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Evaluation of Palm Kernel Shell Ash Particle Reinforced Aluminium 6061 Alloy Matrix Composites Using Physio-Chemical and Microstructural Methods

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ABSTRACT

Metal matrix composites are an appealing alternative to monolithic metals for a variety of technical applications due to their superior mechanical and physical properties throughout a broad range of operating conditions. In the current study, different weight percentages of 150 µm palm kernel shell ash (PKSA) particles were used to reinforce aluminium 6061 alloy (2.5%, 5%, 7.5%, and 10%). Stir-casting was used to prepare the composite in a permanent mild steel mould. A number of the composites' physical, chemical, and microstructural characteristics (density, percentage porosity, XRF and SEM-EDS) were assessed, compared, and analysed with those of the matrix alloy. Oxides that could enhance the composites' mechanical, physical, and structural qualities were found during the structural assessment evaluation of the reinforcement. The microstructural analysis demonstrated that the PKSA reinforcements' secondary phase was uniformly distributed throughout the primary phase of the aluminium matrix. The added PKSA particles decreased the produced composite's density below that of the base alloy, but the percentage porosity of the composites rose as the palm kernel shell ash content increased and remained within the upper limit allowed for cast aluminium metal matrix composites. The composites that were created showed evidence of intermetallic compound formation.

1. Introduction

Aluminium is the most extensively used metal after steel due to its versatility. Stronger, lighter, and less expensive materials are being needed for engineering applications. High specific strength, low coefficient of thermal expansion, high thermal resistance, good damping capacities, superior wear resistance, high specific stiffness, and acceptable levels of corrosion resistance are some of the property combinations that set aluminium 6061 metal matrix composites apart [1-10]. In numerous fields, including aerospace, automotive, and defence, metal matrix composites (MMCs) are quickly taking the place of traditional monolithic metallic alloys [1, 11-14]. Applications for aluminium metal matrix composites (AMMCs) are limited by their high cost when using traditional reinforcements like silica (SiO2), tungsten (W), calcium oxide (CaO), aluminium oxide ($Al2O_3$), silicon carbide (SiC), titanium carbide (TiC), and so on [15]. Composites made of aluminium alloy are becoming more and more important in the engineering areas as a result of current industrial developments. Due to its capacity to improve the many qualities of the composite material, the use of agricultural waste ash in reinforcement—such as groundnut shell ash (GNSA), rice husk ash (RHA), palm kernel shell ash (PKSA), corn cob ash (CCA), coconut shell ash (CSA), bamboo leaf ash (BLA), etc.—is becoming more and more relevant [15-20].

The amount of trash produced by industrial, mining, and agricultural processes has significantly increased as a result of the global population growth and rising living standards brought about by technological advancements. The amount of waste produced is starting to worry environmentalists and people everywhere [21]. Aluminium matrix composites (AMCs) are currently made using several traditional and proprietary techniques. The processing technique determines the characteristics of AMCs. Although a liquid method, like casting, is more straightforward and cost-effective, its application is restricted by the reinforcement's poor wettability in molten aluminium. Stir casting is the method of choice for making aluminium metal matrix composites because of its economy, simplicity, and capacity to produce big and complex pieces [15, 21, 22]. Utilising waste materials could lessen environmental contamination, and recycling waste materials by turning them into valuable resources for the automotive, aerospace, and construction industries could prevent natural disasters from happening to the planet [15].
It has been discovered that agricultural waste ashes include large percentages of refractory materials that can be investigated for the creation of composites, including alumina ($Al2O_3$), silica (SiO_3), hematite ($Fe2O_3$), carbonate ($CaCO_3$), and calcium (Ca) [15, 6, 7].

2. Materials and methods

2.1. Materials

The materials used were AA6061 as the matrix material which was obtained from Alna Aluminium Inc., China. Palm kernel shell ash (PKSA) particulate as the reinforcement material which was obtained from Ogwashi-Uku, located at a longitude: of 6o10’41” N and latitude: of 6o31’28” E, Delta State, Nigeria

2.2. Experimental methods

2.2.1. Collection and preparation of palm kernel shell

The gathered palm kernel shells were cleaned with warm water, dried for two weeks in the sun, and then ground into a fine powder in the Ogwashi-Uku market using a regular grain (wheat, corn, beans, etc.) grinding machine. The ground palm kernel powder of 1000 g was loaded in batches into a muffle furnace for ashing at 550°C for one hour and fifteen minutes. The temperature and time used for the ashing were obtained after several trials and is to allow for complete ash formation and to maintain a single-phase material. The optimal ashing was virtually observed at 550°C for one hour and fifteen minutes. The ashing was conducted at 450°C, 500°C, 550°C, and

600°C for 45 minutes, one hour, one hour 15 minutes, and one hour 30 minutes. The powdered palm kernel shell ash is displayed in Plate 1(a).

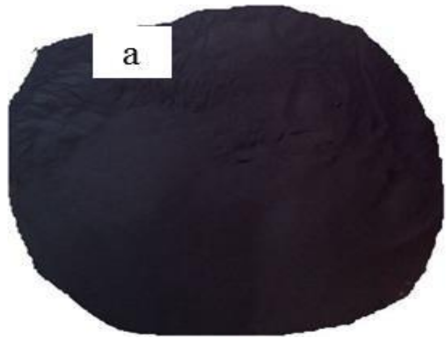


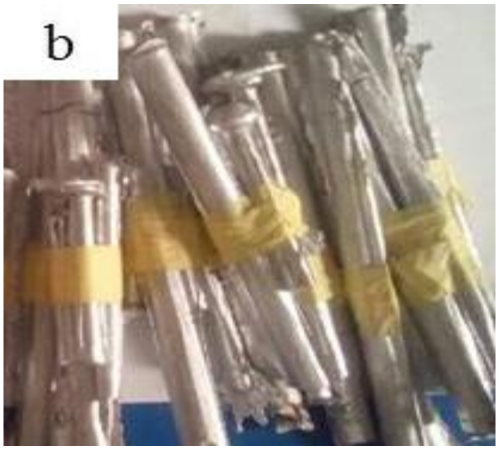
Plate 1. (a) Palm kernel shell ash powder

2.2.2. Size Analysis

At Delta State Polytechnic in Ogwashi-Uku's Metallurgical Engineering Laboratory, an analysis of the palm kernel shell ash particle size was conducted. To accomplish thorough classification, 1000 g of the PKSA was put into a series of sieves arranged in decreasing order of fineness, and the mixture was agitated for 15 minutes. The PKSA particles that were kept below the 150 µm sieve were used in the study.

2.2.3. Stir casting

The stir casting method was utilised in the metallurgical engineering laboratory of Delta State Polytechnic, Ogwashi-Uku, to fabricate the metal matrix composite. The sample was made by adjusting the weight percentage of the reinforcing material (palm kernel shell ash) particles at intervals of 2.5 weight per cent, within the range of 0 to 10 weight per cent, with the remaining balance being the aluminium AA601 alloy matrix. The aluminium was divided into various PKSA weights. An electric resistance furnace was used to melt the aluminium alloy charged into a stainless steel melting pot that had been preheated. For three hours, the furnace was heated to ± 700°C. To increase the wettability and balance the temperature, the PKSA particles were heated to 50°C in an oven for three hours before being added to the molten aluminium. The alloy was fully melted in the furnace by raising the temperature to 750°C, and it was then cooled to 600°C to maintain a semi-solid condition. At this point, the hot particles of palm kernel shell ash were introduced and manually mixed using a steel stirring rod by [23, 24]. The composite slurry was manually mixed, then heated to 750°C in the furnace before being put into a 200 mm long by 16 mm diameter permanent cylindrical mould that had been preheated. Plate 1(b) and (c) display representative cast composites and the mild steel permanent mould, respectively.



(b) As-cast AA6063/PKSA composites

(c) Fabricated permanent mould

2.2.4. Determination of density

After precisely weighing the clean AA6061/PKSA composite samples on an electrical scale, they were immersed in water. The samples' weight in water was ascertained, and the Archimedean principle was used to calculate the sample's volume based on the effect of water displacement. The density was computed using the expression provided in equation (1) and the experimental density of the composite was tabulated (Table 1) and is also shown in Figure 1.

$$Density = \frac{Mass(M)}{volume(V)} \quad (1)$$

2.2.5. Determination of percentage porosity

Using an electrical scale, the measured weight of a test sample was divided by its measured volume to find the experimental density of each grade of composite that was generated. The evaluation of the per cent porosity of the composites was based on a comparison between the experimental and theoretical densities for each composition of the composites generated (Table 2) and (Figure 2). The per cent porosity was calculated using the relation below [23, 25, 26]

$$percentage\ porosity = \left(\frac{\rho^{T} - \rho^{EX}}{\rho^{T}}\right) * \frac{100}{1} \quad (2)$$

Where ρ^{T} = Theoritical density and ρ^{EX} = Experimental density.

2.2.6. Chemical analysis

The chemical composition of the reinforcement was analysed using XRF methods. The quantitative and qualitative oxide contents of the reinforcement were ascertained in this investigation using an Energy Dispersive x-ray fluorescence (EDXRF) spectrometer model called "Minipal 4." With great resolution and quick analysis, XRF finds elements between sodium (Na, Z = 11) and uranium (U, Z = 92).

2.2.7. Microstructural evaluation

The microstructural characteristics and qualitative elements composition of the composites were thoroughly examined using a JSM 7600F Jeol ultra-high resolution field emission gun scanning electron microscope (FEG-SEM) fitted with an EDS.

3. Results and discussion

3.1. Density

Figure 1 displays the findings of the density measurement of AA6063 with different weight percentage additions of PKSA. The outcome demonstrates that when palm kernel shell ash addition to the matrix rises, the density of the reinforced alloy AA6061/PKSA falls. This pattern aligned with research results from [23, 27]. When adding 2.5 weight per cent of PKSA, the density of the AA6061/PKSA reinforced composites was 2.62 g/cm3, but at 10 weight per cent, it dropped to 2.41 g/cm3. This is because PKSA particles have a lower density than those of aluminium alloy, and research has shown that using PKSA to manufacture lightweight composites appropriate for automotive applications might reduce energy usage.

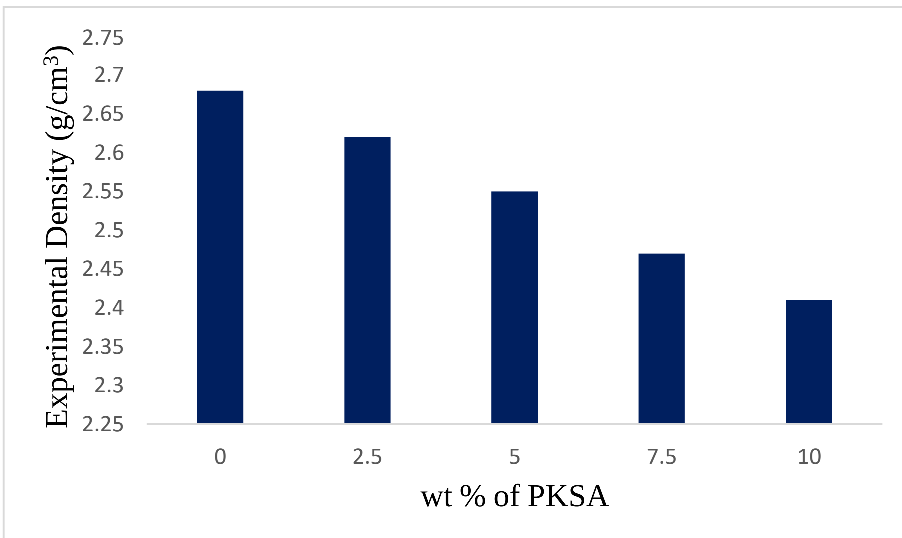


Figure 1. Experimental density variation with wt % PKSA composites produced

3.2. Percentage porosity

The discrepancy between the experimental and theoretical densities divided by the theoretical densities of the composites is explained by the porosity of the resulting composites. It was noticed that porosity rose as the amount of reinforcing PKSA particles increased. Trapped air or the reinforcement's low wettability are the causes of the porosity level. Poor mechanical characteristics and strength are the results of high porosity. The outcome demonstrated that the composites' apparent porosity values increased marginally with the weight percentage of PKSA addition. This is shown in Figure 2. At 2.5 weight per cent of PKSA addition, the reinforced composite's porosity was 0.65%; at 10 weight per cent of PKSA addition, it was 1.51%. The percentage of pores and voids in the AMMC increases with the value of the reinforcement. However, all of the generated composites had percentage porosities below the upper limit that is allowed for cast metal matrix composites [23, 28, 24].

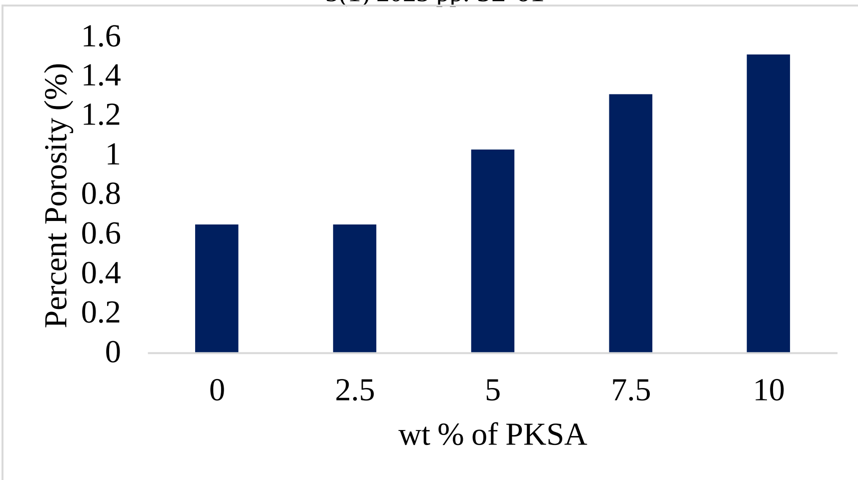


Figure 2. Percent porosity variation with wt % PKSA composites produced

3.3. Chemical analysis

3.3.1. X-ray fluorescent spectrophotometer (XRF) results

Based on XRF analysis, the PKSA's chemical composition (in oxide form) is displayed in Table 3. Table 3 suggests that the following oxides have higher concentrations of SiO_2, Fe_2O_3, Al_2O_3, P_2O_5, and CaO. Higher concentrations of silica, alumina, phosphorus, and other oxides were confirmed by [23, 29, 30]. The palm kernel shell may be employed as particle reinforcement in metal matrix composites due to the presence of hard components such as SiO_2, Al_2O_3, Fe_2O_3 and CaO. Therefore, the results of this study point to the feasibility of using PKSA as a particulate reinforcement in the production of metal matrix composites. The XRF results are compatible with various particle organic and agricultural waste reinforcements, like rice husk ash, coconut shell, periwinkle shell, and bagasse ash, which are currently used in matrix composite, due to their similar chemical composition [23, 31, 32, 33]

Table 3. Chemical Composition of PKSA

Compound (Oxide)	Conc. (%)
SiO_2	48.53
Al_2O_3	7.43
Fe_2O_3	8.45
MgO	5.72
P_2O_5	3.24
TiO_2	0.05
MnO	0.03
CaO	6.52
K_2O	7.61
CuO	0.02
ZnO	0.01
Ni_2O	0.03

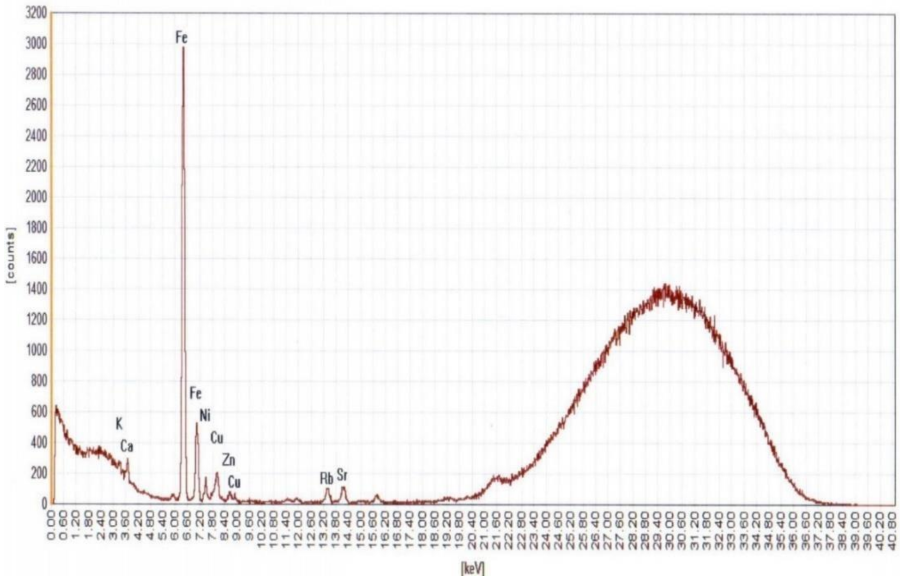


Figure 3. XRF spectra showing the elemental constituent of the palm kernel shell ash (PKSA) particles.

3.4. Microstructural examination

Representative morphological characteristics of the unreinforced AA6061 (0 weight percent PKSA) are shown in Figure 4. An array of needle-like shapes is clearly visible in Figure 4. Nevertheless, there are toughening mechanisms brought on by the presence of PKSA particles in the composite with 10 weight percent PKSA particles (Figure 5). The morphology demonstrated that the PKSA reinforcements' secondary phase was uniformly distributed throughout the primary phase of the aluminium matrix. The elements Al, Mg, Si, C, and O were found in the EDS result of the unreinforced alloy (0 weight percent PKSA), whereas the elements Al, Mg, Si, C, Fe, Cr, Mn, O, and Cu were found in the matrix composite AA6061 reinforced with 10 weight percent PKSA particles (Figure 5). The microstructural analysis of the alloy indicates an intermetallic grain and the presence of Mg_2Si and AlFeSiMn as intermetallic phases. It was discovered by the SEM and EDS studies that the needle-shaped AlFeSiMn intermetallic existed. According to additional observations by [34], the intermetallic phase forms in aluminium due to Fe and Mn impurities.

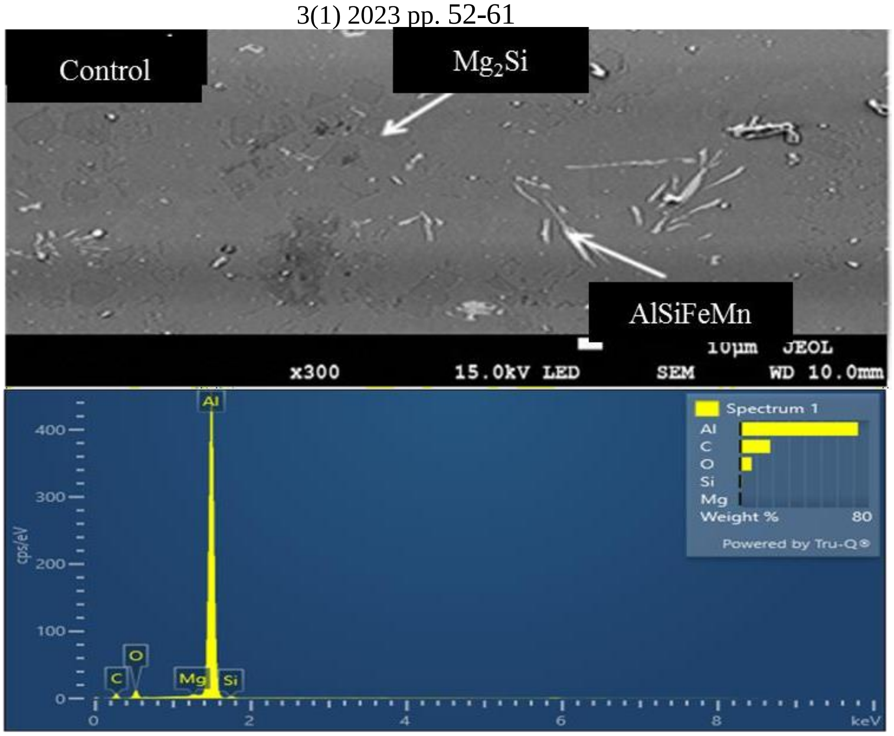


Figure 4. SEM-EDX micrograph of Al 6061 alloy as-cast

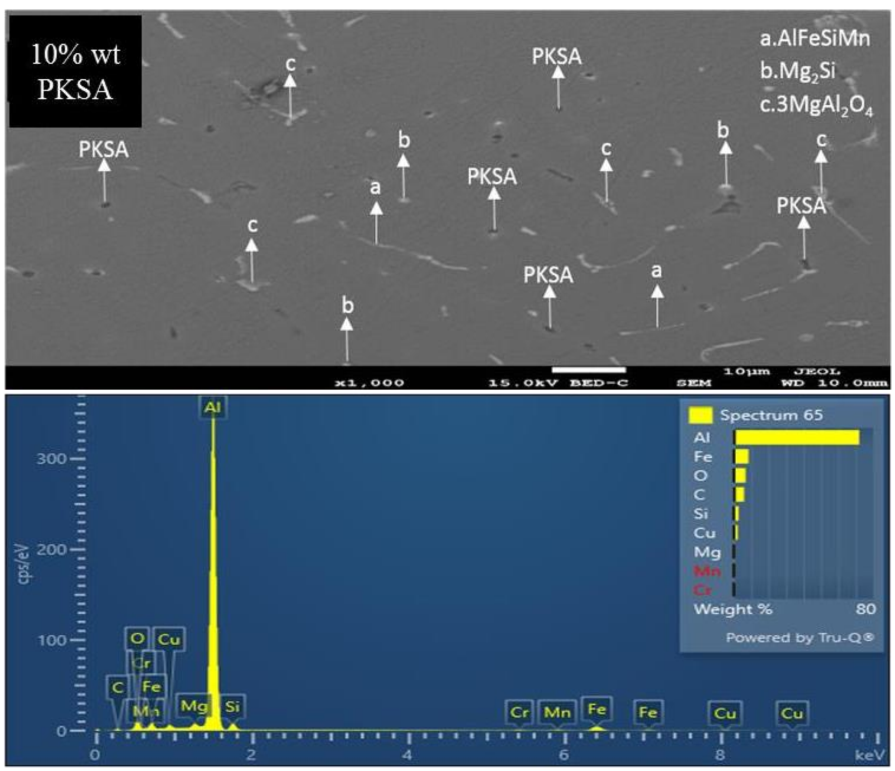


Figure 5. SEM-EDX micrograph of Al 6061 + 10%PKSA

4. Conclusion

Double stir casting was used to create the AA6061/PKSA composites. Because PKSA has strong oxides, it can be used as a reinforcement material when making AMMCs. As the amount of palm kernel shell ash in AA6061/PKSA composites increased, their density dropped. This suggests that palm kernel shell ash particles can be used as reinforcement in the fabrication of lightweight metal composites. Particles of palm kernel shell can be included in the matrix of aluminium alloy (AA6061) to produce lightweight, inexpensive aluminium composites with enhanced structural and physico-mechanical characteristics.

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