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Assessment of Mechanical Properties of Aluminium Metal Matrix Composite Reinforced with Carbonized Eggshell Ash (CESA)

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ABSTRACT

A useful alloying agent for aluminium-based composites is eggshell powder, which has a well-deserved reputation for hardness. Aluminium cans and eggshells are regarded as waste and a pollutant because they are no longer needed. Conversion of wastes into useful products will be of economic boost for a nation and make the environment clean. Eggshell particles were studied for their reinforcing properties in a waste aluminium alloy in this study. An eggshell particle of 150 µm in size and a weight fraction of 2%, 4.4%; 6.6%; 8.8%; and 10% was incorporated into aluminium produced from recycled aluminium wastes during casting. A Light Emission Polyvac Spectrometer was used to determine the alloy's constituent makeup. The required experimental procedures and tools were used to measure the tensile strength, hardness, and impact strength. Using a weight fraction of reinforcement of 2, 4, 6, 8, and 10%, tensile strength was found to be 78.07098MPa; 81.09587MPa; 83.04546MPa; 86.12769MPa; and 89.12769MPa respectively. Hardness values of 75.25Hv, 77.03Hv, 78.27Hv, 80.15Hv, and 85.72Hv were obtained at the same specified% weight fraction. Impact strength values of 12.64J, 10.08J, 7.39J, 7.12J, and 7.39J were obtained at the same composition. It may be inferred that the mechanical characteristics of the aluminium alloy reinforced with eggshell particles improved considerably with the number of eggshell particles used and the study, therefore, converted waste to worth.

1. INTRODUCTION

Composites with a primary bulk phase of metal are known as "metal matrix composites." Reinforcements are materials that are added to the matrix phase to improve the material's properties. Particles or fibers, depending on the shape, are spread throughout the metal matrix. Particulate metal matrix composites are metals reinforced with hard particles like boron carbide or aluminum oxide. Fiber-reinforced composites are formed when long or short fibers such as carbon fibers are added. Furthermore, laminate composites may be categorized into unidirectional, bi-directional, or multi-directional mats, reinforced in a metal matrix of fiber-reinforced composites [1]. Because of its potential uses in sectors such as aerospace, automotive, thermal management, electrical and electronic, as well as sports, aluminium metal matrix composites (AMCs) have received a lot of attention over the years. Unlike many commercially available high-strength monolithic materials, AMCs are designed materials manufactured by adding non-metallic reinforcements to aluminum or its alloy to increase attributes such as strength, hardness, stiffness, electrical, and thermal conductivity. AMCs have a good strength-to-weight and stiffness-to-weight ratio [2]. The high cost of AMCs limits their applications, necessitating the search for low-cost agricultural resources to serve as reinforcements [3]. Continuous and discontinuous fibers, whiskers, or particulate matter could be used as reinforcement [4]. High performance, economy, and environmental benefits are the key driving forces behind the use of AMCs in most industries. Reduced weight, which affects consumption, higher efficiency, less noise, lower pollution, and improved shock-absorbing capacities are some of the primary benefits of AMCs in the transportation sector [5].

Local fowls are raised by many households in both rural and urban areas of Nigeria. It has been developed and converted into a profitable enterprise in recent years. Despite the numerous benefits derived from the business, the manufacturing process continues to face problems [6]. Poultry farming is a prominent agricultural enterprise in India, with an average annual growth rate of 6% in egg production. As a result, eggshells will be a biodegradable waste that can also be used as a low-cost reinforcing material in the composite matrix [7]. It was also described as a rich supply of calcium carbonate with carbonization capabilities that can be utilized to strengthen metals [8]. When mild steel was reinforced with eggshell mixed with sugar cane, melon shell waste, and flower waste, it was revealed that its hardness value improved dramatically. When employed as an alloy or reinforced, aluminum has features such as ductility, brittleness, corrosion resistance, high electrical conductivity, low relative density, excellent strength to weight ratio, and high tensile strength. These desirable properties of aluminum make it a good attribute for metal forming, machined, and fabrication even when the alloy is used or reinforced. Engineers and scientists are continually looking for ways to enhance the properties of any material that could be practically used in any scope of their practice and ensure the environmental effects are also well considered. Many types of research have been carried out in the development of AMCs but little attention has been given to waste conversion to worth as regards base material and reinforcement at the same time [9].

Engineers in developing countries like Nigeria have not taken the advantage of recycling waste to generate money from the fast-growing technological advancement and revolution being experienced in the world. This has led to the increase in waste materials around the community without being channeled appropriately. It has been identified in developed countries that waste such as scrap automobile parts, scrap building materials, beverage cans, piston and roofing sheets, papers, and much more waste can be recycled to produce more useful materials. Also, the problem of animal waste disposal is posing a challenge to the general public as this waste pollutes our environment as well as is an eyesore to the public. Therefore, if these wastes can be used to produce a new composite, it will be a good solution to the problem of waste pollution, disposal, and control. Aluminum matrix composite from the study has shown to have several advantages over unreinforced monolithic material such as greater strength, improved stiffness, and reduced weight, among others [9]. The need for composite materials that can serve better and save energy by recycling aluminum scrap is the focus of this research.

2. MATERIALS AND METHODS

2.1 Preparation of carbonized eggshell ash (CESA) and production of aluminium alloy (Matrix)

The matrix material selected for the study is discarded aluminium cans and the eggshell which is an agro waste material were sourced from Afe Babalola University Ado Ekiti (ABUAD) cafeteria and ABUAD farm respectively.

Figure 1. (a) Raw eggshell (b) Pulverized eggshell (c) Milled eggshell (d) Sieved carbonized eggshell (e) Sourced aluminum cans (f) Unreinforced samples casted

The Eggshells (Figure 1a) were washed with demineralized water to remove foreign particles and the thin outer membrane [7]. The eggshells were sun-dried for 48 hours and later put in a preheated furnace at 1000°C for 1 hour to obtain carbonized eggshell ashes (CESAs). The dried carbonized eggshells were pulverized (Figure 1b) with a blending machine and then grind to a powder (Figure 1c) using the grain miller operated at 250 rpm speed after cooling to room temperature. The obtained powder was passed through sieves of the required size (150 µm) to obtain particles with a fine grain (Figure 1d). Sourced aluminium cans (Figure 1e) of 5 kg were packed in a crucible furnace and re-melted in a diesel-fired furnace and heated to 900°C after which the crucible containing melt of aluminum-can was removed from the furnace so that the slag floating on top of the melt of aluminium-can due to plated paint of the cans could be screamed off the surface of the melt [6]. The melt in the crucible was returned to the furnace and then heated to 900°C. Then, the melt was poured into a trapezoidal shape metal mould to produce the billet presented in Figure 1f.

2.2 Production of composites aluminium alloy reinforced with eggshell

Figure 2. (a) Furnace (b) Cylindrical and rectangular mould (c) Eggshell reinforced casted aluminum

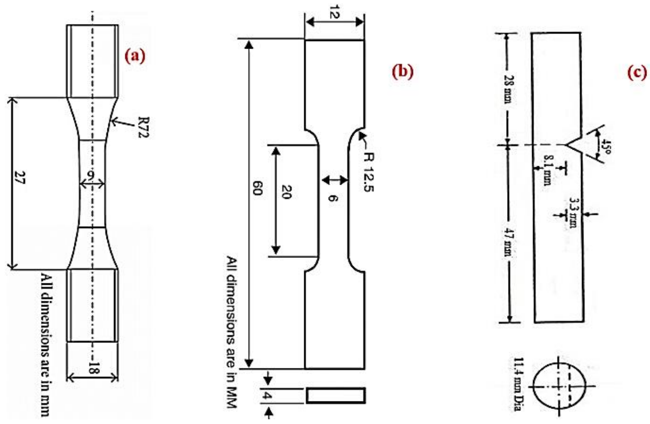

Figure 3. Sample dimensions for (a) Tensile testing (b) Fatigue testing (c) Impact testing

The aluminium was reinforced with eggshell particles of average size 150 µm, at 2%, 4%, 6%, 8%, and 10% weight fractions, to produce a composite of Al/ESA-MMCs by melt-stir technique. A Crucible pot and furnace (Figure 2a) were used to melt aluminum alloy. The cast aluminium alloy melted at 750°C and eggshell ash of the stated percent weight fractions and particle sizes were measured and preheated to about 100°C before incorporating into the melt that has already been degassed to control the porosity. To enhance the wet ability between the egg-shell particles and aluminium alloy melt, 1% by weight of magnesium was simultaneously added into the molten melt. The molten metal was thoroughly stirred for 10 minutes. The mixture was poured into the cylindrical and rectangular die (Figure 2b) moulds which has been preheated to about 250°C before pouring into the mould. During the pouring process, slag and any form of impurity were removed. This procedure was carried out for the control sample and different weight fractions (Figure 2c) of the composites. These cast samples were all machined to the dimensions shown in Figures 3a-c for various tests and their microstructural analysis.

2.3 Tensile test

The sample was machined to a suitable dimension (Figure 3a) on a lathe machine to determine the tensile strength. The tensile test was carried out at room temperature on Instron Extensometer, (model: Instron 3369), at Engineering Materials Development Institute (EMDI) Akure, Ondo State, Nigeria. According to the standard procedure, (ASTM C496) the sample was fixed in the tensile testing machine and a pulling force is applied to the sample axially as shown in Figure 4. Each test was conducted 3 times to ensure the reliability of the results obtained.

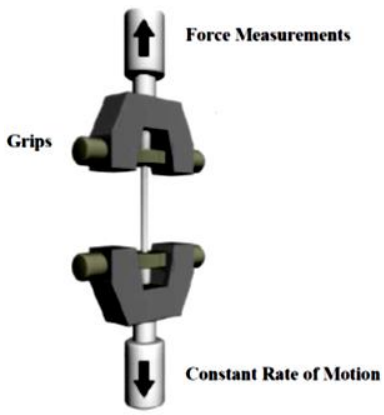

Figure 4. Experimental setup description

2.4 Hardness test

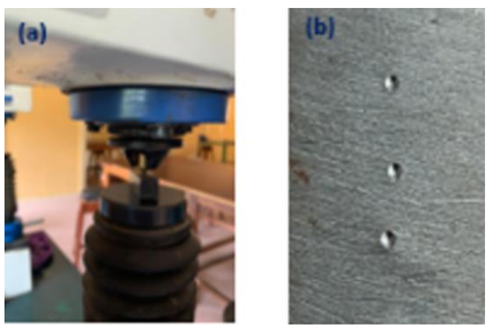

Figure 5. (a) Hardness testing machine (b) Hardness test sample with indent

The Vickers diamond test was conducted on the Vickers hardness tester shown in Figure 5a (LECO AT700 Micro Hardness Tester) for each of the control samples and five composites' samples. All samples were prepared with fine-grained emery polishing papers. The sample was mounted on a Vickers hardness testing machine using phenolic powder, grinded, and polished to produce a hardness sample with a smooth surface finish. The diamond indenter was indented under an applied load of 490.3mN with a dwelling time of 10s at three different points and the depth of penetration of the indenter on the sample was noted and read directly from the calibrated gauge of the machine. The average value was calculated and recorded. The hardness readings were evaluated following standard procedures (ASTM-18-07). Multiple hardness tests were performed on each sample at three different positions of interest (Figure 5b) and the average of the best values taken as a measure of the hardness of the sample.

2.5 Impact test

The impact energy test was carried out on Avery Denison Universal Impact Testing Machine at the Mechanical Engineering Department, the University of Lagos Nigeria after the sample has been machined to a suitable size on a lathe machine. The dimension is a cylindrical shape with a diameter of 11.4 mm and a length of 75mm as presented in Figure 3c. The size of V-notches is 45° and 3.3 mm depth in according with the report in [9, 10, 21]. The impact test was conducted according to particle size and weight fraction of the composites together with the control sample.

2.6 Fatigue test

The fatigue sample was machined on a lathe machine and the test was conducted on SM 1090 Rotating Fatigue Machine (Tech Equipment Ltd, 2014) at the Mechanical Engineering Department, Lagos State Polytechnic, Nigeria. Five samples of Al-MMC and monolithic Al alloy (control sample) were prepared with ASTM standard dimensions for different weight fractions (Figure 3b). Number of cycles Counts to fracture for each sample at a constant load rate were taken and recorded.

2.7 Optical microscopy (OM)

The grain morphology samples started by filing these samples with a coarse file and then with a smooth file to provide the initial flatness followed by surface grinding. Preliminary machine grinding of the extruded specimen surface followed by grinding with 1000B grain size emery paper to achieve smooth and shinning surface using metal series model 2000, Germany. Finally, polishing with the diamond paste of grade B (3mm) was performed until a smooth and mirror-finished surface was obtained using a polishing machine. The specimen was etched in 2% HNO3 (Nital) for about 10 seconds, dried with a methylated spirit to remove moisture and examine on the Optical microscope.

3. RESULTS AND DISCUSSIONS

The various results obtained from the experimental analysis of the Al-based alloy reinforced with eggshell are discussed as follows in sub-sections 3.1-3.4.

3.1 Tensile strength results

The plot in Figure 6 shows the tensile strength response gotten from reinforcing Aluminum alloy with eggshells. From the plot, it was deduced that reinforcing the aluminum alloy with 2% weight of eggshell particulate of size 150µm increases its tensile stress from 83 MPa to 130 MPa. Further increase in the eggshell reinforcement percentages to 4%, 6%, 8%, and 10% lead to an increase in tensile stress to 150 MPa, 161MPa, 169MPa, and 173MPa respectively. This is in good agreement with the results previously reported in [10].

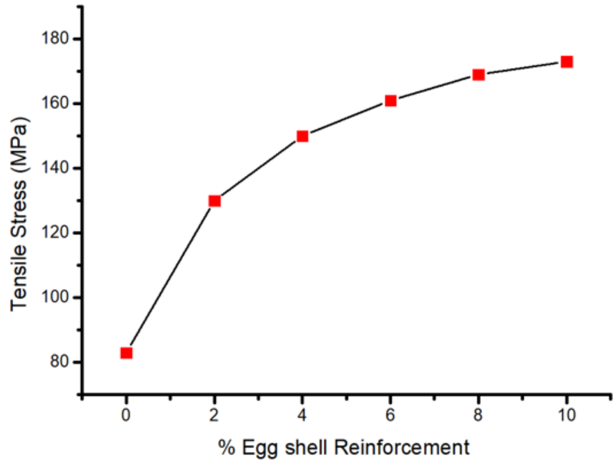

Figure 6. Tensile stress response to percentage weight of eggshell reinforcement

3.2 Hardness test results

Figure 7 describes the hardness response of aluminum alloy to percentage eggshell reinforcement. From the Figure, it was observed that hardness increases with an increase in the percentage weight of the reinforcement; 2% reinforcement weight gives an average hardness value of 78. 05. This shows a minor increase in hardness relative to the control sample's hardness (77.3 Hv). A major increase in hardness (82.8Hv) was noticed when the percentage weight reinforcement was increased from 2% to 4%. A minor increase in hardness value was noticed when eggshell reinforcement was further increased from 4% to 6% (83.1Hv) while another major increase in hardness was observed at 8% weight reinforcement (85Hv) compared to 6% weight. There was no increase in hardness value at 10% weight reinforcement compared to 8%. It can be deduced from this plot that hardness does not respond pronouncedly well to percentage weight reinforcement at 2% interval while the more pronounced response was noticed at 4% interval. This may be due to grain refinement as a result of a greater percentage of calcium carbonate and consequently, lead to improved hardness [11].

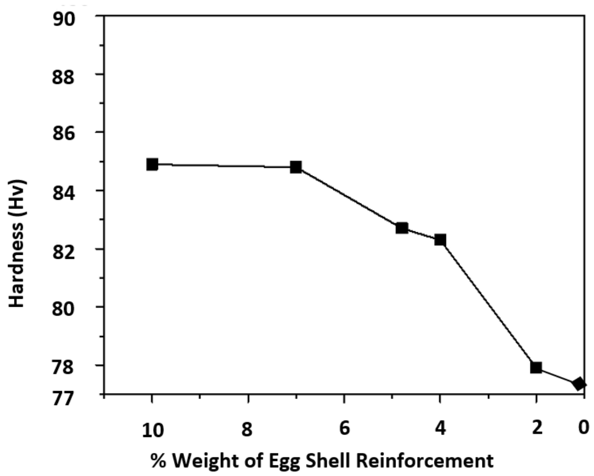

Figure 7. Hardness response to percentage weight of eggshell reinforcement

3.3 Impact energy test results

Figure 8 is the impact energy result obtained at different percentages of reinforcement. It was observed that impact energy decreases with a decrease in the percentage weight of the reinforcement and vice-versa. 10%, 8%, 6%, 4%, and 2% weight of reinforcement give average impact energy of 12.64J, 10.08J, 7.39J, 7.12J, and 7.02J respectively while that of the control sample is 6.13J. This implies that materials with a high percentage of reinforcement absorbed more energy during fracture and therefore tougher than materials with a lower percentage of reinforcement [12].

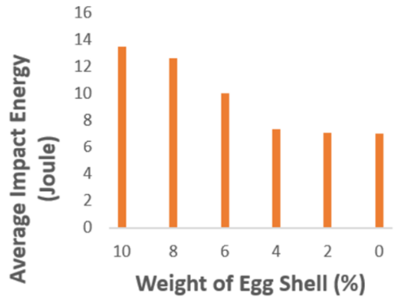

Figure 8. A plot of average impact energy vs weight of eggshell (%)

3.4 Fatigue strength results

It was observed that fatigue strength increases with an increase in percentage weight of the reinforcement as presented in Figure 9. 2%, 4%, 6%, 8%, and 10% weight of reinforcement gives an average fatigue strength value of $0.87x10^6$, $1.05x10^6$, $1.36x10^6$, $1.46x10^6$ and $1.65x10^6$ cycles respectively while the control sample gave an average fatigue strength of 0.65 $x10^6$ cycles. From the results, every increase in the percentage weight of reinforcement exhibits fatigue strength of aluminum alloy and the result is in conformance with [13-15].

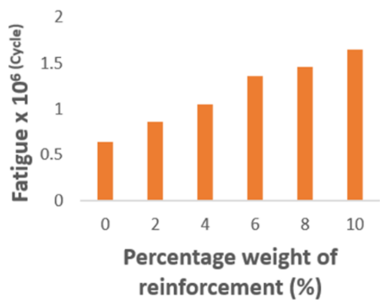

Figure 9. A plot of fatigue vs percentage weight of reinforcement

3.5 Microstructural analysis of the sample

Eggshell particles were successfully incorporated into aluminum alloy by using the stir casting technique as reflected in the micrographs shown in Figure 10. The microstructure analysis shows the uniform distribution of eggshell particles in the aluminum alloy. The microstructure also revealed good retention of uncarbonized eggshell particles in the matrix. The uniform distribution of the eggshell particles in the microstructure of the composites is the major factor responsible for the improvement in the mechanical properties

[16-18]. It was observed that the addition of carbonized eggshell ash at varying percentages was obvious in the micrographs. As observed in the results of tensile, hardness, fatigue as well as Impact tests that the reinforcement with 10% had the best of values. This was also demonstrated in the Images obtained from Optical microscopy where there is an agglomeration of particles, especially at 8% and 10% and this is in agreement with the work reported in [19-21].

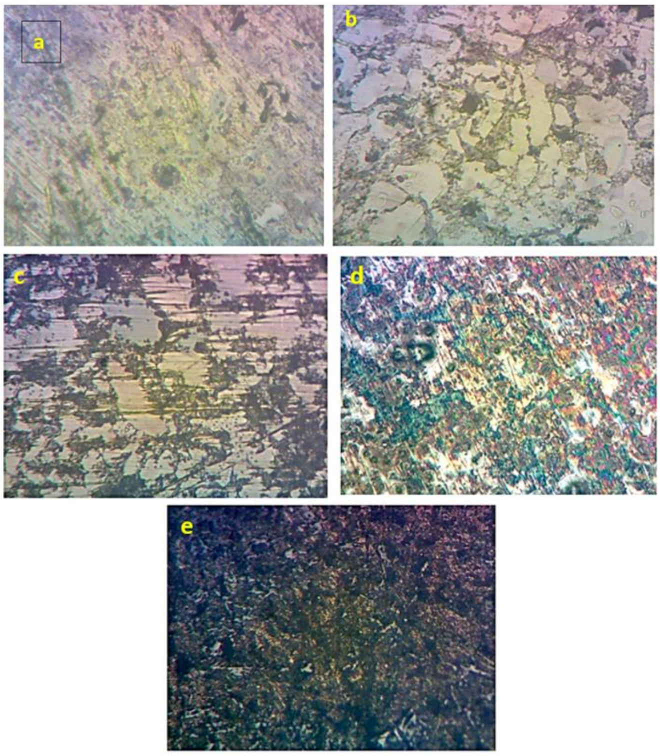

Figure 10. Micrographs of the aluminium/eggshell composite reinforcement at (a) 2% (b) 4% (c) 6% (d) 8% (e) 10% Mag: X500

4. CONCLUSIONS

Aluminum alloy increased the tensile strength and the hardness value of the Al/eggshell particulate composites. The incorporation of eggshell particles in the aluminium matrix can lead to the production of low-cost aluminium composites with improved hardness and tensile strength. These composites can find applications in automotive components like pistons, cylinder liners, and connecting rods as well as applications where lightweight materials are required with good stiffness and strength such as drink cans.

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