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RESEARCH

Recycled Aluminium Cans/Eggshell Composites: Evaluation of Mechanical and Wear Resistance Properties

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A B S T R A C T

Aluminium based metal matrix composites have been produced from recycled aluminium cans and 150μm sized eggshell particles using a stir cast process. The mechanical properties of the control and aluminium can/eggshell composites produced have been investigated. The microstructures of the aluminium can/eggshell composites were examined with the aids of Scanning Electron Microscope (SEM) after the sample surfaces have been carefully prepared and etched with aqueous solution of 0.5 cm^3 nitric acid. Micrographs revealed that there was a homogenous distribution of eggshell particles within the aluminium can matrix. An indication of effective stirring action during the melting process. The wear resistance was also investigated under different applied loads (6 to 14 N) on an abrasive surface emery paper of grade 220. The results revealed an increase in Young's modulus of elasticity and yield stress from 1,206.45 and 50.23 Mpa respectively of the cast aluminium can with 0 % eggshell particle to the maximum of 3,258.87and 73.2 MPa of aluminium can/12 % eggshell composites. The hardness values increased from 66.23 to 75.13 VN. There was a gradual increase in wear rate of the tested samples as the applied load increased. However, the wear resistance of the aluminium can/6 % eggshell and aluminium can/12 % eggshell composites increased significantly. Hence, recycling of aluminium cans and eggshells can be harnessed into development of useful engineering metal matrix composite materials.

1. INTRODUCTION

Aluminium alloy cans is widely used in the canning industries for food storage in place of traditional glass jars, bottle and steel cans. This trend is informed by the peculiar mechanical properties of aluminium such as light weight, formability, corrosion resistant, excellent barrier, reduced thickness, damage tolerance, ease of transportation, attractiveness and ease of printing a high-quality image on the cans [1-2]. The first aluminium alloy can was invented in 1972 when their weight was ten times less than that of glass jars. Modern cans in use today are even 40 % lighter than those cans used as far back as in 1972.

In Nigeria, the traditional bottle based packaging companies such as Cocacola, Seven –up have completely modernised their production line or in some cases shifted completely to the use of aluminium can for packaging. The transition from the traditional bottle packaging to aluminium can packaging has come with their environmental issues. Large volumes of aluminium cans drinks are being consumed daily across Nigeria and the empty cans are not properly disposed. Environmental pollution is increasing greatly, becoming uncontrollable; streets and drainages are being littered by empty drink cans, plastics, polythene bags used in our day to day lives. Those wastes were dropped in drainages, preventing water from flowing leading to water logging which aids breeding of mosquitoes and disease outbreaks. At extreme cases, canals, drainage and gutters are blocked. In rainy season, this leads to over flooding of cities which at times claiming many lives [3].

Eggshells are naturally occurring structural composites which form an embryonic chamber for the developing chicks. It provides mechanical protection and exchange of gas for the chicks. It is a container for egg. It provides egg protection against mechanical damage and contamination [4-6]. The eggshell contains several mutual layers of calcium carbonate. Previous studies have indicated that eggshells contain 95 % calcium carbonate in form of calcite and 5 % organic matters that include polysaccharides, protein and collagens [7-10]. Calcite in eggshells is lighter than naturally deposited ones. Majorly eggshells contain calcium and other elements in traced amounts are magnesium, sodium, phosphorus, boron and carbon [11-12]. Discarded eggshells are obtained in large quantities in hatcheries, homes and fast food industries [13]. Disposal of eggshells has caused various challenges which include cost, availability of disposal sites, odour and flies. Poor management of eggshells has been identified as one of the causes of environmental hazards especially in countries where large quantities of eggs are consumed either domestically or industrially [14]. However, they can be processed into useful materials such as fertilizer for enhancing crop growth; human and animal nutrition; building materials and particulate powder for metal and polymer reinforcement in composite development.

In order to reduce if not completely eliminated menaces associated with poor waste management, there is a need for recycling of waste materials [15-16]. As the name implies, recycling is the new emerging technology which involves waste conversion into raw materials for production of new materials for various engineering applications and also for wealth creation. In 1992, the Commonwealth Government released the National Waste Minimisation and Recycling Strategy with a target of reducing the amount of solid waste going to landfill per capita by 50 % from 1990 to 2000 [17]. The recycling of wastes reduces waste, saves energy, conserves natural resources, lessens use of municipal landfills and provides recyclers and municipalities with considerable revenue [17-18]. Aluminium is 100 % recyclable. Recycling of aluminium uses only 5 % of the energy required for its initial extraction and processing, 10 % of the initial capital equipment costs and saves 97 % of the greenhouse gas (GHG) emissions. Aluminium is an ideal materials used for architectural, automobile and aerospace applications because of its light weight, corrosion resistance and ease of formability but its low strength and hardness has greatly limited its use in high strength, hardness and surface wear resistance applications [19].

Mechanical properties are the properties possessed by materials as a result of reactions to the action of external pressures to which materials are subjected in service. Such properties are strength which may be tensile, compressive, flexural, torsional or fatigue as the case may be, hardness, brittleness, ductility and toughness. Uses of a material in particular application will not be ascertained until the properties of such material is established through a test known as mechanical test with the aids of standard equipment such as extensometer for tensile test, universal testing machine for impact test, hardness tester for hardness value measurement. This test requires a sample preparation in accordance with a particular standard [20-21].

Besides mechanical test, another vital approach to materials characterisation involves X ray diffraction analysis and microstructural examination. X ray diffractions reveal phases present in a material, their chemical formula and composition. It also suffices information on the degree of segregation of such phases within the matrix. The straining effect due to presence of phases can also be examined with the aids of X ray diffraction analysis [22]. Microstructural examination can be carried using optical microscope, scanning electron microscope and transmission electron microscope. Micrographs obtained from such analysis can be used to aid interpretation of mechanical test results since materials application depends on properties of materials and the properties in turn depends on microstructure of the materials [23].

Agunsoye et al [19] has studied effects of cocosnucifera (coconut shell) on the mechanical and tribological properties of recycled waste aluminium can composites. Their experimental results revealed that tensile strength and wear resistance of the composites increased as volume fractions of coconut shell increased whereas there is light reduction in impact energy absorbed by the composites. Also aluminium cans reinforced with 10 %volume fraction of coconut shell particles at finest size used (50 μm) displayed the highest tensile strength and optimum wear resistance. Hassan et al, (2012) [10] developed polyester/eggshell particulate composites. Their experimental results showed that carbonised eggshells enhanced the mechanical properties of the polyester matrix composites more than uncarbonised eggshells. Hussein et al [24] investigated water absorption and mechanical properties of (high-density polyethylene /eggshell) composites as a function of egg shell powder weight content in the grain size (75,125 μm). Result of their work disclosed that addition of eggshell powder to the polymer caused a decrease in tensile strength, modulus of elasticity, shore-D hardness while on the other hand it increases the % elongation at break, and the impact strength.

In this present work, metal matrix composites have been produced from discarded aluminium cans and eggshells. The aim of this work is to study mechanical and wear resistance properties of the produced aluminium can/eggshell metal matrix composites. This work is also aimed at providing solution to menaces associated with poor management of aluminium cans and egg shells through recycling of these waste materials. It embraces conversion of waste into wealth which on a large scale production will enhance technological development and economic growth.

2. MATERIALS AND METHODS

The materials used in this work include egg shells, aluminium cans, 220-400grade emery papers and polishing cloth. The elemental analysis of the aluminium can used is shown on Table 1.

Table 1. Percentage composition of the aluminium can.

Element	Al	Si	Fe	Cu	Mn	Mg	Ti
%Comp	98.10	0.53	0.51	0.03	0.77	0.02	0.04

Eggshells were obtained from Fast Food Centre and aluminium cans were procured from Waste Dumping Centre of University of Lagos.

Chemicals used in this work includes methylated spirit, nitric acid, and distilled water which are all available at Metallurgical and Materials Engineering Laboratory of University of Lagos. Major equipment used includes Instron testing machine, available at Engineering Materials Development Institute (EMDI) of Akure, Ondo State, Nigeria. Universal Testing Machine at Midwal Testing Centre, Ogba, Lagos State and Scanning Electron Microscope (SEM) at Material Laboratory of Kwara State University, Malete Kware State.

2.1 Processing of Eggshells

1 kg eggshells were rinsed in water to remove the membrane and then packed in a circular stainless steel tray. The rinsed egg shells contained in the tray were dried in the sun for 6 hours.

The dried eggshells were crushed manually with the aids of hand compression and then finally pulverised in a planetary ball mill. This milling was done for 3 hours after which the mill was offloaded. Figure 1 reveals the eggshells in two different forms.

a)

b)

Fig. 1. Eggshell Samples: (a) Unpulverised Eggshells; (b) Pulverised Eggshells.

The eggshell powders were sieved into different sizes using sieves of different mesh sizes ranging from 50 to 300 μm. Retained particles on each sieve was packed in a transparent sample bottle and then labelled for the purpose of identification.

2.2 Remelting of Aluminium Cans

5 kg of compressed aluminium cans were packed in a crucible, remelted in an oil fired furnace and superheated to 850 ^{0}C after which the crucible containing melt of aluminium cans was removed from the furnace. The slag floating on top of the melt of aluminium cans (due to plated paint around the cans) was screamed off the surface of the melt. The melt in the crucible was returned to the furnace and then heated to 850 ^{0}C. Then the melt was water atomised into small aluminium can balls [25]. The balls were weighed and packed into 7 different packs each of total mass of 500 g.

The first pack of the balls were remelted, heated to 800 ^{0}C inside the crucible and then poured into a metallic die cavity mould. The melt was allowed to solidify and cool to the room temperature (40 ^{0}C) while inside the mould. Then, casts of aluminium can bars were gently knocked out of the mould. These represent control sample.

2.3 Synthesis of Aluminium Cans/Egg Shells Composites

Another pack of the balls was reheated to 800 °C. The crucible containing the melt was brought out of the furnace and 10 g of 150 μm sized eggshell particles equivalent to 2 % of remelted aluminium can balls was added to the melt and stirred manually until the temperature of the melt falls to 670 ^{0}C$\pm$ 5 °C after which the mixture was poured into the mould. The melt was left to cool to the room temperature after which the casts of aluminium can/2 % eggshell composites were gently removed from the mould.

The same processing technique was repeated for the synthesis of the remaining aluminium can/eggshell composites with increasing %weight of eggshells at 2 % interval until a maximum of 12 %wt of eggshell particle addition to the melt of aluminium cans.

2.4 Characterisation of Aluminium/Eggshell Composites

Control sample and sample from each batch of aluminium/eggshells composites were machined using Colchester/triumph 2000 Lathe Machine and Adcock Shipley Milling Machine, (Model 2E operating at maximum Speed 1200 rev/min) to standard samples for tensile property test and wear resistance measurement.

2.5 Microstructural Analysis

Cubic samples each of side 5mm was cut from casts of aluminium can/eggshell composites of 2 and 12 %weight of eggshell particle additions. Each of the cubic samples was mounted using resin which forms a polymeric compound around the sample for proper handling during grinding and polishing processes. Surface of the sample was prepared on emery papers of 220, 320 and 400 grades mounted on the grinding/polishing machine.

The ground surface of the sample was cleaned with soap solution washed in distilled water. The washed surface was finished using Selvyet polishing cloth covered with magnesia powder. The finished surface was thoroughly washed and etched in an aqueous solution of 0.5 cm^3 nitric acid. The etched surface was dried in boiling ethanol and then examined with the aids of scanning electron microscope, (Model: ASPEX 3020).

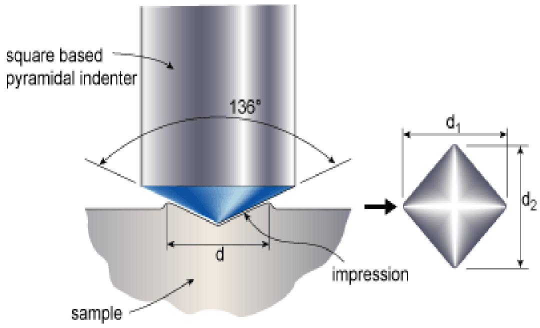
2.6 Tensile Property Test

Prepared samples of the control aluminium can and aluminium eggshell composites were subjected to the tensile load with the aids of Instron testing machine. Each sample was loaded gradually at a strain rate of $3X10^{-3}$ s^{-1}. During loading, the sample was stretched with a gradual increase in gauge length but reduction in cross sectional area until the sample breaks after necking. The superimposed stress-strain graph for each sample was automatically plotted by the machine.

2.7 Hardness Number Measurement Test

Cylindrical samples of 14 mm diameter and 10mm height of the cast aluminium can and aluminium can/eggshell composites were loaded vertically in a compressive manner by square based pyramid indenter as shown in Fig. 2 to measure the hardness values of the control and aluminium/eggshell composites by Vicker hardness approach.

a)



b)

Fig. 2. Vicker Hardness Approach (a) Vicker Hardness Tester in Operation; (b) Vicker's Indentation and Impression Diagonal Measurement (Midwal Materials Testing).

2.8 Wear Resistance Measurement

Resistances to surface wear of the casts of aluminium can and aluminium can/eggshells composites were evaluated using Pin on Disc Tribometer. A 60x10x10 mm sample each of control sample and aluminium can/eggshell composites of 2, 6 and 10%weight of egg shell particle additions were tested. The initial masses and the densities of those four samples are (12.95 g, 2.158 gcm^{-3}); (15.52 g, 2.587 gcm^{-3}), 12.65 g, 2.108 gcm^{-3}) and (13.90 g, 2.316 gcm^{-3}) respectively.

The surface of the wear sample held in a wear rig under the application of 6 N was placed in contact with the surface of rotating emery paper of 220 grade, mounted on the surface of the Pin on Disc Tribometer for an average period of 60 s. After this time, the sample was removed from the rig and the examined surface was cleaned off the worn particles with the aids of cotton wool soaked in methylated spirit. The surface of the emery paper was also cleaned off the worn particles with the help of a hard brush. Then the final mass of the sample was taken with the aids of a digital Pioneer balance (by Ohaus Corporation, USA), having a maximum capacity and readability of 210 and ±0.0001 g accuracy.

The process was repeated with increasing applied loads up to a maximum of 14 N at an interval of 2 N. Initial and final masses of the respective samples were recorded before and after wear investigation. The mass loss in each case was calculated using the formula in eq. 1.

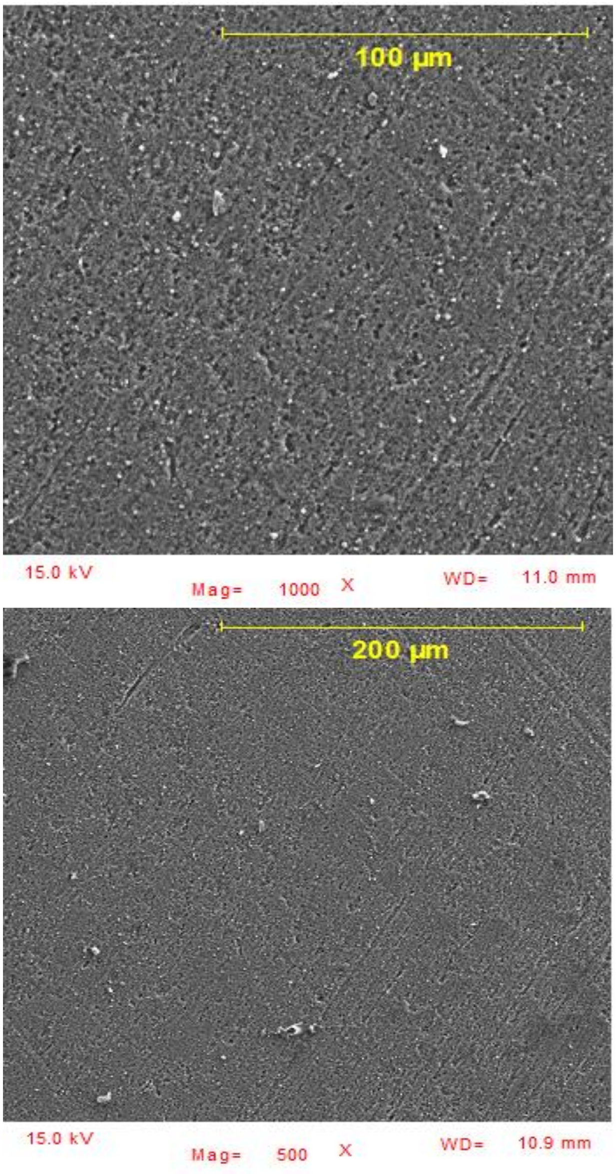
$$Mass\ loss = m_1 - m_2 \quad (1)$$

Where m_1 = mass of the sample before wear test; m_2 = mass of the sample after test.

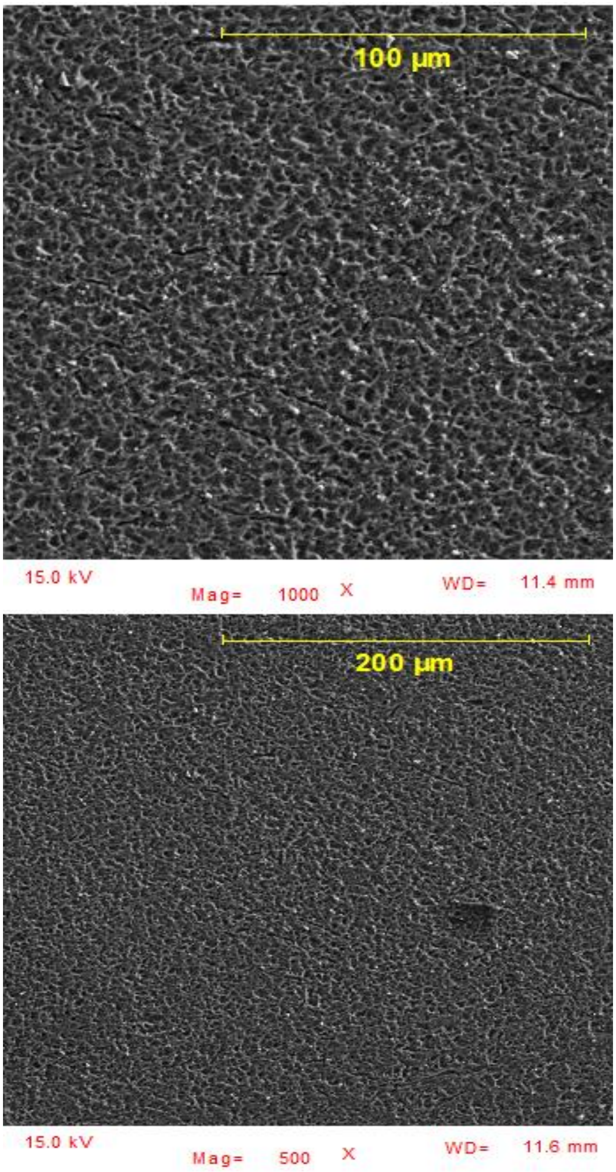
3. RESULTS AND DISCUSION

3.1 Micrographs

Figures 3a-b shows the scanning electron micrographs of aluminium can/2 % eggshell and the aluminium can/12 % eggshell composites respectively. From both Figs. 3a and 3b, it is observed that there are even distributions of eggshell particles (indicated by white colour) within the matrix of aluminium cans. However, the micrograph in Fig. 3b revealed more evenly distributed eggshell particles in the aluminium can matrix and has higher number of grain boundaries than that in Fig. 3a. This is attributable to higher %weight (12 %) of eggshell particles and effective stirring of the composite melt prior to pouring.



a)



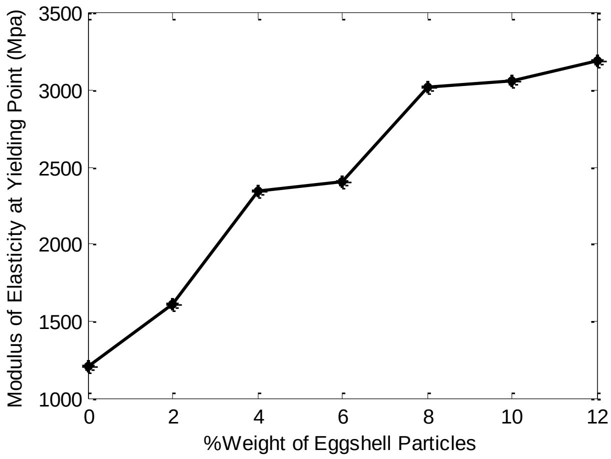
b)

Fig. 3. Scanning Electron Micrographs of (a) Aluminium Can/2 % Eggshell Composite at 1000 and 500X; (b) Aluminium Can/12 % eggshell Composite at 1000 and 500X.

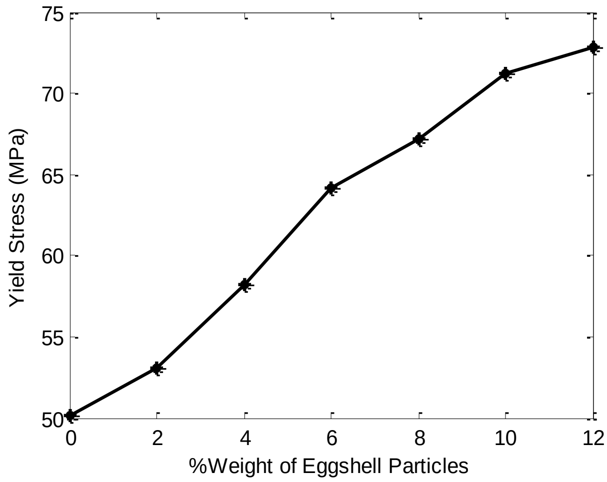
3.2 Tensile Properties

Figures 4a-f show the results of tensile test conducted both on the casts of aluminium cans and aluminium/eggshell composites.

Figure 4a is a plot of modulus of elasticity at yielding point (zero slope) and %weight of eggshell particles additions. It revealed an increase in the modulus of elasticity as the %weight of the eggshell particle addition increased from 2 to 10 % whereas from 10 to 12%weight of the eggshell particle additions, the increase is minimal. This explains an overall decrease in the strengthening efficiency of the eggshell particles as its %weight increase reaches the saturation point within the aluminium can matrix (Figs 4e-f). In Fig. 4b, the yield stress also increased in an approximate linear behaviour as the %weight of the eggshell particle additions increased.



a)



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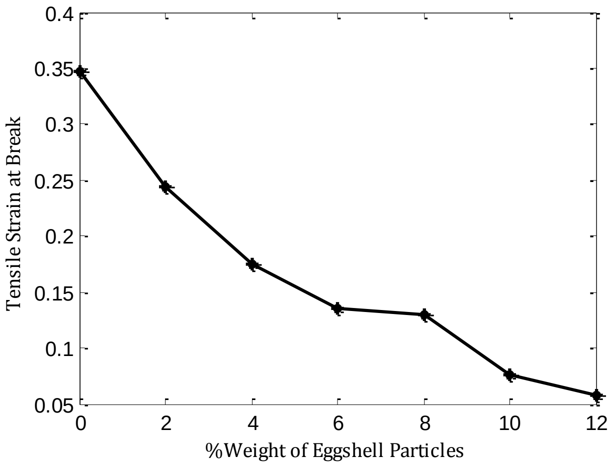

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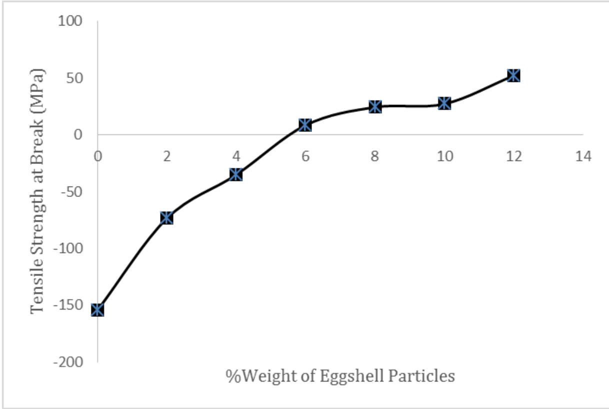
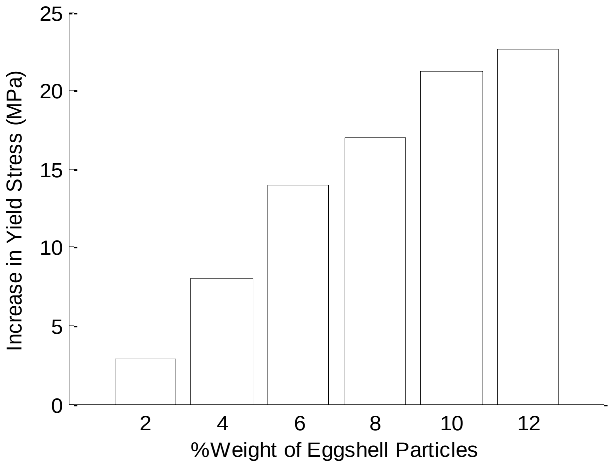
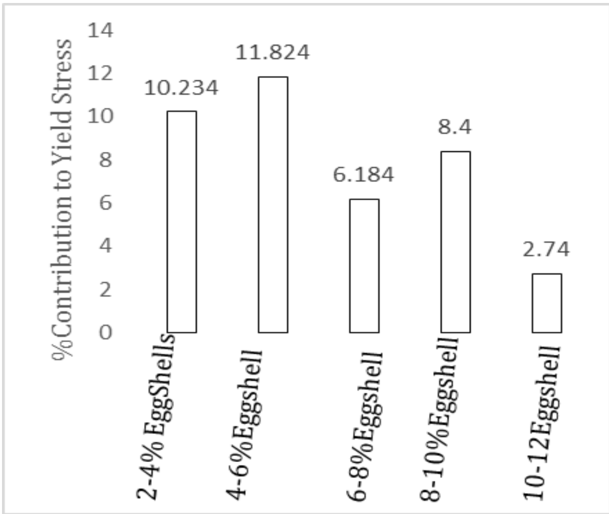


d)



e)



f)

Fig. 4. Tensile Property Graphs: (a) Modulus of elasticity; (b) Yield Stress; (c) Increase in Yield Stress; (d) Tensile Strain at Break; (e) Tensile Strength at Break with % Weight of Eggshell Particles Addition (f) % Contribution to Yield Stress with 2 % Eggshell Particle Stepwise Addition.

Generally, the increase in modulus of elasticity and yield stress with an increase in %weight of the filler is attributable to an increase in packing density of the eggshell particles within the aluminium can matrix (Figs. 3a-b). As %weight of eggshell particles increases, a dislocation impingement increases which results in the strengthening of the aluminium can/eggshell composites. Also, the release of CO_2 at 670 °C from calcite resulted in the formation of stable calcium oxide [8]. The calcium oxides distribute evenly within the matrix and impinged the dislocation movement. This also contributes to enhancement in the strength of the Al can-eggshell composites. Figures 4c-d shows the variation of tensile strain and strength at break with %weight of eggshell particle additions. Figure 4c show a decrease in tensile strain while Fig. 4d reveals an increase in the tensile strength as the %weight of the eggshell particle additions increased. The decreasing trend in the tensile strain may be attributable to brittleness of the calcite which is the main component of the eggshell and then carbon, boron and phosphorus present in the eggshell in traced amount.

3.3 Hardness Number

Figure 5 shows the hardness values of the aluminium can cast and aluminium can eggshell composite samples. It reveals an increase in hardness number as the %weight eggshell particle addition increased. This is in agreement with result of yield stress in Fig. 4b.

3.4 Wear Resistance

Figure 6 displays the plot of wear rate as a function of the applied loads during the wear investigation. It shows a gradual increase in the wear rate as the applied loads increase.

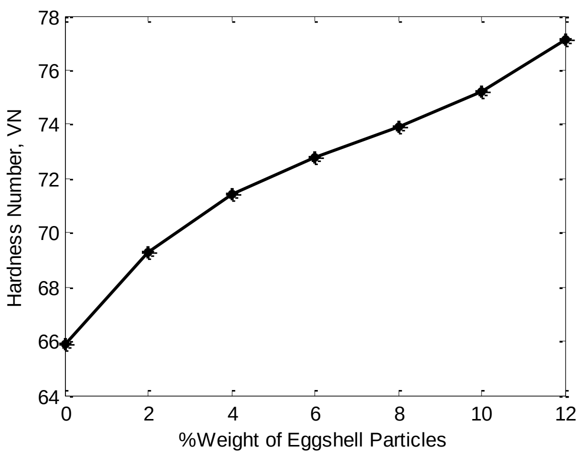


Fig. 5. Graph of Hardness Number with %Weight of Eggshell Particle Addition.

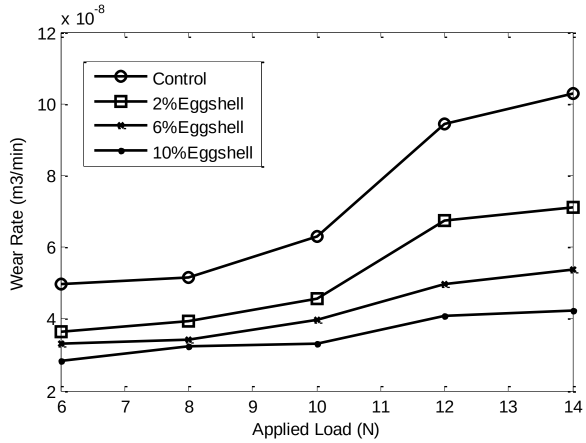


Fig. 6. Graph of Wear Rate with Applied Loads.

The resistance which each sample offers to the surface wears increases from the control to aluminium can/10%eggshell composites which has the maximum wear resistance among its examined counterparts. This is reflected in the minimum wear rate of the composite as the load increased. This is in perfect agreement with Fig. 4a that reveals rigidity of aluminium can/10 % eggshell composite having highest value than that of aluminium can/6 % eggshell composites, aluminium can/2 % eggshell composite and the control aluminium can sample. Also, an effect of applied load from 6 to 8 N on the wear rate is of little significance because the portions of the lines within these applied loads are parallel to the applied load axis. Beyond these loads, effects of the applied loads in wear rate is very high in the case of the control sample and aluminium can/2 % eggshell composite whereas in the case of aluminium can/6 % eggshell and aluminium can/10 % eggshell composites, the same behaviour prevails as for 6 and 8 N but with little increase in wear rate. The implication of this is that both aluminium can/6 % eggshell and aluminium can/10 % eggshells composites can be used in an area where the applied load is within 14 N without significant surface wear of the composites.

4. CONCLUSIONS

From the results and discussion of this research work, the following conclusions can be made:

- A vital metal matrix composites peculiar to fan parts (such as fan blades, fan blade guard); metallic ladder; sliding door; window framing system and automobile parts have been developed.

- Addition of eggshell to the recycled aluminium can has enhanced the modulus of elasticity which in turn increases the rigidity of the produced composites
- The yield stress and tensile strength at fracture increase with increase in %weight of eggshell particle additions.
- The low values of the tensile strength of the control and aluminium can/2 % eggshell composites is an indication of very high ductility of the materials because of their prolonged elongation before the final fracture of the tested samples.
- The enhanced wear resistance and hardness of the aluminium can/eggshell composites over the aluminium can cast is attributable to high strength and hardness of the eggshell particles.
- Although the wear rate is increased with increase in the applied load, however, there is no any significant increase in the wear rate as the load increased from 6 to 8 N.

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