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Potentials of castor seed shell as a reinforcement in aluminum matrix composite development

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Abstract

Castor seed shell is solid waste discarded after retrieving the seed and contributes to environmental hazard and pollution. The utilization of this solid waste in the development of less dense and low cost reinforcement for aluminum matrix composite is the focus of this paper. The high cost and relative scarcity of synthetic reinforcements for aluminum motivated this study. The elemental compositions of the castor seed shell ash were determined using X-ray fluorescence while the chemical bonds in the shell ash were identified by Fourier transform infrared spectrometer. The microstructure study of the shell ash was done with scanning electron microscope complemented by EDX and physical properties of the castor shell powder was carried out using the density determination. CuO, SiO_2 and Na_2O were the major constituents of the castor shell ash while K_2O, MgO, P_2O_5, Fe_2O_3, Al_2O_3, BaO, CuO, ZnO, TiO_2 and ZrO_2 were found to be present in traces. FTIR detected a numbers of peaks which implies that castor shell ash is a complex structure with single, double and triple bonds. The micro-analysis by EDX of the castor seed shell ash consists of carbon (C), oxygen (O), calcium (Ca), silicon (Si), aluminum (Al), phosphorus (P) and potassium (K) and the density of the ash is 0.7318 g/cm^3. Employing this natural waste material derivatives in developing aluminum matrix composite will not only reduce solid waste burden but provide environmental friendly less dense material at low cost and thus contributes to green economy.

Keywords: Castor shell ash; aluminum matrix composite; less dense; green economy.

Nomenclature

ρ	density (kg/cm^3)
m	mass (kg)
V	volume (cm^3)

1. Introduction

Castor plant (Ricinuscommunis) is indigenous to Eastern Africa, Southeastern Mediterranean Basin, and India, although it has spread to all tropical regions including Nigeria (Phillips and Rix, 1999). It thrives in both tropical and temperate regions (Balami et al., 2012; Javier, 2019).The shell constitutes of around 30 % of the weight of a castor seed (Abdullah et al., 2013). The seed can be processed into oil or biodiesel (Conceição et al., 2007; Nivea et al., 2009; Ismail et al., 2016; Nakarmi and Joshi, 2016; Muhammad et al., 2018). Javier (2019) believed that the shell has the potentials for biomass. Other possible use of castor seed shell is water remediation (Oladoja et al., 2008). The shells are either discarded to the land thus causing soil pollution, or burned in the fields thus leading to environmental pollution. Increase in human population and activities had led to enormous generation of castor seed shell with corresponding disposal challenges and environmental threats (Kolawole et al., 2017).

Castor shell has its major components as cellulose, hemicelluloses, and lignin (Abdullah et al., 2013). Nwigbo et al., (2013) reported the chemical compositions of castor seed shell using the X-Ray Fluorescence (XRF) analysis as silicon, iron, potassium, manganese, chromium, copper, vanadium, phosphorus and cobalt. It is believed that calcium and silicon have the potentials to improve the strength of the aluminum composite also vanadium and iron could contribute to ductility of the aluminum composite. It is interesting to note that cobalt and vanadium contained in castor seed shell have wear resistance capacity.

The light weight and availability of the castor seed shell can be utilized in the development of environmental friendly aluminum composite which will facilitate green economy. Composite material is a multiphase material usually produced for improved properties (Kolawole et al., 2017). Composite material is bonded on macroscopic scale while an alloy is bonded on microscopic scale (molecular level). This implies that one or two constituents of the composite material are insoluble in one another. It is made up of a continuous matrix and dispersed reinforcement; both phases remain distinct while forming a single material. Composite materials are produced from two or more constituent materials with significantly different physical or chemical properties which remain separate and distinct at the macroscopic or microscopic scale within the finished product. Recent advancement in material technology has opened up variety of possibilities in composite material development and applications. Composite material offers hope for future breakthroughs in engineering practice as there are potentials of using composite materials in bioengineering, wind turbine, high pressure systems and corrosive environments (Obende et al., 2017).
Using low cost agro and industrial waste by-products as the reinforcement particulate could reduce the cost and the weight of energy intensive metals for potential applications in engineering components (Ochieze, 2017). Bodunrin et al., (2015) had earlier enumerated some benefits of using agro waste derivatives in aluminum matrix composite (AMC) production to include low cost, easy accessibility, low density, and reduced environmental pollution. Industrial and agro wastes had been reported to have wettability and good dispersion in aluminum matrix (Bienia et al., 2003; Naresh, 2006; Aigbodion et al., 2010;Aigbodion, 2014; Asafa et al., 2015; Esione, 2017; Ochieze, 2017; Ochieze et al., 2018; Tobins et al., 2018, Nwobi-Okoye and Ochieze, 2018). Hence, aluminum based composites could be produced with inexpensive agro and industrial waste reinforcement such as castor seed shell. The objective of this study is to characterize castor seed shell ash as a potential material for reinforcing aluminum matrix by appraising its elemental compositions and microstructural properties.

2.0 Material and methods

2.1 Material and Equipment

The materials used for this study were castor seed shell (figure 1) obtained from local farmers in Achi Oji-Rivers Local Government Area, Enugu State, aluminum cable (Al), silicon (Si) and magnesium (Mg). Equipment used in this work were: measuring cylinder, tong, sieves, heat treatment furnace, cascade TEK- forced air laboratory oven, hammer mill, Sartorius BP 410 digital scale with precision of 0.001 g, Fourier transform infrared spectrometer, TESCAN Vega3 XMU scanning electron microscope (SEM) with Energy dispersive X-ray spectroscopy (EDX), bale out furnace, Ametek Ez-250 digital tensile and compression tester, Leeb hardness tester HM-6.

Figure 1: Castor seed shell

2.2 Sample Preparation

The castor shells were sundried for three weeks afterwards they were oven dried at 105 °C for 10 minutes. The shells were crushed into powder of 150 µm with ball mill. They were also carbonized at 800 °C for 2 hours to form particle ash in heat treatment furnace. Aluminum alloy and castor shell reinforced composite samples were produced for mechanical strength evaluation. 321.96 wt. % of Al, 28.28 wt. % of Si, 5.25 wt. % of Mg and 12 wt. % of castor shell ash were used in the production of the samples. Stir casting technique was employed in the preparation of samples. The bale out furnace was first preheated to 150 °C with 5 kg capacity steel crucible. Initially, aluminum cable was charged into hot steel crucible and was heated until the aluminum melted at temperature of about 660 °C. The furnace temperature was raised to 782 °C and the melt was held at this temperature for 8 min before the addition of silicon and magnesium. It was stirred thoroughly in the furnace to prevent the elements from settling at the bottom before casting into a sand mold prepared with a circular galvanized steel of 25mm diameter and length of 304.8 mm to produce aluminum alloy. Also, the composite was produced following the same procedure with the addition of the reinforcement during the stirring.

2.3 Characterization of Castor Seed Shell

The elemental compositions of the castor seed shell ash were determined using Shimadzu EDX-720 X-ray fluorescence (XRF). The analysis was conduct in vacuum following the ASTM E1621-13 standard procedure and the system was cooled using nitrogen gas. Fourier transform infrared spectrometer was used to identify the chemical bonds in the castor seed shell ash. Buck scientific M530 USA FTIR was used for the analysis. This instrument was equipped with deuteratedtriglycinesulphate (DTGS) detector and beam splitter of potassium bromide. The software used to obtain the spectra and to manipulate them was GRAMS/A1. Also, the microstructure study of the castor seed shell ash was determined by TESCAN Vega3 XMU scanning electron microscope (SEM) complemented by EDX.

2.4 Determination of Density

The basic method of determining the density of a specimen by measuring the mass and volume of the specimen was used. The density of the specimens were estimated from the basic formula for density given as:

$$\rho = \frac{m}{V} \tag{1}$$

The samples were weighed using Sartorius BP 410 digital scale. Archimedes principle was employed in determining the volume of the samples. The samples were suspended in three-quarter filled measuring cylinder containing water and the rise in water level gave the volume.

2.5 Determination of Mechanical Properties

The Vicker's hardness test was performed in accordance with ASTM E384-17 at room temperature. It was measured using Leeb hardness tester HM-6580. It measures hardness according to Leeb reflection method. The body bounces on the sample surface, and the intensity of the reflection is subsequently used as an indication of the hardness of the sample. And tensile testing of the samples was conducted in accordance with the ASTM E8 standard on round tension test specimens of gauge length 25mm using Ametek Ez-250 digital tensile and compression tester. It was conducted at room temperature.

3.0 Results and Discussions

3.1 X-ray Fluorescence (XRF) of Castor Seed Shell Ash

The result of x-ray fluorescence (XRF) of castor seed shell ash is presented in table 1. Table 1 presented the oxides contained in the castor shell ash distinct from the elemental constituents of un-carbonized castor seed shell presented by Nwigbo et al., (2013). Nevertheless, calcium and its oxide remained the principal constituents of the castor seed shell.

Table 1: X-Ray Fluorescence (XRF) analysis of castor shell (CS)

Analyte	CaO	SiO_2	Al_2O_3	MgO	BaO	CuO	ZnO	K_2O	Fe_2O_3	Na_2O	TiO_2	P_2O_5	ZrO_2
Content	74.01	19.6	0.03	0.12	<0.001	<0.001	<0.001	1.02	0.03	1.89	<0.001	0.08	<0.001

The XRF chemical composition of the castor shell ash as presented in table 1 indicated that CaO, SiO_2 and Na_2O were the major constituents while K_2O, MgO, P_2O_5, Fe_2O_3, Al_2O_3, BaO, CuO, ZnO, TiO_2 and ZrO_2 were found to be present in traces. Similar oxides had been found in some particulate ashes that had been successful employed as reinforcement in aluminum matrix composite (Apasi et al., 2012; Atuanya et al., 2012; Bhaskar and Abdul, 2012; Abhulimen and Orumwense, 2017; Kumar and Birru, 2017; Atuanya et al., 2018; Ochieze et al., 2018). Calcium oxide (CaO) was found to be the major constituent in castor shell. It constituted more than 70 % of total chemical content. CaO had been reported to have reduced the specific wear rate and coefficient of friction of composite materials (Gangwar et al., 2015). Also, Bharath et al., (2014) reported that increasing aluminum oxide (Al_2O_3) reinforcement from 6 – 12 wt% increased the hardness, tensile strength and yield strength of 6061Al-Al_2O_3 metal matrix composite produced by stir casting. Indeed, some of the constituents of the castor seed, calcium oxide (CaO), silicon dioxide (SiO_2) aluminum oxide (Al_2O_3) and iron (III) oxide (Fe_2O_3), have been reported to be among the hard substances used in the reinforcement of aluminum matrix (Apasi et al., 2012; Atuanya et al., 2012; Kolawole et al., 2017). The presence of these substances in the castor shells encourage their potential usage as reinforcements of aluminum matrix. Reinforcing with castor seed shell ash could enhanced the overall strength of the composite due to the possibility of the formation of a strong intermetallic bond between the aluminum matrix alloys and the hard substances of the ash (Kolawole et al., 2017).

3.2 Fourier Transformed Infrared Result for Castor Seed Shell Ash

Figure 2 revealed that a numbers of peaks were detected, it implies that castor shell ash is a complex structure. In the single bond region (2500-4000 cm-^{1}), several peaks were detected signifying that compounds detected within this area have single bonding. Nevertheless, hydrogen bond is not suspected since no broad absorption band in the range of between 3650 and 3250 cm-^{1} was detected. In the triple bond region (2000- 2500 cm-^{1}), some peaks were detected informing the presence of triple bond in the castor shell structure. Also, in the double bond region (1500-2000 cm-^{1}), some peaks were detected showing, hence the possibility of double bond in the material. Results as presented in table 2 indicate that the peak values around 691.0513 cm^{-1}, 820.2957 cm^{-1}, 804.0013 cm^{-1} were assigned to C-CI stretching vibration of halogenous compounds. The absorption band around 1286.009 cm^{-1} was assigned to C0 stretching vibration of ether compound. The height around 1484.609 cm^{-1} was assigned to C=C stretching vibration of ethene compound.

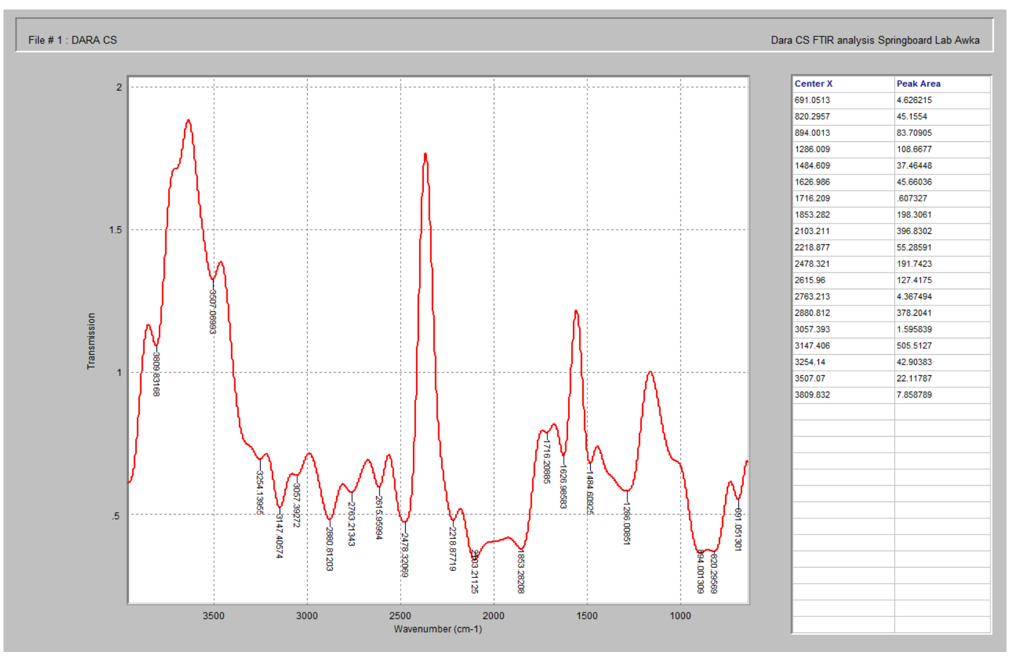

Figure 2: FTIR spectra of castor seed shell particle at wavenumbers of 4000-600 cm^{-1}

The medium band around 1626.986 cm^{-1} and 1716.209 cm^{-1} was assigned to N-H stretching vibration of 1^0 amine compound. The peak around 1853.282 cm^{-1} was assigned to C0 stretching vibration of cyclic ester compound. The band around 2103.211 cm^{-1} and 2218.877 cm^{-1} were due to C00 anti-symmetric stretching vibration of carboxylic acid and carbonyl compounds respectively whereas the peak height around 2478.321 cm^{-1} was assigned to C≡N anti-symmetric vibration of nitrile compound. The weak band around 2763.213 cm^{-1}, 2815.960 cm^{-1}, and 2880.812 cm^{-1} were due to C-H stretching vibration of methylene compounds respectively. The strong band around 3057.393 cm^{-1}, 3147.406 cm^{-1} , 3254.140 cm^{-1}, 3507.070 cm^{-1} and 3809.832 cm^{-1} were assigned to 0H stretching vibration of 1^0 , 2^0 and 3^0 alcoholic compounds respectively. The complex nature of the castor seed shell ash will provide a better interfacial bonding with aluminum matrix. Fourier Transformed Infrared (FTIR) technique is an important tool used to identify the characteristic functional groups, which are instrumental in determination of functional groups and organic compounds inherent in any given sample. FTIR spectra of castor shell were depicted in figure 2. Their interpretations were presented in table 2.

Table 2 Fourier Transformed Infrared Interpretation for Castor Shell

S/N	Frequency	Functional group	Compounds
1	691.0513	C-CI	Chloro C-Cl symmetric stretch
2	820.2957	C-CI	Chloro C-Cl symmetric stretch
3	894.0013	C-CI	Chloro C-Cl symmetric stretch
4	1286.009	R-0-R	Ether C0 symmetric stretch
5	1484.609	H_2C=CH	Ethene CH anti-symmetric stretch
6	1626.986	RNH_3	1^0 amine NH stretch
7	1716.209	R-C00	Cyclo ester C0 stretch
8	1853.282	R-C00	Cyclo ester C0 stretch
9	2103.211	RC00H	Carboxylic acid C0 stretch
10	2218.877	RC=0	Carbonyl C0 antisymmetric stretch
11	2478.321	R-C≡N	Nitriles CN antisymmetric stretch
12	2763.213	CH_2	Methylene CH stretch
13	2815.960	CH_2	Methylene CH stretch
14	2880.812	CH_2	Methylene CH stretch
15	3057.393	RCH0H	1^0 alcohol 0H stretch
16	3147.406	RCH0H	1^0 alcohol 0H stretch
17	3254.140	R_2CH0H	2^0 alcohol 0H stretch
18	3507.070	R_3CH0H	3^0 alcohol 0H stretch
19	3809.832	R_3CH0H	3^0 alcohol 0H stretch

3.3 Microstructure Analysis of Castor Seed Shell Ash

Figure 3 presented the scanning electron microscopy micrograph showing the surface morphology of castor seed shell ash particles. The sample image was taken at 2000X magnification, with acceleration voltage of 20 kV, working distance of 20 µm. The castor seed shell ash particles were solid in nature with longitudinal and smooth spherical surface having more surface area for interaction. The SEM image of the castor seed shell ash comprises of different particles in various sizes. The castor shell ash surface morphology will do an important role in the case of composite materials. External surface features of particles such as contours, defects and damage and surface layer were not observed in the SEM. The micro-analysis by EDX (figure 4) of the castor shell particle ash consists of peaks of carbon (C), oxygen (O), calcium (Ca), silicon (Si), aluminum (Al), phosphorus (P) and potassium (K). These results are consistent with previous work on seed shell ashes (Atuanya et al., 2012; Atuanya et al., 2014).The ash does not contain radioactive and harmful materials. The castor shell ash showed a higher proportion of carbon atom and oxygen atom (83.3 % and 13.1 % respectively). The higher proportion of carbon and oxygen in the particles can be attributed to the carbonization of the castor shell ash.

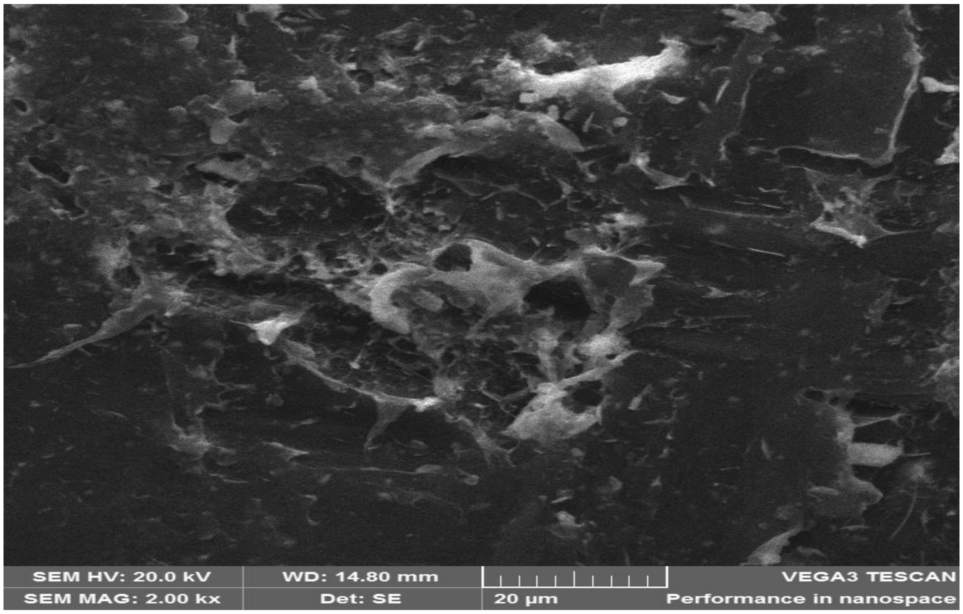

Figure 3: Scanning electron microscopy micrograph of castor seed shell

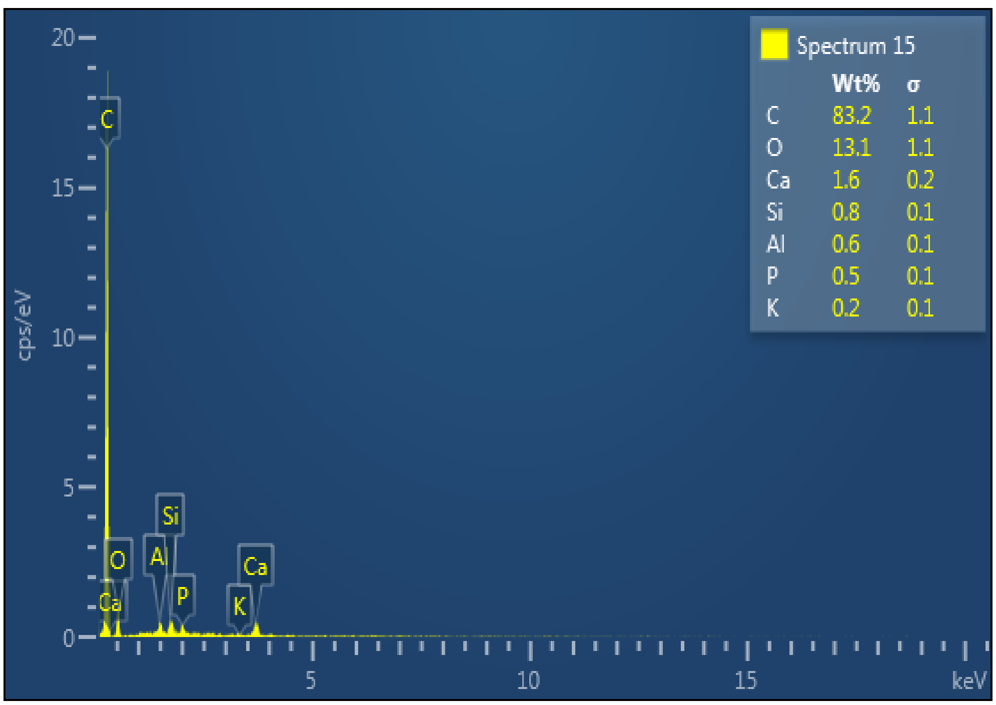

Figure 4: EDX of castor seed shell

3.4 Density of Castor Seed Shell Ash

The castor shell particle ash has a density of 0.7318 g/cm^3. Castor shell is less dense compared with other agro waste reinforcements (bamboo stem ash, snail shell ash, breadfruit seed hull ash, coconut shell ash, egg shell and cow horn particulate). Atuanya et al., (2018) reported the density of bamboo stem ash as 0.97 g/cm^3. It could be seen that the density of castor seed shell is about 32.55 % less than bamboo stem ash. Kolawole et al., (2017) reported the density of snail shell as 1.63 g/cm^3, this value is 46.54 % higher than the density of castor shell ash. Both Atuanya et al., (2012) and Hassan and Aigbodion, (2013) reported the densities of breadfruit seed hull ash and eggshell ash as 1.98

g/cm^3. Their densities are 63.04 % higher than the density of castor shell ash. Also, Ochieze et al., (2018) reported the density of cow horn particulate as 2.62 g/cm^3, this value is more than three times the density of castor shell ash. The lesser density of castor shell will contribute to overall reduction of the weight of aluminum composite when incorporated. This will definitely lead to light weight components and machines prompting energy savings and lesser pollution. The low value of the density of castor shell ash makes it a prospective better material in the production of aluminum matrix material.

3.5 Mechanical Properties of Castor Shell Reinforced AMC

Table 3 Comparison of with unreinforced aluminium alloy with castor shell reinforced AMC

Samples	UTS (MPa)	Hardness (MPa)
Aluminum alloy	124.23	95.9
Castor shell reinforced AMC	154.03	137.3

Table 3 showed the variation of ultimate tensile strength (UTS) of aluminum alloy with castor shell ash reinforced aluminum composite. It revealed that the UTS increased of the aluminum composite increased due to addition of the reinforcement. This improvement in UTS is about 24 % compared with unreinforced aluminum. Bharath et al., (2014) suggested that the increase in the value of UTS is perhaps due to the thermal disparity between the aluminum matrix and the reinforcement. Also, there was increase in the hardness of aluminum from 95.9 MPa to 137.3 MPa as a result of reinforcing with castor shell. This implies that the aluminum recorded about 43.2 % increase in hardness value. Hence, hitherto soft aluminum could be hardened by reinforcement with low density castor shell ash. Nevertheless, the increase in hardness value will lead to reduction in ductility value. Therefore, basic application must be considered to determine the level of reinforcement.

4.0 Conclusions

This paper considered the potentials of castor seed shell particulate ashes reinforcement for aluminum matrix composite. Castor shells are essentially discarded as waste in our environment causing solid pollution and hazard to human. Castor seed shells are abundant in Nigeria and largely unused agricultural wastes. It has been revealed that the castor shell ash contains hard oxides such as calcium oxide (CaO), silicon dioxide (SiO_2) aluminum oxide (Al_2O_3) and iron (III) oxide (Fe_2O_3) which have been hitherto used in the reinforcement of aluminum matrix. Also, the low density of the castor shell ash could be harnessed in developing light weight composite materials for automobile and aerospace applications. Exploiting this natural wastes materials derivatives in developing new material will not only reduce solid waste burden, but provide environmental friendly material at low cost and thereby contributes to green economy.

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