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ASSESSMENT OF THE WEAR RESISTANCE AND THE DENSITY REDUCTION OF ALUMINIUM WHEN REINFORCED WITH COCONUT SHELL CHARCOAL AND COW BONE ASH

***[1]Oghoghorie O., [2]Ebhojiaye R. S. and [3]Amiolemhen P. E.**

[1]Department of Mechanical Engineering, Benson Idahosa University, Benin City.
[2,3]Department of Production Engineering, University of Benin, Benin City.

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***Corresponding Author**
Oghoghorie O.
Department of Mechanical Engineering, Benson Idahosa University, Benin City.

ABSTRACT
In this study, the wear resistance and the density reduction of aluminium alloy when reinforced with coconut shell charcoal and cow bone ash was investigated. The design of experiment employed was D-Optimal Mixture Design. It gives the different percentage by ratio of coconut shell charcoal, cow bone ash and aluminium matrix. The casting of the composite was done using the stir casting process. It was observed from the test carried out that the density and the wear rate of aluminium alloy were reduced by 13.89% and 51.45% respectively. Also from the SEM analysis, it was observed that the reinforcement particles were uniformly distributed. The empty space between the particles of the aluminium matrix (Al) was agglomerated with the granules of the coconut shell charcoal (CSC) and the cow bone ash CBA) and there was a proper bonding of the Al, CSC and CBA, hence the improvement on the properties of the aluminium.

KEYWORDS: Aluminium Metal Matrix, Composite, Coconut Shell Charcoal, Cow Bone Ash, Stir Casting.

1. INTRODUCTION
The desire of design engineers and manufacturers is to produce automobile parts with good mechanical and physical properties such as high tensile strength, hardness with low wear rate, low density etc. There is no single engineering material that has all the properties naturally. Therefore, there is a need to look into how a new engineering material known as composite

that can possess to a reasonable extent, most of the mechanical and physical properties which enable their usage in the production of machines and engines, such as the internal combustion engine parts like the cylinder head. The proper joining of dissimilar materials in the right proportion is called composite.

Metal matrix composites (MMCs) are the materials with less density and higher specific properties such as strength and stiffness. These materials are combinations of two or more materials, exhibiting properties that are hard to obtain from a single material. The compressive strength and tensile strength of cement was greatly increased when 5% bone powder was added to it.[1] According to Ebhojiaye et al., (2018).[2] in their paper titled "A New Lightweight Material for Possible Engine Manufacture" found out that the weight of an internal combustion engine block was reduced by 63.03% when a developed material that comprises aluminium, palm karnel shell and periwinkle shell was used to replace the grey cast iron that was used. They also found out that when all other components are replaced by the newly developed material, there will be a reduction in the weight of the engine by 25.36%. Jinsheng Ma. et al., 2017.[3] carried out research on the Application of Composite Materials in Engine. They were able to develop lighter piston with a commensurate property with the existing ones using a composite material. Vishwavidyalaya et al., 2018.[4] carried a review on Lightweight Composite Materials for Automotive. They found out that by replacing steel and cast-iron conventional components with lightweight composite materials such as Mg and Al metal matrix composite, carbon & glass fiber reinforced polymer composites can directly reduce the weight of the parts of an automotive. With the increasing emphasis on the need to improve automotive fuel economy, automotive engineers are motivated to develop a lighter engine that will reduce fuel consumption and enhance power of the engine. (Yadollahi and Boroomand, 2013; Zhao et al., 1999).[5-6] Ferdinand et al., 2014,[7] studied the Effect of load on the wear behaviour of polypropylene/carbonized bone ash particulate composite. The work established that carbonized bone can be used to increase the wear resistance of polypropylene composites.

In this study, composite material that comprises coconut shell charcoal (CSC) and cow bone ash (CBA) as reinforcements and aluminium as the matrix element was developed.

2. MATERIALS AND METHOD

2.1 Materials

Agro waste materials used in this study are the coconut shell and cow bone. These two materials served as the reinforcement agents in the composite formulation, while scrap aluminium was used as the matrix. Pure magnesium powder was used as the wetting agent. Some equipment used include a tensile testing machine, electric furnance, scanning electron microscope, crucible furnance etc.

2.1.1 Coconut Shell

Coconut shell is an agro waste that is predominantly generated in coconut candy production industry or coconut oil production facility. The coconut shell used in this study was obtained in large quantity from a coconut candy company in G.R.A, Benin City. It was dried in the sun for about 4hrs after which it was heated in an electric furnace at a temperature of 700^0C for about 3hrs. The shell turned to charcoal after being heated in the furnace. The coconut shell charcoals were grinded into smaller particles and taken to the laboratory to sieve. Figures 1a and 1b show the coconut shell charcoal before and after sieving.

Figure 1a: Coconut shell charcoal before passing through 212μm sieve.

Figure 1b: Coconut shell charcoal after passing through 212μm sieve.

According to Madakson et al., 2012 [8], X-Ray Fluorescence (XRF) chemical composition of the coconut shell charcoal analysis confirmed that SiO_2, Al_2O_3, MgO and Fe_2O_3 were found to be major constituents of coconut shell charcoal. The Silicon dioxide, iron oxide and alumina are known to be among the hardest substances. Table 1 shows the XRF analysis of Coconut shell charcoal.

Table 1: XRF analysis of Coconut shell charcoal (Madakson et al., 2012).

Element	Al_2O_3	CaO	Fe_2O_3	K_2O	MgO	Na_2O	SiO_2	MnO	ZnO
%	15.60	0.57	12.40	0.52	16.20	0.45	45.05	0.22	0.30

The chemical analysis of the coconut shell Charcoal morphology consists mainly of Si, C, O, Mg, Al with small amounts of Fe.

2.1.2 Cow Bone

Cow bow wastes usually litter environments where abattoirs are located. The cow bones used in this study were obtained in large quantity from an abattoir located within Benin City. The cow bones were sun to dry after which they were heated in an electric furnace at a temperature of 700^0C for 3hrs. The bones were crushed to smaller particles and taken to the laboratory to sieve. Table 2 shows the chemical composition of the cow bone **(**Agunsoye et. al., 2013).[9]

Table 2: Chemical composition of the cow bone (Agunsoye et. al., 2013)

Metal	Ca	Fe	Au	Sr	Sn
% Composition	23.326	2.602	Nil	Nil	Nil

Figures 2a and 2b show cow bones ash before and after sieving respectively.

Figure 2a: Cow bone ash before passing through 425μm sieve.

Figure 2b: Cow bone ash after passing through 425μm sieve.

2.1.3 Aluminium Scraps

Aluminuim scraps were bought at Uwelu spare parts market in Benin City. The scraps were melted in a local furnace to remove some percentage of the impurities present in it as shown in Figure 3.

Figure 3: Aluminium metal obtained from aluminium scraps.

2.2 METHOD

2.2.1 Design of Experiment (DOE)

A three variable mixture design was used to design the experimental plan for this study using D-Optimal Mixture Design. This is the most suitable experimental design method for optimizing formulation processes in which the input factors are the components of the product being formulated.[10] The coded and actual levels of the factors are shown in Table 3.

Table 3: Coded and actual levels of the factors.

Factors	Unit	Symbols	Variable levels	
			Low level	High level
Aluminum alloy	X_1	%	69	98
Coconut shell charcoal	X_2	%	1	20
Cow bone ash	X_3	%	1	20

The design expert produced 16 runs of the different percentage of the input factors as shown in Table 4. The composites were prepared using stir casting technique and sand moulds. Sixteen (16) samples of the different mix ratios as obtained from the DOE were produced, and another sample that contained only aluminium metal without the addition of reinforcements was produced to serve as the experimental control sample. Wear rate and density tests were done on all the samples produced.

Table 4: Experimental design matrix.

Run	Actual values of factors		
	Aluminum ingot (%)	Coconut shell charcoal (%)	Cow bone ash (%)
1	69	11	20
2	79	1	20
3	79	20	1
4	90	1	9
5	79	1	20
6	69	11	20
7	85	1	14
8	69	19	12
9	98	1	1
10	84	14	1
11	69	19	12
12	76	14	10
13	79	20	1
14	98	1	1
15	90	9	1
16	83	9	8

2.2.2 Wear Rate test

Wear test was carried out to predict the wear performance and to investigate the wear mechanism. The test is performed to evaluate the wear property of a material so as to determine whether the material is adequate for a specific wear application. Wear measurement is done to determine the amount of material that is removed after a wear test has been conducted for a specific period of time. The material worn away can be expressed either as weight (mass) loss, volume loss, or linear dimension change depending on the purpose of the test, the type of wear, the geometry and size of the test specimens, and sometimes on the availability of a measurement facility. Common techniques of wear measurement include using a precision balance to measure the weight (mass) loss, profiling surfaces, or using a microscope to measure the wear depth or cross-sectional area of a wear track so as to determine the wear volume loss or linear dimensional change.

In this research, the Taber Abrasive machine with ASTM D4060 standard specification was used. The sample to be tested was weighed and the result was recorded in mg. The test specimen was mounted on the turntable platform of the Taber abrasion tester and the side to be ground faced up, fixed with splint and nut. The two grinding wheels with a load of 4.9KN just touching the surface of the sample. The number of rotations was set, vacuum cleaner was opened, and the test started. The test specimen was subjected to abrasion at 500rpm in 10secs until wear was observed. The test specimen was removed and any loose abrading remaining on it was removed by light brushing after wish the sample was reweighed. The loss in weight (Mass) and the Tuber Wear Index were determined for each sample. Taber Wear Index indicates the rate of wear, and is calculated by measuring the loss in weight (in milligrams) per thousand cycles of abrasion. The lower the wear index, the better the abrasion resistance. Equation 1 shows the Wear Index formular.

$$Wear\ Index(W.I) = \frac{(M) \times 1000}{RPM} \qquad (1)$$

$M = (M_1 - M_2)$ (mg), where M = weight loss, M_1= weight (mass) of specimen before abrasion, M_2 = weight (mass) of specimen after abrasion. A load of 4.9KN was used in 10 secs for 500 rpm for each sample. The test was done at Federal University of Technology, Akure (FUTA), Nigeria. Figure 4 shows the wear rate samples and figure 5 shows Taber Type Abrasion Tester.

Figure 4: Wear rate samples.

Figure 5: Taber Type Abrasion Tester.

2.2.3 Density of the Specimen.

The density of a substance is the ratio of its mass to its volume. The densities of the specimens were determined using the ASTM standard D792-00 specification. Equation 2 shows the formular for density. The different masses of the composites were obtained by weighing the samples using the digital mass balance. The corresponding volumes were obtained by applying the Archimedes' Principle. A graduated cylinder was filled with water to a certain level and the initial volume of water was recorded. The specimen was placed in the graduated cylinder that contains water. The final volume of water was recorded. The difference in the volume of water gave the volume of the specimen. This was repeated for all samples. Hence, from equation 2, density was easily calculated for.

$$\rho = \frac{m}{v} \quad (2)$$

Where, m = mass is in kg, v = volume is in m^3 and ρ = density is in kg/m^3

3. RESULTS AND DISCUSSION

3.1 Wear rate Result

The wear rate results obtained for the 16 experimental samples and the control sample are shown in Table 5. The experimental procedure was replicated thrice for each of the specimen composition and the average values were determined for each and recorded. Same was done for the control specimen. From the results obtained in Table 5, Specimen 17 which is the control sample with 100%. wt aluminium, 0%. wt coconut shell charcoal and 0%. wt cow bone ash has the highest Wear Index of 0.622 $x10^{-4}$mg/rpm and specimen 15 with 90%. wt aluminum, 9%. wt coconut shell and 1%. wt cow bone has the lowest wear Index of 0.302 $x10^{-4}$mg/rpm. This showed that the reinforcements (i.e., coconut shell charcoal and cow bone ash) have reduced the wear rate of the composite material by 51.45%.

Table 5: Wear Rate Test Results.

Samples	Initial mass of sample, M_1 (g)	Final mass of sample, M_2 (g)	$M = M_1 - M_2$(g)	M (mg) (10^{-3})	Wear Index (10^{-4}) (mg/rpm)
1	125.163	124.991	0.172	0.172	0.344
2	148.136	147.922	0.214	0.214	0.428
3	149.416	149.140	0.276	0.276	0.552
4	117.729	117.561	0.168	0.168	0.336
5	128.205	128.048	0.157	0.157	0.314
6	126.323	126.077	0.246	0.246	0.492
7	128.740	128.558	0.182	0.182	0.364
8	130.537	130.379	0.158	0.158	0.316
9	129.517	129.254	0.263	0.263	0.526
10	163.092	162.837	0.255	0.255	0.510
11	130.536	130.380	0.156	0.156	0.312
12	120.207	120.040	0.167	0.167	0.334
13	149.415	149.141	0.274	0.274	0.548
14	118.424	118.201	0.223	0.223	0.446
15	127.372	127.221	0.151	0.151	0.302
16	127.968	127.810	0.158	0.158	0.316
17	126.712	126.401	0.311	0.311	0.622

Figure 6 shows the graphical representation of the wear rate obtained for the produced composites.

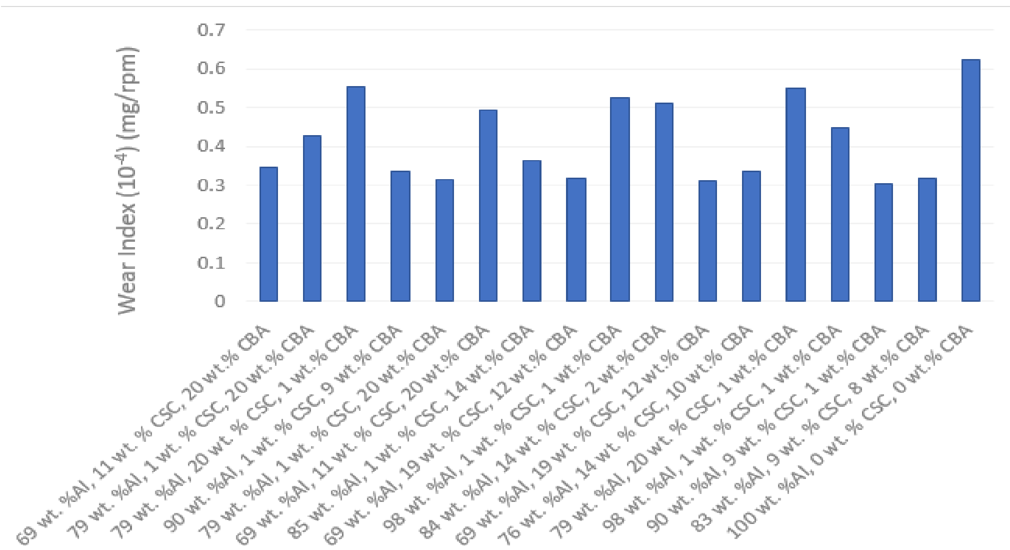

Figure 6: Graphical representation of the wear index of the produced composites.

3.2 Density Result

From Table 6, Specimen 17 which is the control sample with 100%. wt aluminium, 1%. wt coconut shell charcoal and 9%. wt cow bone ash has the highest value of density as 2707.00 Kg/m^3 and specimen 4 with with 90%. wt aluminium, 1%. wt coconut shell and 9%. wt cow bone has the least value of density as 2350.00 Kg/m^3. Comparing sample 4 with the control sample 17, the percentage reduction in density is 13.89%. This showed that the reinforcements that is, coconut shell charcoal (CSC) and Cow Bone Ash (CBA), have decreased the density of the composite material by 13.89%. Figure 7 shows the graphical representation of the densities of the produced composites.

Table 6: Test Results for Density.

Samples	Mass, M_1(g)	Mass, M_2 (kg) (M_1 x10^{-3})	Initial Volume, V_1, of Water (mL)	Final Volume, V_2, of Water (mL)	Volume of composite (m^3) (V x 10^{-6})	Density (Kg/m^3)
1	31.3	31.3	150.0	162.0	12.0	2608.33
2	44.6	44.6	150.0	168.0	18.0	2477.78
3	31.1	31.1	150.0	162.0	12.0	2591.67
4	32.9	32.9	150.0	164.0	14.0	2350.00
5	31.7	31.7	150.0	162.0	12.0	2641.67
6	32.3	32.3	150.0	162.0	12.0	2691.66
7	32.5	32.5	150.0	163.0	13.0	2500.00
8	34.7	34.7	150.0	163.0	13.0	2669.23
9	47.9	47.9	150.0	170.0	20.0	2395.00
10	34.8	34.8	150.0	164.0	14.0	2485.71
11	34.6	34.6	150.0	164.0	14.0	2471.42
12	42.2	42.2	150.0	167.0	17.0	2482.35
13	31.0	31.0	150.0	162.0	12.0	2583.33
14	34.8	34.8	150.0	163.0	13.0	2676.92
15	33.9	33.9	150.0	164.0	14.0	2421.43
16	32.5	32.5	150.0	163.0	13.0	2500.00
17	8.12	8.12	57.0	60.0	3.0	2707.14

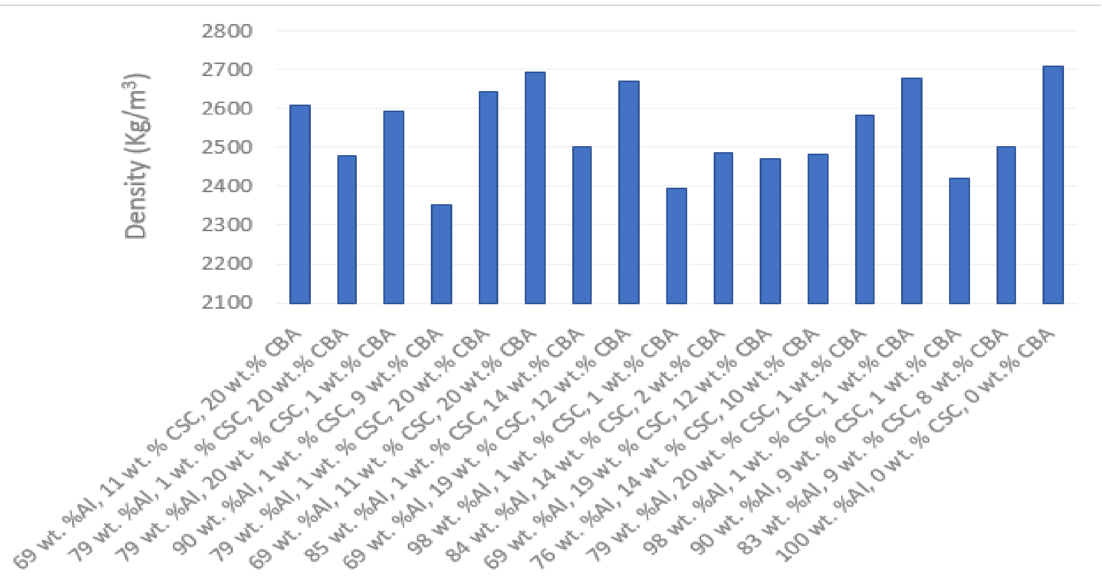

Figure 7: Graphical representation of the densities of the produced composites.

3.3 Scanning Electron Microscope (SEM) Analysis

Figures 8 to 12 show the micrography of four samples with different percentage of the coconut shell charcoal, cow bone ash and the aluminium matrix and the control sample.

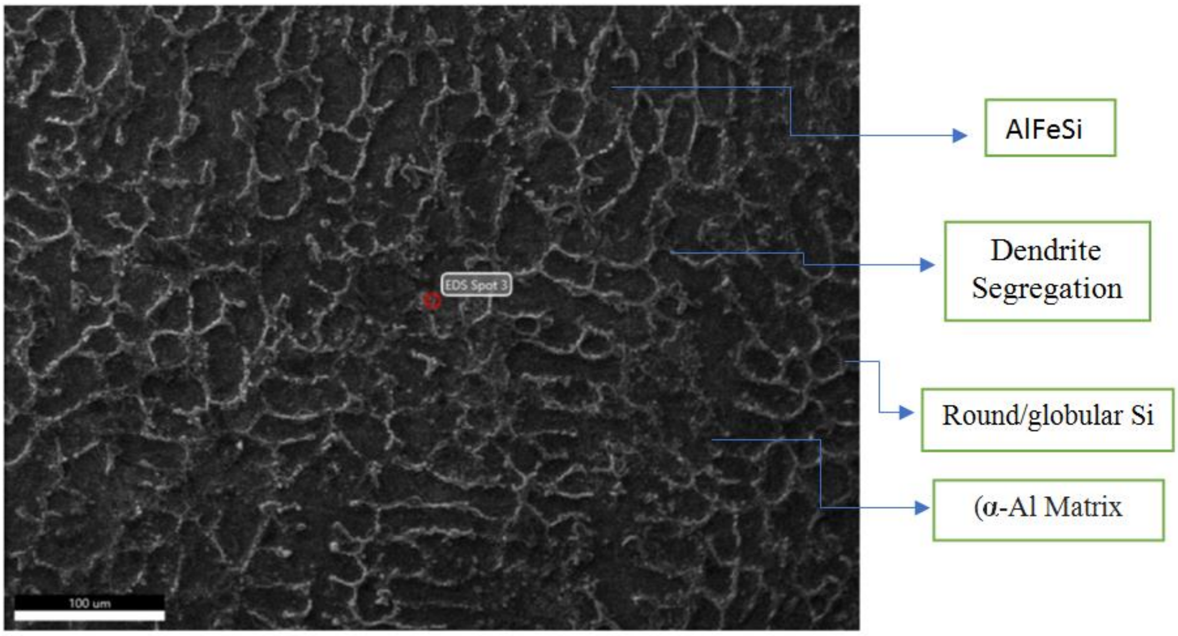

Figure 8: SEM micrography of sample four (4) (Aluminium matrix 90%, Coconut shell charcoal 1% and Cow bone ash 9%).

From figure 8, Sample four (4) has composition of Aluninium matrix of 90%, coconut shell charcoal of 1% and cow bone ash of 9%. They were thoroughly mixed together with the stirring machine and cast to get the rod like shape of which a small part was cut, grinded and polished using diamond paste and etched with 2% Sodium Hydroxide and viewed under the SEM machine. A multiphase structure with eutectic silicon crystals having some round/globular silicon with well-defined dendrite segregation was seen. The uniform distribution of coconut shell charcoal and the cow bone ash particles increased the tensile strength, hardness and the melting temperature of the material since the dislocation density of the composite has been increased by the reinforcement. The creep rate, wear index and the density were reduced.

Figure 9, Sample 12 has composition of Aluninium matrix of 76%, coconut shell charcoal of 14% and cow bone ash of 10%. The microstructure which comprises α-Al Matrix has a uniform distribution of eutectic silicon grains. The improvement in the mechanical properties of the composite material like the tensile strength and hardness was as a result of the increase in dislocation density.

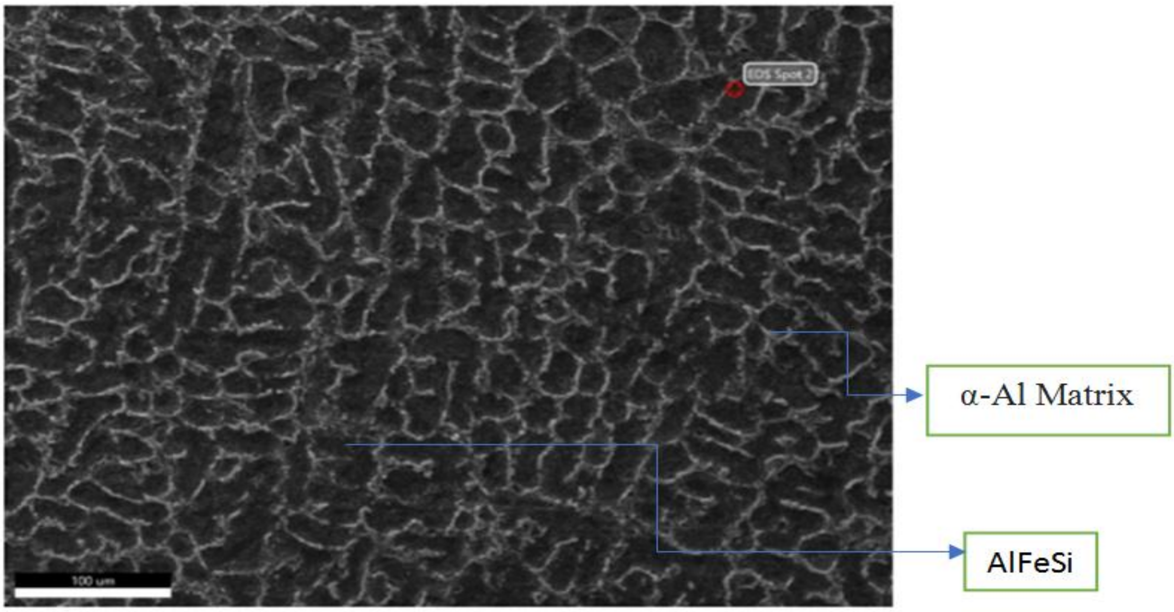

Figure 9: SEM result of sample twelve (12) (Aluminium matrix 76%, Coconut shell charcoal 14% and Cow bone ash 10%).

Figure 10, Sample 16 has aluminium matrix of 83% with coconut shell charcoal of 9% and Cow bone ash of 8%. The reinforcement particles were uniformly distributed. There were some fragmented Si that were spread all over the surface with round and globular Si.

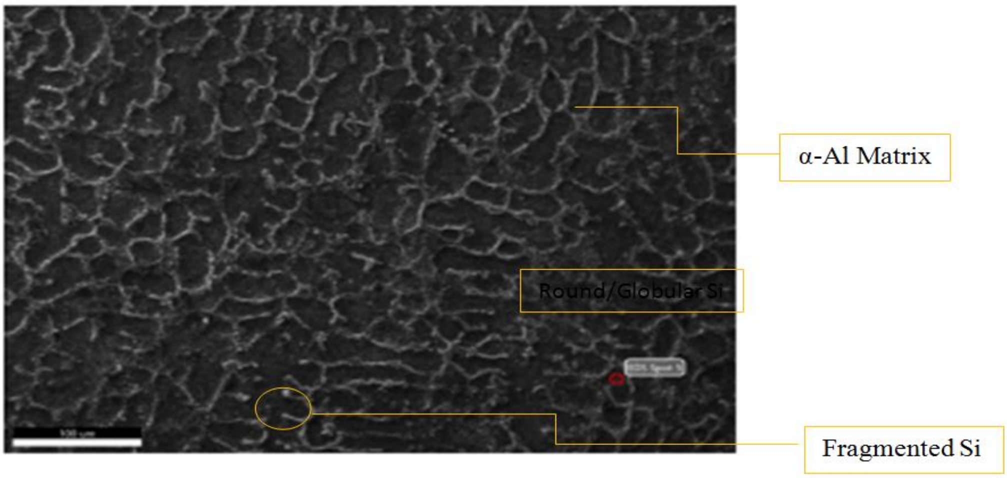

Figure 10: SEM result of sample sixteen (16) (Aluminium matrix 83%, Coconut shell charcoal 9% and Cow bone ash 8%).

Figure 11 shows the control sample which has no percentage of cow bone ash and coconut shell charcoal but only the Aluminium matrix. It has a long and round coalescence of the silicon constituent with the insoluble iron-rich phase remaining unchanged. It has some acicular flakes and fragmented Si. Its mechanical properties are not as good as other samples that have reinforcements.

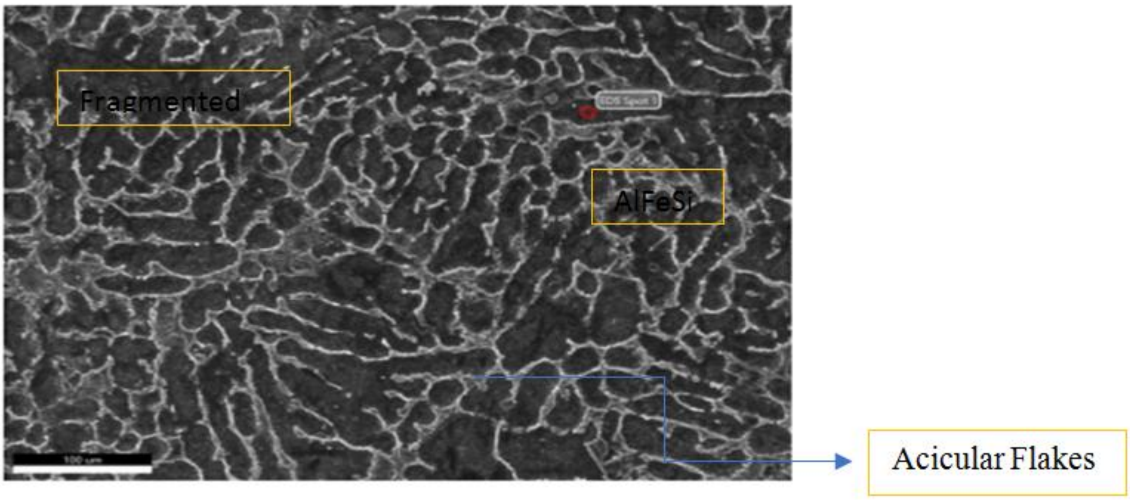

Figure 11: SEM result of sample seventeen (17) (Aluminium matrix 100%, Coconut shell charcoal 0% and Cow bone ash 0%).

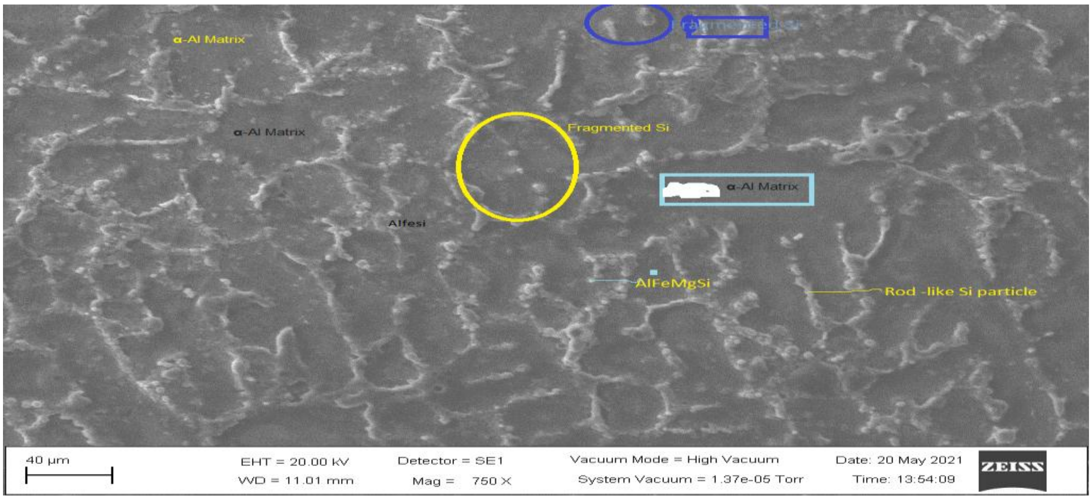

Figure 12: SEM result of the optimum sample (Aluminium matrix 81.75%, Coconut shell charcoal 8.36% and Cow bone ash 9.90%).

The optimum sample has Aluminium matrix to be 81.75% with Coconut shell charcoal of 8.36% and Cow bone ash of 9.9%. The SEM result reveals dispersed precipitate in the primary aluminium dendrite's matrix and the reinforcement particles were uniformly distributed. The proper combination of coconut shell charcoal and Cow bone ash as reinforcement on the aluminium matrix with the aid of a stirring machine gives a better mechanical and physical properties like low wear rate, low density, etc., Predominantly AlFeSi constituent is shown in the dendrite interstices. It has also fragmented Si. The optimum sample has the best mechanical and physical properties. The empty space between the particles of the aluminium matrix (Al) was agglomerated with the granules of the coconut shell charcoal (CSC) and the cow bone ash CBA) and there was a proper bonding of the Al, CSC and CBA.

4. CONCLUSION

The study shows that the reinforcement of aluminium with coconut shell charcoal and cow bone ash has reduced the density and the wear rate of the aluminium. The density and the wear rate were reduced by 13.89% and 51.45% respectively. From the SEM analysis, it was observed that the reinforcement particles were uniformly distributed. The empty space between the particles of the aluminium matrix (Al) was agglomerated with the granules of the coconut shell charcoal (CSC) and the cow bone ash CBA) and there was a proper bonding of the of the Al, CSC and CBA, hence the improvement on the properties of the aluminium.

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