

PAPER 66 – CHARACTERIZATION OF ALUMINIUM-MATRIX COMPOSITE WITH ACID-TREATED CARBONIZED COCONUT HUSK REINFORCEMENT

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ABSTRACT

Aluminium alloys have been widely applied in the automobile, aerospace, defence, and other engineering sectors but low strength and low melting point were always seeming problematic. Many researchers have made use of synthetic reinforcement such as SiO₂ and SiC to solve the problem, but expensive. Similarly, many studies have been done on agricultural wastes as reinforcements with and without acid treatment. Considering the above, the effect of acid-treated carbonized coconut husk reinforcement on the properties of aluminium-matrix composites was studied. The stir-casting method was used to make composites with reinforcement ranging from 1.2 wt.% to 4.8 wt.% at a 1.2 wt.% interval. The mechanical, microstructural, thermal, and physical properties were investigated. The hardness and tensile strength of the composites increased from 9.40 BHN and 1200 MPa to 12.20 BHN and 1600 MPa in the sample containing 4.8 wt.% reinforcement, respectively. The newly developed aluminium metal matrix composite can find application in automobile parts production.

KEYWORDS: Reinforcement, carbonization, acid treatment, composite, coconut husk

1. INTRODUCTION

Aluminium and its alloys are commonly used as structural materials particularly in the aerospace industry due to their lightweight property (Dursun & Soutis, 2014; Georgantzia *et al.*, 2021; A. M. Usman *et al.*, 2014). The low strength, low melting point, and poor wear resistance are still a problem (A. Usman *et al.*, 2014). The use of reinforcements such as SiO₂, SiC particles and whiskers, or other elements or compounds as alloying elements was the common way of solving such problems (Arun *et al.*, 2013; Senapati *et al.*, 2014). The cheap way to improve aluminium's mechanical properties is to reinforce it with the available waste as reinforcement in the composite formulation. Research efforts have thus focused on the use of recycled wastes for composite development. Composite materials are materials made of two or more constituent materials with different physical or chemical properties that produce a material with different characteristics from the individual components when combined. Agricultural wastes are therefore the best substitute for expensive reinforcements because of increased farming activities and the deployment of modern technology resulting in vast renewable waste materials (Lancaster *et al.*, 2013).

Agricultural wastes are by-products or residues of agricultural processing. Bahrami *et al.* (2016) enumerated several benefits of using agro wastes as reinforcements including reduced production costs, availability, renewability, environmental conservation and safety. The use of naturally sourced particulates has been reported to offer good reinforcement constituents (Alaneme & Olubambi, 2013; Joseph & Babaremu, 2019; Nwobi-Okoye & Ochieze, 2018).

The present work focuses on the effect of treated carbonized coconut husk (TCCH) on the properties of aluminium matrix composites (AMCs)

2. MATERIALS AND METHODS

2.1 Materials

The materials used in this work include coconut husk (CH) which was sourced locally at Badagry, Lagos State. HCl was purchased at Tony Nigeria Enterprises, Ojota, Lagos. Aluminium scraps were obtained from the Materials and Metallurgical Engineering foundry. Some apparatus and equipment used include a muffle furnace, digital weighing balance, Whatman No.1 filter paper, sieve, laboratory blade mill, distilled water, carbonization chamber, oven, stirrer, and crucible furnace, available at the Department of Materials and Metallurgical Engineering, University of Ilorin, Nigeria. Equipment used for characterization includes Brinell hardness tester, and a Universal testing machine (UTM), both available at the Department of Mechanical Engineering, University

of Ilorin, Nigeria. Thermogravimetric analysis (TGA), X-Ray Diffractometry (XRD) and X-Ray Fluorescence (XRF) were carried out at the Centre for Solid Minerals Research & Development, Kaduna State Polytechnics, Nigeria. Scanning Electron Microscope (SEM) and Energy Dispersive X-ray Spectroscopy (EDS) at the Tshwane University of Technology, Department of Chemical, Metallurgical and Materials Engineering, Pretoria, South Africa.

2.2 Methods

The coconut husk was sorted to remove impurities, washed and sun-dried for 7 days to reduce the moisture content. This was carbonized at a temperature between 500 – 550 °C in a carbonization chamber for 60 minutes. The carbonized coconut husk (CCH) was pulverised using a laboratory blade mill and sieved to obtain particles below 100 µm. This was then leached with 0.5 M HCl for 120 minutes at laboratory temperature. This was filtered using Whatmann No.1 filter paper, rinsed several times with distilled water and thereafter dried in the oven to obtain TCCH.

The stir-casting method was used to produce specimens for characterization. Aluminium scrap was melted in a crucible furnace at a temperature of 700 °C. A measured amount of CCH was preheated to 300 °C for 3 hours in an electric oven to remove moisture. A calibrated pouring cup was used to tap 250 g of the molten metal and the preheated CCH was then mixed thoroughly for homogeneity. The mixture was poured into the preheated mould cavities at a maintained pouring temperature of 680 °C. The composite was then allowed to solidify, and samples were removed, cleaned, labelled, and kept for characterization. The formulation of the composites is presented in Table 1.

Table 1: Weight percentage of aluminium scraps and carbonized coconut husk

| SAMPLE ID | ALUMINIUM SCRAP (g) | CCH (g) | ALUMINIUM SCRAP (wt.%) | CCH (wt.%) |
|-----------|---------------------|---------|------------------------|------------|
| A | 250 | 0 | 100 | 0 |
| B | 250 | 3 | 98.8 | 1.2 |
| C | 250 | 6 | 97.6 | 2.4 |
| D | 250 | 9 | 96.4 | 3.6 |
| E | 250 | 12 | 95.2 | 4.8 |

TGA, XRF and XRD were carried out on CH to determine its thermal stability up to 900 °C, chemical composition and phase identification, respectively. Tensile, SEM/EDS, XRD and hardness of the composites were carried out to establish their mechanical and chemical properties.

3. RESULTS AND DISCUSSION

3.1 Treated Coconut Husk Features

The thermal characteristics of coconut husk by heating from room temperature to about 900 °C is presented in Figure 1. The thermal decomposition of agriculture was elucidated in Adebisi *et al.* (2019) as three stages of dehydration, volatilization and carbonization in an inert environment. The weight loss curve showed the first inflection at a temperature of 190 through 205 °C, which corresponds to the commencement of hemicellulosic compounds. This stage is more rapid from 280 to 375 °C. Cellulose decomposition occurred up to around 430 °C after which lignin and the main carbonization stage occurred. The first stage of dehydration is not pronounced in the TG curve, unlike the derivative (DTG) curve which indicated moisture loss up to around 100 °C. The derivative of the thermo-gravimetric analysis (DTG) curve shows the energy loss when the coconut husk was heated at room temperature, presenting a case of an exothermic process. The second stage of this thermal decomposition has been reported as the most crucial stage when all volatiles thermally left biomass to leave a residue of carbon char (Adebisi *et al.*, 2019; Munir *et al.*, 2009; Nurhayati & Fauziah, 2013). The char left is principally the carbon skeleton of the biomass, which is about 20% as reported in Adebisi *et al.* (2019) to range between 18.60–29.40%. This carbon network is a ceramic with brittle nature and thus enhances the pulverization of the carbonized biomass.

As presented in Table 2, the compounds that constituted coconut husk are MgO, Al₂O₃, SiO₂, P₂O₅, SO₃, Cl, K₂O, CaO, TiO₂, V₂O₅, Cr₂O₃, MnO, Fe₂O₃, CuO, ZnO, SrO, BaO, and PbO. With carbon as the major element, silicon, iron, potassium, magnesium, and manganese also constitute about 95%. There is clear evidence of the removal of soluble silica from the TCCH. The presented elements are similar to the chemical composition obtained in coconut husk reported by Anuar *et al.* (2018), Anuar *et al.* (2020) and A. Usman *et al.* (2014). Phase identification of

compounds in a treated carbonized coconut husk, as shown in Figure 2, presented more crystalline reinforcement particles than untreated carbonized coconut husk. The XRD spectrum obtained for TCCH showed the most prominent peak at 27° as against 32° in TCC.

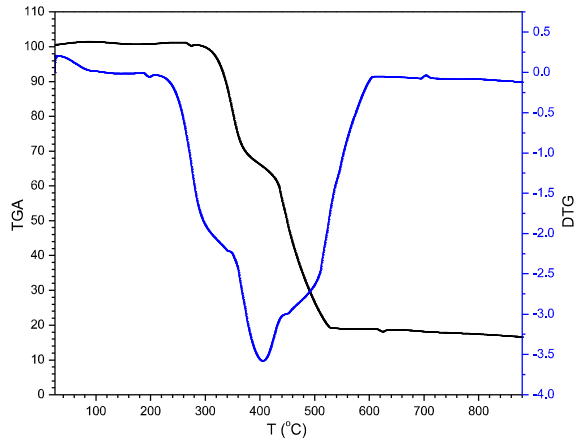


Figure 3: Thermogravimetric analysis of coconut husk

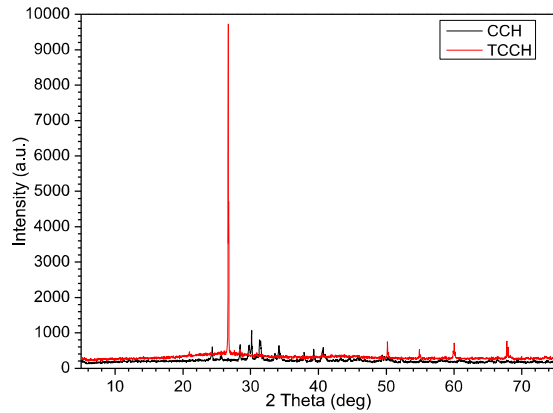


Figure 4: XRD of carbonized coconut husk and treated carbonized coconut husk

Table 2: Elemental composition of carbonized coconut husk and treated carbonized coconut husk

| Compounds | MgO | Al ₂ O ₃ | SiO ₂ | P ₂ O ₅ | SO ₃ | Cl | K ₂ O | CaO | TiO ₂ | V ₂ O ₅ | Cr ₂ O ₃ | MnO | Fe ₂ O ₃ | CuO | ZnO | SrO | BaO | PbO |
|------------|------|--------------------------------|------------------|-------------------------------|-----------------|------|------------------|------|------------------|-------------------------------|--------------------------------|------|--------------------------------|------|------|------|------|------|
| CCH (wt%) | 4.16 | 0.16 | 72.13 | 0.49 | 0.24 | 1.28 | 6.89 | 1.24 | 0.09 | 0.06 | 0.06 | 3.27 | 8.78 | 0.43 | 0.02 | 0.01 | 0.80 | 0.74 |
| TCCH (wt%) | 4.20 | 1.43 | 61.95 | 1.02 | 0.29 | 1.28 | 8.37 | 5.38 | 0.13 | 0.07 | 0.09 | 4.07 | 8.16 | 0.31 | 0.41 | 0.01 | 2.10 | 0.73 |

3.2 Properties of Aluminium Treated Carbonized Coconut Husk Composites

The chemical composition of the aluminium scrap and composites produced showed that the addition of TCCH to the molten scrap increases the amount of almost all the constituting elements except silicon and titanium.

Table 3: Composition of the aluminium alloy and Composites Produced

| Elements | Al | C | Fe | Ag | Si | Ca | Cl | K | Mg | S | O | Ti | P |
|----------|-------|------|------|------|------|------|------|------|------|------|------|------|------|
| 0 wt% | 89.66 | 2.93 | 2.11 | 1.59 | 1.03 | 0.64 | 0.57 | 0.48 | 0.27 | 0.24 | 0.20 | 0.19 | 0.08 |
| 2.4 wt% | 85.70 | 4.42 | 2.51 | 2.55 | 1.00 | 0.76 | 0.64 | 0.59 | 0.35 | 0.45 | 0.75 | 0.00 | 0.28 |
| 4.8wt % | 77.89 | 4.72 | 2.16 | 3.39 | 1.36 | 1.08 | 2.49 | 0.92 | 0.43 | 1.16 | 3.50 | 0.00 | 0.82 |

Figure 3 shows the XRD spectra for the scrap and composites. The addition of TCCH resulted in a shifting peak and lowered the intensity of the unreinforced aluminium. The strengthening of the produced composites is influenced by the nature of the reinforcing phases. The hardness values for the aluminium composites produced

are shown in Figure 4. The addition of TCCH slightly increases the hardness values of the composites. This may be a result of poor wettability of the reinforcement in the aluminium scrap used during casting.

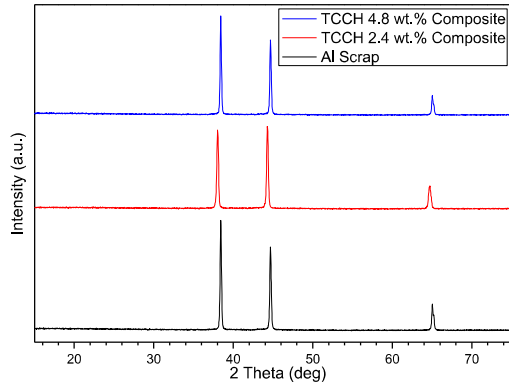


Figure 5: XRD patterns for unreinforced aluminium scrap and produced composites

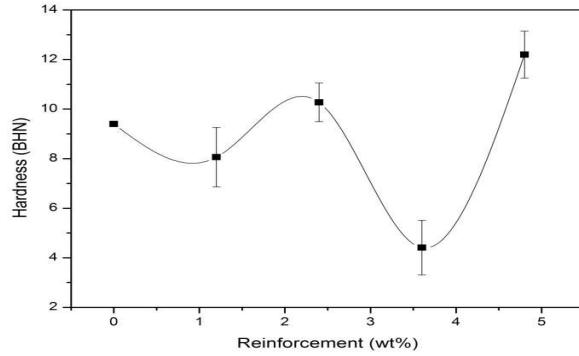


Figure 6: Hardness values for aluminium carbonized coconut husk composites

In Figure 5, tensile strength was observed to decrease by introduction of TCCH but later increased. The improved strength could be associated with the addition of TCCH well dispersed within the matrix. When the amount added exceeds a certain limit, agglomeration of the particles may be a source of stress raiser that will eventually result in failure (Oghenevweta *et al.*, 2016). The tensile strength improved from 1143 MPa to about 1600 MPa for 4.8 wt.% addition.

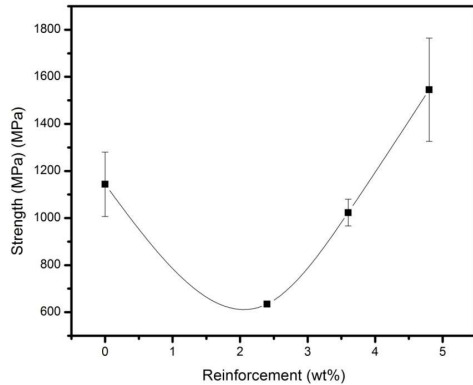


Figure 7: Ultimate tensile strength of the composites

4. CONCLUSION

This work has provided insight into the effect of introducing acid-treated carbonized coconut husk as reinforcement into the aluminium alloy. It was observed that:

1. The hardness of the composite materials increased from 9.40 BHN to 12.20 BHN.
2. The tensile strength of the composites increased from about 1200 MPa to 1600 MPa.
3. Microstructural analysis results show that Quartz (SiO_2) and Graphite (C) have the highest percentage among all the compounds and elements present in the reinforcement.

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