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ORIGINAL ARTICLE

Influence of sawdust ash on the microstructural and physicomechanical properties of stir-cast Al6063/SDA matrix composite

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Abstract
Mechanical, physical, and corrosion properties of pure aluminum cannot meet the requirements of the modern industries. This has led to increase in demand for aluminum alloys and aluminum matrix composites with enhanced properties. These properties make them suitable for most applications. This article analyzes the physicomechanical and microstructural properties of stir cast Al6063 alloy matrix reinforced with different weight fractions (2, 4, and 6 wt.%) of sawdust ash (SDA). The density, porosity, hardness, tensile strength, and impact strength of the unreinforced alloy and developed composite samples were evaluated while microstructural analysis was also carried out. The results showed reduced density values with increased SDA contents while percentage porosity ranged between 1.56 and 2.23%. The hardness (88.3–106.93 BHN) and tensile strength (112.13–132.71 MPa) of the composites were 21.09% and 18.35% better than those of Al6063 alloy. However, the impact strengths (45.48–35.51 J) of the composites were lower when compared to the unreinforced Al6063 alloy with a reduction of 21.92%. Microstructural images showed evenly distributed reinforcement particles within the matrix, while the XRD analysis also revealed the presence of different intermetallic phases in the composite samples. The micrographs of the composites showed plastic deformation during straining. The findings from the study indicate that SDA particulates incorporated into alloy matrix influenced the properties with increased hardness and tensile strength and reduced impact strength. Hence, the aluminum matrix composites will be suitable for use in lightweight engineering applications.

Keywords Metal matrix composites · Waste materials · Sawdust ash · Al6063 alloy · Stir casting

1 Introduction

Composites are poly-phase materials that consist of matrix and reinforcement, which were developed to fulfil the demand of modern-day engineering construction based on their thermal properties and good mechanical characteristics which include higher strength, hardness fracture, toughness, and higher resistance to wear and corrosion [1]. Metal matrix composites (MMCs) consist of a metal matrix as the base material along with the reinforcement materials. There has been an increased demand for MMCs in the automobile, marine, and aerospace industries due to their enhanced properties such as wear resistance, toughness, lightweight, and density compared with their based alloys [2–5]. Researchers in recent years have focused more on aluminum matrix composites [6–10].

Aluminum alloys are the predominant nonferrous metal used in various applications due to their properties such as good strength to weight ratio, corrosion resistance, and heat and electric conductivity [1, 11]. Over the years, aluminum alloy has had many improvements as a result of vast research work done on it to form aluminum matrix composites. These researches have been carried out with the sole aim of improving its properties to the required material properties to meet the need of modern engineering products and industries.

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These products require materials with high strength, good wear resistance, and high elastic modulus among others. Thus, the necessity for further research efforts to develop more aluminum matrix composite (AMC) [12, 13].

Several methods of fabricating AMCs are available [11]. However, stir casting process was used to develop a reinforced matrix composite in this study. Stir casting procedure is one of the most commonly used techniques in the fabrication of metal matrix composites and most especially aluminum matrix composites [2]. The stir casting technique allows for uniform distribution and dispersion of the reinforcement particles with the matrix material, thereby granting the resulting composite good wettability and reactivity [13, 14].

Various researchers have reinforced aluminum matrix composites by different reinforcement materials. These include graphene [15], titanium oxide [16], aluminum oxides [17], silicon dioxide [18], boron carbide [19], silicon carbide [20, 21], titanium di-boride [22], and so on. Murugan et al. [23] noticed that the addition of silicon carbide (20 wt.%) to Al6061 alloy increased the tensile strength of the base material. Avinash and Ganesh [24] also reported that the addition of 5 wt.% silicon carbide to Al6061 lowered the wear rate of the metal matrix. The results from an experiment carried out by Rahman and Rashed [25] showed that the introduction of SiC (20 wt.%) in aluminum matrix increased its hardness and tensile strength. Hence, this implied that the improvement of the properties of matrix alloy is dependent on the reinforcement particulates introduced into the alloy for composite development. Petrovic et al. [26] investigated the microstructural and mechanical properties of MMCs produced using aluminum alloy EN AW 6061 reinforced with hybrid materials of Al_2O_3 (5 wt.%) and walnut-shell ash (WSA) (1, 2, and 3 wt.%) particulates. The composite materials developed showed improved mechanical properties compared to the unreinforced alloy. This was evident with the hardness and tensile strength increase with an increase in the amount of WSA while there was reduction in the elongation. There was homogeneous distribution of the hybrid reinforcement particulates of Al_2O_3 and WSA in the matrix alloy. Singh and Goyal [27] examined the effect of hybridization of the particulates of B_4C and SiC at different volume ratios on AA6082-T6 alloy and reported superior hardness and tensile strength with increase in the weight percentage of the hybrid reinforcements. However, at 20 wt.% of SiC and B_4C, the hardness and tensile strength witnessed some reductions. It was also reported that the percentage elongation, impact strength, and density decreased with increased volume of reinforcement. In a study by Surya and Gugulothu [28], it was reported that noticeable improved mechanical properties were observed when 15% SiC was used in the development of the MMCs using Al7075 as matrix compared to the 5 and 10% SiC composite samples. Even distribution of the particulates was observed with good interfacial matrix-reinforcement bonding.

However, the high cost of synthetic ceramic reinforcements has made researchers search for alternative reinforcement materials in the production of aluminum matrix composites. For this reason, attention has been turned to the utilization of biomass and industrial wastes and their derivatives, which have been considered environmental wastes. These are readily available and can be used as cheap reinforcement material for aluminum alloy. Rice husk was used by Saravanan and Senthil [29] to reinforce an aluminum alloy. The results reveal that increase in the percentage reinforcement of RHA increased the ultimate tensile strength, compressive strength, and hardness of the composite. Kulkarni et al. [30] reinforced aluminum 356 alloy with fly ash. In the work, various mechanical characterizations like tensile, compressive, and hardness of AMCs manufactured by stir casting method were studied. The results showed that in the hybrid composite, superior properties were observed for comparatively lower densities. Hybrid reinforced Al6063 composite was synthesized with palm kernel shell ash (PKSA) and SiC at different percentage variations and the resulting composites from the experiment showcased increased hardness and tensile strength [5]. Bamboo leaf ash (BLA), at weight ratios 2, 4, and 6%, served as the reinforcing particulates in the fabrication of MMCs with Al-4.5% Cu alloy as the matrix. The stir casting method was utilized for the processing of the composites. The micrograph of the sample showed the homogeneous dispersion of BLA particulates with intra-granularity of the BLA in the matrix. To obtain a lightweight sample with BLA addition, the density of the composite reduced with the BLA increase. The hardness and tensile strength were improved up to 4% BLA addition. However, BLA increase beyond the 4% content caused the hardness and tensile strength values to decline [31]. The effects of bean pod ash (BPA) as reinforcement in A2009 aluminum alloy were investigated by Kumar and Birru [32]. In the study, the mechanical properties (hardness and tensile strength) improved with the addition of the BPA particles. However, the BPA addition gradually reduced the impact energy of the composites. BPA was said to be a promising reinforcement for bio-composite development. Kanth et al. [21] analyzed the effect of fly ash/SiC particle reinforcement on Al-Zn-alloy based composite. Results from the analysis showed that the addition of fly ash in the composite results in grain refinement. The addition of fly ash also increased the hardness and tensile strength of material according to the experimental results.

Several researchers have developed different aluminum hybrid matrix composites which are being used across the globe, though, new research works are still ongoing to discover more suitable compositions or reinforcement

Table 1 Chemical composition of Al6063 alloy

Al (wt.%)	Mg (wt.%)	Si (wt.%)	Fe (wt.%)	Mn (wt.%)	Ti (wt.%)	Cu (wt.%)	Cr (wt.%)	Ca (wt.%)	Zn (wt.%)
98.251	0.7832	0.5630	0.3238	0.0232	0.0078	0.0041	0.0024	0.0003	0.0001

Table 2 Chemical composition (%) of the sawdust ash (SDA)

Oxides	SiO_2	CaO	Al_2O_3	Na_2O	P_2O_5	K_2O	MgO	TiO_2	Fe_2O_3	MnO	SO_3	LOI
%	65.31	9.98	6.08	0.95	0.56	0.64	5.78	0.99	3.27	0.01	2.83	3.60

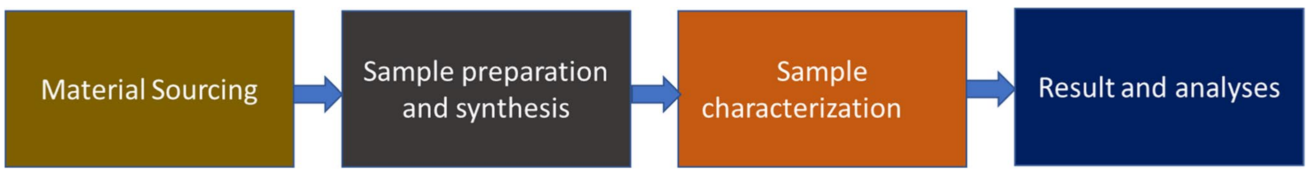


Fig. 1 Schematic diagram of the experimental procedure

materials. However, little or no research work has been carried out on the effect of saw dust ash as a monolithic reinforcing particulate in aluminum matrix alloy for AMCs synthesis. Therefore, in this study, metal matrix composites with *Tectona grandis* sawdust ash (SDA) as reinforcement particulates are synthesized for the foremost time using stir-casting technique. This study investigated the microstructural and physicomechanical properties of stir-cast Al6063 alloy matrix composite reinforced with the sawdust ash of *Tectona grandis*.

2 Materials and methods

2.1 Materials

The Al6063 alloy used as the matrix material for this research work was purchased in Akure, Nigeria. The chemical composition of the alloy is presented in Table 1. The Al6063 alloy was cut into pieces for them to fit into the crucible and weighed using an electronic weighing balance prior to charging into the furnace. The reinforcement material used to produce the aluminum matrix composite was sawdust from teak wood (*Tectona grandis*) (SDA). Sawdust of teak wood (*Tectona grandis*) was obtained from a local sawmill in Akure, Ondo State. The sawdust was ashed in a furnace at 600 °C for 4 h. The ash was then sieved to a particle size less than 40 µm to help the homogeneity of the composite. Table 2 displays the chemical oxides present in the SDA.

2.2 Method of synthesizing the composite

The metal matrix composite was produced through stir casting method. Figure 1 shows the flowchart of the synthesizing processes. The volume fraction of the SDA contents used for the reinforcement in the Al6063 matrix was 2, 4, and 6 wt.%, as shown in Table 3. A method used by Ikubanni et al. [5] was utilized in this study, where the Al6063 alloy was placed in a furnace for 2 h and fired to a temperature above its liquidus (> 750 °C) to ensure complete melting. The sawdust ash was preheated to 250 °C simultaneously to get rid of impurities and possible moisture in the materials and to also improve its wettability with the Al6063 matrix. The molten matrix obtained was then permitted to cool down to a semi-solid state in the furnace before charging the preheated reinforcement material into it at a pre-determined volume percentage. The preheated sawdust ash was fed into the crucible containing the matrix material by a feeder and then the slurry was stirred for 5–10 min to attain uniform distribution of the reinforcement particles throughout the mixture. Then, slurry was then superheated to about 800 °C. The melt was then poured

Table 3 Composite sample designation

Sample designation	Composition
A0	Al6063 alloy
A1	Al6063 alloy + 2 wt.% SDA
A2	Al6063 alloy + 4 wt.% SDA
A3	Al6063 alloy + 6 wt.% SDA

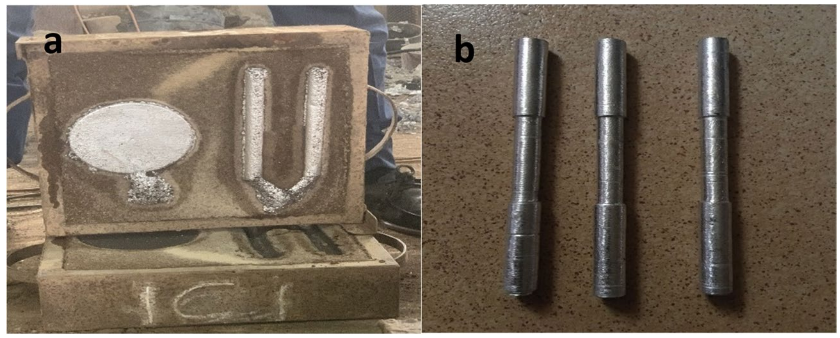


Fig. 2 **a** Solidified metal composite. **b** Machined metal composite

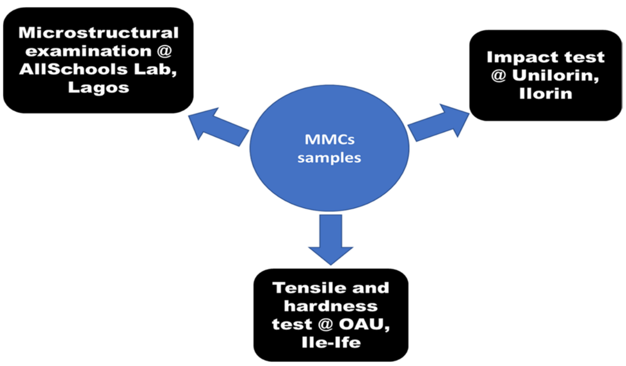


Fig. 3 Schematic diagram for sample and its experimental location

into a prepared mold until it solidified. Figure 2 shows the solidified composite in the mold box and the composite after machining. Figure 3 displays the schematic diagram of the locations where experiments such as tensile, hardness, impact, and microstructural analyses were carried out.

2.3 Microstructural characterization and X-ray diffraction

To obtain the surface morphology of the composite, samples were coated with platinum coating of electrically conducting material by low-vacuum sputter coating deposition. Scanning electron microscopy (Vega 3 Tescan model) was utilized in obtaining the morphological structure of the developed samples. Samples were cut from the machined rods obtained after production of the composites. To obtain a shining surface preferred for morphological examination, grinding and polishing the surface of the samples were done with the aid of different grits of emery paper and polishing clothes. The scanning electron microscope was loaded with the samples for the examination.

For the X-ray diffraction, samples were run through the Rigaku D/Max-lllC X-ray diffractometer developed by the Rigaku Int. Corp. Tokyo, Japan and set to produce diffractions at a scanning rate of 0.026°/min in the 5 to 90° at room temperature with a Cu-Kα radiation set at 40 kV and 20 mA. The diffraction data (*d* value and relative intensity) obtained was compared to that of the standard data of minerals from the mineral powder diffraction file, ICDD which contained and includes the standard data of more than 3000 minerals. Similar diffraction data means the same minerals as standard minerals which exist in the sample.

2.4 Physical properties test

2.4.1 Density

The density of the specimen was determined by weighing the specimen in air (m) and weighing it in distilled water (m_1) while the difference in water was noted according to Saba et al. [33]. The parameters gotten were inputted into Eq. 1 to determine the density of the composite (ρ_c).

$$\rho_c = \frac{m}{m - m_1}\rho_w \tag{1}$$

where ρ_c, m, m_1, and ρ_w are composite density, mass of sample in air, mass of sample in distilled water, and distilled water density (1000 kg/m^3), respectively.

2.4.2 Porosity determination

The method used by Prasad et al. [34] was adopted to determine the porosity of the samples by using Eqs. 2 and 3.

$$porosity = \frac{\rho_{th} - \rho_m}{\rho_{th}} \tag{2}$$

ρ_{th} is the theoretical density and ρ_m is the measured density (in kg/m^3).

$$\rho_{th} = \rho_{Al}V_{Al} + \rho_{BA}V_{BA} \tag{3}$$

where ρ_{Al}andρ_{BA} are the densities of the aluminum matrix and biomass ash, respectively.

2.5 Mechanical tests

The mechanical properties of the composite material were obtained through series of tests on the material. The essence of measuring the mechanical properties of the material is to determine its suitability for different applications.

2.5.1 Hardness test

The hardness test was carried out on the samples according to the ASTM E10-18 standard using the Brinell hardness machine. A hard spherical indenter was forced into the surface of the metal. The diameter of the hardened steel (or tungsten carbide) indenter was 10.00 mm with a constant load of 500 kg for a 10 s dwelling time. Five indents were made on surface of each sample. The diameter of the indentation left in the surface of the material was measured and a Brinell hardness number was calculated from the average value of the indented diameters.

2.5.2 Tensile test

Tensile strength testing of all specimens was conducted based on ASTM E8 standard. Three identical test specimens for each section thickness per sample were tested at room temperature at a strain/loading rate of 10^{-3}/s using a computerized Instron Testing Machine (model 3369). Load displacement plots were obtained on an X–Y recorder and ultimate tensile strength, yield strength, and percentage elongation values were calculated from the load-displacement diagrams. The test was done in triplicate on the samples of each composition for reproducibility and reliability of the results.

2.5.3 Impact test

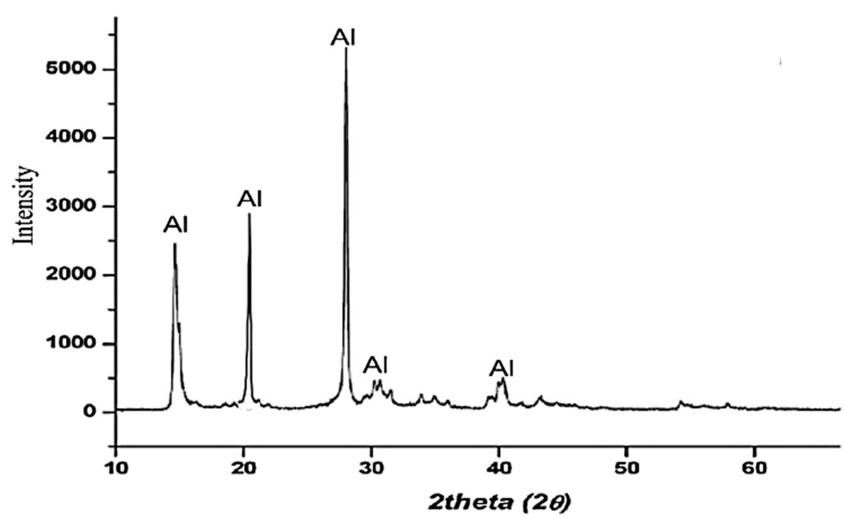
The impact test was carried out using the Hounsfield balanced impact machine (Model No:4562). The sample was turned down to a 5/16 in. diameter and held in the chuck. The Hounsfield impact machine struck the specimen, which was held in a spring-forced wedge to secure the steel, with its pendulum arms allowing energy to transfer to the specimen and causing failure. The test was done in triplicate on the samples of each composition for reproducibility and reliability of the results.

3 Results and discussion

3.1 X-ray diffraction of the composites

The XRD patterns displaying the various phases present in the aluminum matrix composites for the samples are in Figs. 4, 5, and 6. In Fig. 4, it can be observed that the phases present are that of an aluminum cubic crystal system with only aluminum phases and peaks. This may be attributed to the fact that the reinforcement particle addition in the matrix alloy is still in very minute quantity, thereby not producing any significant phase peaks to be noticed or detected. However, in Fig. 5, the presence of new phase peaks was noticed and they correspond to the composition of both the matrix and reinforcement. The new phase peaks observed were that of Fe, Si, and Ti, which were strongly related to the presence of the sawdust ash (Table 2). An additional phase of Ca, with those observed in Fig. 5, was present in the XRD spectrum of the sample reinforced with 6 wt.% SDA (Fig. 6). It can be observed that the diffraction peaks appear in a pattern that corresponds to a phase of a good crystalline structure and support the fact that there was a proper mixing of the sawdust ash within the matrix. Overall, the XRD analysis shows the absence of any significant reactive compounds such as Al_4C_3, which are constituents that can be detrimental to the mechanical properties of the composite by causing segregation of the

Fig. 4 X-ray diffraction of 2% SDA reinforced composite



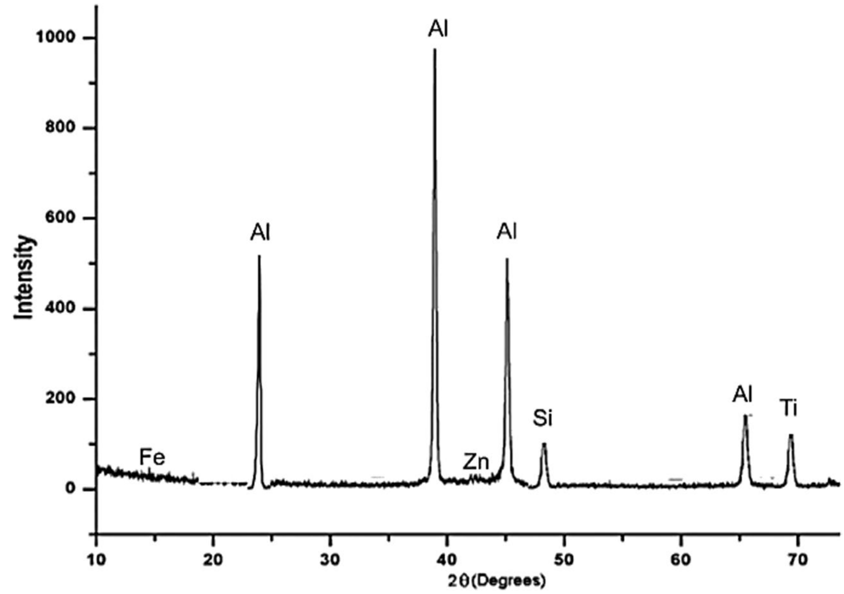


Fig. 5 X-ray diffraction of 4% SDA reinforced composite

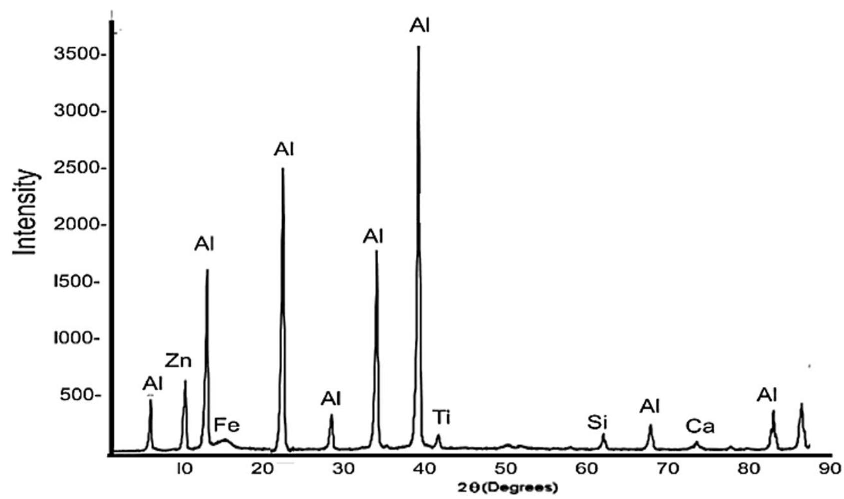


Fig. 6 X-ray diffraction of 6% SDA reinforced composite

particulates and increase the corrosion sensitivity of the composite [35]. No major carbide phases were noticed in the composite which indicated that there was no chemical interaction between the matrix and the reinforcements according to Devadiga et al. [36]. Although Lloyd [37] reported that interfacial reactions were observed to occur at temperature greater than 750 °C, but this was not the case in this present study. Based on the results presented in Figs. 4, 5, and 6, no intermetallic compounds were observed owing to the non-chemical interaction of the SDA particles with aluminum. This can be attributed to the clean interface between the aluminum matrix and the SDA particles, if not the reaction products will accumulate at the surface and inhibit load transfer mechanism during tensile loading [38].

3.2 Microstructural characterization of the composites

Figure 7a–c shows the SEM surface morphologies of produced reinforced composites. From the SEM micrographs, clear understanding of the phase distribution of the Al6063/sawdust ash composite was obtained. The reinforcements present in the composite were uniformly dispersed in the matrix as it can be observed from the SEM micrographs. The stir casting technique used to produce the composites showed a great impact in the improvement of the Al6063 matrix composites as homogeneous dispersion of particulate reinforcement within the matrix was observed. In light of the effective interfacial interaction and homogenization between the matrix and the reinforcement,

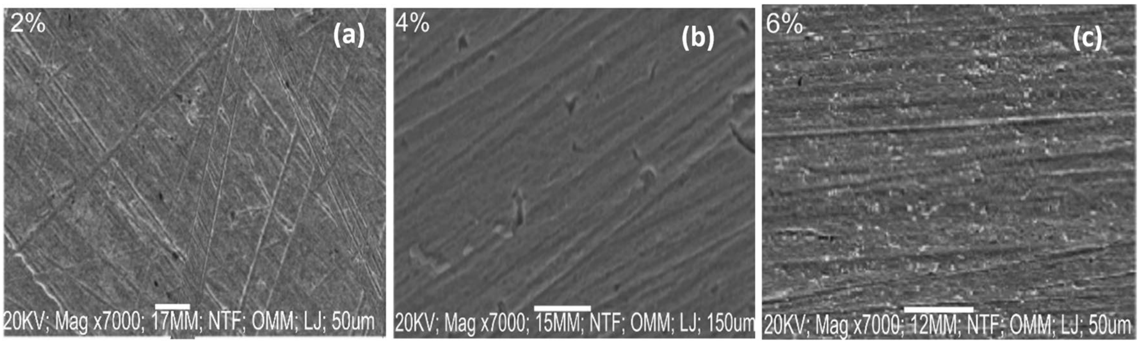


Fig. 7 SEM of composites with **a** 2 wt.% SDA, **b** 4 wt.% SDA, and **c** 6 wt.% SDA

Table 4 Density and porosity value of the fabricated aluminum matrix composites

Samples	Theoretical density (g/cm^3)	Experimental density (g/cm^3)	Porosity (%)
A0	2.700	2.658	1.55
A1	2.663	2.607	2.09
A2	2.676	2.566	2.28
A3	2.589	2.539	1.91

there was absence of any enlarged cavities and crack. This can be attributed to the stir casting route used to fabricate the composite as it allowed for proper dispersion as well as escape of any trapped gas bubbles to prevent pores and cavities. This observation agrees with the result of Ikubanni et al. [5] when SiC and palm kernel shell ash were used as reinforcement materials in Al6063 matrix, and the result of Daramola et al. [39] when coconut shell ash was used to reinforce Al6063. Alaneme and Bodunrin [40] also reinforced Al6063 with alumina and reported absence of pores, proper dispersion, and no crack formation due to the efficient stir casting technique route utilized for the fabrication of their composite. The clear SEM images coupled with the low porosity values of the samples ascertain that the stir casting technique is a reliable route for producing good quality composites.

3.3 Influence of SDA on the physical properties

Table 4 shows the values of the experimental densities, theoretical densities, and percentage porosity of the produced samples. The unreinforced Al6063 matrix had a density of 2.66 g/cm^3 which is 4.46% higher than the composite reinforced with 6 wt.% SDA having a density of 2.54 g/cm^3. It can also be observed that there is a little difference in the values of the theoretical and experimental densities of the composite. It was observed that increment in the SDA particles led to reduction in the densities of the aluminum matrix composite. This may be due to the lower density of the biomass ash particles used as reinforcement compared with the density of Al6063 matrix. However, this lower density enhances the homogeneity of the composite and thus there was no significant rise in the porosity level of the composites. The particle size of the SDA reinforcement used in the development of the composites is a pointer to proper homogeneity of the particles of the reinforcement in the matrix composite. The reduced density makes the composites suitable for lightweight applications and further buttresses that stir casting is a reliable method for the production of aluminum matrix composites. In a similar work by Subrahmanyam et al. [41], it was observed that by reinforcing Al2024 with fly ash particles, the density values dropped with increasing fly ash particles. This result was also consistent with findings by Sharma and Akhai [42] where the density of the aluminum fly ash composite reduced with increased quantity of fly ash particles in the composite, and consequently reducing the weight when compared with the aluminum matrix metal.

The variations in experimental densities and theoretical densities were majorly caused by voids and pores which indicate some level of porosity in the composite [43]. The porosity percentage was within the range of 1.55–2.30%, which is within the acceptable range (4%) of porosity percentage for metal matrix composites as reported in several literatures by Alaneme and Sanusi [44] and Ikubanni et al. [5]. These authors reported the maximum permissible porosity percentage in cast metal matrix composites to be 4%. This low porosity percentage can be attributed to the route used in the production of the composite, which allowed for the escape of gas bubbles and preventing trapped air bubbles and cavities in the composite. It also reduces the surface tension between the Al6063 melt and the particles to facilitate better wetting and mixing of the SDA particles in the melt. High porosity reduces the strength of the composite and depletes other mechanical properties [45].

3.4 Mechanical properties of the composites

3.4.1 Impact of SDA on the hardness of the properties

Figure 8 shows the hardness values of the Al6063 matrix and the fabricated aluminum matrix composites. The hardness values were observed to increase with an increasing percentage of saw dust ash particle additions. This may be due to the presence of hard phase and strengtheners of the saw dust ash particles in the ductile matrix. According to Saravanan and Senthil [29], the hardening behavior of composite is affected by the addition of reinforcements into the base matrix. It is thought that the higher the amount of the ceramic particles in the matrix, the higher the density of the dislocation, this in turn helps to increase the hardness of the composite. This is similar to the observation Jagdeep et al. [46], where groundnut shell ash (GSA) was utilized as the reinforcement in Al6063. It was reported that increase in the weight percentage of the GSA led to increase in the hardness value of the composite. The increase in hardness can also be attributed to the increasing reinforcement surface area and matrix grain size reduction as a result of addition of reinforcement particles. Also, the resistance to indentation of Al6063 improved according to a work by Daramola et al. [39] where it was observed that the addition of coconut shell ash (CSA) increased the hardness values of the aluminum matrix composites. The increase in hardness value from the unreinforced Al6063 to the reinforced matrix with 12 wt.% of CSA was about 11.3% which was attributed to cold rolling and heat treatment and to the stoichiometry ratio of SiO_2 to Al_2O_3. In general, it is expected that the hardness of a single or hybrid reinforced composite are higher than that of the unreinforced Al6063 matrix due to the presence of reinforcements which improved the hardness of the composites [47]. The results from this present study indicate that the produced metal matrix composites are suitable for lightweight applications where there is need for mild hardness.

3.4.2 SDA influence on the tensile strength

Figure 9a displayed the stress–strain plot for some of the samples. It can be observed that the reinforced alloys have similar graph patterns. According to Aigbodion and Ezema [10], brittleness is a general occurrence in cast composites which has direct linkage with premature failure at optimum strength attainment. This phenomenon was not observed in this study. This could be attributed to the fine grain size and grain boundary which suffers pinning leading to high dissolution density of the composites. The free dislocation movement restriction within the grain boundary is generated by the high dislocation density; thus, it raises the material strength [10]. The tensile strength and fractured tensile samples of the fabricated aluminum matrix composites are presented in Fig. 9b and c. The tensile strength follows the trend observed in the hardness values of the reinforced composites. Both properties were observed to increase as the quantity of the sawdust ash particles increased in the matrix. The increase in this property can be attributed to the strong particle and matrix bonding interaction resulting from the uniform dispersion and distribution of biomass ash particles within the Al6063 matrix. It can also be attributed to the hard nature of the biomass ash particles which were reinforced into the A16063 matrix [48]. This is owing to the number and the total surface area of SDA particles increased with increasing weight percentage of the SDA particles. According to Ashish et al. [49], the tensile strength of aluminum was improved by the addition of alumina and fly ash as reinforcements. The reason for the improvement was reported to be linked to the interfacial gaps between the matrix and the reinforcements. Meena et al. [50] also noticed that the tensile strength value of RHA reinforced matrix was greater than the tensile strength values of the unreinforced matrix and that which was reinforced by SiC alone. In another similar study by Surinder and Gora [51], it was noticed that the addition of CSA to Al6063 alloy increased the tensile strength when compared to

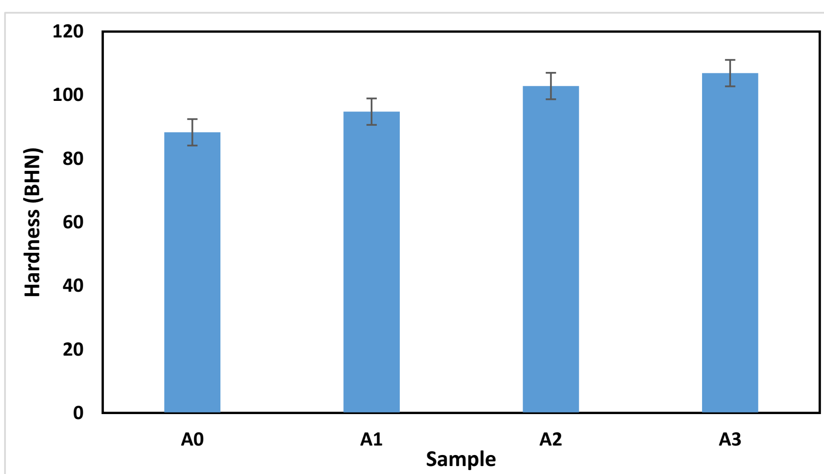


Fig. 8 Hardness values of the produced composites at various SDA wt.%

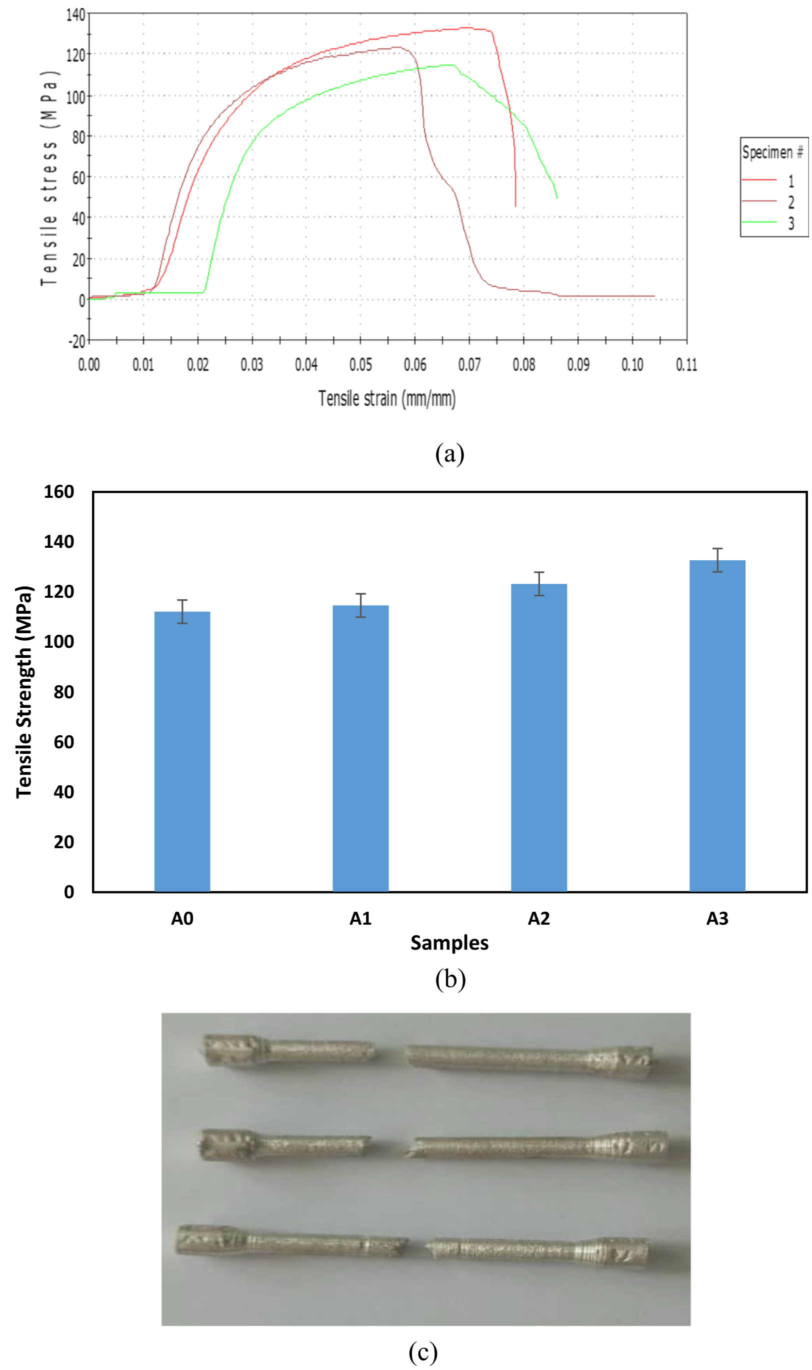
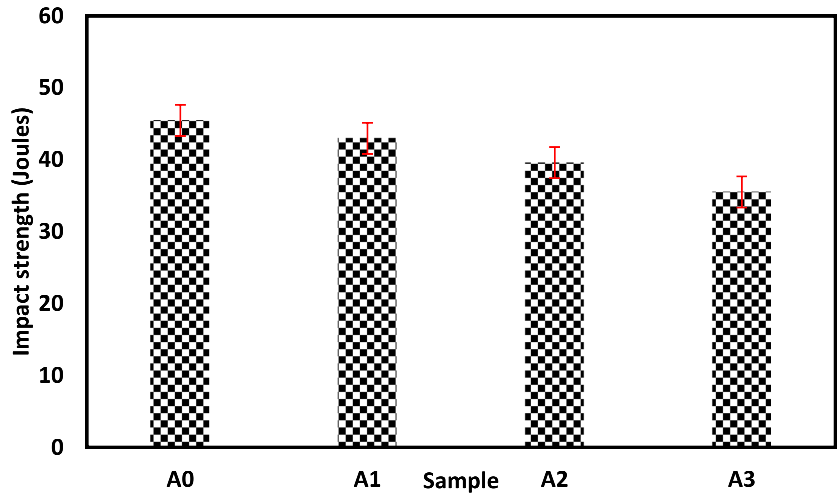


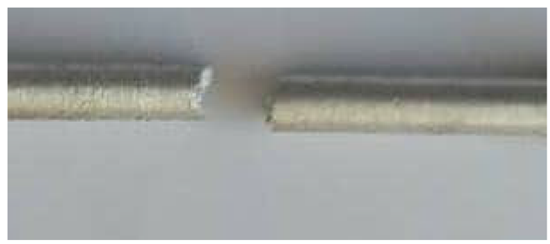
Fig. 9 **a** Stress-strain curves for the reinforced samples. **b** Tensile strength values of the produced composites at various SDA wt.%. **c** Fractured tensile samples

the unreinforced Al6063 alloy. It was stated that the increase was attributed to the proper mixing of the molten composites or the good interfacial bonding between the particle matrix interface. Ikele et al. [52] reported that the increase in the tensile strength of an aluminum matrix composite can be attributed to the synergic effect of particle strengthening and dispersion strengthening mechanisms. The thermal mismatch phenomenon between the matrix and reinforcement in terms of their thermal expansion coefficients is another reason good reason for the improved strength of the composite material developed. Another major improvement mechanism is that of the Orowan bypass mechanism, where there is grain refinement of the matrix alloy as a result of the reduction in the grain size of the metal matrix to accommodate the reinforcement particles during production and processing of the composites [5, 10, 53].

Fig. 10 **a** Impact strength of the produced composites at various SDA wt.%. **b** Fractured impact sample



(a)



(b)

3.4.3 Effect of SDA on the impact strength

Figure 10a shows the impact strength of the Al6063 matrix and the fabricated composites. The impact test was carried out to determine the amount of energy absorbed by the Al6063 and the metal matrix composite before fracture (Fig. 10b). The impact strengths were observed to decrease upon addition of SDA reinforcements with the unreinforced Al6063 alloy having the highest impact strength. The amount of energy absorbed during fracture decreased with an increase in percentage of the SDA particles in the Al6063 matrix. The reduction in impact strength can be attributed to the brittleness of the SDA particles used for reinforcement and fusion of voids in the composite [54]. The variation of the impact strength values of the metal matrix composites also depends on the interfacial adhesion between the reinforcement and the matrix. In all, it was observed that when SDA was added to the Al6063 matrix a decrease in impact strength occurred. The inoculation of fly ash in Al5083 as reported by Nagaraja et al. [54] decreased the impact strength with the increase in size and wt.% of fly ash reinforcement. Also, Hayrettin et al. [55] reported that the impact strength of aluminum matrix composites produced with fly ash reinforcement increased to a threshold limit of 8 wt.% composition after which the impact strength reduced. Ashish et al. [49] reinforced Al6061 with Al_2O_3 and reported similar results to this present study with the impact energy noticeably reducing with increased reinforcement volume fraction. However, the study of Kumar [56] observed about 24.30% increase in impact strength when Al 6063 was reinforced with TiB_2 and Gr compared with the unreinforced Al6063. This result differs from the observation in this present study because the hybrid reinforcements used in the study are harder compared to the brittle SDA particles used in this study.

3.5 Microstructural examination of the fractured surface

The microstructure examination of the fractured surfaces as a result of the tensile load application on the samples is shown in Fig. 11. Figure 11a represents the fractured surface of the unreinforced alloy. The propagation of crack that resulted into failure was due to the absence of reinforcement particulates in the matrix alloy. The reinforcement particulates have the tendency of reducing the crack propagation due to the material flow restriction. This observation was in accordance with the study of Yadav and Bauri [57] when SiC and tungsten carbide (WC) were used as reinforcement in Al6061 matrix. The increase in the tensile strength of the reinforced composite as the reinforcement particles increased could be linked to the homogeneity of the SDA

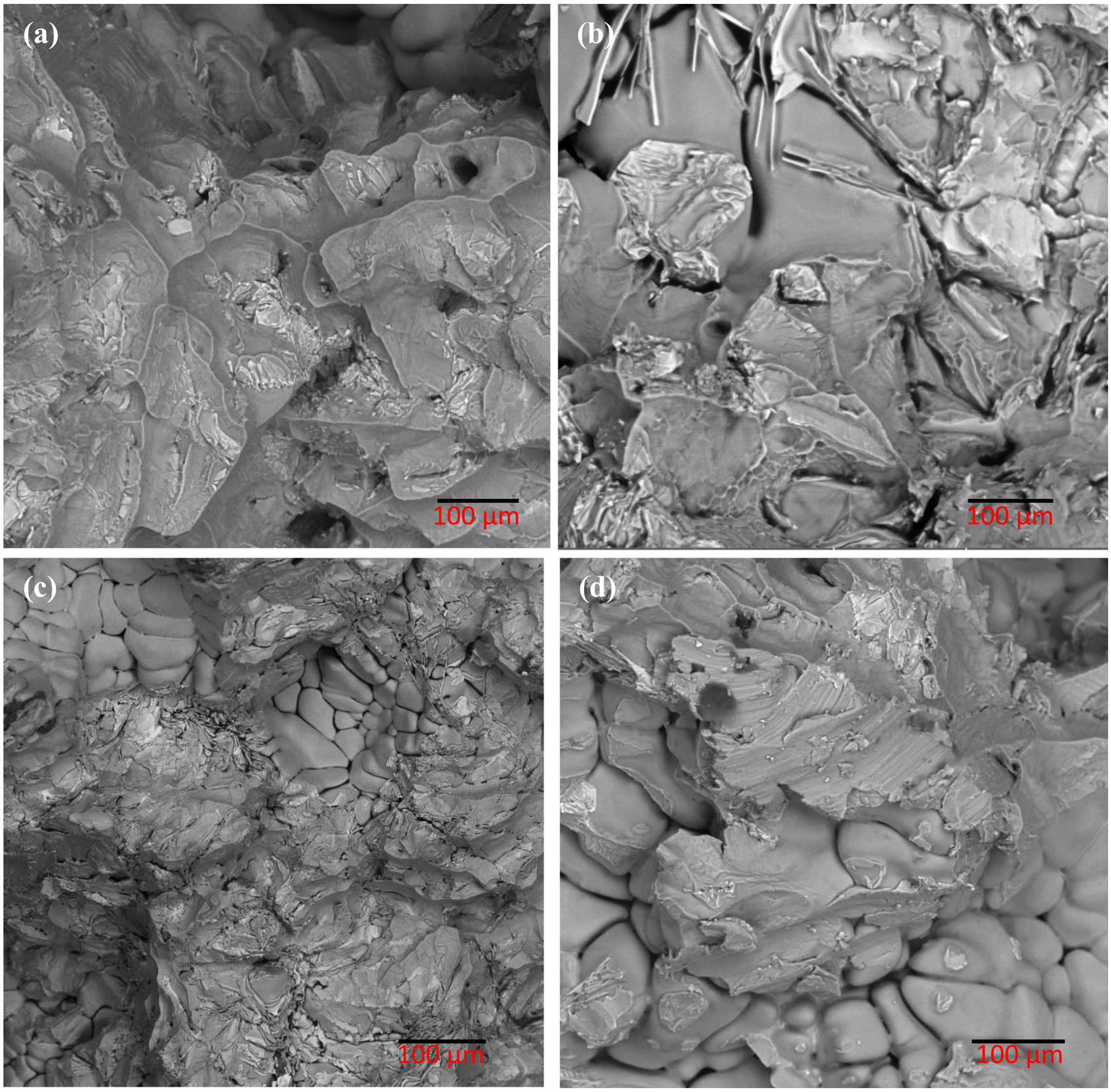


Fig. 11 Micrograph of the fractured surface **a** unreinforced alloy, **b** 2% SDA, **c** 4% SDA, and **d** 6% SDA

particulates in the matrix alloy leading to porosity reduction as well as the refinement of grains. More so, the addition of reinforcement particulates enhances the plastic deformation of the composites while the elastic deformation is reduced with increased load of composites [58]. Comparatively, the micrographs (Fig. 11b–d) showed better compatibility as the SDA content increased in the matrix alloy. This observation could be linked to the increased hardness and tensile strength values as indicated in Figs. 8 and 9b, respectively.

4 Conclusions

This present study used environmental biomass waste derivative, sawdust ash (SDA), as reinforcing particulates in the Al6063 alloy for the development of monolithic reinforced composites using the stir casting route. The structural phases, microstructure, and physicomechanical properties of the developed matrix were investigated to determine the influence of SDA particulate addition on the properties of metal matrix developed. The following conclusions were derived:

- The sawdust ash contained Fe, Si, Ca, and Ti which served as strengtheners that influenced the physicomechanical and microstructural properties of the composite.
- Homogenously dispersed sawdust ash particulates were in the metal matrix composite and there were no major pores and cracks based on the SEM images.
- The density of the resulting composites reduced as the sawdust ash particles increased with the porosity percentage not exceeding the acceptable limit of 4%.

- The hardness and tensile strength of the composite increased by 21.09% and 18.35% respectively with an increase in weight percentage of the reinforcement particles. However, the impact energy reduced in value with an increase in reinforcement particles in the matrix composite.
- The study further established that stir-casting is a reliable fabrication route for quality metal matrix composites with homogenous dispersion between the matrix and the reinforcement.
- Sawdust dust ash is established through this study to be useful in the development metal matrix composite that would be suitable for lightweight engineering applications.

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Author contribution Adekunle A. Adeleke, Peter P. Ikubanni, and Jamiu K. Odusote conceived the research idea. Adekunle A. Adeleke, Peter P. Ikubanni, and Boluwatife B. Olujimi did the production of the composite materials and preparation of the samples for further experiments. Adekunle A. Adeleke, Peter P. Ikubanni, Jude A. Okolie, and Boluwatife B. Olujimi did further experiments on the samples to obtain the required data. Adekunle A. Adeleke and Peter P. Ikubanni did the data analyses and prepare tables and figures. Jamiu K. Odusote and Boluwatife B. Olujimi wrote the first draft of the manuscript. All authors contributed to the scientific discussion and reviewed the manuscript.

Data availability Data will be made available upon request.

Declarations

Ethical approval All authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of authors" as found in the Instructions for Authors and are aware that with minor exceptions, no changes can be made to authorship once the paper is submitted.

Competing interests The authors declare no competing interests.

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