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EFFECT OF MECHANICAL PROPERTIES AND WEAR BEHAVIOUR ON LOCUST BEAN WASTE ASH (LBWA) PARTICLE REINFORCED ALUMINIUM ALLOY (A356 ALLOY) COMPOSITES

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ABSTRACT
The wear and mechanical properties of aluminium alloy (Al-Si-Mg)/ locust bean waste ash particles composites developed by stir casting were studied. The composites were based on the A356 alloy reinforced with locust bean waste ash (LBWA) particles. X-ray fluorescence (XRF) analysis on the LBWA particles was carried out. The mechanical properties tested are hardness, tensile strength and impact energy while the wear behaviour of the developed composites was studied by conducting dry sliding wear test using a ball-on-disc tribometer. Results revealed that there is a high influence of reinforcement addition on the tested mechanical properties. The wear rate decreased significantly with increasing weight fraction of LBWA particles. The highest hardness, tensile strength and wear resistance are obtained with the addition of 10% wt. LBWA particles.

Keywords: Hardness, tensile strength, impact energy, reinforcement, synthesis

INTRODUCTION
Aluminium alloy based metal matrix composites, in recent times, are gaining outstanding role in several engineering applications. Among others are automotive and aerospace applications (Khan and Khan, 2016). A356 alloy has been used as the matrix material because of its good formability, mechanical and manufacturing properties (Sridhar *et al.*, 2017). Additionally, A356 alloys are ever more accepted for the aforementioned applications due to their high strength-to-weight ratio and its thixotropic structure. Its specific tensile strength and rigidity are superior to other Aluminium alloys. These qualities lead to less vehicle and aircraft weight and better fuel economy (Sridhar *et al.,* 2017; Mahanthesh, n.d). The mechanical and surface properties of the A356 alloy are enhanced by fabricating Aluminium Metal Matrix Composites (AMMCs) with ceramic reinforcements (Logesh *et al.,* 2020). In similar research works, researchers have frequently utilized Granite (Dodo *et al.,* 2018), Alumina (Al_2O_3) (Chou *et al.*, 2006; Sajjadi *et al.*, 2012), Silicon Carbide (SiC) (Miskovic *et al.*, 2006; Mazahery and Shabani, 2012a), Boron Carbide (B_4C), Carbon nanotube (Shayan and Niroumand, 2013; Kim *et al.*, 2013) and Graphite as reinforcements in A356 alloy matrix (Logesh *et al.*, 2020). All with the sole aim of developing A356 alloy based composite with low density and at low cost. However, the use of naturally sourced particulates (agro-waste) has been discovered to be a very good reinforcement constituent, owing to the availability and immensely low-cost of acquiring them. So, many researchers have worked largely on several natural wastes from agriculture, and have identified them to be rich in silicon and magnesium oxide constituents, among others (Saravanan and Kumar, 2013; Joseph and Babaremu, 2019). A few of the widely recognized agro-wastes are groundnut shell, coconut shell, corn cob ash, cow horn and bagasse. It was revealed by the authors of Bodunrin *et al.,* 2015), that some typical agricultural wastes, like bamboo leaf ash, bagasse, corn cob ash, rice husk ash, corn stalk ash and palm kernel shell ash, are repeatedly used agro-waste reinforcements for metallic matrix composites (Joseph and Babaremu, 2019). On the other hand, locust bean pod husks are waste byproducts of agricultural process of the African locust bean fruit (*Parkia biglobosa*). Its ash could be used as reinforcement for AMMCs. The pod is the material resource required for the production of locust bean waste ash (LBAW). From the extensive literature survey, it is clear that the effect of mechanical properties and wear behaviour of locust bean waste ash (LBWA) particle addition in A356 alloy has not been sufficiently explored. Therefore, the present study is aimed at the characterization of mechanical properties and wear behaviour of A356 alloy reinforced with LBWA particles.

MATERIALS AND METHODS
Locust Bean Waste Ash (LBWA) Preparation
The locust bean waste ash (LBWA) used was obtained from the burning of locust bean husks sourced from Bomo village of Zaria, Kaduna state. The husks were completely burnt under controlled atmospheric condition within a temperature range of 700 – 800°C for about 7 – 8 hours measured with a thermocouple. The ash obtained was sealed in plastic bags and transported to the laboratory. The ash was passed through British Standard No 200 sieve (75 μm aperture).

Synthesis of Aluminium Alloy Matrix Composites

The synthesis of the aluminium alloy (A356) matrix composites that was used in this research was achieved by using stir casting method at the department of Metallurgical and Materials Engineering workshop, Ahmadu Bello University, Zaria, Nigeria. The specimen was produced by varying the locust bean agro waste ash in the range of 2, 4, 6, 8 and 10 wt.%.

A356 alloys were charged in the graphite crucible on the resistance furnace. After the melting, the temperature of the furnace was raised to about 700°C for the purpose of superheating the melt. Locust bean agro waste ash particles was earlier preheated to 150°C to release volatile matters. The melt was removed from the furnace for the purpose of adding the locust bean agro waste ash particles. 2%wt of the preheated locust bean agro waste ash particles was added to the melt and mixed manually for about 5 minutes and then returned to the furnace. The temperature was controlled between 680°C and 700°C for about 3 minutes and then split mould with diameter of 20mm and 350mm length were used to produce the bars. This procedure was repeated for all samples that were produced with the addition of LBWA at various proportions from 2 to 10 wt.% at an interval of 2wt.%. The Al-Si-Mg/LBWA composite samples produced were machined to the standard dimensions for mechanical properties tests.

Tensile Strength

The tensile test was conducted using a computerized Hurston Universal Testing Machine of load capacity 100 kN. The test was conducted in accordance with ASTM D3039-76 (2000) specification. The Al-Si-Mg/LBWA composite samples with dimension 100mm x 20mm x 3mm were prepared by making the specimen gauge length with pink punch mark and measuring the cross sectional area of the reduced section.

Tensile test was carried out by gripping the end of the specimen in a tensile testing machine and applying a load on to the specimen till it fractures. During the test, the tensile load as well as the elongation of a previously marked gauge length in the specimen were measured with the help of load dial of the machine and extensometer respectively. These readings help plot stress- strain curve. After fracture, the two pieces of the broken specimen were placed as if fixed together and the distance between two gauge marks and the area at the place of fracture were noted.

Hardness

The hardness test was carried out by using the Rockwell hardness machine (Model PR-21 Durometer) in accordance with ASTM D2483 (2000) using 1.56mm steel ball indenter, minor load of 10kgf, major load of 100kgf and hardness value of 101.2HRB as the standard bloc. The sample has a dimension of 10mm x 3mm. Before the test, the mating surface of the indenter, plunger rod and test samples were thoroughly cleaned by removing dirt, scratches and oil. The samples were placed on the anvil, which act as a support for the test samples. A minor load of 10kgf was applied to the sample in a controlled manner without inducing impact or vibration and zero datum position was established, and then major load of 100kgf was then applied. The reading was taken when the large pointer came to rest or had slowed appreciably and dwelled for up to 2 seconds. The load was then removed by returning the crack handle to the latched position and the hardness value read directly from the digital scale.

Impact Strength Determination

The impact strength test of the Al-Si-Mg/LBWA composites samples was conducted using Avery Denison impact testing machine. A charpy impact energy test was carried out on the notched samples. Standard square impact test sample measuring 75mm x 10mm x 10mm with notch depth of 2mm and a notch tip radius of 0.02mm at an angle of 45° in accordance with ASTM (2000) was used. Before the test, sample was mounted on the machine; the pendulum was released to calibrate the machine. The test samples were then gripped horizontally in a vice and the freely swinging pendulum provided the force required to break the bar. The value of the angle through which the pendulum swung before the test sample got broken correspond with the value of the energy absorbed in breaking the sample and then read from the calibrated scale on the machine (Usman *et al.,* 2020).

Wear analysis

A ball-on-disk tribometer (Anton Paar Gmbh Tribometer, TRN; SN: 10000162991, Switzerland) facilitated the dry-wear tests at room temperature according to ASTM G99-95 standards. Wear test specimen disc of diameter 25 mm and thickness 5 mm were machined from each of the composites. During testing, a stainless-steel ball presses against the surface of the specimen placed on the rotary disk. The tests used an applied load of 5N at 153 rev/min wheel speed and a dwell time of 3.26 minutes. The sliding speed used was 2m/s. Finally, wear rate data have been generated for the composites (Usman *et al.,* 2020).

RESULTS AND DISCUSSION

The chemical analysis of the locust bean waste ash (LBWA) was carried out by X-ray fluorescent (XRF). The result obtained is given in Table 1.

Table 1: Composition of LBWA (wt. %) using XRF

CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	Na_2O	K_2O	P_2O_5	LOI
1.08	55.38	14.98	0.28	0.09	0.18	2	0.23	10.63

The analysis confirmed that SiO_2, Al_2O_3, K_2O, CaO and Fe_2O_3 were found to be major constituents of the ash. Silica, iron oxide and alumina are known to be among the hardest substances. Other oxides viz. Na_2O, MgO, k_2O and P_2O_5 were also found to be present. The presence of hard compounds like SiO_2, Al_2O_3, K_2O, CaO and Fe_2O_3 suggested that the LBWA can be used as particulate reinforcement in various metal matrixes. Therefore, the present work suggests the possibility of LBWA as particulate in metal matrix composite since the chemical composition has similarity with the XRF analysis of rice husk ash, fly ash and bagasse ash currently used in metal matrix composite (Abdulwahab *et al*., 2017; Siddharth *et al.*, 2017; Oghenevweta *et al.*, 2016; Saravanan *et al.*, 2014 and Aigbodion, 2010). The result obtained from XRF analysis indicated that (SiO_2) has the highest percentage composition followed by (Al_2O_3) while (Na_2O) is the least.

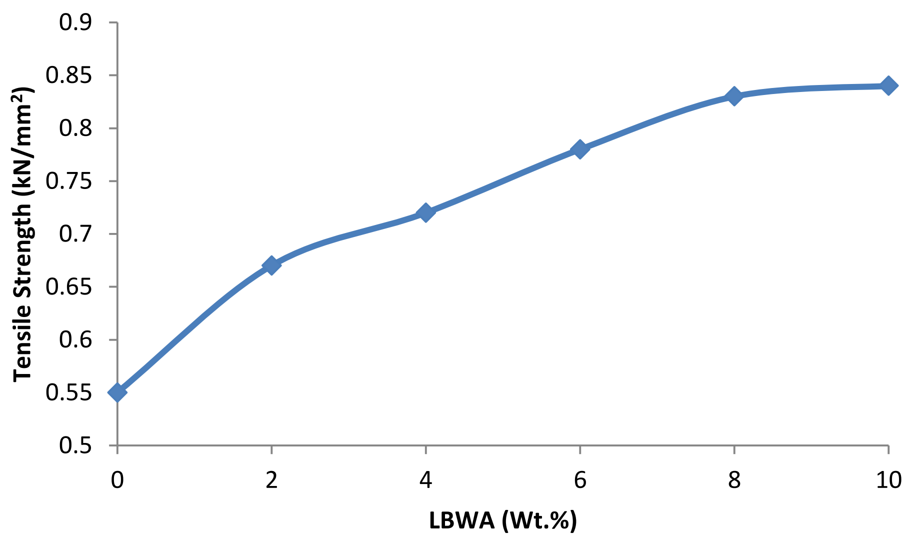

Fig. 1: Tensile strength value of Al-Si-Mg/LBWA composite at various compositions of LBWA (wt.%)

It is clear from Figure 1 that there is a quite significant improvement in tensile strength when LBWA particles are added to the Al-Si-Mg alloy. The strength reaches a peak value at 10 wt% reinforcement. It is believed that the progressive enhancement in tensile strength observed in these composites is due to good distribution of the LBWA particles and low degree of porosity, which leads to effective transfer of applied tensile load to the uniformly distributed strong LBWA particles (Mazahery and Shabani 2012b; Zhao *et al.*, 2008; Habibnejad-Korayema *et al.*, 2009).

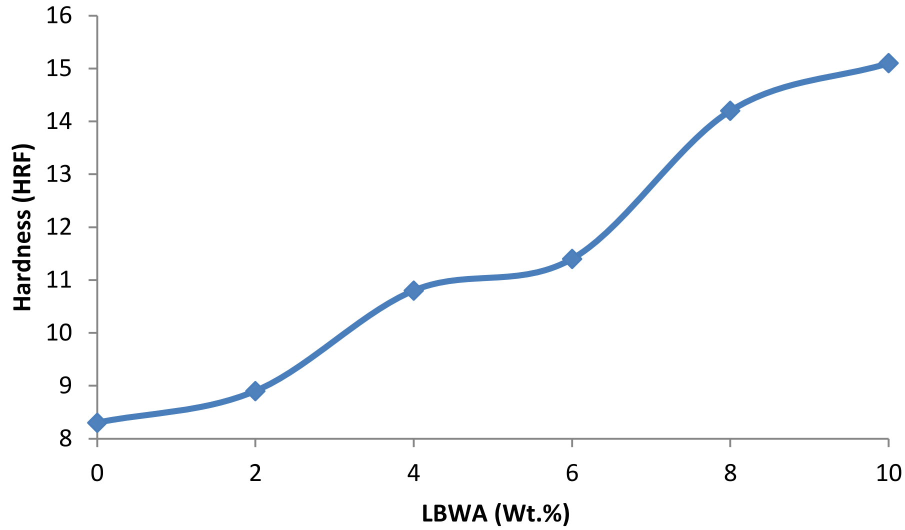

Fig. 2: Variation of hardness as function of addition of LBWA particulates

It is noted from Figure 2 that hardness of the composites is significantly higher than that of the non-reinforced alloy. The enhancement in the hardness of the composites could be connected to the fact that LBWA particles act as obstacles to the dislocation movement. As noticed, hardness increases with the addition of LBWA particles. It is believed that since LBWA particles are harder than aluminum alloy, more filler addition resulted in higher hardness property (Mazahery and Shabani 2012b; Mondal *et al.*, 2006).

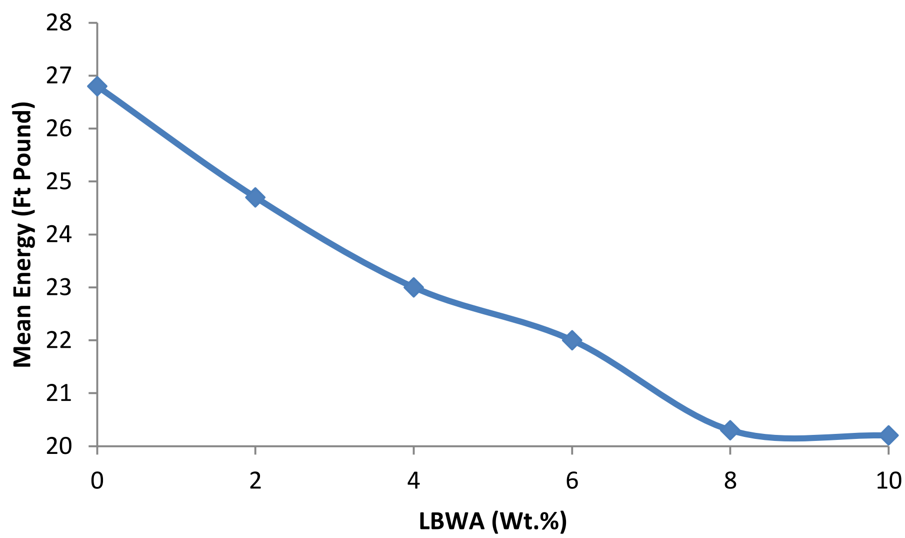

Fig. 3: Impact Energy value of Al-Si-Mg/LBWA composite at various compositions of LBWA (wt.%)

It is deduced from Figure 3 that the added LBWA particles reduce the impact energy of the alloy markedly. Perhaps, addition of LBWA particles creates different interfaces between the filler particles and the matrix. Thus crack initiation and propagation results. This accounted for the sharp decrease in impact energy with the reinforcement addition. Similar occurrence has been reported (Dodo *et al.*, 2018).

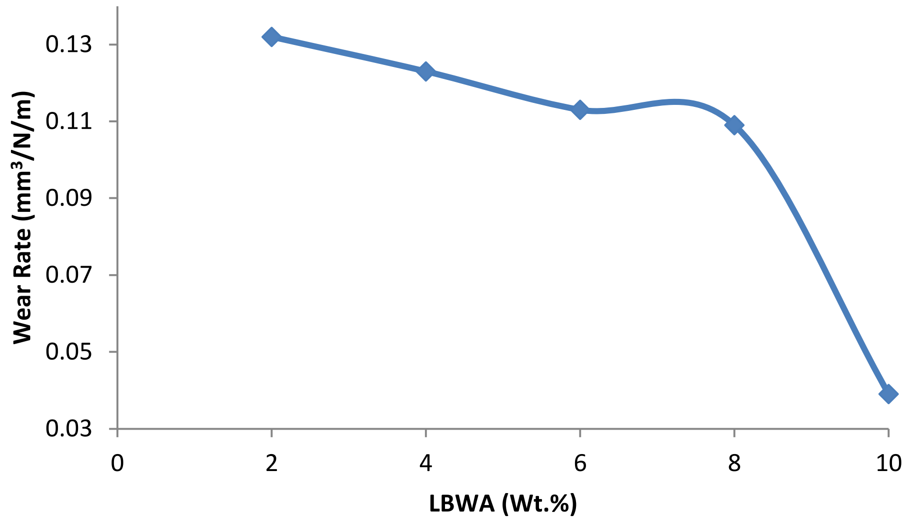

Fig. 4: Wear rate of Al-Si-Mg/LBWA composite at various compositions of LBWA (wt.%)

The beneficial effect of the reinforcement on the wear resistance of the Al-Si-Mg alloy composites is noted to be the best at high LBWA particles additions. With higher LBWA loading, occurrence of plastic deformation becomes difficult. Consequently, developed Al-Si-Mg/LBWA composites exhibit low wear rate. This is similar to the results of (Apasi *et al.*, 2012).

CONCLUSIONS

From the above results and discussion, the following conclusions are made:

LBWA particles are successfully incorporated into the A356 alloy matrix. The addition of LBWA particles results in substantial increase in hardness and tensile strength of the composites. The obtained results could be linked to the strengthening mechanisms such as mismatch between the LBWA particles and matrix, the load bearing effects, etc. Additionally, impact energy of the developed composites sharply decreases with the LBWA particles loading. Similarly, incorporation of the LBWA particles in the Al-Si-Mg alloy matrix led to a marked improvement in the wear resistance of the alloy. It is noticed that the dry sliding wear resistance of the Al-Si-Mg/10wt.% LBWA composite is more than 3.3 times higher than that for the base alloy and gives the best wear resistance.

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