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CHARACTERIZATION OF EGGSHELL REINFORCED ALUMINIUM COMPOSITES

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Abstract

The study evaluated the mechanical properties of eggshell-reinforced aluminium. Six different specimens of aluminium composites were prepared using varying percentages of eggshell powder as reinforcement as follows: 0%, 2%, 4%, 6%, 8% and 10% identified as samples A, B, C, D, E and F respectively. Eggshell was used as reinforcement material in order to support the ever-increasing scientific research efforts to convert waste to wealth. One of the study's objectives was to develop an eco-friendly composite and manage food wastes safely in our environment. The base aluminium material used for the study was designated as 0% eggshell reinforced samples. Test specimens were subjected to tensile, impact, compressive and hardness tests. Results showed that adding 4%, 6%, 8% and 10% eggshell powder to aluminium improved hardness by 5.61%, 19.31%, 15.32% and 19.03%, respectively. Samples were ranked in the descending order of performance as: D, B, F, A, C, and E using combination of properties criteria, which implies that sample D had the best combined properties. In contrast, sample E had the most minor performance. The study concluded that reinforcing aluminium with 6% eggshell powder produced a composite with best combination of mechanical properties. Manufacturing of Boat hulls and other marine structures are among the possible uses of the developed composites since they have good compressive strength. Eggshell-reinforced aluminium can also improve the performance and durability of various athletic goods, such as helmets, racquets, and bats. The study has demonstrated the potential use of eggshell powder as a reinforcement material for aluminium to produce light weight composites with good mechanical properties. The outcome of this study could benefit poultry farmers, food sellers, manufacturers and egg consumers across the globe.

1.0 INTRODUCTION

Poultry eggshells are agricultural waste materials generated from chick hatcheries, bakeries; fast food centres and restaurants. These can litter the environment and consequently constitutes environmental pollution, thus require proper handling [1]. In the ever-increasing efforts to convert waste to wealth, the efficacy of converting eggshells to beneficial use has become an idea that is worth exploring. According to [2], eggshell contains 93.70% calcium carbonate, 4.20% organic matter, 1.30% magnesium carbonate, and 0.8% calcium phosphate. Calcium trioxocarbonate (IV) is an important constituent of eggshells and seashells [3]. Best-quality eggshells of commercial layers contain approximately 2.2 grams of calcium in the form of calcium carbonate [4]. Many factors influence eeggshells' quality, including nutrient adequacy, flock health problem, environmental

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condition and breeding type [5]. Apart from the fact that the controlling parameter of egg weight also contributes to its quality, it is not dependent on the thickness of eggshell [6]. A thinner eggshell is sometimes more substantial than a thick eggshell [6].

Several sectors have recently sought the usage of lightweight materials [7]. Given that many sectors have physical constraints that are difficult to get around, the lightweight material is crucial to humanity. One technology that might aid in creating more robust and lighter materials is additives. According to [8], metals with extra materials added for reinforcement are known as composites with a metal matrix. Enhancing the properties of the base metal, such as hardness, tensile strength, fatigue strength, etc., is a typical purpose for reinforcements [8]. Researchers continuously pay attention to metal matrix composites because of their numerous uses in the automotive and industrial sectors [8]. Aluminum is a silvery-white metal, the 13th element in the periodic table [9]. One surprising fact about aluminum is that it is the most widely spread metal on Earth, making up more than 8% of its core mass [9]. Aluminum is also the third most common chemical element on our planet (earth), ranking next to oxygen and silicon. It is one of the lightest available metals in the world [9]. Aluminum is almost three times lighter than iron. However, it is moderate in Ultimate Tensile Strength (U.T.S.), extremely flexible and corrosion resistant because its surface is always covered in an extremely thin and has a strong oxide film layer [10]. Aluminum is not magnetic but is a good electricity conductor and forms alloys with practically all other metals [10].

According to [11], Aluminium alloys are used ubiquitously in commercial manufacturing and laboratory applications due to their availability, good mechanical properties, light weight, and high corrosion resistance. The natural passivation of aluminium is a major component in the relatively high corrosion resistance of aluminium compared to other metals in practical use [11]. However, in practical use, aluminium is commonly used with components of different materials that provide the desired properties, [12]. Pure materials are the essential elements of all-natural and artificial structures [13]. Technological progress is associated with continuously improving material properties and expanding material structural classes and types [14]. Composites materials are combined to use their characteristics better and minimize their deficiencies [15]. The process of optimization can relieve designers of the constraints associated with the selection and manufacture of conventional materials [16]. Most designers are looking for materials having lighter weight and good mechanical properties [12]. The composites that satisfy these requirements with cheaper cost are preferred by designers and manufacturer [15].

Metal matrix composites (MMCs) have outstanding mechanical properties because they combine a hard reinforcement like silicon (Si) with a ductile matrix material like aluminium or magnesium [17]. Compared to unreinforced alloys, metal matrix composites (MMCs) have significantly better qualities, such as high specific strength and specific modulus, damping capacity, and strong wear [18]. Similarly, composites with low-density and inexpensive reinforcements are becoming more popular due to their combination of high strength, low density, machinability, availability, durability, and being manufactured using various processes [19]. Aluminium metal matrix composites (AMMCs) are among advanced applications' most widely utilized composites. In recent times, AMMCs have been successfully used in automotive and aircraft engines production and the manufacture of disc brakes [19].

The mechanical and physical properties of Al-eggshells, Al-CaCO3, and Al-SiC metal composite were evaluated by [20]. Results showed that adding SiC reinforcement particles to Al alloy improved its hardness and heat-treatable properties relative to eggshell particles. However, porosity and total cost increased when SiC particles were added to the Al alloy. Their findings showed that employing carbonized eggshells as reinforcing in the Al matrix generated superior physical characteristics at a reduced cost when compared to SiC particles. In [20], the researchers examined the microstructural, mechanical, and physical characteristics of an aluminium metal matrix composite made of silicon carbide (SiC) and aluminium eggshell. According to their findings, the Al-2.5% SiC-7.5% carbonized eggshell sample improved specific strength and reduced porosity. Metal composite with and without eggshell was created by [21], using stir casting. Overall mechanical qualities were enhanced by the combination of eggshell particles and aluminium, as opposed to the Al 6061 alloy. The mechanical qualities, including hardness and tensile strength, were found to be improved by the incorporation of eggshell. Al7075, a stir-cast composite made of glass fibre and eggshell, was tested for tensile strength and corrosion resistance by [22]. By acting as a corrosion inhibitor, the eggshell added to the composite's resistance to corrosion. Additionally, the use of glass fibre increased the tensile strength.

Rice husk ash, red mud and fly ash are among the most affordable and low-density reinforcements available in significant quantities as solid waste by-products [23]. In addition to saving money, utilizing these wastes could also lead to the generation of foreign exchange and the reduction of environmental pollution [19]. However, it is possible to obtain desired properties by arranging the metal matrix and adding reinforcement like coconut shell ash. Coconut shell is an abundant agricultural waste across the world's tropical regions [23]. The tensile strength of pure aluminium, around 90 MPa, can be increased to over 690 MPa for some of its alloys and matrix composites [24]. The exceptional ability of aluminium to form alloys and matrix composites expands its reach across industries and applications. In this research eggshell was used as reinforcement for aluminium in order to determine its impact on the mechanical properties (ultimate tensile strength, compressive strength, impact strength, and hardness) of aluminium.

Globally, there is the continuous quest to improve the mechanical properties of aluminium, a versatile material in manufacturing, thereby making Scientists worldwide look for better ways to turn industrial and agricultural wastes into raw materials for the manufacturing industry. In addition to saving money, utilizing these wastes like eggshell for useful purposes could also lead to the generation of foreign exchange and the reduction of environmental pollution. Obtaining desired application properties of aluminium is possible by adding eggshells as reinforcement material. The impact of eggshell-reinforced aluminium is seldom reported in literature. The properties of aluminium can be tailored or adjusted significantly to suit the demands of different industrial applications by suitable combinations of matrix, reinforcement and processing route. Currently, several grades of AMCs are manufactured by different routes. Materials and the manufacturing processes are selected based on cost and strength, among other factors. In addition, aluminium does not have high endurance limit like ferrous metals and will fail if it goes through several stress cycles. Pure aluminium is soft, so other mineral elements are usually added to strengthen it. These additional elements not only improve the hardness of aluminium metal but also improve its corrosion resistance.

Environmental conditions could influence the quality of eggs and eggshells [5, 6]. Hence, eggshells generated from eggs produced from poultries in Ozoro and its environs in the oil reach Delta State of Nigeria were used for this research. The area is densely populated because the defunct Delta State Polytechnic Ozoro, now Delta State University of Science and Technology Ozoro and a campus of the Delta State University Abraka, Oleh Campus and many oil companies. The presence of these tertiary institutions and oil companies has attracted many tourism and hospitality facilities such as hotels, fast food eateries and restaurants as well as massive investment in poultry farms. All these have led to a tremendous increase in the consumption of eggs, which in turn generate large quantity of eggshells. Studies on the use of eggshell from this part of the country for aluminium composite reinforcement has either not been reported or are scanty.

The points discussed above opened knowledge gaps, considering aluminium's strategic position for domestic and industrial applications, which necessitates this scientific study. Hence, this research took advantage of the abundant wasted eggshells to reinforce aluminium and investigate its impact on the mechanical properties. This research's outcome will be benefit manufacturers and users of aluminium and its derivatives.

2.0 MATERIALS AND METHODS

2.1 Materials

Aluminium cable used as base material was procured from an electric material store in Awka, Anambra state, Nigeria. The equipment used for the research includes electronic weighing scale, temperature gauge, furnace; wrenches of different sizes and shapes; electric blender, mechanical tools box; hack saw, hand file; Universal Testing Machine (UTM); die cast mould, mould; sieve; stir casting machine; powder mixing machines; scanning electron microscope; Impact Testing Machine; Micro Hardness Tester; optical microscope; M530-Buck scientific infra-red spectrophotometer; and an X-MET 17500 XRF spectrometer.

2.2 Methods

The study was carried out by the application of research methodology as follows:

2.2.1 Preparation of eggshell powder

Poultry eggshells were locally sourced and washed thoroughly, sterilized and sun dried to remove the dirt. The sterilized eggshell was dried in an electric oven at 50°C for 2 days, then blended into smooth powder using an electric blender. After that, the eggshell powder was sieved into fine powder with the aid of a 50µm stainless steel sieve. The well-sifted (sieved) eggshell powder was mixed properly using mixing machines and sent to a laboratory for Fouriertransform infrared spectroscopy (FTIR) analysis to determine its chemical composition.

2.2.2 Composition test of raw aluminium material prior to the experiment

Aluminium material was sourced from Awka metal market and taken to Turret Engineering services laboratory in Port Harcourt, Rivers State for composition analysis to determine its chemical composition. This material was used as the base material for the experiment. The results of composition test are presented in Table 1.

The eggshell-reinforced aluminium samples were designed to be identified as A, B, C, D, E and F containing 0%, 2%, 4%, 6%, 8% and 10% by weight of eggshell powder, respectively. Sample A containing 0% eggshell powder (i.e. without eggshell addition) was the control. The various percentages were chosen to determine the composition with the best combination of properties.

2.2.3 Preparation of eggshell reinforced aluminium sample

The eggshell-reinforced aluminium samples were prepared using stir casting method by applying the steps stated as follows: sourcing of pure aluminium material; preparation of cylindrical die-cast mould with dimension of 40 mm x 100 mm; melting of aluminium being the base material into molten state; casting of base specimen containing 0% eggshell powder (aluminium); introduction of 2%, 4%, 6%, 8% and 10% eggshell, which were measured in grams (g) i.e. weight percent (wt%). The pictures of samples are presented in Figure 1.

Figure 1: Pictures of samples

2.2.4 Test of mechanical properties of specimens

Test of mechanical properties of experimental samples to know their tensile strength; compressive strength; impact strength; and hardness using universal testing machine and other relevant equipment and standard. The detailed procedures for testing each of the four mechanical properties of specimens are presented as follows:

(a) Tensile test

The tensile strength of samples was determined using United DFM Series Floor Model of Universal Test Machine following ASTM D3039 standard. The tensile strength of the specimens was calculated using the Equation 1:

$$\text{Tensile strength} = \frac{\text{Force at fracture}}{\text{Cross-sectional area of the specimen}} \qquad (1)$$

Where, force at fracture is the maximum force applied to the specimen before it fractured in N, and cross-sectional area of the specimen is the area of the specimen at the gauge length mm^2.

The whole procedure was repeated for each sample. Values obtained from tensile test were organized and presented in Figure 4. Schematic diagram of the Tensile test specimens' dimension is presented in Figure 2.

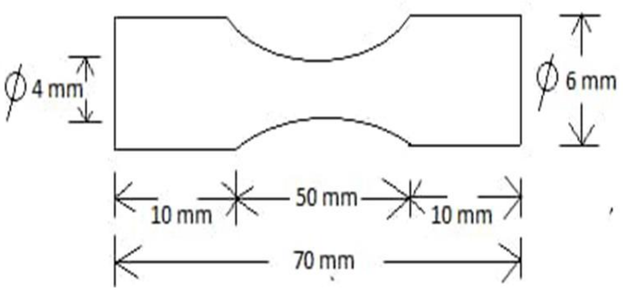

Figure 2: Sketch of tensile strength specimens

(b) Compression test

The compression test of samples was carried out using United DFM Series Floor Model Universal Test Machine (UTM). The compression testing machine recorded the force applied to the specimen and the specimen's shortening throughout the test. The compressive strength of the sample was calculated using Equation 2:

$$\text{Compressive strength} = \frac{\text{Force at fracture}}{\text{Cross-sectional area of the specimen}} \qquad (2)$$

Where, force at fracture is the maximum force applied to the specimen before it fractured in N, and cross-sectional area of the specimen is the area of the specimen at the gauge length mm^2. The whole procedure was repeated for each sample and the results are presented in Figure 5.

(c) Hardness test

The Hardness test of samples was carried out using MCT^3 model of Micro Combi Tester. Samples were made flat and smooth, ensuring no defects on the surface and polished to achieve the desired surface finish. A measuring microscope was used to measure the diameter of indentation using Brinell hardness technique (method). The hardness of the sample was

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calculated using Brinell hardness equations as follows:

$$HB = \frac{2P}{\pi d^2} \quad (3)$$

Where, HB is Brinell hardness; P is the applied load in N; and d is the diameter of the indentation in mm). The test procedure was repeated at multiple locations and average of the results were determined in each case. Results obtained are presented in Table 2.

(d) Impact Test

The impact test of samples was done using AVERY Model 6703 Impact Testing Machine. The impact samples were notched in accordance with the ASTM E23 standard. The equipment's data acquisition system recorded the absorbed energy during the impact event. Data were collected and analysed. The test was done for different samples to reduce the effects of any local variations in the impact toughness of the sample. The results obtained are presented in Table 3. Schematic diagram of the sample's dimension is presented in Figure 3.

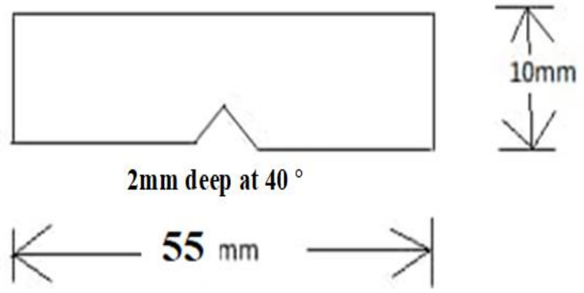

Figure 3: Sketch of impact sample

2.2.5 Optical microscopic examination (OME)

M13.5850, BD+PL, XYZ motorized model of metallurgical optical microscope, was used to study the microstructure of reinforced aluminium samples. Figure 7 - 12 present the micrographs of the optical microscope examination of specimens at a magnification of x100.

2.2.6 Scanning electron microscope examination (SEM) of some fractured specimens

Fractured test samples were examined using Field Emission SEM5000 model of scanning electron microscope in order to study and understand the mode of fractures of test sample using the step-by-step procedure presented as follow: The SEM images were analysed to reveal information about the surface morphology and microstructures of the fractured samples eggshell-reinforced aluminium. The micrographs of some fractured specimens are presented in Figure 13 to 15.

3.0 RESULTS AND DISCUSSION

Table 1 presents the chemical composition of the base material (aluminium) used for this investigation. It showed the composition of the base material for the experiment as follows: Al = 98.26%; Si = 1.16%; Fe = 0.2 %; Co = 0.2%; Hf = 0.07% and Zn = 0.2%.

Table 1: Composition of raw aluminium

Element	%	±	Limit
Al	98.26	1.174	98.80-100.00
Si	1.16	0.329	-
Fe	0.2	0.028	0.00-1.00
Co	0.2	0.02	0.00-0.50
Hf	0.07	-	-
Zn	0.2	0.0027	0.00-0.40

This composition obtained is however, slightly different from that obtained by [25] in which they gave aluminium chemical composition roughly includes 5.6-6.1% zinc, 2.1-2.5% magnesium, 1.2-1.6% copper and less than half a percent of silicon, iron, manganese, titanium, chromium, and other metals. This slight difference is because aluminium from different sources could vary slightly ranging from 98 to 99% aluminium and other trace metals like copper, which is supported by the views of [26].

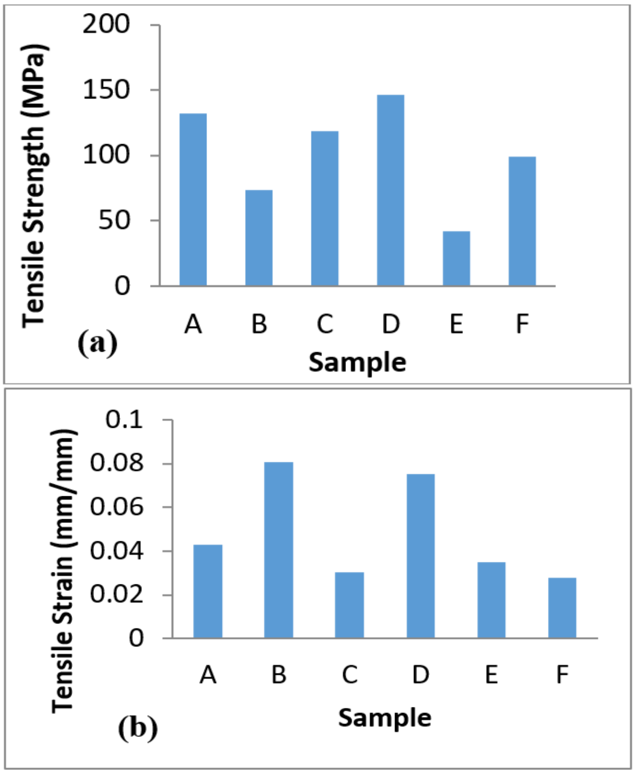

Figure 4: Tensile properties (a) Tensile strength of samples, (b) Tensile strain of samples

Results of the tensile strength test presented in Figure 4 showed that the tensile strength of the eggshell powder reinforced samples did not increase or decrease in any definite order with increasing weight percentage of eggshell reinforcement. However, the highest tensile strength of 146.34139 MPa was obtained for the sample "D" having 6% eggshell reinforcement. This represents an increase of 10.9 % compared to the unreinforced aluminium sample (control sample). However, this is not significantly different from the 18% increase in tensile strength using coconut shell ash as reinforcement for aluminium composites by [27]. The control sample had tensile strength of 131.95 MPa. The lowest tensile strength of 41.88837 MPa was obtained for the sample "E", having 8% eggshell reinforcement, representing a decrease of 40.9% compared to the unreinforced aluminium, which is similar to 35% improvement in tensile strength through addition of fly ash to aluminium composite by [28]. The improvement in tensile strength of eggshell-reinforced aluminium in the case of sample "D" could be attributed to several factors, including the following: the eggshell particles are hard and strong, and they act as a barrier to the dissociation in the aluminium particles [29]. This made it more difficult for the composite to deform, which led to an increase in tensile strength, and the eggshell particles may have also helped to refine the grain structure of the aluminium being the base material. Usually, a finer grain structure is associated with higher tensile strength. This is agreement with the results given by [30].

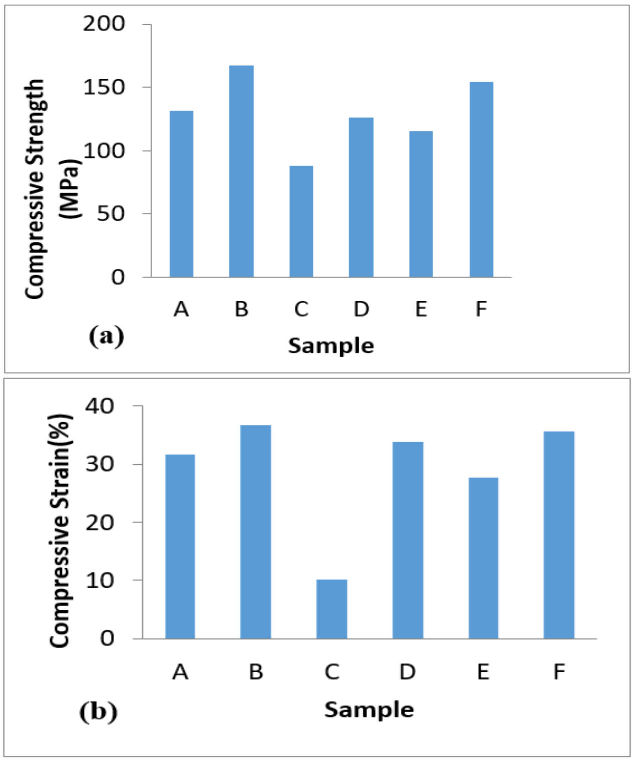

Figure 5: (a) Compressive strength of samples (b) Compressive strain of samples

Results of the compressive strength test is presented in Figure 5 showed that the compressive strength of the eggshell powder reinforced aluminium samples did not increase or decrease in any definite order with increasing weight percentage of eggshell reinforcement. The control sample had compressive strength of 131.19337MPa. However, the highest compressive strength of 167.11659MPa was obtained for sample "B" having 2% eggshell reinforcement, which represents an increase of 27.3% compared to the unreinforced aluminium sample (control sample "A"). In comparison, the lowest compressive strength of 88.37107MPa was obtained for sample "C" having 4% eggshell reinforcement, which represents a decrease of 40.9% compared to the unreinforced aluminium. The compressive strength improvements obtained in this study agree with the opinion of [31], in which said "eggshells can also be employed in constructing floor tiles and in cement to enhance compressive strength".

Considering the views of [19], the improvement in compressive strength of sample "B" compared to that of unreinforced aluminium sample (control sample "A") can be attributed to the following factors: the eggshell particles act as a barrier to the dissociation,; the eggshell particles might have also helped to refine the grain structure of the aluminium matrix, which further improves the strength of the composite; and lastly, the eggshell particles also have a high modulus of elasticity, which contributes to the overall stiffness of the composite to which it is added. Eggshell-reinforced aluminium has the potential to be used in a variety of applications where high strength and stiffness are required, which is in agreement with the views of [32]. In addition to the above, it is also worth mentioning that the compressive strengths of materials are generally higher than their tensile strength. This is because compressive loads push the material together, while tensile loads pull it apart. The eggshell particles in the eggshell reinforced-aluminium help to resist the compressive loads by preventing the dissociation and refining the grain structure of the aluminium matrix.

Table 2: Hardness test results

Sample Tag	Percentage of eggshell (%)	Hardness Value (HV)	Improvement (%)
A	0	105.1	-
B	2	100.3	-4.57
C	4	111	5.61
D	6	125.4	19.31
E	8	121.2	15.32
F	10	125.1	19.03

Table 2 shows that hardness of test samples increased with a corresponding increase in percentage of eggshell reinforcement. The control sample had hardness values of 105.1HV. Eggshell-reinforced

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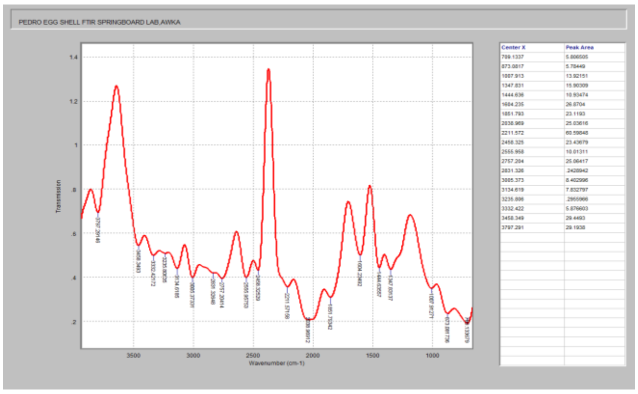
sample “D” having 6% reinforcement had the highest hardness value of 125.4HV. From the results, it can be observed that addition of eggshell powder to aluminium up to 10% as reinforcement improved its hardness. The hardness of eggshell reinforced aluminium samples obtained is similar to that obtained from the works of [27], in which they showed about 17% improvement in hardness of aluminium by adding ground nut husk ash to aluminium. Results presented in Table 2 also showed that addition of 4%, 6%, 8 % and 10% eggshell powder to samples C, D, E and F improved their hardness by 5.61%, 19.31%, 15.32% and 19.03% respectively. In comparison, adding 2% eggshell powder to sample B decreased its hardness by 4.57%.

Table 3: Impact test

Sample Tag	Percentage of eggshell (%)	Impact Test Result (J)	Improvement (%)
A	0	10.99	-
B	2	12.05	9.65
C	4	10.15	-7.64
D	6	11.21	2
E	8	10.48	-1.64
F	10	11.18	1.73

Table 3 shows that Impact Strength test samples did not increase or decrease in any definite order. The control sample had an impact strength of 10.99J. Eggshell-reinforced sample “B”, having 2% eggshell reinforcement, had the highest impact strength of 12.05J, while sample “E”, having 8 % reinforcement, had the lowest impact strength of 10.48J. The practical implication of this result is that there is some improvement on the impact strength of aluminium by reinforcing it with eggshell. The result gotten from this study is not significantly different from that reported by [27] in which they reported maximum of 12% decrease in the impact strength of aluminium hybrid composites by the addition of groundnut shell ash particles as reinforcement. Results presented in Table 3 also showed that addition of 2%, 6% and 10% eggshell powder to samples B, D and F improved their impact strength by 9.65 %, 2.00% and 1.735% respectively, while addition of 4% and 8% eggshell powder to samples C and E decreased their impact strength by 7.64% and 1.64 %.

The obtained FTIR spectrum is summarized in Figure 6, revealing nineteen (19) distinct peaks at well-defined wave numbers, indicative of various functional groups and molecular vibrations. The peak at 709.1337 cm^{-1} signifies bending vibrations, possibly arising from C-H, N-H, or C-O functional groups. This suggests the presence of complex organic compounds within the eggshell matrix. 873.0817 cm^{-1} peak corresponds to C-H bending vibrations, indicative of aliphatic compounds or hydrocarbon chains. The peak observed at 1007.913cm^{-1} corresponds to C-O stretching vibrations, indicating the presence of oxygen-bearing functional groups in organic compounds. The result obtained from FTIR is similar to that of [33] in which they stated that “microscopically, eggshell is made of a network of protein fibres, which in turn are associated with crystals of calcium, magnesium carbonate and calcium phosphate along with certain other organic substances like water”.



Center X	Peak Area
709.1337	5.806505
873.0817	5.78449
1007.913	13.92151
1347.831	15.90309
1444.636	10.93474
1664.235	26.8704
1851.793	23.1193
2038.969	25.03616
2211.572	60.59848
2458.325	23.43679
2555.958	10.01311
2757.204	25.06417
2831.326	.2428942
3005.373	8.402996
3134.619	7.832797
3235.896	.2955966
3332.422	5.876603
3458.349	29.4493
3797.291	29.1938

Figure 6: FTIR spectrum of eggshell powder

3.1 Ranking of Mechanical Properties of All the Samples

Tables 4 and 5 present the ranking of the samples based on combination of all mechanical properties tested. Table 4 shows the position of each sample for each of the measured properties. The sample with the highest measured value for each property occupies the first position, compared to the sample with the lowest value in the sixth position.

Table 4: Comparison of samples’ performance based on the mechanical properties tested

Position	Tensile	Strain Max	Compression	Impact	Hardness
1st	D	D	B	B	D
2nd	A	B	F	D	F
3rd	C	A	A	F	E
4th	F	F	D	A	C
5th	B	C	E	E	A
6th	E	E	C	C	B

Weights were assigned to each sample’s measured properties based on its position on that particular measured property. The sample that showed the highest property is assigned 6, next 5 in that order to the least 1 as shown in Table 5. The weights were selected to tally with the number of samples (i.e. 1 – 6). The total weighting is evaluated for all the samples.

Table 5: Ranking of the samples in terms of mechanical properties performance

Sample	Weighting of Measured Properties						Ranking
	Tensile	Strain	Compression	Impact	Hardness	Total	
A	5	4	4	3	2	18	4th

B	2	5	6	6	1	20	2nd
C	4	2	1	1	3	11	5th
D	6	6	3	5	6	26	1st
E	1	1	2	2	4	10	6th
F	3	3	5	4	5	20	2nd

Ranking in terms of preference is in the descending order of the total weight for each sample. This implies that sample with the highest total weight is ranked first (i.e. most preferred) and the one with the lowest total weight is ranked sixth (i.e. the least preferred) as depicted in Table 5. Consequently, sample D has the best combination of properties followed by B and F with tie of 20 each, followed by A, C and E. The implication is that reinforcing aluminium with 6% eggshell powder yielded composite with best combined mechanical properties. Here, all properties were assumed to be of equal preference, but this may differ for some applications, where some properties may be preferred to others.

Figure 7: OM image of control sample (x100)

Figure 8: OM image of sample “B” (x100)

Figure 9: OM image of sample “C” (x100)

3.2 Micrograph from Optical Microscope (OM) Examination of Prepared Aluminium Composites

Figure 7 to 12 present the micrograph of all prepared samples. The micrographs revealed dispersion of the eggshell powder (dark brown colour) in aluminium matrix (light brown or orange colour).

Figure 10: OM image of sample “D” (x100)

Figure 11: OM image of sample “E” (x100)

Figure 12: OM image of sample “F” (x100)

Optical Microscope Examination (OM) Images of samples presented in Figure 7 to 12 showed that micro-particles of the base samples are more closely packed together. However, the micro-particles of sample “C” which contains 4% eggshell reinforcement are dissociated and less held together. The OM Image of sample “F” which had 10% eggshell reinforcement shows a high level of dissociation of the micro-particles of the sample by addition of eggshell. From the surface morphology of samples’ OM images, one can deduce that the level of dissociation of micro-particles of samples increased with increase in the percentage of eggshell as reinforcement

3.3 Scanning Electron Microscopic Examination (SEM) of Some Fractured Test Samples

The SEM Images of samples are presented in Figure 13 to 15. The SEM image of sample 'A’ revealed a well-defined microstructure within the sample which

https://doi.org/10.4314/njt.v43i4.9

suggests homogeneous distribution of particles. The sample 'A' surface morphology appears smooth and relatively free from surface defects, such as cracks, pores, and inclusions. This suggests that the manufacturing process has effectively minimized surface irregularities. This is similar to the views of [35]. However, the micro-particles of sample "B" which contains 2% eggshell reinforcement are dissociated and less held together than those of the control sample.

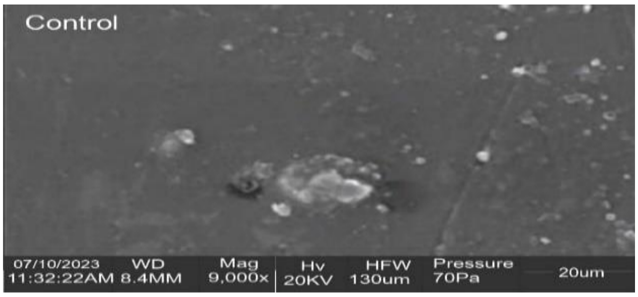


Figure 13: SEM Image of Control Sample ("A")

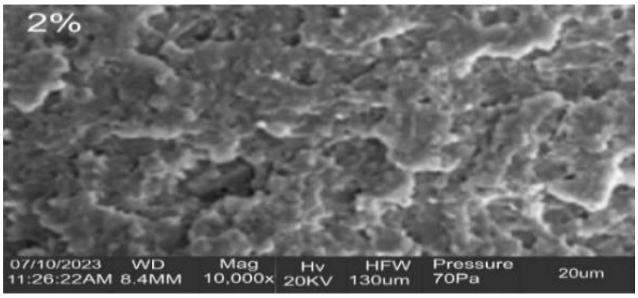


Figure 14: SEM Image of Sample "B"

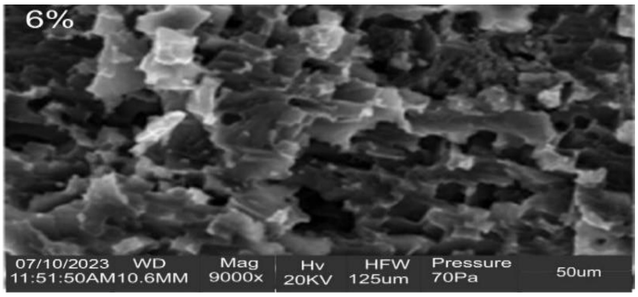


Figure 15: SEM Image of Sample "D"

The SEM image of sample "D" shows a very high level of dissociation of the particles of the sample by adding eggshell. From the result of the SEM images of samples, one can infer that the level of dissociation of particles of samples increases with an increase in the percentage of eggshell as reinforcement. The distribution of relatively uniform micro-particles in sample 'A' indicates minimal clustering of micro-particles. This uniform distribution is crucial for achieving consistent mechanical properties and ensuring the composite's overall integrity, which also agrees with the opinion of [36].

4.0 CONCLUSION

The following conclusion was drawn: aluminium-eggshell composites have been developed in this research. Eggshell was added to aluminium with varying percentage (2%, 4%, 6%, 8% and 10%). Mechanical properties and microstructural examinations were conducted on pure aluminium and the developed composites. The detailed mechanical properties test showed that 6% of eggshells in aluminium produced the highest tensile strength, tensile strain and hardness. While 2% eggshell produced composite with the highest compression strength and impact toughness. The microstructure revealed that the improvement in properties is due to dispersion of hard eggshell particles in soft aluminium matrix. Generally, it was observed that sample ''D'', which is the sample containing 6% eggshell powder has the best combined mechanical properties. Hence it was concluded that eggshell powder can be used to develop aluminium composites with enhanced mechanical properties. This is significant because eggshells are abundantly available waste products, and using it to reinforce aluminium could also help to reduce environmental pollution caused by improper disposal of eggshell being waste. Manufacturing of Boat hulls and other marine structures are among the possible uses of the developed composites since they have good compressive strength. Eggshell-reinforced aluminium can also improve the performance and durability of various athletic goods, such as helmets, racquets, and bats. The study has demonstrated the potential use of eggshell powder as a reinforcement material for aluminium to produce lightweight composites with good mechanical properties. The outcome of this study could benefit poultry farmers, food sellers, manufacturers and consumers of egg across the globe.

5.0 AUTHORS' CONTRIBUTIONS

P.E.E, S.C.I., S.O-O.S., M.E., and P.O.O conceived the study idea and established the guiding framework. The laboratory work, data gathering and analysis were coordinated by P.E.E, S.C.I., P.O.O., M.C.O., and F.E.U. P.E.E., S.C.I., S.O-O.S., M.E., and P.O.O drafted the original manuscript and organized the data obtained for better clarity and understanding. M.E edited the English of the manuscript after drafting. All authors read and approved the final manuscript. S.C.I., P.E.E handled the submission processes and correspondences.

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