we added roughly 3g of magnesium to increase the molten metal's wettability. Different fractions of snail shell powder were mixed into the melt using the graphite stirrer for constant circulation under suitable stirring settings. Figure 1 shows the stir casting machine used in the study, and Table 1 shows the stirring conditions for the stir casting process. Figures 2 and 3 show the reinforced and unreinforced aluminium matrix composites. Figure 4 shows the picture of snail shell powder, and Table 2 shows the weight fraction of the sample.

Figure 1. *Stir Casting Machine.*

Table 1. *Stirring Conditions for A Stir Casting Process.*

PROCESS PARAMETER	SELECTED PARAMETER
Processing temperature	1000°C
Preheat temperature of mold	300°C
Reinforcement particles reheat temperature	400°C
Stirring speed	350-600 rpm
Stirring time	3 min
No of blades	4
Blade angle	45°

Figure 2. *Reinforced Aluminium Matrix Composite.*

Figure 3. *Unreinforced Aluminium 6061.*

Figure 4. *A picture of snail shell powder.*

Table 2. *Weight fraction of samples.*

Sample Designation	Weight of Snail Shell (%)	Weight of AA 6061 (%)
AA 6061	0	100
AA 6061 + 4% snail shell	4	96
AA 6061 + 8% snail shell	8	92
AA 6061 + 12% snail shell	12	88
AA 6061 + 16% snail shell	16	84

3. Results and Discussion

3.1. Mechanical Properties

3.1.1. Microhardness Analysis of Clay Reinforced Aluminium Alloy

The greatest value of HRB was attained after adding 16 wt.% of snail shell to the composite shown in Figure 5, according to the results of the Rockwell hardness test. The reinforced aluminium matrix was found to be tougher than the unreinforced sample, the reinforcements made the alloy matrix stronger, and the material's improved hardness demonstrated that the snail shell had a good impact on the MMC. According to the hardness statistics, the reinforced alloys increased in hardness from 55.2 HRB for the unreinforced alloy to 63.5 HRB at a 15.04% increase. It shows that the hardness of the specimen improves as the weight percentage of reinforcement supplied increases. Hence, there is a direct proportionality relationship between the hardness value and the mass fraction of composite as one grows with the other.

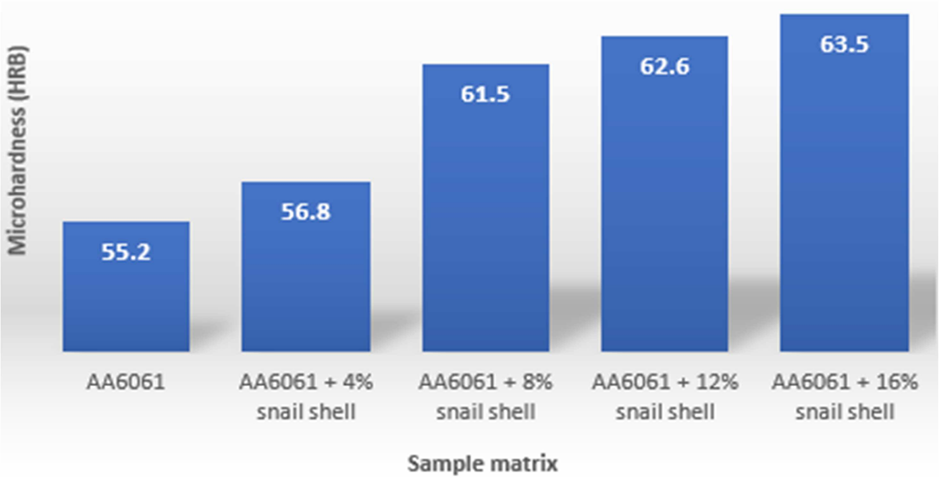

Figure 5. *Hardness test chart of samples.*

3.1.2. Ultimate Tensile Strength Analysis of Clay Reinforced Aluminium Alloy

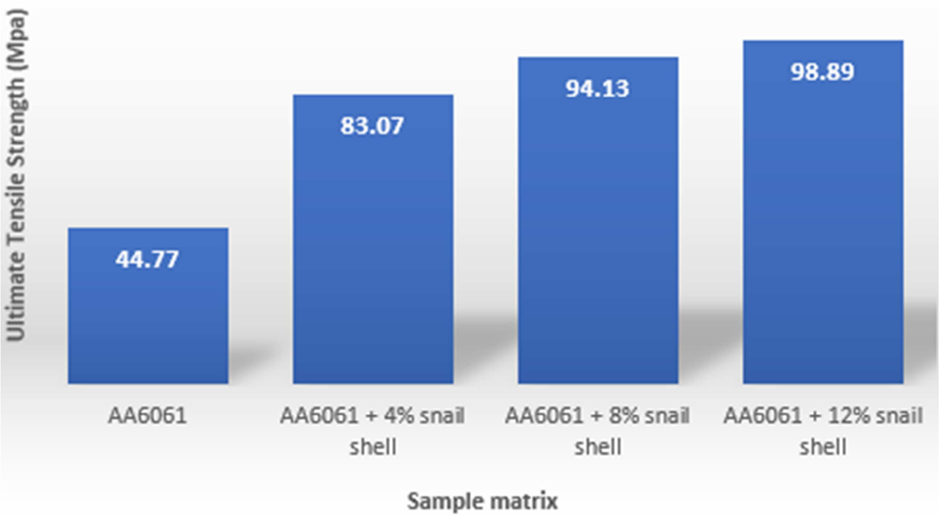

Figure 6. *Tensile stress chart of reinforced samples.*

It was observed that for the reinforced composite, the values of the properties increased as the mass fraction increased, and the 12% reinforcement was observed to possess the highest properties in comparison to the other mass fraction of reinforcements used in the experiment, as shown in Figure 6. The relation between the tensile strain and the tensile stress is shown in this experiment as they are directly proportional; the tensile strain at maximum tensile increased as the reinforcements increased and are generally greater in comparison to the control sample.

3.2. SEM/EDS Analysis

Figure 7 shows a micrograph of unreinforced aluminium alloy. The SEM image was taken at a magnification of 35000X with a voltage of 15kV and a working distance of 20µm. From the image, the SEM revealed the crystal arrangement of the aluminium alloy and showed substantial pores of different shapes and sizes. The control sample was further studied using EDS to reveal the constituent elements of the alloy.

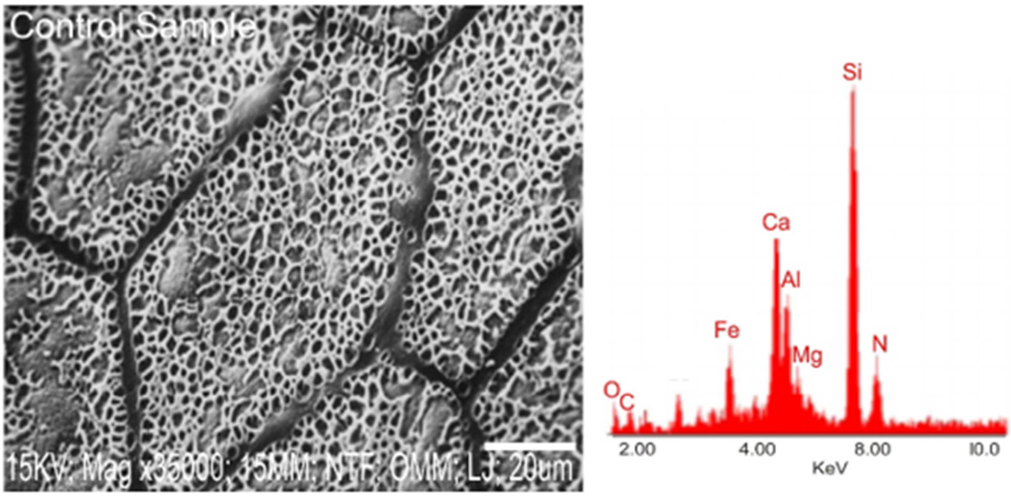

Figure 7. *SEM/EDS analysis result of the control sample.*

Figure 8 shows the SEM image of the aluminium alloy reinforced with a 4% snail shell; it was observed to be completely dispersed, which according to (Asafa et al., 2015) it is influenced by the good wettability of the snail shell particles by the molten metal and good bonding between particles and matrix material. The specimen was taken at a magnification of 33000X with a voltage of 15kV and a working distance of 100µm. The EDS shows the constituent elements of the specimen, such as aluminium, calcium, carbon, oxygen, silicon, and magnesium, at different peaks as a result of the addition of snail shell reinforcement. Figure 9 shows a SEM image of uniformly distributed particles with small dendrite for the aluminium alloy reinforced with an 8% snail shell. Figure 10 shows an SEM image of uniformly distributed particles with flake-like surface morphology when the aluminium alloy is reinforced with a 12% snail shell. Figure 11 shows the SEM image of the composite to have a well-defined crystalline lattice structure at a percentage reinforcement of 16%.

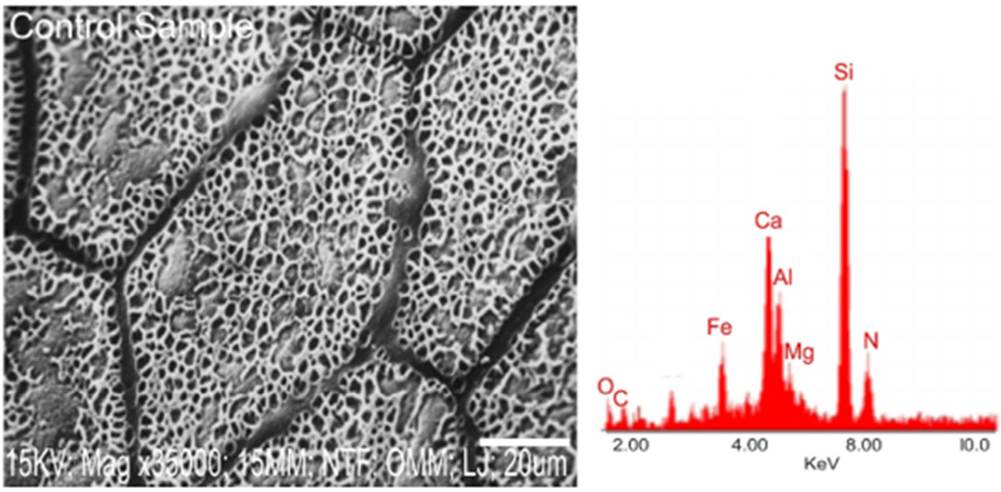

Figure 8. *SEM/EDS analysis result of AA6061 + 4% snail shell.*

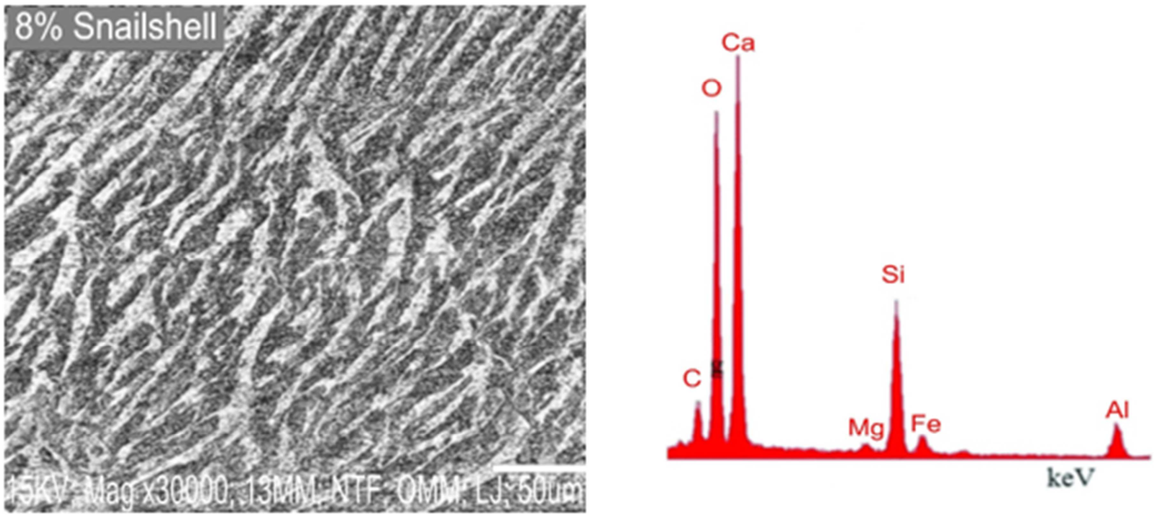

Figure 9. *SEM/EDS analysis result of AA6061 + 8% snail shell.*

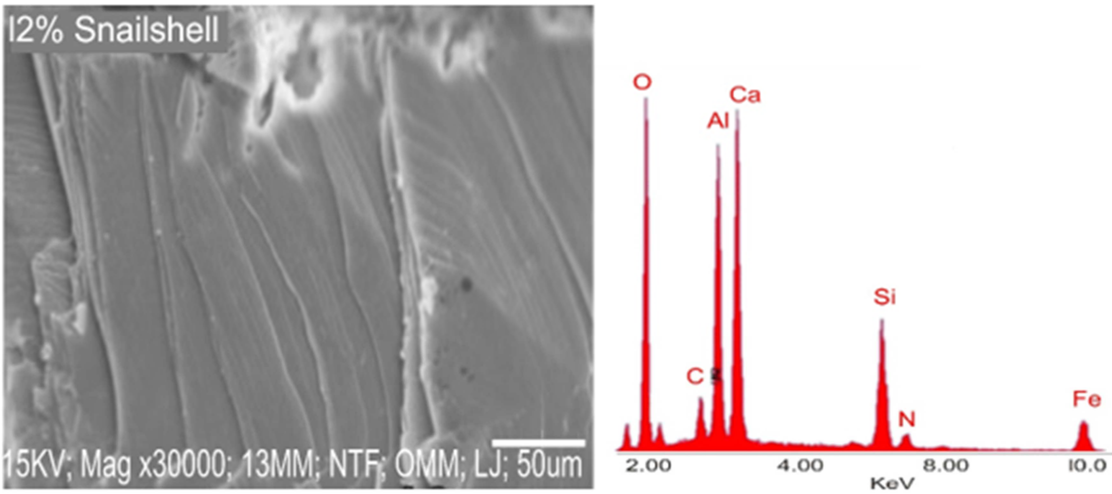

Figure 10. *SEM/EDS analysis result of AA6061 + 12% snail shell.*

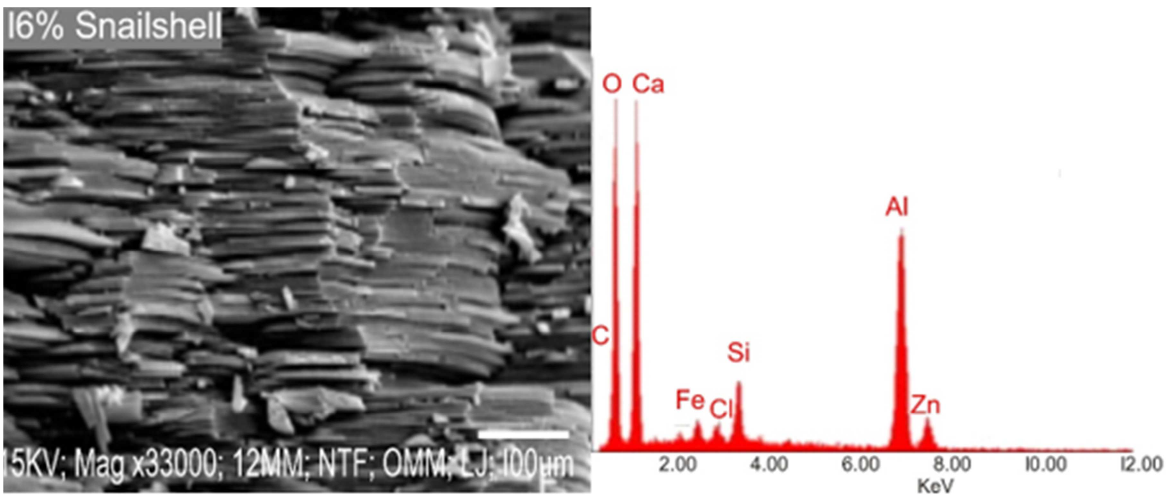

Figure 11. *SEM/EDS analysis result of AA6061 + 16% snail shell.*

XRD analysis of the control sample and the reinforced aluminium alloy

X-ray analysis was conducted on the unreinforced aluminium alloy and the reinforced aluminium alloy with varying weight fractions of snail shell to identify the crystalline phase of the material using an X-ray diffractometer.

The samples were set to produce X-ray spectra at scanning rate of 2°/min in the 2 to 50° at room temperature with a CuKa radiation set at 40kV and 20mA. The data obtained were 2θ angle and the intensity of the X-ray spectra.

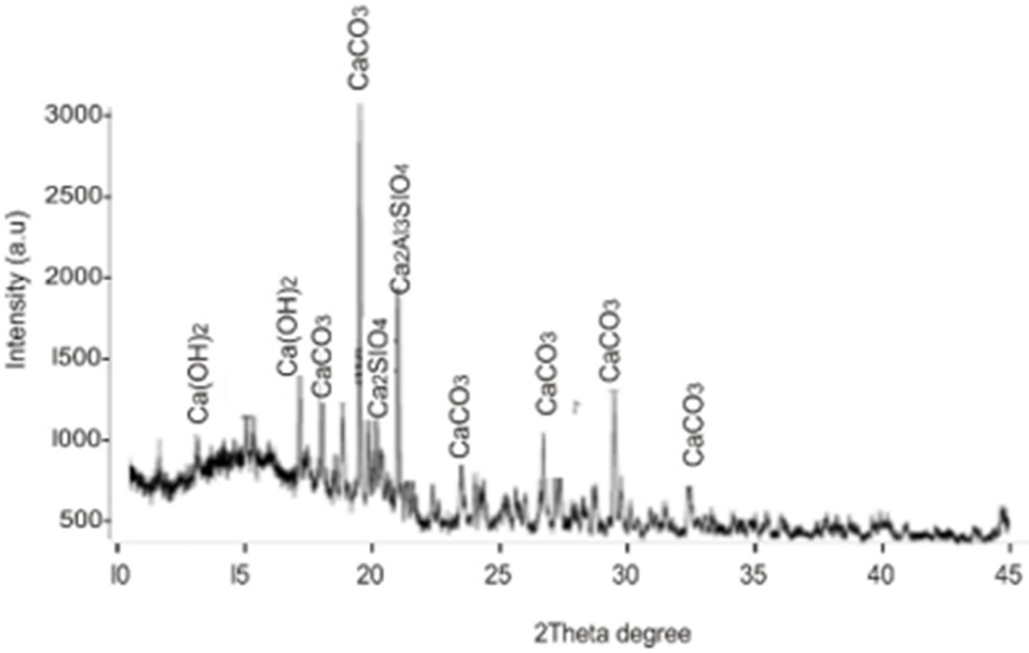

Figure 12. *XRD analysis result of the control sample.*

Figure 12 shows the XRD analysis result of the control sample at different peaks; it contains the major constituent of the control sample, which is pure aluminium. Figure 13 shows the XRD analysis result of the reinforced AA6061 + 4 wt% snail shell at different peaks. The crystalline phases were obtained at Bragg angles of 20° to 55° and intensity of 500 to 3000; it showed trace elements of hydroxyapatite, calcium hydroxide ($Ca(OH)_2$), calcium aluminate silicate˟ ($Ca_2Al_3SiO_4$), calcium silicate (Ca_2SiO_4), and calcium carbonate ($CaCO_3$). The XRD pattern shows calcium aluminate silicate˟ ($Ca_2Al_3SiO_4$) with the highest intensity of over 2500 and the presence of hydroxyapatite, indicating snail shell particle in the composite. Figure 14 shows the XRD analysis result of the reinforced AA6061 + 8 wt% snail shell at different peaks. Figure 15 shows the XRD analysis result of the reinforced AA6061 + 12 wt% snail shell at different peaks. Figure 16 shows the XRD analysis result of the reinforced AA6061 + 16 wt% snail shell at different peaks.

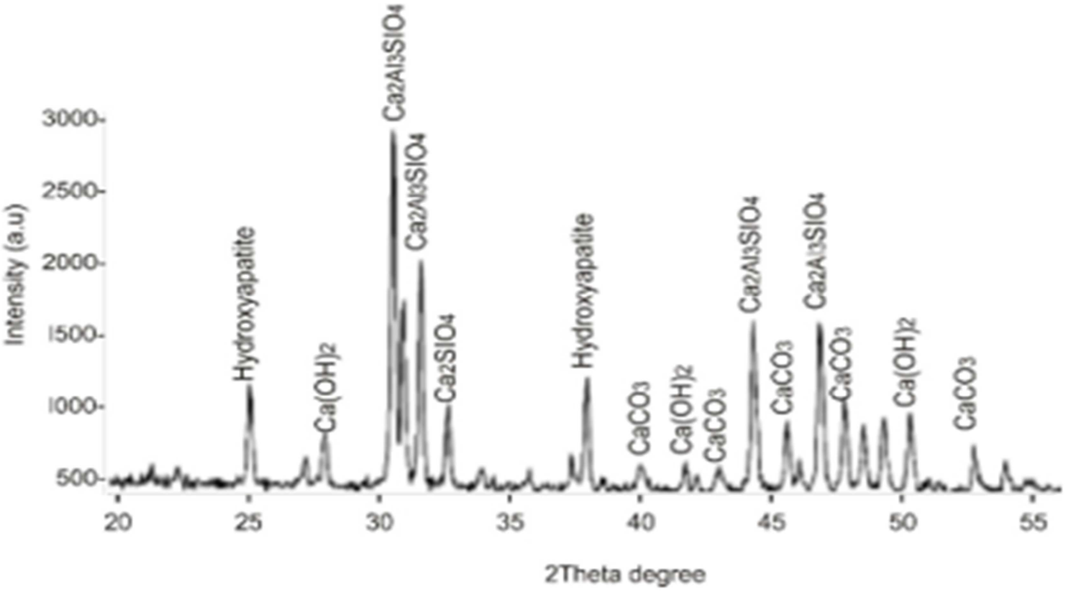

Figure 13. *XRD analysis result of AA6061 + 4% snail shell.*

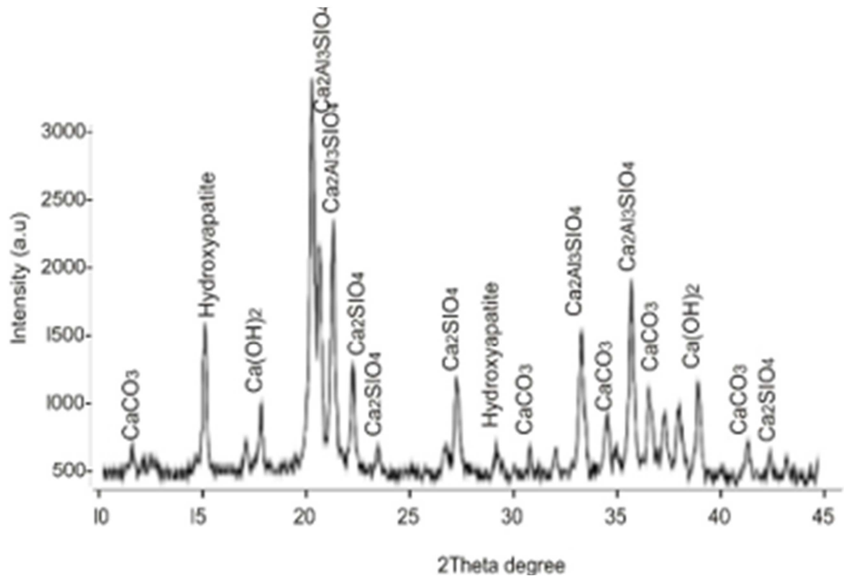

Figure 14. *XRD analysis result of AA6061 + 8% snail shell.*

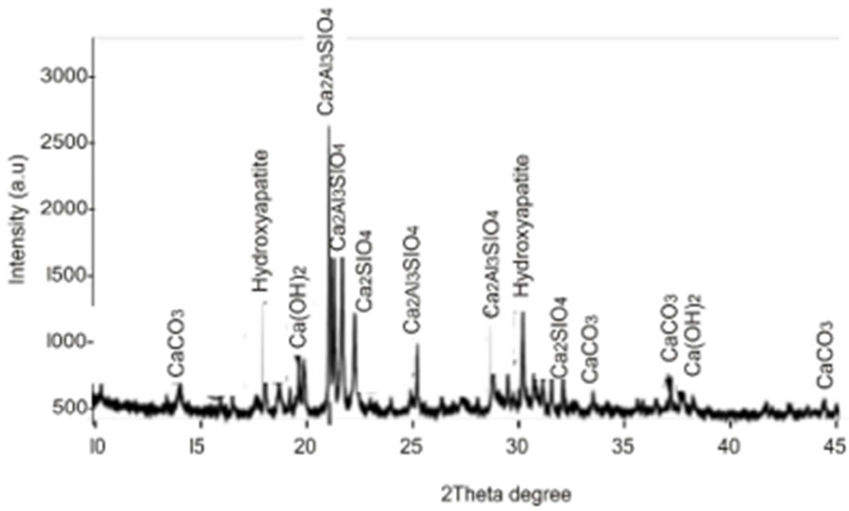

Figure 15. *XRD analysis result of AA6061 + 12% snail shell.*

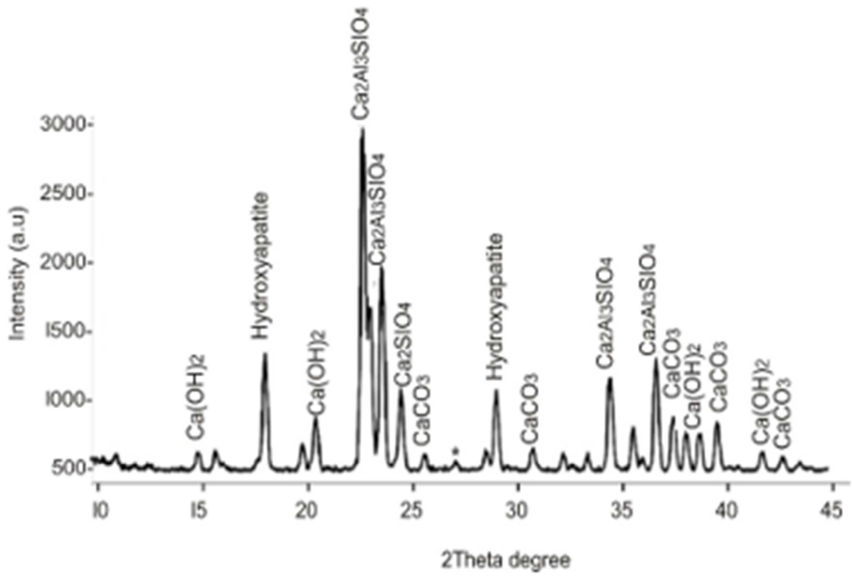

Figure 16. *XRD analysis result of AA6061 + 16% snail shell.*

Electrical Analysis for Unreinforced and Reinforced Material

The conductance of the reinforced material has improved in contrast to the unreinforced sample, using 0.2 volts as reference. The improvement indicates that the addition of snail shell as reinforcement had an impact on the conductance of the material, the highest conductance was observed at AA6061 + 8%wt. snail shell at 3.23S (siemens). The resistivity of each sample was calculated by using the formula $\rho = \frac{RA}{L}$, given R as the average of average resistance of a sample, A as the area, and L as length. Figures 17 and 18 shows the graphical representation of the resistivity and the conductivity of each samples respectively. Due to the high calcium content in the reinforced aluminium composite, the conductivity increased from 31.9693 S/m at the control sample to 34.65 S/m at 8%wt. snail shell allowing the reinforced aluminium to conduct electricity better and the resistivity reduced from 0.03128 Ω-m at control sample to 0.02886 Ω-m at 8%wt. snail shell. The electrical properties of all the reinforced aluminium were observed to have increased compared to the unreinforced aluminium indicating the functionality of the composite created.

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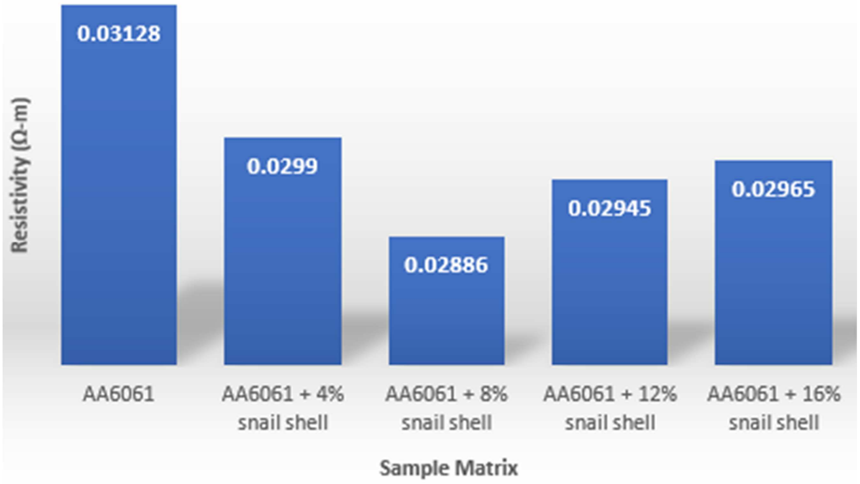

Figure 17. *Resistivity result chart of each sample.*

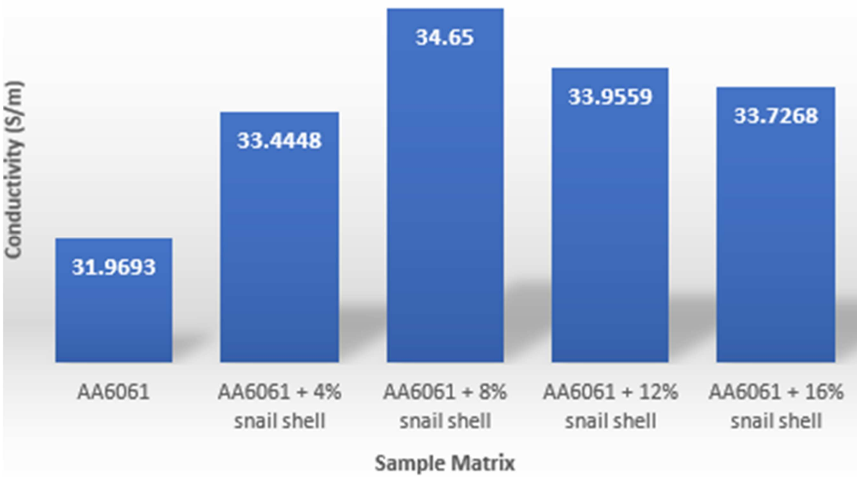

Figure 18. *Conductivity result chart of each sample.*

4. Conclusion

The following conclusions were derived from this study:

1. Agro-waste can be employed as reinforcement as the snail shell integrated with the aluminium matrix to form a composite.
2. The tensile strength increased as it was highest at 8% wt. snail shell.
3. The Rockwell's hardness showed a proportional increase in value with the addition in weight fraction.
4. The electrical conductivity test showed an improvement in the electrical properties as the conductivity was highest at 8% wt. snail shell.
5. The SEM/EDS analysis shows a homogeneous reinforcement dispersion in the composite.

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