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Research article

Morphological investigation and mechanical behaviour of agrowaste reinforced aluminium alloy 8011 for service life improvement

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ABSTRACT

Aluminium composite materials are beneficial in most engineering applications, most notably, because of their lightweight to strength ratio amongst many others. This study reports the reinforcement of aluminium alloy 8011 with cow horn and corncob in varying weight percentages of 5wt%, 10wt%, 15wt% and 20wt%. This study adopted the Stir casting method based on availability and cost-effectiveness as the cheapest method amongst others. The developed composite materials were in eight different samples alongside one control sample of the aluminium alloy base material. The samples used for this experimental study were tested for tensile strength, hardness and microstructural analysis. The outcome of the study shows that the sample with 20wt% of cow horn reinforcement gave the best-improved properties in terms of yield strength, ultimate tensile strength (UTS) and hardness with percentage improvement of 57%, 52.6% and 54.4% respectively. Hardness was also improved with 52.6% over the control sample with the 15wt% cow horn reinforced sample. Cow horn of 10wt% reinforcement improved the material by 61%. The results shown have justified the relevant effect of agro-waste materials in composite development.

1. Introduction

Aluminium is the most preferred material in any engineering application when light-weight to strength ratio becomes an essential matrix for consideration. Owing to high strength, robust thermal conductivity, ductility and natural abundance of aluminium and it's various alloys, it is progressively used in several automobile, construction and cooking utensil manufacturing industries [1, 2]. Amongst many other advantages of choosing aluminium as the preferred base material for its relevant application are, good mechanical properties, high strength, low weight, corrosion resistance and better ductility [2, 3, 4, 5].

Aluminium matrix composite is now gaining more recognition in the network of research findings and research application because of its improved strength, optimized mechanical, electrical, thermal and corrosion resistance properties. This significant improvement is as a result of the addition of reinforcement particulate which could be ceramic or agro-waste in a granular form of application [1, 2, 3, 4, 5, 6, 7].

In recent time, several research inputs have gone into metal matrix composite for improved and optimized properties as a result of their gradually increasing usage. The bank of literature has given some very relevant and vital findings to corroborate the significance of this study further. B_4C and red mud reinforced aluminium 8011 composite samples developed with varying ratio of the weight percentage of the particulate through stir casting method has shown a significant increase in the hardness and strength of the composite with decreasing rate of the particulate reinforcement [8].

Also, characterization of the mechanical properties and the microstructure of SiC and Al_2O_3 reinforced hybrid aluminium 7075 composites showed that the four specimens used for the study behaved better than the parent sample under the same experimental condition. Furthermore, an increase in the fraction of particulate added to the composite resulted in an increase in yield strength, tensile strength and hardness of the developed composite.

An experimental investigation by Wessley et al., [9] used fly ash and alumina oxide to reinforce AA6061 aluminium base material. The authors added particulates in varying weight percentages. The result shows improved mechanical properties over the base material.

In an experimental study by Fayomi et al., [10], hybrid nano ZrB_2 and Si_3N_4 were used as reinforcement particulates to develop a composite

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Table 1. Chemical composition.

Element	AA8011									
	Mg	Si	Mn	Cu	Zn	Ti	Fe	Sn	Pb	Al
Composition (wt.%)	0.45	0.58	0.16	0.15	0.22	0.01	0.86	0.02	0.017	Bal.

Table 2. Sample mixtures of particulates and AA8011.

Samples	Al (wt %)	Corncob (wt %)	Cow horn (wt %)	Total (wt %)
C	100	-	-	100
CC_1	95	5	-	100
CC_2	90	10	-	100
CC_3	85	15	-	100
CC_4	80	20	-	100
CH_1	95	-	5	100
CH_2	90	-	10	100
CH_3	85	-	15	100
CH_4	80	-	20	100

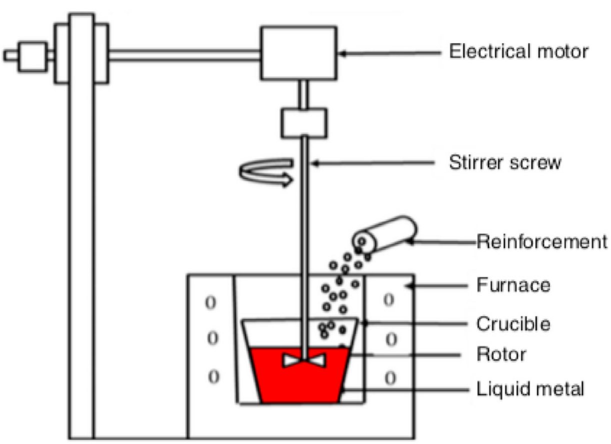

Figure 1. Stir casting setup.

Figure 2. Ingot of the developed composite.

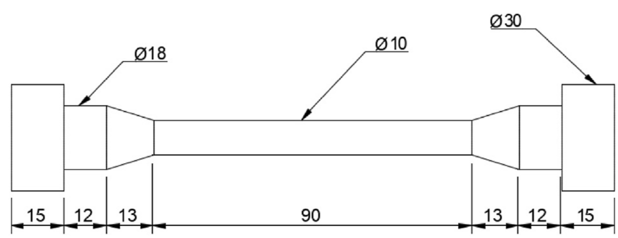

Figure 3. Schematic view of the tensile sample.

with Aluminium alloy 8011 as the base material. It was reported by the authors that the corrosion and thermal performances of the composite was investigated for automobile application. The result of the experiments shows that there was a significant decrease in the corrosion rate with the successive increase in reinforcement.

Another experimental investigation was done by Reddy et al., [11], where a gray-taguchi optimization approach was adopted to improve the mechanical properties of AA8011. The outcome of the study explains that the rate of heating and quenching aluminium parts determines its mechanical behavior.

A concise investigation was done by Aryshenskii et al., [12] on the effect of thermomechanical treatment conditions with local inhomogeneity on aluminium alloys microstructure evolution. The authors reportedly used Aluminium alloy of 8000 series (AA8011) for the study with the adoption of three experimental processes which are breakdown reversal commercial milling, plane strain deformation and laboratory rolling. Electron backscatter diffraction, optical microscope and x-ray texture methods were used for analysis in the study. The outcome of the experimental analysis was relatively compared with the output of the mathematical simulations. The experimental investigation showed the immense impact of the parameter's homogeneity on the texture and structure evolution of the thermomechanical treatment in the first stage.

Aluminium alloy 8011 is getting more relevance over time owing to its novelty in terms of dynamic properties. Researchers are gradually beginning to harness its potentials via various experimental studies in a bid to develop an improved material with the AA8011 base metal alloy. However, this study majorly points towards improving the mechanical properties of the base material by reinforcing it with agricultural waste.

2. Materials and methods

2.1. Procurement of materials

The parent material used for this experiment is aluminium 8011 which was obtained from the Aluminium Rolling Mill (ARM), Ota, Nigeria. The aluminium samples were acquired in billet shapes. The particulates used for the reinforcement were corncob and cow horn. The corncob was obtained from Covenant University farms in chunks. The cow horn was obtained from an abattoir in Lagos.

2.2. Materials preparation

2.2.1. Aluminium

Aluminium samples used for this study was 8000 series specifically AA8011 with precise elemental composition, as shown in Table 1. The as-received samples came in billet form in varying masses. The size

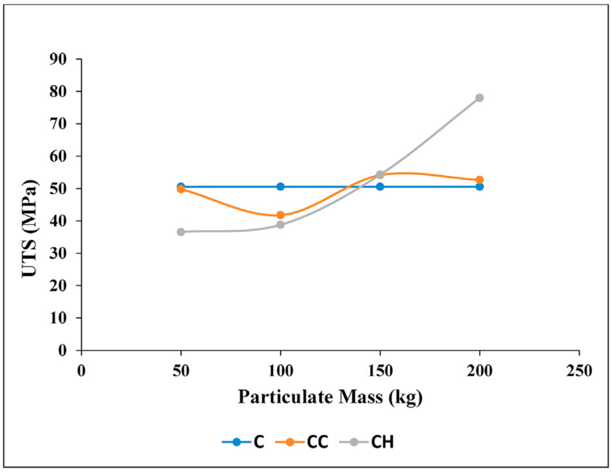

Figure 4. Graph showing variation in ultimate tensile strength of the composite samples.

reduction process started with the use of a power arc saw in the workshop in the mechanical engineering department, covenant university to reduce the aluminium samples into varying masses as needed for the study as given in Table 2.

2.2.2. Corncob

The as-received corncob was in chunk form. It was crushed in a hammer mill as the first size-reduction step. Since the corncob had been reduced to smaller granules, further particle size reduction was done using a burr mill. The crushed corncob sample was sieved using a sieve of 75 nano micron to get the powdery form of the sample that was needed for the research work.

2.2.3. Cow horn

Cow horn for this experiment was obtained from an abattoir. It was then dried under direct sunlight to reduce the moisture content. After the cow horn was fully dried, it was crushed using a bone crusher with a big mesh to reduce the granules of the sample. The mesh size of the bone crusher was reduced till the desired form of the sample was obtained. The cow horn was not burnt like the usual procedure [13]; it was processed in its natural state with all its fibres intact. The final grain size of the crushed cow horn sample was sieved using the same 75 nano microns used for the corncob and further portioned for casting as given in Table 2.

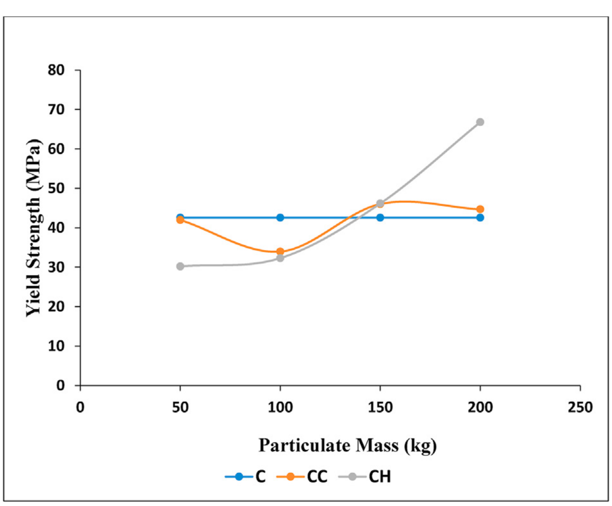

Figure 5. Graph displaying the variation in yield strength of the composite samples.

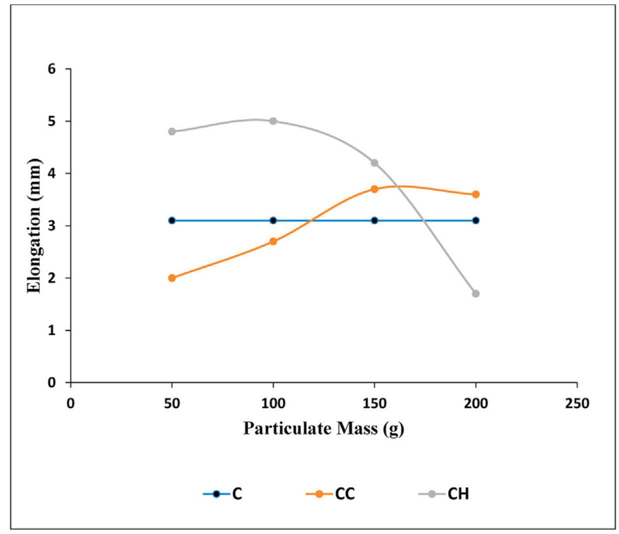

Figure 6. Elongation graph of the composite specimens.

From Table 2, eight new composites were developed with a varying constituent of the particulates. The control sample 'C' was weighed to be 1000g with 100% of the aluminium alloy sample. Samples CC_1, CC_2, CC_3, and CC_4 were reinforced with 5%, 10%, 15% and 20% of corncob respectively. While Samples CH_1, CH_2, CH_3, and CH_4 were reinforced with 5%, 10%, 15% and 20% of cow horn respectively.

2.3. Casting

Stir casting method of forming metals is a process that utilizes mechanical stirrer to uniformly mix the reinforcement that is poured into the matrix material, as shown in (Figure 1). This method was adopted for this study owing to its peculiarity in terms of availability, simplicity and affordability. A typical sir casting setup has a mechanical stirrer, reinforcement particulate feeder and a furnace. The furnace serves the primary purpose of heating and melting of the matrix materials before casting. The furnace was initially heated, the aluminium alloy at a superheating temperature of 800 °C was melted at a temperature above the melting point of the alloy. This was done for 5hours with the use of a charged furnace in a graphite crucible. The preheating temperature for the particulates used for reinforcement was about 450 °C in a bid to

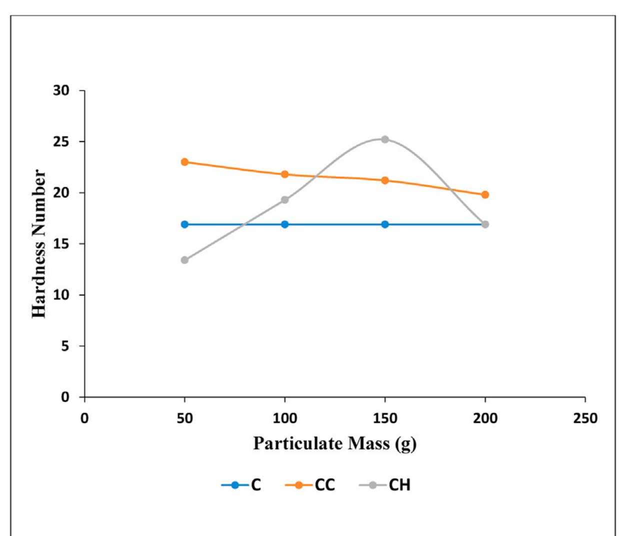

Figure 7. Hardness result of the experiment.

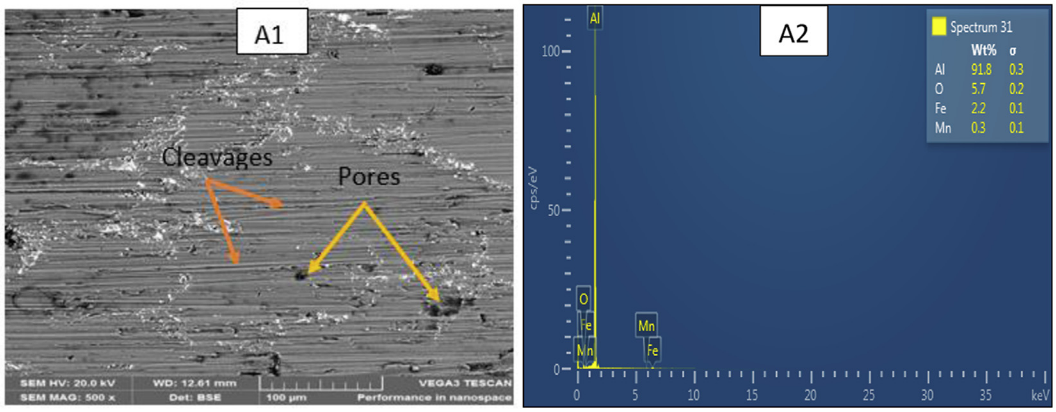

Figure 8. Morphology and elemental composition of the control sample (A1) SEM of AL-Alloy, (A2) EDS of AL-Alloy.

oxidize and degas the surface layer for uniform dispersion. After the preheating of the reinforcements, they were feed into the melted matrix material, while the mechanical stirrer was at stirring speed of 500rpm for 5minutes to enable uniform distribution of the particulate during the casting. In this process, a pattern was first made in the desired shape of the cast. The end product of the casting process, called ingot (Figure 2) was further machined into various experimental specimen sizes and shapes.

2.4. Machining of ingot

Upon the completion of the casting process, the ingot, which is the as received cast from the newly developed composite was carefully machined. The machining was done with the aid of a lathe machine as the samples were machined into universal tensile samples according to its schematic representation as shown in Figure 3.

2.4.1. Tensile test

The investigation was done using a TQ SM1000 Universal Testing Machine that has two different hubs that are located at the top and bottom of the test space within the machine. Once the initial force was applied, the sample was observed to have gradually gained percentage elongation. Then, the sample began to deform till it finally got broken at a point mostly close to the middle of the sample. The Ultimate Tensile Strength was determined by subtracting the initial force from the peak force.

2.4.2. Hardness test

This was conducted in the Civil Engineering department of Covenant University Ota, Nigeria, using a TQ SM1000 Universal Testing Machine that has a 10mm diameter steel ball indenter.

The circular shape sample is placed such that it aligns to the steel ball indenter. The steel ball is dropped on the sample, and the speed of dropping is controlled by a lever that works on the principle of hydraulics. Once the ball rests on the sample, you count for fifteen [12] seconds and then record the peak force shown on the digital display. The diameter of the indentation on the specimen is read and recorded using a Granule which is a magnifying glass with a calibrated scale. The Brinell Hardness Number was also calculated using the formula in Eq. (1).

$$BHN = \frac{2F}{\pi . D \left(D - \sqrt{D^2 - d^2} \right)} \tag{1}$$

Where;

BHN = Brinell hardness number

F = Load in kg

D = Steel Ball Diameter in mm

d = depression diameter on specimen

2.4.3. Morphological characterization

The scanning electron microscope of TESCAN VEGA3 model made in Czech republic equipped with oxford instrument for EDS was used to study morphology and compositional characteristics of a sample. The samples were well polished, and the etchant used was Keller's reaction. The electron beam was focused on the surface of the specimen by an objective lens followed by the generation of signals from the specimen. The generated signals were acquired by the detector and processed to form an image or spectrum on the screen.

2.4.4. Elemental composition analysis

The energy dispersive spectrometer affixed to the microscope allows detection and identification of the elemental composition of the specimen. The narrower probing beams both at low and high electron energy provided by the field emission cathode in the electron gun of the microscope improves spatial resolution and minimizes sample charging and damage.

3. Results and discussion

3.1. Tensile test

One of the tests carried out to examine the mechanical properties of the samples was a tensile test. This was done and explicitly categorized into three segments of relevance such as ultimate tensile strength, yield strength and elongation. The parametric values of the experiment are discussed below. There is a significant impact that porosity has on the mechanical properties of the cast material which covers for tensile stress, elongation, yield strength and hardness as discussed in this study. Porosity represents the cavity or void areas developed during the casting process to final solidification. It is a stress raising agent that reduces the available materials that could bear or carry the applied load during active use or testing. The behavior of the 10wt% of corncob presented in the graph in (Figures 4, 5, and 6) displayed a level of weakness owing to the presence of pores as seen in the morphological view in (Figure 10-B1). The cow horn has lesser pores, and successively displayed increased strength with increased amount of an reinforcement.

3.1.1. Ultimate tensile strength

The ultimate tensile strength result shown in Figure 4 infers that the composite samples reinforced with cow horn had the most significant impact with respect to increase in the percentage of added particulate compared to others. This also means that sample with 20wt.% of the cow horn particulate has the maximum bearing stress before the fracture occurred as a result of the applied load and cross-sectional area

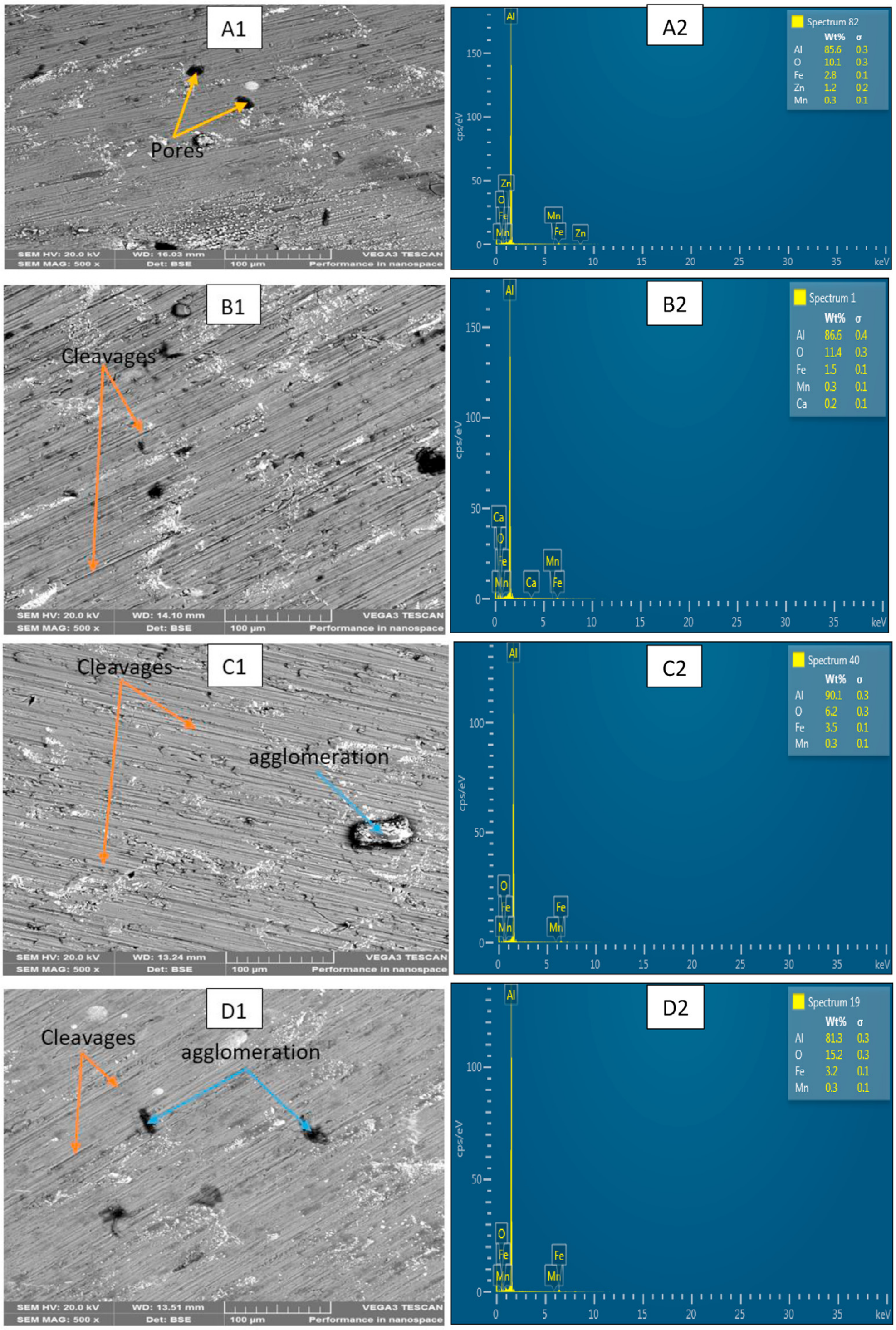

Figure 9. Morphology and elemental composition of the Cowhorn reinforcement particulate (A1) SEM of 5%wt, (A2) EDS of 5%wt, (B1) SEM of 10%wt, (B2) EDS of 10%wt, (C1) SEM of 15%wt, (C2) EDS of15%wt, (D1) SEM of 20%wt and (D2) EDS of 20%wt.

[14]. There was a successive increase in the UTS value of the samples with cow horn reinforcement. This has a direct proportion to the increase in the addition of the particulates from 5wt% to 20wt%. On the contrary for the corncob combined particulate, there was a fluctuating reduction in the UTS value with successive increase in the added particulate.

3.1.2. Yield strength

The effect of the various particulate in aluminium alloy composite development on the yield strength of the materials depicts a clear improvement in the mechanical property of the AA8011 base material for this experiment [8]. The 20wt% cow horn reinforced sample had a percentage improvement of 57% over the control sample of aluminium alloy, which gave a better performance than the corncob reinforced samples, as shown in Figure 5. This is as a result of the presence of some elemental constituents of cow horn like silicon and calcium amongst others that influenced the mechanical strength of the developed samples. Corncob impacted less on the mechanical properties of the composite because of the insufficient composition of the required elemental contents for improvement.

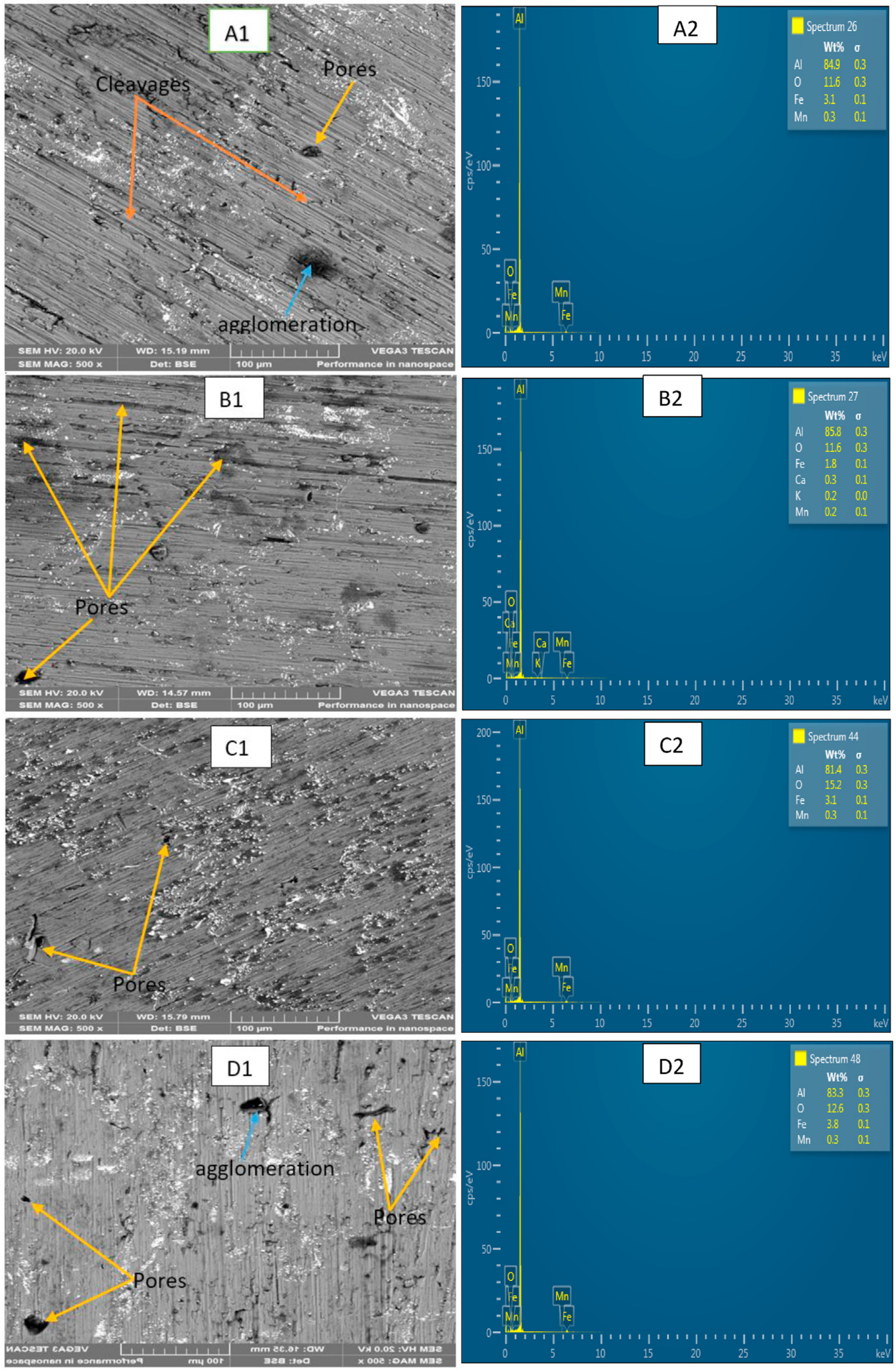

Figure 10. Morphology and elemental composition of the Corncob reinforcement particulate (A1) SEM of 5%wt, (A2) EDS of 5%wt, (B1) SEM of 10%wt, (B2) EDS of 10%wt, (C1) SEM of 15%wt, (C2) EDS of15%wt, (D1) SEM of 20%wt and (D2) EDS of 20%wt.

3.1.3. Elongation test

In this experimental study, the elongation test was carried out in a bid to determine the level of elongation of various aluminium composite that was developed. The elongation that was measured for each specimen under the same experimental condition gave a point of reference for the ductility of the various materials. According to Wessley et al., [9], elasticity justifies the rate of resistance of a material to any induced change(s) of its shape without any form of crack. The elongation test results are represented in Figure 6 below.

From Figure 8, it is observed that there was a significant increase in elongation with respect to the increase in the particulate of the specimen that had a mixture of cow horn and corncob reinforcement. The Al alloy that was reinforced with corncob alone had a better elongation with the 150g mass of reinforcement which gave a percentage improvement of

19% over the control sample. The increase in the cow horn reinforcement showed a step increase in the value of elongation within the particulate range of 50g and 100g. Afterwards, there was a decline in amount of elongation viz a viz the successive increase in the particulate mass. However, from the graph shown in Figure 6, at mass 100g for the cow horn particulate, the best elongation value was gotten with a very significant percentage improvement of 61%.

3.2. Hardness test

Hardness is a property of a material that defines the materials ability to give resistance to a press-in effect or a scratch of an object on the material. The result is measured in Brinell Hardness Number (BHN), which connotes the expression of the amount of pressure load on the press point per unit area.

It is observed that almost all the reinforcements in varying percentages gave an appreciable value of the hardness number with respect to the control sample, as shown in Figure 7. The increase in the corncob particulate mass reinforcement of the developed composites had an inversely proportional effect on the hardness of the samples. However, the most significant improvement is seen in the matrix of 150g of mass cow horn Aluminium reinforced composite with a percentage improvement of 52.6% which eventually had a decline because of the subsequent addition of the particulate, which was as a result of agglomeration of particulate in some parts of the ingot due to uneven stirring and insufficient stirring timing. Prabu et al. [15] suggested the adoption of 600rpm stirring speed and 10 min timing duration as the best combination for attaining a very uniform value of hardness for the composite. However, it could also be said that further addition of the cow horn particulate to the matrix beyond 150g will gradually reduce the hardness of the material as it had gotten beyond the limit of the required constituent.

3.3. Morphological examination

Figure 8 shows the surface morphology of the unreinforced Aluminium alloy. Several micro-porosities and cleavages were observed on the aluminium surface. Figure 9a, b, c & d shows the effect of the increasing percentages of CH in aluminium AA8011 alloy. There was no much improvement in the structure of the alloy after the addition of 5% CH and 10% CH. However, significant improvement was noticed upon addition of up to 20% CH (Figure 9d). The micro-pores and cleavages were eliminated to a large extent. The reduction in pores and cleavages could be perceptible to be due to the inclusion of CH in the alloy matrix (Fayomi et al., [16]).

Figure 10a-d shows the effect of increasing percentages of CC in AA8011 alloy from 5% wt. to 20% wt. Negligible micropores were observed in the SEM micrograph in Figures 10a-d when compared to the control in Figure 8. This outcome is most likely due to the presence of CC in the casting. Similar results were obtained for the cow horn (CH) reinforcements.

From Figures 8(a-d), 9(a-d) & 10(a-d), the EDS views clearly shows the analysis of the elemental composition of the control sample and all the other developed aluminium alloy composite samples. The peaks attained by all the elemental constituents for every sample is also presented. All the SEM images reveal the grain boundaries, particle distribution, and agglomeration of the particulate reinforcement used to develop the composite. The composite reinforced with 20wt% of cow horn that averagely gave the best mechanical behavior also displayed a significant effect in the morphological analysis compared to others. The agglomeration of particles discovered is as a result of uneven stirring of the mixture during the casting process.

4. Conclusion

Upon the completion of this study, twelve different samples were developed using cow horn and corncob in varying percentages as the reinforcement particulates for the developed composites. The experiment covered a range of tests which includes tensile strength, hardness, morphological and compositional analysis of all the samples in a bid to improve the mechanical properties of the base metal alloy (AA8011). The characterization of the samples shows that the alloy was significantly improved. Sample of 20wt % cow horn reinforcement particulate gave the best ultimate tensile strength and yield strength during the experiment with a percentage improvement of 54.4% and 57% respectively. The elongation behavior of the samples under the same experimental condition was peculiar for 10wt % of cow horn reinforcement with 61% improvement over the control sample.

Declarations

Author contribution statement

Babaremu K. O.: Performed the experiments; Wrote the paper.
Joseph O. O.: Conceived and designed the experiments.
Akinlabi E. T.: Contributed reagents, materials, analysis tools or data.
Jen T. C., Oladijo O. P.: Analyzed and interpreted the data.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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