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EVALUATING THE ENGINEERING PROPERTIES OF RICE HUSK ASH/YAM PEEL ASH HYBRID SCRAP ALUMINUM MATRIX COMPOSITE

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Agricultural wastes, composites, environmental protection, mechanical properties, sustainability

Abstract
This research was aimed at the production of aluminum (scarp aluminum) matrix composite reinforced with various quantities of rice husk ash (RHA) and yam peels ash (YPA) using the stir casting methods. Four aluminum matrix composite samples were produced through the hybridization of RHA and YPA, at the rate of 4, 8, 12 and 16% wt. The hardness, tensile strength and compressive strength of all the composite samples and the scrap aluminum were measured in accordance with America Standard Testing Material (ASTM) International approved guidelines. The results obtained from the investigated depicted that the fillers had substantial effect of the composite mechanical properties. It was noted that the composite samples tensile and compressive strengths increased from 115 MPa to 153 MPa, and 128 MPa to 244 MPa, respectively, as the fillers volume increased from 4% to 12%; while the hardness increased from 54.31 to 67.18 as the fillers quantity increased to 45 to 16%. Findings of this research had affirmed that higher fillers quantity – greater than 12% - caused noteworthy deterioration in the tensile and compressive strengths of the hybrid composite developed. The significant mechanical properties recorded in the hybrid composite produced from the RHA and YPA is an indication that, biodegradable materials can used to produce essential lightweight machine parts for the aeronautical and automobile industries.

1.0 INTRODUCTION

Sustainable development is one of the major environmental goals of the century. It can be attained through substituting environmental unfriendly materials with environmentally friendly materials. This will aid the reduction of greenhouse gases (GHS) and other toxic material emissions into our ecosystems. Studies have revealed that organic materials have environmentally friendly characteristics and good engineering properties that make them excellent substitute materials, for inorganic materials, during engineering materials production (Muni *et al.*, 2019; Ijabo *et al.*, 2019; Edafeadhe *et al.*, 2020; Sydow *et al.*, 2021). Engineering properties of agricultural materials

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are dependent on the prevailing climatic and soil conditions and, on processing and storage conditions. Also, combustion has been established to increase the oxides component of agricultural products, hence increasing their suitability for composites production, and in soil stabilization (Chandla *et al.* 2017; Rajeev *et al.*, 2022; Uguru *et al.*, 2021).

Scrap metal recycling is another method of converting waste to wealth, as they can be recycled, reinforced and thereafter used to produce other forms of sustainable materials. Apart from wealth creation, material (both organic and inorganic) recycling plays an essential role in solid waste management, which is a major problem in numerous countries (Vinod *et al.*, 2019; Akbar *et al.*, 2020; Agbi and Uguru, 2021). Poor waste management had been identified as one of the major contributors to the prevalence of chronic ailments in mankind. Metallic components of solid wastes lead to heavy metals toxicity which can results in brain, kidney and liver disorder in humans and animals, while the organic components of solid wastes tend to increase the pathogenic microorganism population in the environment (Zainal *et al.*, 2018; Uguru *et al.*, 2022).

Composites are materials produced through incorporation of either particulates, fibres or both particulates and fibres into a matrix, to produce a new material with better engineering properties when compared to the matrix or the reinforcement materials. Three main types of matrices - polymers, ceramics and metals - are used in composite production to produce materials with desirable engineering qualities (Edafiadhe *et al.*, 2019; Padnuru Sripathy and Gupta, 2021; Islam *et al.*, 2023). Aluminum matrix - a metal matrix – is widely used in the composite industry to produce aluminum matrix composite (AMC). Aluminum matrix composites are often preferable to other metal matrix composites (MMCs), due to their light weight and other appreciable engineering properties (Bodurin *et al.*, 2015; Chinta *et al.*, 2017). According to Anilkumar *et al.* (2011) and Kumar *et al.* (2022), AMCs are extensively employed in the sport, aerospace, medical, automobile and marine industries, to produce most of their essential operational components.

Agricultural waste materials are cheaply available during the produce harvesting and processing periods, and are widely recycled to produce different products. In engineering sciences and the engineering industry, there are several composites reinforcement materials (Aigbodion, 2012; Nath *et al.*, 2018; Obukoeroro and Uguru, 2021; Uguru *et al.*, 2023). Remarkably, numerous studies have shown that incorporating agricultural waste materials into aluminum matrix yielded AMCs with good engineering behaviour (Siddharth and Rao, 2017; Daramola *et al.*, 2018; Udoye *et al.*, 2020). Likewise, Jadhav *et al.* (2015) reported that coconut shell ash (CSA) reinforced aluminum matrix produced a composite with a hardness value of 60.96, while the hardness value of the composite produced through hybridization of CSA and groundnut shell ash (GSA) was 76.96. Similarly, Kumar and Kumar (2020) in their research into the engineering properties of rice husk ash (RHA) reinforced aluminum matrix composite observed that, the hardness value and tensile strength of Al7075 increased from 60 to 125 and 120 MPa to 270 MPa, respectively, after the introduction of 8% RHA.

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Though several related literature searches had revealed information on the hybridization of agricultural waste materials in metal composite production, there is however information dearth on the specific hybridization of rice husk ash/yam peel ash. These raw materials are abundant in several regions of the world. Therefore, the purpose of this study is to produce and evaluate the mechanical properties of rice husk ash/yam peel ash hybridized aluminum matrix composite.

2.0 MATERIALS AND METHODS

2.1Scarp aluminum

The scarp aluminum was procured from a scrap metal collection yard in Delta State, Nigeria. It was washed under running water to remove the dirt and other foreign bodies from it. Scarp aluminum packaging are extensively employed as disposable containers for several beverages and they often end up as solid waste and scraps after numerous entertainments and parties.

2.2 Yam peels ash and rice husk ash

Rice husk and yam peels were burnt in an electrical furnace at a temperature of 600^{o}C, to obtain rice husk ash (RHA) and yam peels ash (YPA) respectively.

2.3 Composite production

The hybrid composite was produced in accordance with component reinforcement ratios shown in Table 1. The Stir casing method as described by Chinta *et al.* (2017) was used to produce the composite. The equipment used for this technique comprises of a non-reactive graphite vessel with melting point greater than 900^{o}C, a mechanical feeder, and a stirrer that rotates with speeds that ranged between 50 revolution per minute (rpm) and 500 rpm.

Table 1: The composite reinforcement plan

Sample code	Composite component
SAM 1	Pure scrap Al
SAM 2	Scrap Al + 2% RHA + 2% YPA
SAM 3	Scrap Al + 4% RHA + 4% YPA
SAM 4	Scrap Al + 6% RHA + 6% YPA
SAM 5	Scrap Al + 8% RHA + 8% YPA

2.4 Mechanical properties testing

Tensile test

The samples tensile strength (TS) was determined in accordance with America Standard Testing Material (ASTM) E8/E8 M-11 procedures, by using the Universal Testing Machine to measure the maximum snapping force at a speed of 1 mm/min. Thereafter, the TS value of each sample was calculated through Equation 1.

$$Tensile\ strength\ (\sigma) = \frac{Force_{Max}}{Area} \qquad 1$$

Compressive test

The samples compressive strength were determined in accordance with the ASTM E9 (2019) approved procedures for metallic materials.

Hardness test

The Rockwell Hardness Test (RHT) was used to determine the hardness of the composite in accordance with ASTM - E18 (2022) guidelines.

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3.0 RESULTS ANALYSIS AND DISCUSSION

3.1Tensile strength of the composite

The tensile strength (TS) of the hybridized composite samples is shown in Figure 1. It can be seen that the fillers have significant effect on the tensile strength of the scarp aluminum, as its TS value increased non-linearly from 79 MPa, as the quantity of the reinforcement materials (RHA + YPA) in the composite increased from 4% to 16%. Additionally, findings from this study revealed that a 12% filler (6% RHA + 6% YPA) loading developed the peak TS (153 MPa), this declined to 136 MPa as the filler loading increased to 16% (8% RHA + 8% YPA). This could be attributed to the poor bonding between the matrix and the fillers, resulting from excessively large quality of the fillers thus resulting to fragile interfacial bonding in the composite (Uguru and Oghenerukevwe, 2021). Similarly, Esegbuyota *et al*. (2019) stated that plants materials tend to improve the engineering properties of composites at lower reinforcement ratios, but become detrimental at higher reinforcement ratios. The increment in the composite's tensile strength can be linked to the higher strength resistance of both RHA and YPA (Seikh *et al*., 2022).

Results obtained from this study are similar to those reported by Aigbodion (2012) for RHA/iron hybridized AMC, as the TS increased unevenly from 115 to 122 MPa as the RHA quantity increased from 5% to 20%. Similarly, Tile *et al*. (2018) in their investigation into engineering properties of composites observed that, the tensile strength of Al-Mg-Si/groundnut shell filler composite declined gradually at the fillers loading increased from 4 wt% reinforcement to 10 wt%.

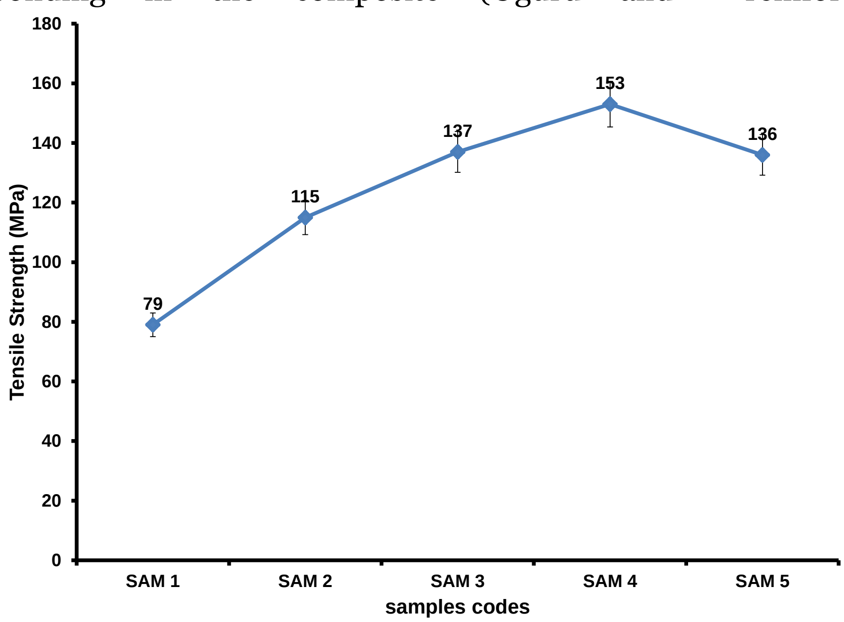

Figure 1: Tensile strength of scrap Al and Al matric hybrid composite

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3.2 Hardness of the composite

Figure 2 shows the hardness of the scrap Al and the composite samples produced through hybridization with RHA and YPA. It can be seen that the hardness values of the composite samples ranged from 54.31 to 67.18; while the pure scarp Al (SAM 10 had the least hardness value of 47.70. Also, it was noted that the composite produced through hybridization of scarp Al, and 16% RHA and YPA (SAM 5) had the highest hardness value of 67.18. Generally, the composite hardness increases as the volume of the scrap Al matrix declined from 100% to 84%. Furthermore, the results revealed that the composite hardness values increased non-linearly as the RHA and YPA reinforcement quantity in the composite increased from 4% to 16%. According to Mohanavel and Ravichandran (2019), the composites hardness values is directly proportional to the fillers reinforcement quantity, if the fillers volume did not exceed 30% wt. Similar results were reported by Daramola et al. (2018) during their research into the mechanical properties of recovered silica particles reinforced Al matrix composite.

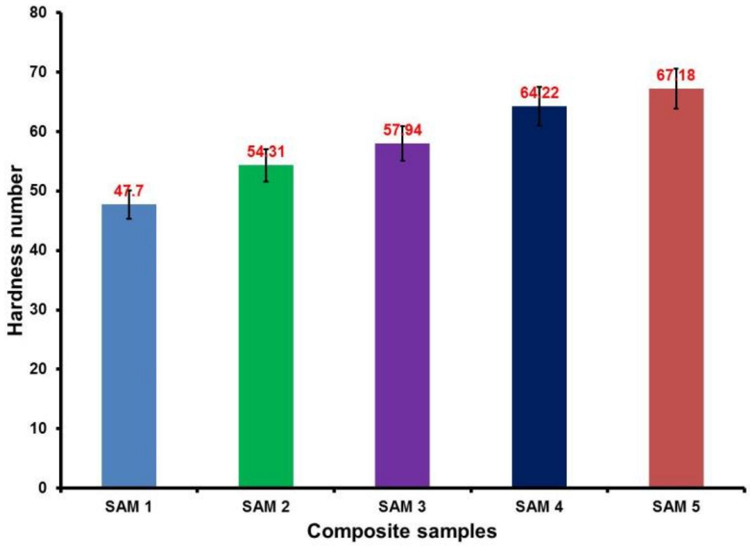

Figure 2: Hardness of the scrap Al and Al matric hybrid composite

3.3 Compressive strength of the composite

The mean results of the composite's compressive strength are presented in Figure 3. The compressive strength values increased unevenly from 128 MPa to 226 MPa, as the fillers volume increased from 0% to 16%. As shown in Figure 3 the compressive strength value of SAM 1, SAM 2, SAM 3, SAM 4 and SAM 5 composites samples were 128 MPa, 157 MPa, 203 MPa, 244 MPa and 226 MPa respectively. These findings revealed that when the quantity of RHA and YPA in the Al matrix composite is increased below 12% wt., the compressive strength increases up to the 12% mark, while above 12% wt. there is deterioration in the compressive strength of the composite. This

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signified that above 12%, filler loading produced weaker compressive strength of the composite. Chinta *et al*. (2017) reported similar variation in the compressive strength of RHA/SiC reinforced hybrid AMC, with gradual increment in the volume of the RHA and SiC in the composite. According to the research results of Pazhouhanfar and Eghbali (2018), fillers volume and particle size exhibit significant influence on the engineering properties of composites.

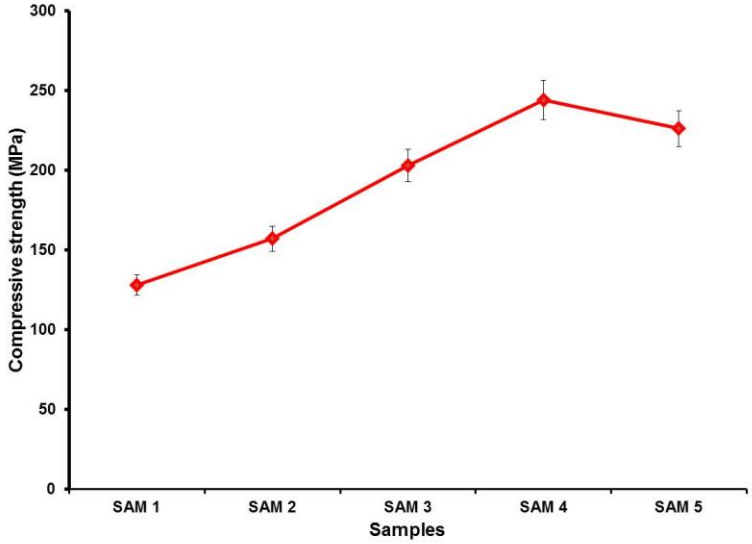

Figure 3: Compressive strength of the scrap Al and hybrid composite

The difference in the engineering properties of the composites produced in this research, when compared to the results of other authors (Fatile *et al*., 2014; Singh *et al*., 2015; Haque *et al*., 2016) who used similar materials in their composites production, could be attributed to: maturity stage of the produce, storage and processing operations employed on the produce, crop variety, recycling techniques, and farming patterns. The above mention factors affect the mechanical properties of agricultural waste products, which directly translates to the mechanical behaviour of materials produced with them (Maalekuu *et al*., 2014; Ekruyota *et al.,* 2021; Awad *et al*., 2022; Beautin Nirsha *et al,* 2023). Also, production techniques and reinforcement placement pattern greater contribute to the engineering properties of the composites produced (Kumar *et al*., 2022). Through the Al matrix composite reinforced with agricultural materials produced in this study had lower engineering properties, when compared to Al matrix composites reinforced with metallic/inorganic materials (Chinta *et al*., 2017; Kumar *et al*., 2022; Pendhota *et al*., 2023), the appreciable values recorded in the green composite produced is an indication that organic materials can used to produce machine parts for the automobile industry.

4.0 CONCLUSION

The engineering properties of scarp aluminum matrix hybrid composite containing 4, 8, 12 and

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16% wt. rice husk ash (RHA) and yam peels ash (YPA) combined, as reinforcement fillers were investigated, in accordance with the procedures of America Standard Testing Material (ASTM). Findings of the laboratory tests revealed that the fillers had significant impact on the three mechanical properties (tensile strength, compressive strength and hardness) investigated for the composite samples produced. It was observed that the hardness, tensile strength and compressive strength of hybrid composite samples produced increased with an increase in the fillers fractions. Furthermore, it was established that high filler volume (greater than 12%), had a deteriorating impact on the composite's tensile and compressive strength. Interestingly, the findings of this research had affirmed that high quality composites, which can be used in the automobile and marine industries, can be produced through metallic hybridization of green materials.

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