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Development of an Al-4.1%Cu-1.7%Mg Alloy Reinforced with Periwinkle Shell Ash (Turritella Communis) Particulate for Lightweight Engineering Applications

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Abstract- It was investigated in this study how a periwinkle shell ash (PSA) reinforced Al-4.1%Cu-1.7%Mg alloy can be developed for lightweight engineering applications. Ash from the periwinkle shells (Turritella communis) collected from Calabar, Nigeria and calcined at 1200°C for 5 hours was characterised using X-ray fluorescence (XRF) and X-ray diffraction (XRD). CaO (40.84%), SiO_2 (32.84%), Al_2O_3 (10.20%), and Fe_2O_3 (7.02%) made up the majority of the ash, according to XRF analysis. The composites 0 wt % PSA, 5 wt % PSA, 10 wt % PSA, 15 wt % PSA, 20 wt % PSA, 25 wt % PSA and composite of 30 wt % PSA were produced by double stir casting process. Standard procedures were employed to estimate the mechanical parameters (impact energy, yield strength, ultimate tensile strength and hardness) and physical qualities (density and porosity). Data was collected three times for each test and analysed using both Python and MINITAB. The results showed that the porosity increasingly changed from 0.09% to 0.33% and the density increasingly changed from 2.93 to 2.60 g/cm³ (11.3%), as the concentration of PSA increased. Hardness rose by 58.2%, from 55.47 to 87.73 HRF. Ultimately, the strength of the material in terms of ultimate tensile strength (UTS) showed an increase up to 25 weight percent PSA (31.7% increase) before again dropping at 30 weight percent PSA (w/PSA). This trend was also observed for yield strength (maximum of 151.60 N/mm2 with 25 weight percent of PSA (31.2% higher) and impact energy (a decrease from 10.00 to 4.80 J, 52.0% lower). It was observed that over the optimum PSA concentration of 25 wt. percent, performance was hindered by particle agglomeration. Response Surface Methodology (RSM) was used to perform multi-response characterisation of the composite and to generate contour plots and 3D surface graphs, and to do desirability optimisation to confirm the optimum reinforcement content. Indubitably, the statistical analysis (ANOVA and Tukey HSD) indicated that the PSA concentration had significant effects ($p < 0.05$) on all the properties evaluated. In this work, periwinkle shell ash which is a common farm waste was determined to be a low-cost and low-energy-consuming reinforcement for Al-Cu-Mg alloys.

Keywords: Composite, Engineering, Metals, Periwinkle Shell

I. INTRODUCTION

Materials engineering has undergone a massive transformation over the past decades due to the tireless search for materials of greater mechanical performance, lighter weight and lower costs. Metal, polymer, and ceramics are the conventional monolithic materials each of which has fundamental limitations that limits its use in challenging engineering situations. Usually, metals are not stiff enough, or otherwise do not have sufficient wear resistance for their weight and size. Ceramics themselves are very hard and can endure high temperatures, but also are fundamentally brittle and liable to catastrophic failure. Even though they are lightweight, resistant to corrosion and light in weight, they are weak in strength and have low thermal stability (Callister & Rethwisch, 2020). These restrictions have compelled the scientists to investigate and study different material systems that combine the desirable properties of two or more of the component phases, which then led to the invention of composite materials. But according to Bowen (2024), a composite material is an important pillar of engineering and materials science due to the increasing demand for lightweight, high performance and multifunctional systems. In most cases, the reinforcement will carry most of the applied loading, giving the composite its better mechanical properties, and in general the reinforcement is stronger, stiffer and harder than the matrix (Ubi et al., 2022).

Research on Periwinkle Reinforced Composite examined.
Umaru et al. (2019) investigated the effects of isothermal heat treatment of the aluminum-periwinkle shell ash biocomposites. The researchers used a stir casting technique to produce Al-Si alloy matrix composites with 5, 10, 15, 20 and 25 wt% of PSA. The calcinations temperature of periwinkle shells was 1000°C for time duration of 3 hours in order to produce PSA. The as-cast composites were subjected to isothermal heat treatments of 1, 2, 3, 4 and 5 hours at 500°C and were cooled naturally afterwards. The results showed that the as-cast composite with 15% PSA had a hardness of 68 HRF and a tensile strength of 145 MPa. A heat treatment of three hours at 500ºC resulted in the optimal properties of the material, with a hardness of 95 HRF (a 40% increase over the base material), and a tensile strength of 188 MPa (a 30% increase over the base material); longer heat treatment times resulted in over-aging and damage to the properties. The elongation of the as-cast composite was reduced from 8% to 4% following the heat treatment.

Umunakwe et al. (2017) investigated the mechanical properties and micro structure of the particulate periwinkle shell-Aluminium 6063 (Periwinkle shell/Al) metal matrix composite produced by casting in 2 step. The Periwinkle fruit shells collected from Bayelsa State, Nigeria were washed, boiled for 40 minutes at 100°C, dried and then sieved to 75 μ and 150 μ using metal sieves to obtain the ground particles. The two-step casting procedure was employed to manufacture the composites with 1, 5, 10 and 15 wt % filler incorporated. The periwinkle shell particles were added to the aluminium ingot which was heated to 730°C and then cooled to the semi-solid condition of 600°C after which the mixture is hand stirred for 5 minutes. After heating to 730°C, the slurry needed to be rapidly stirred for five minutes, before casting into a metallic die. The X-ray fluorescence research revealed that calcium content was the most predominant (70.33%) in the periwinkle shell particles, while there were smaller amounts of iron, silicon and aluminium. The hardness was measured using a Vickers Hardness Tester and the tensile test was performed using the Instron Universal Testing Machine according to ASTM E8M-91. The microstructural examination was carried out using Optical microscopy. However, the optical micrographs at the filler showed that the two step casting process resulted in uniform filler dispersion in the matrix. The other composites, with larger 150 µm diameter particles, had poorer mechanical properties – finer grains, greater strength, ductility and toughness – than the 75 µm particle ones. The investigators concluded that decreasing the particle size led to improved mechanical properties and the two-step casting process also produced homogeneous dispersion of particles. This study brings the attention to the particle size influence on the mechanical parameters and also the efficacy of doing double stir casting of periwinkle shell-reinforced Aluminium composite.

The use of crushed periwinkle (P) shell as partial sand replacement in concrete was investigated by Otunyo et al. (2013). The researchers converted periwinkle shells into sand sizes of 2.36 mm, 1.18 mm, 0.6 mm and 0.3 mm, which can replace 0% to 50% (by volume) of river sand in concrete. The concrete mix used contained 350 kg/m³ of cement and the water-cement ratio was 0.5. The results have shown that the density of the concrete decreased by 12.5% from 2400kg/m3 when the replacement is 0% to 2100kg/m3 when the replacement is 50%. The compressive strength at 0%, 10%, 20% and 50% replacement decreased by 0%, 12.5%, 22% and 37.5% respectively after 28 days.

Orji et al. (2017) conducted a study on Periwinkle shell-rice husk composite as an alternative to granite in making concrete. The researchers fabricated concrete specimens with 0%, 10%, 20%, 30%, 40% and 50% replacement of granite coarse aggregate by hybrid aggregate which consists of 50% crushed periwinkle shells (natural coarse aggregate) and 50% rice husk (pozzolanic cement). From the result, the density decreased by 20% from the value 2450kg/m³ at 0% replacement to 1950kg/m³ at 50% replacement.

The compressive strength of the 0% replacement of 35 MPa decreased to 30 MPa at 10% replacement (14% reduction), 28 MPa at 20% replacement (20% reduction), and 22 MPa at 50% replacement (37% reduction), after 28 days. The splitting tensile strength for 20% reduction was found to be 2.8 MPa as compared to 3.5 MPa for no reduction.

By Kumar & Thakur (2023) the mechanical and wear properties of the stir cast AZ91D/Al2O3 magnesium matrix composites made by ultrasonic-assisted casting have been studied. To produce the composites of AZ91D magnesium alloy (Mg-la) reinforced with 5, 10, and 15 wt % Al2O3, two different methods – viz, regular stir casting and ultrasonic-assisted stir casting (20 kHz, 500 W) were used. The data indicated that the resulted composite with 10% Al2O3 percentage had yield strength about 165Mpa, ultimate tensile strength 215Mpa and hardness of HV 92. Compared with the conventionally cast composite which had hardness of 77 HV, ultimate tensile strength of 187 MPa and yield strength of 147 MPa, this increased hardness by 20 per cent, the ultimate tensile strength by 15 per cent, and the yield strength by 12 per cent. The grain size of the ultrasonic-assisted composite was 18 μm, which is 49% reduction compared to the traditionally cast composite's grain size of 35 μm. The wear rate of the ultra-sonic assisted composite was 0.18×10-3mm3/N.m which is a 40% decrease from the wear rate of the conventionally cast composite (0.30×10-3mm3/N.m).

Synopsis of Reviews

The empirical review looked at 43 studies linked to Al-4.1%Cu-1.7%Mg/PSA composites in five different topic areas. Research on the processing of Al-Cu-Mg based matrix composites with conventional reinforcement materials such as SiC, Al2O3, and graphene nanoplatelets (GNP) suggests that the maximum hardness and tensile strength values achieved at the optimum volume fraction of reinforcement ranges from 25–50% and 20–40%, respectively, as algae derived from Wang et al. (2022), Yuan et al. (2025), Cai et al. (2023), and Han et al. (2022). However, synthetic reinforcements that are expensive are not feasible for general commercial use in such studies. The studies on agro-waste reinforced aluminium composites indicate that the addition of low-cost materials such as rice husk ash (RHA), bagasse ash (BA), and coconut shell ash (CoSA) can improve the hardness by 20–50% and tensile strength by 15–35% (Ekop et al., 2021; Akande et al., 2024). Most of these research focused on Al Si matrices (AA 6061, AA 6063 and A356), however, and not on the stronger AlCuMg system. According to investigations on periwinkle shell reinforced composites, job materials (PSA) is effective as reinforcement (Adah et al., 2024; Umaru et al., 2015; Atuanya et al., 2024). Adah et al. (2024) reported a 50% increase in the tensile strength of HDPE/PSA composites at 20 wt% PSA content and Umaru et al. (2015) reported improvement in the tensile strength of the Al-Si/PSA composites by 40% after heat treatment. There is no established ideal percentage of PSA in aluminium matrix alloys as the optimums have been reported to be between 20 wt% (Adah et al., 2024). However, there are no studies on assessing PSA reinforcement in Al-4.1%Cu-1.7%Mg alloy. There are also gaps in current research, where a full characterisation of the Al-PSA interface is missing, statistical verification of results is lacking, and a systematic study of the relationship between PSA content and the mechanical properties across a wide range of reinforcement is lacking. This work, therefore, took into consideration the lack of systematic experimental data for Al-4.1%Cu-1.7%Mg PSAs. The study analyzed the PSG in this specific alloy, in 5 Wt. % increments from 0 to 30 Wt. %, with triplicate measurements and statistical analysis (ANOVA and Tukey's HSD) and the extensive characterisation using XRF, XRD, SEM/EDS and density, porosity, hardness, tensile properties and impact energy.

II. METHODS AND MATERIALS

Thus, a certain material was selected in this work to reinforce the periwinkle shell ash particle to the Al-4.1%Cu-1.7%Mg Alloy. The pure Aluminium wire was obtained from Cutix Nigeria Limited at Oba in Anambra State, Nigeria. Cutix Nigeria Limited is a well known manufacturer of copper and aluminium cables & wires, and recognized for producing quality materials according to Nigerian Industrial Standards (NIS). Aluminium metal wire purity manufacturer's specification was 99.7% of which only a small proportion was trace elements including Copper 0.02%, Silicon 0.05% and Iron 0.2%. These impurity levels are below the allowed limits for the manufacture of aluminium alloys from the 2000 series where the minor impurities have little effect on the precipitation hardening reaction (Wang & Starink, 2005). Coils of aluminium wire with a diameter of 9.5 mm were given. The wire shape was chosen for a number of reasons. The first is that the high surface area to volume ratio of the wire introduces rapid melting and reduces the time required to achieve 100% melt of the wire (Callister & Rethwitsch, 2020). Second, no additional cutting or scaling is necessary since it is easy to weight and charge the wire into the crucible furnace. Thirdly, the constant diameter of the wire provides for uniformity during several casting runs. The wire was cut into small segments (approx. 150-200 mm) with a pair of heavy duty (cutting) bolt cutters, and then fired into the crucible. The pure copper (99.9% pure) and pure aluminium (99.7% pure) were equally mixed together under controlled condition to make the master alloy and then cast into small ingots or shot (Polymear et al., 2017). It was a purposeful decision based on known metallurgical practice to adopt a master alloy instead of pure copper. Compared to aluminium, which has a melting point of 660°C, pure copper has a melting temperature of 1085°C (Callister & Rethwisch, 2020). As pieces of solid copper are dropped into an aluminium melt, at 720°C, the copper will gradually go into solution, but not completely to the end of this process, and the copper may also be deposited in the bottom of the crucible. In order to attain the necessary copper content of 4.1 weight percent with the least amount of danger of composition inhomogeneity, the master alloy dissolves fast and evenly in the aluminium melt (Callister & Rethwisch, 2020; Wang & Starink, 2005). The magnesium was also obtained from the same Onitsha chemical supply store, in Anambra State, Nigeria. The magnesium was obtained from highly pure (manufacturer's certificate 99.5%) ingot pure magnesium. The magnesium ingots were sliced into small pieces of about 10-20 g, with a hacksaw. The formation of fine magnesium dust, which is particularly flammable and may catch fire in the air on its own, was minimised .Magnesium shards were stored in a sealed container, some mineral oil was placed on top of the shards to prevent oxidation, and the cutting was performed in a well-ventilated area. The desired magnesium content in the alloy was set to 1.7 weight per cent because for various reasons. It is expected then that the incorporation of the PSA particles and the precipitation hardening reaction will both be enhanced by the amount of 1.7 weight percent magnesium in the matrix alloy. To ensure full dissolution of the copper, magnesium was added to the melt afterwards since this element is more likely to be oxidized and lost. It would be tough to attain the desired composition if magnesium were introduced at the start of the melting cycle because of the substantial losses. Increasing the magnesium concentration, later in the process when the melt is flux coated and the melt temperature has stabilised, can reduce magnesium loss (Callister & Rethwisch, 2020).

The periwinkle shells came from Watt Market popularly called Ndidem ISO which is located in Calabar, Cross River state, Nigeria. Calabar is one of the major processing centres of periwinkle in Nigeria (Adah et al., 2024). Periwinkles are abundant in the coastal waters of Cross River state where they are caught by native women and fishermen using hand-held baskets and traps (Ekop et al., 2021). Periwinkle meat is popularly eaten locally because of its richness in protein, omega-3 fatty acid and low fat (Ituen, 2020). The shells removeable after the meat come from the organism make up about 70–80% of the total weight, and are often left behind as trash (Tobin et al., 2022). Ituen (2020) and Ferguson et al. (2020) reported that these discards accumulate in dumpsites, and shorelines creating environmental problems including aesthetics concerns of coastal landscapes, obstruction of drainage channels, and potential health issues to surrounding community.

III. RESULTS AND DISCUSSION

XRF Analysis of Chemical Makeup of Periwinkle Shell Ash.

The chemical composition of periwinkle shell ash was assessed with a XRF (X-ray fluorescence) spectrometer, MiniPal. After triplicate analyses an

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average composition was obtained and is presented in Table below

Chemical composition of periwinkle shell ash particles

Constituent	Concentration (wt%)
CaO	40.84
SiO_2	32.84
Al_2O_3	10.20
Fe_2O_3	7.02
MgO	1.47
TiO_2	1.07
Mn_2O_3	0.78
SO_3	0.26
Na_2O	0.24
K_2O	0.14
P_2O_5	0.01

The XRF results indicated that two primary components of periwinkle shell ash are calcium oxide (CaO), and silicon dioxide (SiO_2), with 40.84 weight percent and 32.84 weight percent, respectively. Together, these two oxides make up around 74% of the content of ash. Periwinkle shells mostly consist of calcium carbonate (CaCO3), which is decomposed to calcium oxide (CaO) on calcination along with the formation of carbon dioxide (CO_2) hence a high amount of CaO is expected. Very high silica content in the shells indicates that the shells contain silica possibly due to its sea dwelling nature by the periwinkles (Ituen, 2020). Iron oxide (FeO_3) was found to be present at 7.02 wt % and aluminium oxide (AlO_3) was found to be present at 10.20 wt %. The PSA particles' hardness and wear resistance are enhanced by these oxides, which are hard ceramic phases (Akande et al., 2024). 1.47 weight percent magnesium oxide (MgO) and 1.07 weight percent titanium dioxide (TiO_2) were found. The presence of MgO is of great significance as it is known to improve the wettability of the ceramic powders due to its melting temperature of aluminium (Nie et al., 2021). Therefore, MgO could be incorporated into the PSA during the manufacturing of composite, in order to enhance the matrix-reinforcement bonding. Manganese Oxide Mn_2O_3 (MnO_2) was found to be 0.78 Weight percent (Wt %) and Sulphur Trioxide SO_3 was 0.26 Wt %. The amounts of sodium oxide (Na2O), potassium oxide (K2O) and phosphorus pentoxide ($P2O_2$) were 0.24 weight per cent, 0.14 weight per cent and 0.01 weight per cent, respectively. All of these trace elements are regular in shell-based materials and do not affect the reinforcing qualities of the PSA (Onuoha et al., 2021). The presence of hard particles like CaO, SiO_2, AlO_3, FeO_3, MgO, and TiO_2 makes Periwinkle shell ash suitable for use in a particle reinforcement metal matrix composite (MMc) (Adah et al., 2024). Benefits of these hard ceramic phases are that they render the aluminium matrix composite stronger, harder and wear resistant is expected (Akande et al., 2024). PSA has a chemical composition similar to other agro-waste reinforcements reported in the literature, such as: Eggshell ash (95–98% CaO), rice husk ash (85–95% SiO_2) (Prasad et al., 2014). But what makes PSA special is that it has a well-balanced mix of SiO_2 and CaO, which might have synergistic reinforcing effects (Saeed et al., 2025).

XRD Analysis of Periwinkle Shell Ash's Phase Composition

The periwinkle shell ash was analysed for phase composition using Philips X-ray diffractometer (Model: PW 3040/60) with CuKα radiation of wavelength 0.15418nm (Adah et al., 2024). The diffraction pattern was collected over 2θ from 20° to 90° by using a scan speed of 3°/min (Cullity & Stock, 2014). The acquired diffraction pattern was compared with that in ICDD (Goldstein et al., 2017) reference pattern and was indexed. The following were among the stages found; see the table below.

Phases identified in the X-ray diffraction pattern of periwinkle shell ash

Phase	Chemical Formula	Frequency
Calcium silicate with silica and magnesium iron silicate	$Ca_2SiO_4 \cdot SiO_2 \cdot Mg_3Fe_2(SiO_4)_3$	3
Calcium silicate with magnesium iron silicate	$Ca_2SiO_4 \cdot Mg_3Fe_2(SiO_4)_3$	3
Calcium silicate with silica, titanium dioxide, and magnesium	$Ca_2SiO_4 \cdot SiO_2 \cdot TiO_2 \cdot Mg_3Fe_2(SiO_4)_3$	3

iron silicate		
Magnesium manganese calcium silicate with titanium dioxide	$Mg_{0.9}Mn_{0.10}\cdot Ca_2SiO_4\cdot TiO_2$	1
Calcium silicate with silicon dioxide	$Ca_2SiO_4\cdot SiO_2$	2
Titanium dioxide with magnesium iron silicate	$TiO_2\cdot Mg_3Fe_2(SiO_4)_3$	2
Calcium silicate, belite	Ca_2SiO_4	1
Magnesium iron silicate, olivine group	$Mg_3Fe_2(SiO_4)_3$	1

The XRD analysis revealed that the periwinkle shell ash is primarily constitute of complex silicate phases such as titanium dioxide (TiO_2), magnesium iron silicate ($Mg_3Fe_2(SiO_4)_3$) in olivine group of minerals and calcium silicate (Ca_2SiO_4) also known as belite (Cullity & Stock, 2014). From these stages, it is established that the PSA contains some hard ceramic compounds that are thermally stable for the reinforcement of aluminium matrix (Akande et al., 2024). This silica phase in PSA is mainly of calcium silicate (Ca2SiO4) (Saeed et al., 2025). This phase is formed when calcium oxide (CaO) and silicon dioxide (SiO_2) some of the components of the kiln react during calcination. The high melting point (Ituen, 2020) of calcium silicate of about 2130°C makes it suitable for high temperature applications since it does not melt. It is anticipated that the PSA's calcium silicate content would increase the composites' strength and hardness (Akande et al., 2024). $Mg_3Fe_2(SiO_4)_3$ (Magnesium iron silicate) is another major constituent found in the PSA (Onuoha et al., 2021). It is a member of the olivine group of minerals, which are characterized by their extreme thermal stability and high Mohs hardness of 6.5 – 7.0 (Goldstein et al., 2017). It is expected that this step will enhance the composites' resistance to wear (Pillari et al., 2024). Titanium dioxide (TiO_2) was also present in the PSA, either alone or together with magnesium iron silicate (Saeed et al., 2025). With a Mohs hardness of 6.0–6.5, titanium dioxide is a hard ceramic that is known to increase composite materials' resistance to wear (Wang et al., 2022). Hence, the addition of TiO_2 to the PSA has a positive impact on the tribological properties of the composites (Pillari et al., 2024).The calcination condition of 1200°C for 5 hours was sufficient to complete breakdown calcium carbonate to calcium oxide and this was evident from the XRD examination which did not show any sign of unreacted calcium carbonate ($CaCO_3$) (Ituen, 2020). The results of the diffraction pattern indicated that there were no peaks corresponding to CaCO3, suggesting that the calcination procedure was performed successfully (Saeed et al., 2025).

The PSA's 1.47% MgO is beneficial towards creating composites as it improves the wettability of the ceramic particles in the presence of molten aluminium (Akande et al., 2024). This is particularly essential in stir casting for achieving the effective dispersion of these particles and the effective bonding between the matrix and reinforcement (Gudipudi et al., 2020). Adding the 1.7% Mg that is already in the Al-4.1%Cu-1.7%Mg matrix further promotes wetting (Polmear et al., 2017). The results of this characterization agree with previous studies of periwinkle shell ash, also from this region. Ituen (2020) reported that 96.5% CaCO3 was found in shells of the periwinkle of Niger Delta region which on calcination produces CaO. The slight differences in the composition of the shells among the different investigations (Akande et al., 2024) may be due to differences in the shell input, water parameters, or the calcination operating conditions.

Al-4.1%Cu-1.7%Mg/PSA Composites Density

The density of unreinforced Al-4.1%Cu-1.7%Mg alloy is 2.93 g/cm^3 with no weight percent of PSA. This number is in line with the average density range of 2.77-2.84 g/cm^3 for aluminium alloys from the 2000 series, which varies depending on the precise composition and manufacturing parameters. This may have explained the somewhat higher density observed in this investigation when compared to values reported for aluminium which is lighter, 2.70 g/cm^3, and has a lower percentage content of copper, 4.1 weight per cent.

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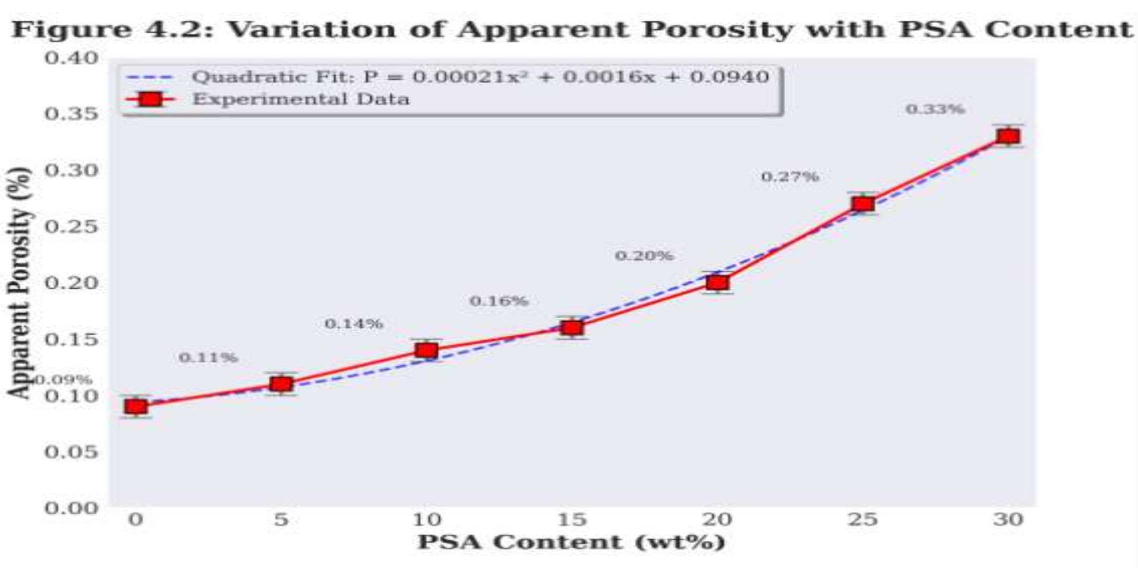
Density of Al-4.1%Cu-1.7%Mg/PSA composites

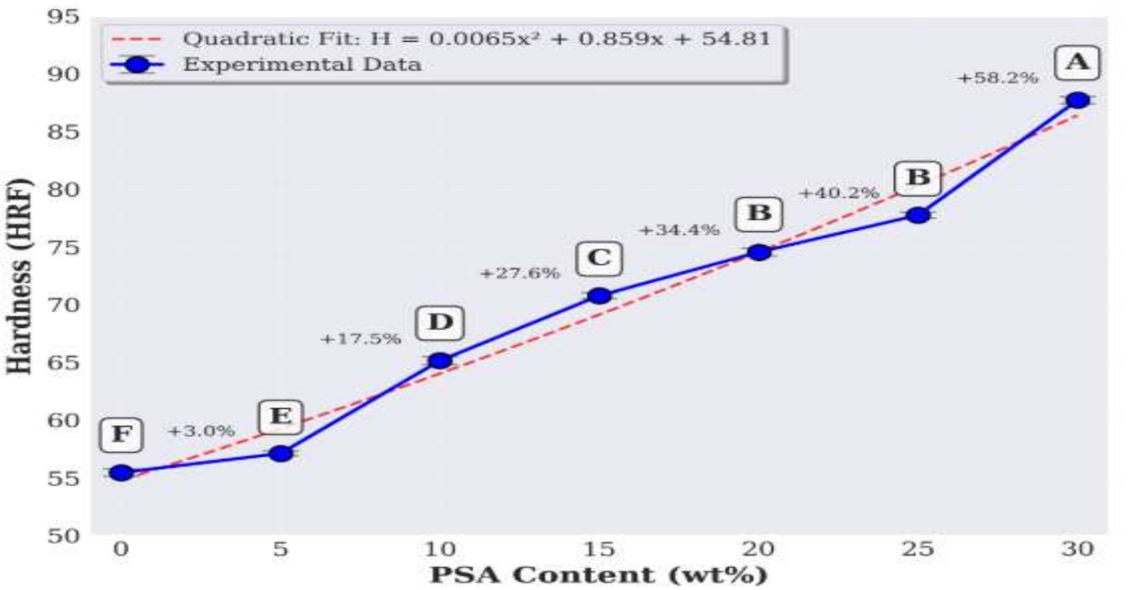
Wt% PSA	Density (g/ cm^3)	Standard Deviation
0	2.93	0.020
5	2.82	0.020
10	2.80	0.020
15	2.76	0.020
20	2.70	0.020
25	2.64	0.020
30	2.60	0.020

The composites' density gradually decreased as the concentration of PSA increased. The density of the composite with 5 weight percent PSA was 2.82 g/cm^3, which was 3.8% less than that of the unreinforced alloy. The density of the 10 weight percent of the PSA composite was 2.80 g/cm^3 (4.4% reduction in density) and the density of the 15 weight percent of the PSA composite was 2.76 g/cm^3 (5.8% reduction in density). The composite with the content of 20 weight percent PSA had a density of 2.70 g/cm^3 that showed a 7.8% decrease, the composite sample with the content of 25 weight percent PSA had a density of 2.64 g/cm^3 that showed a 9.9% decrease and the composite sample with the content of 30 weight percent PSA had a density of 2.60 g/cm^3 that showed a 11.3% decrease. The results indicate that the density of Al-Cu-Mg matrix was successfully reduced by incorporating PSA particles, which can be beneficial in light weight engineering applications. Periwinkle shell ash has a lower density (≈2.4 g/cm³) than the Al-4.1%Cu-1.7%Mg matrix (2.93 g/cm³), so the decrease of density with increasing amount of PSA is expected. The overwhelming rule of mixtures is that the overall composite density decreases with increasing volume fraction of the lower density reinforcement. This trend is in the same line as done in previous studies based on aluminium composites with agricultural products. The decrease in density found in the present study for a 30 weight percent of PSA is comparable to or better than those obtained in previous

The Al-4.1%Cu-1.7%Mg/PSA Composites' Apparent Porosity



In this investigation, the porosity values ranged between 0.09 and 0.33%, that is low compared to several previous stir cast MMC investigations. The reduced porosity observed in the present investigation is due to the twofold stir casting technique which has better dispersion of the particles and less trapping of gas when compared to the traditional single step stir casting process. Low porosity was also due to the use of a covering flux (45% NaCl–55% KCl) and a degassing agent (hexachloroethane), which prevented oxidation and remove the dissolved hydrogen from the melt. A low composite density is equivalent to high porosity and so it is no surprise that the density and porosity results are negatively correlated. With an increase in the concentration of PSA, density decreased and porosity increased. However, the density decrease from 0 to 30 weight percent PSA was 0.33 g/cm^3, which is also larger than the porosity increase from 0 to 30 weight percent PSA of 0.24%. This implies that the density reduction is not because of the porosity but due to the reduced density of the PSA reinforcement itself (Prasad et al., 2014). The experimental densities of the prepared composite are plotted in the figures and are within 1-2% of the optimized dense densities, which indicated that the composites possess low porosity and good bonding at the interface.



Variation of hardness of Al-4.1%Cu-1.7%Mg/PSA composites with PSA content

From this investigation hardness values obtained are in good agreement with other publications on aluminium composites reinforced with agricultural waste. The hardness values obtained in the Al-Cu-Mg matrix during the reinforcement of particle size analysis (PSA) showed that the PSA was highly effective at high levels of reinforcement, 30 weight percent with a greater magnitude of hardness reached, 58.2%. This increasing hardness proved very beneficial for wear resistant technical applications such as automobile brake drums, engine components and other tribology components where the surface hardness is important. The proposed Al-Cu-Mg/PSA composites are interesting other choices of engineering materials in view of their good hardness enhancing property and lightweightness. The strength for Al-4.1%Cu-1.7%Mg/PSA Composite is less than or equal to 14.5 kpsi. The yield strength of the composites has also been determined by using offset method of 0.2% stress-strain curve obtained from tensile testing of the same. Yield strength is the property of a material at the beginning of the plastic deformation, and is an important design consideration for engineering components.

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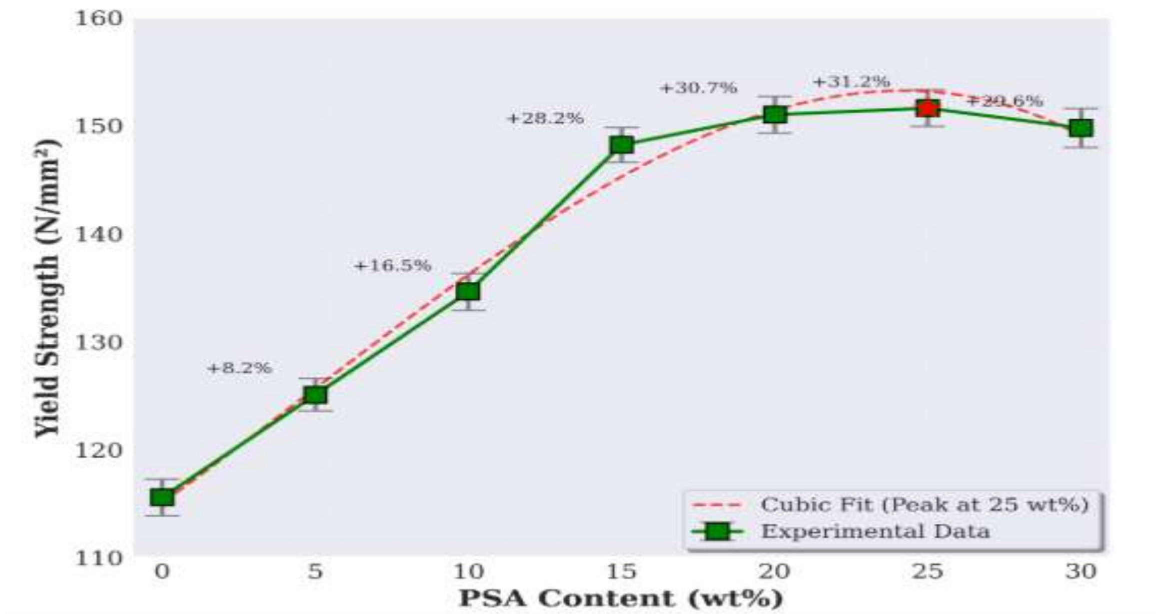
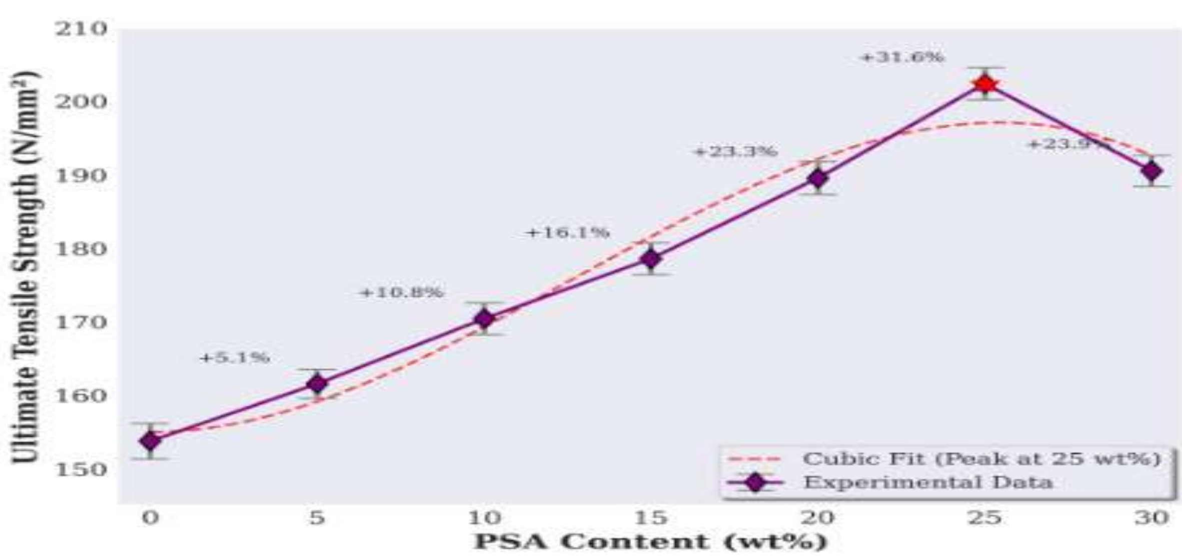


Variation of yield strength of Al-4.1%Cu-1.7%Mg/PSA composites with PSA content

When a reinforcement volume fraction in composite exceeded the optimal value, particle agglomeration was attributed to the slight reduction of the yield strength at 30 wt%PSA. The PSA particles were not uniformly distributed across the matrix but rather seemed to be clustered at 30 wt. % PSA. The agglomerates gave rise to zones of contact between particles, constituting points of stress concentration, and where initiation of fracture could begin, because there was no matrix material between. Moreover, the use of agglomerates also diminished the effectiveness of Orowan strengthening by increasing the effective inter-particle spacings. The ultimate strength of tension that a material can withstand is termed as Ultimate Tensile Strength or UTS. Generally the UTS of particle-reinforced MMCs increases with the increase in reinforcement volume percent to a optimum level, but further increase in volume percent leads to decrease in UTS due to particle-pericle and porosity.



Variation of ultimate tensile strength of Al-4.1%Cu-1.7%Mg/PSA composites with PSA content

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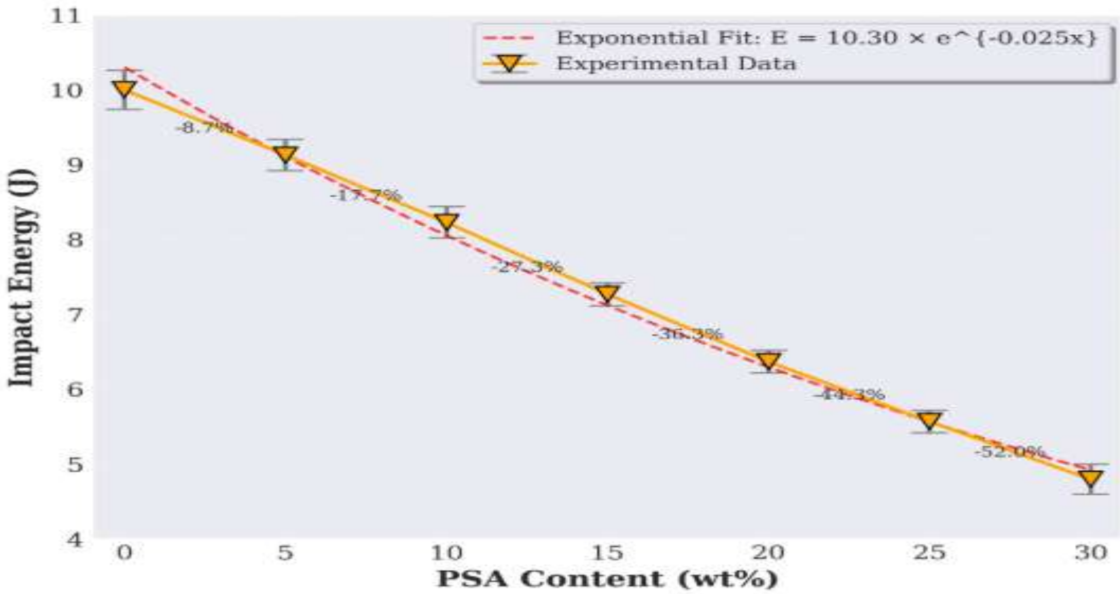
The decrease in the UTS of the composite at the 30 weight percent of PSA was attributed to the particle agglomeration which created initial stress concentrators to initiate premature failure of the composite at stress below the theoretical (calculative) strength of the composite. Even though the optimum weight percentage of the reinforcement for the maximum Tensile Strength was 25 weight percent PSA, it was observed that at 30 weight Percent PSA, the Tensile strength of the material, 190.57N/mm², was still higher than the unreinforced material, 153.77N/mm², indicating that there was still a net benefit to the reinforcement.



Variation of impact energy of Al-4.1%Cu-1.7%Mg/PSA composites with PSA content

This achieved a 52% drop in the effect of energy at 30 wt. % PSA, which is consistent with previous studies. A typical compromise for particle reinforced composites in selecting the optimum reinforcement in for specific applications is between strength or hardness and toughness. A lower amount of PSA (10-15 weight percent) would be desirable for applications where impact resistance is more important, and a higher amount of PSA (20-25 weight percent) would be good for applications that need greater hardness and strength. An impact energy trend on increase of PSA concentration is evident in Figure 4.6 and the line of best fit shows a decreasing trend.

IV. CONCLUSION

Based on the results of the study, the following conclusions are made:

i. The shells of Turritella communis were collected from Calabar, Nigeria and successfully calcined at 1200°C for 5 hrs, after which periwinkle shell ash (PSA) was obtained by crushing and screening the ash to 150 µm. Hard ceramic phases ideal for reinforcing aluminium matrix composites were identified in PSA, according to XRF and XRD examinations.
ii. The double stir casting technique was successfully used to produce Al 4.1%Cu 1.7%Mg/PSA composites with 0,5,10,15,20,25 and 30 weight per cent of PSA. The XRD results for the 25 weight percent PSA composites have confirmed aluminium, intermetallic phases (Al_2Cu, Al_2CuMg) and PSA-derived phases (Ca_2SiO_4, $Mg_3Fe_2(SiO_4)_3$, TiO_2).

V. RECOMMENDATION

i. i.Heat Treatment Studies: This investigation looked at the composites in the as cast condition. In future studies, the effect of T6 heat treatment on the mechanical parameters of Al 4.1%Cu 1.7%Mg/PSA composites should be investigated. It is important to discuss the interactions of PSA particles and precipitation hardening response.
ii. Wear and Tribological Studies: In order to assess the acceptability of Al Cu Mg/PSA composites for brake and engine application in car, further investigation is needed to analyze the dry sliding wear behaviour of these composites in sliding conditions using pin on disc tribometry with varying loads and sliding speed.

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