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Mechanical Properties of Alkaline Modified Snail and Groundnut Shells Fillers Reinforced Glass Fiber Epoxy Composites

Oghenerukewve, P.O.

Department of Mechanical Engineering, Delta State University of Science and Technology, Ozoro, Nigeria

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Abstract

Adequate understanding of the mechanical characteristics of glass fiber epoxy composites combined with treated groundnut and snail shells fillers is essential for their utilization in the automotive sector. This study was conducted to evaluate the impact of fillers volume on the tensile and flexural properties of glass fiber epoxy composites reinforced with a combination of snail shell and groundnut shell fillers (particulate). The particulates were treated with 5% sodium hydroxide solution concentration for 1 hour. All the composite samples were manufactured utilizing the hand lay-up technique. Thereafter, their bending and tensile behaviors determined in accordance with ASTM International approved standards. The findings indicate that organic fillers quantity had a significant impact on the tensile strength, tensile strain, and flexural strength of the composite material ($P \leq 0.05$). it was noted in the results that the composite units tensile strength and tensile elongation ranged 213.9 to 252.21 MPa, and 33.38 to 40.9%, respectively. Similarly, the bending strength of the composite samples varied from 45.3 to 58.7 MPa. The results depicted that the incorporation of treated snail shells and groundnut shells as fillers presents a promising alternative for partially replacing glass fiber in the manufacturing of high-tensile-strength composites.

1. Introduction

Composite is a multifunctional material with enhance engineering properties, produced through the combining two or more materials having significantly different engineering behaviors. Though the resulting composite material produced inherits the fundamental properties of their constituent (primary) materials, the products usually have improve mechanical properties due to the synergistic effects of the sharing and bonding of the primary materials' engineering attributes [1-4]. The primary materials consist mainly of the matrix and reinforcement materials. Their interaction results in the reinforcement materials providing the necessary mechanical supports to the composite, and the matrix distributing the loads uniformly evenly throughout the composite material, resulting in increased mechanical behaviors of the product created. The mechanical properties of composites are dependent on the quantity and quality of the reinforcement materials, production technique and other anthropogenic errors [5]. Poor mix ratios can lead to the presence of excessive fillers/fibers in the composites, resulting in poor bonding (load distribution) between the matrix and the reinforcements, and the composite mechanical performance [6 – 8]. Proper understanding of the mechanical properties of biomaterials is crucial for their successful integration into composite materials for engineering applications [9]. The utilization of agricultural residues as reinforcement materials for composite production is gaining ground, due to the growing awareness of environmental health hazards associated with synthetic materials. Agricultural materials are considered biodegradable, environmental friendly, renewable and sustainable; hence, their utilization in the composite industry helps reduce the dependence on synthetic materials, whose production increases the global carbon fingerprint [10–12]. The strength behaviors of biomaterials are relatively poor (low) compared to traditional engineering materials. However, these properties can be significantly enhanced through chemical modification and blending with other materials, to increase their strength behaviors to appreciable level [13, 14]. Mohammed [15] investigated the suitability of using agricultural waste materials in composites production, and reported that utilization of rice husk in green composite production yielded composite unit with commendable tensile and flexural parameters.

Hybridization is a composite production technique that involved the combination of several fibers/fillers, whether natural or synthetic, to create a composite material with enhanced engineering properties and a broader range of applications [7, 16-17]. Snail shells particulates have been hybridized with other materials to produce composites with high tensile and bending parameters, which were attributed to the high natural calcium carbonate presence in the particulates [1, 18]. Devendra [19] and Ou [20] investigated the mechanical properties of composite made from glass fibers, and highlight the significant influence of integrating organic or inorganic fillers on the mechanical behavior of the composites. Alaneme [21] stated that groundnut shells has promising potential for creating hybridized composites characterized by exceptional durability and structural integrity. The production of high-quality lightweight composites relies heavily not only on the choice of materials and the expertise of the designer, but the composites must also adhere to prevailing environmental and safety standards [22].

Even though, significant works have been done on chemical modification and hybridization of natural fillers [4, 23-25], there is limited focus on the combination of treated snail shell and groundnut shell fillers with glass fiber epoxy composites. This showed that there is paramount need to investigate the engineering properties of composite units, manufactured from the incorporation of treated groundnut shells and snail shells into glass fiber epoxy composites. Proper understanding how natural fillers interact with the matrix, and influence the mechanical performance of the composite created, is very essential for their successful application in composite production [46 - 49]. Therefore, the main objective of this study is to access the influence of NaOH modified groundnut and snail shells fillers on the mechanical properties of glass fiber epoxy composites. Adequate knowledge of the mechanical properties of glass fiber epoxy composites integrated with treated groundnut and snail shells fillers is crucial for their application in the automobile industry.

2.0 Materials and Methods

2.1 Materials

a. Groundnut shells, snail shells, and glass fiber

The groundnut and snail shells were obtained local snail and groundnut processing centers in Delta State, Nigeria. Similarly, the glass fiber (E-glass and in woven pattern) was procured from a laboratory materials shop in Anambra State, Nigeria.

b. Matrix

Epoxy resin (LY556) was the matrix used for the composite production, and it was chosen for its favorable mechanical, electrical, and thermal characteristics [4].

2.2 Methods

a. Samples preparation

The snail shells and groundnut shells underwent a thorough washing process with water to eliminate all debris, followed by sun-drying (30±5°C). Subsequently, they were pulverized using a plate mill and then sifted through a 150 µm sieve to obtain the fine filler.

b. Fillers alkaline modification

The pulverized snail shell and groundnut shell fillers were modified (treated) with 5% NaOH solution for 1 hour at the ambient temperature of 30±5°C. Following this treatment, they were thoroughly washed with acidified water to neutralize any remaining traces of NaOH. Finally, the fillers were dried using an electrical laboratory oven (model Remi 60L, produced in India by International Scientific Instrument) at 85°C for 12 hours.

c. Preparation of the composite sample

Table 1 presents the constituents of the different experimental composite units. The matrix was prepared by combining epoxy resin and hardener in a ratio of 8 parts resin to 1 part hardener. The organic fillers were produced by mixing the snail shell particulate and groundnut shell particulate in the ratio of 1:1. The necessary materials were accurately weighed using an electronic weighing balance. The chosen fillers volume fractions for this research were based on previous studies, which predominantly utilized lower fractions [48]. Furthermore, related literature reviews indicated that higher filler volumes (above 30%) have been associated with detrimental effects on the mechanical properties of the produced composites [31, 49].

Table 1: Compositions of the epoxy composite samples

Code	Constituents
Sample 1	75% Matrix + 25% of glass fiber loading
Sample 2	75% Matrix + 20% of glass fiber + 5% organic fillers loading
Sample 3	75% Matrix + 15% of glass fiber + 10% organic fillers loading
Sample 4	75% Matrix + 10% of glass fiber + 15% organic fillers loading
Sample 5	75% Matrix + 5% of glass fiber + 20% organic fillers loading

d. Composite Preparation

The composite samples were fabricated using the hand lay-up technique in accordance with ASTM International approved standards. During production, the measured quantity of fillers was added to a container containing the appropriate amount of matrix and thoroughly stirred for 30 minutes to create a near-homogeneous mixture. The mixture was poured into the already prepared (oiled) mould containing the right amount of glass fiber, subjected to a dead load of 10 kg for 24 hours to expel any entrapped air bubbles before it was de-moulded [27]. Following the seven-day air curing period, the composite board was trimmed to dimensions of length (300 mm) x width (30 mm) x breadth (10 mm) in preparation for tensile strength testing (Figure 1). Consequently, for the flexural test, the sample was prepared into these dimensions: length (300 mm), width (30 mm) and thickness (30 mm).

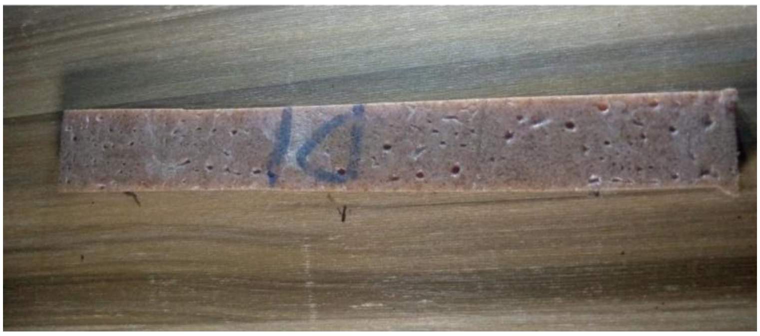



Figure 1: A composite specimen

2.3 Mechanical Testing

a. Tensile test

The tensile strength of the composites was measured with Universal Testing Machine (UTM) (Testometric model, series 500-532), in accordance with ASTM D3039/D3039M [26] approved guidelines. During the testing procedure, the UTM gripped each end of the specimen and applied a slow pulling force at a speed of 0.5 mm/min until fracture occurred. The electronic component of the machine measured the corresponding force and strain during the testing process. Thereafter, the tensile parameters of each tested sample were computed by the microprocessor of the machine and displayed on the computer screen. Equations 1 and 2 were employed for determining the tensile strength and elongation (%), respectively [4].

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

$$Elongation\ at\ Break, EB(\%) \ = \frac{\Delta L}{L} \qquad (2)$$

Where: ΔL = extension at break point, L = original sample length, and $F_{\max}$ is maximum load applied to the sample.

b. Flexural test

The composite flexural test was conducted following the approved procedures outlined in ASTM D7264/D7264M [28], by using the using the 3-point bending fixture, with the aid of the Universal Testing Machine. At the end of each test, the UTM microprocessor calculate and display the flexural parameters of each tested sample on the screen. The bending strength of each sample was determined by using Equation 3.

$$Bending\ Strength, \sigma \ = \frac{3FL}{2bd^2} \qquad (3)$$

Where F is the load (force) at the fracture point (N), L = support span length, b = sample width, and d = sample thickness.

2.4 Statistical Analysis

The relationship between the organic fillers on the mechanical properties of the hybridized composite samples was determined by using SPSS statistical software (version 20.0). The mean was separated using Duncan’s Multiple Range Tests at 95% confidence level. All the experiments were replicated four times, and the average values recorded.

3.0 Results and Discussion

3.1 Effect of the organic fillers on the tensile properties

The ANOVA findings regarding the impact of filler volume on the tensile properties of epoxy composite materials are summarized in Table 2. Table 2 revealed that the organic fillers quantity had significant effect on the tensile strength and strain of the composite ($P \leq 0.05$). The separated means of the tensile strength and tensile elongation are presented in Figures 2 and 3. Figure 2 clearly shows that the organic fillers caused significant impact on the tensile strength of the composite board ($P \leq 0.05$). The recorded tensile strengths (TS) for composite units coded as Samples 1, 2, 3, 4, and 5 were 213.9, 233.3, 252.21, 247.23, and 230.19 MPa, respectively. This portrayed that the composite TE generally increases as the filler quantity increases and the volume of the fiber glass decreases. This is an indication that combination of treated snail shells and groundnut shells as fillers, can serve as a viable alternative to partially substitute glass fiber in the production of high tensile strength composites; which is in confirmation with the observations made by Raju [45].

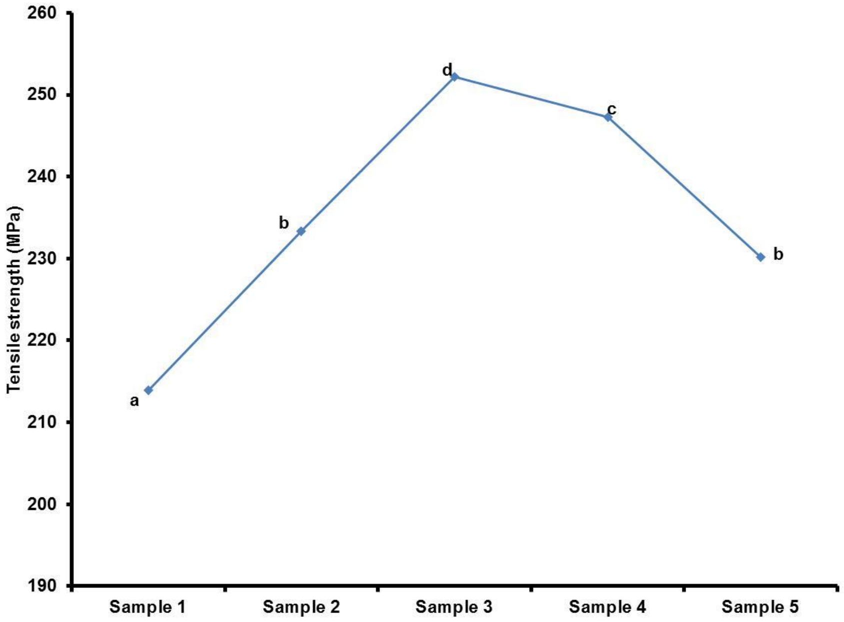
As seen in Figure 3, the tensile elongation (TE) generally decreases as the volume of the glass fiber incorporated into the composite decreases. The TE values of the samples 1, 2, 3, 4 and 5 composite samples were 36.62, 40.9, 37.98, 35.58 and 33.38%, respectively. This portrayed that the fillers retards the ductility of the composite, though they have some desirable mechanical properties, such as high tensile strength. Similar, the results reflects that the glass fiber caused significant increment in the composite ductility behavior; which is similar to the reports of Abdul [29] which stated that fibers have the ability of increasing the ductility of composite materials. Alkaline modification of organic materials enhances the roughness of the materials surface, and helps improve their adhesive characteristics by increasing the surface area available for contact with adhesives [30, 43-44].

These results revealed that prospect of using biomaterials as suitable replacement materials for traditional materials during the manufacturing of composite materials. Umurhurhu [31] and Sareena [42] reported that, the utilizing agricultural residues in composite production could encourage the design and development of novel materials for industrial applications. Green (organic) materials produce composite units that have light-weight, non-toxic, and possessing appreciable mechanical properties. In contrast, composites derived from inorganic materials (such as glass fibers) exhibit lower environmental friendliness attributes [14, 32-33]. The lower TS values recorded in the samples with higher fillers volume (>15% quantity) could be attributed to the poor bonding between the matrix and fillers. This results from excess fillers in the system which leads to overcrowding and hinders the mobility of the matrix chains. Consequently, producing composite with weak bonding interfaces having lower ability to absorb tensile forces [10, 34-35].

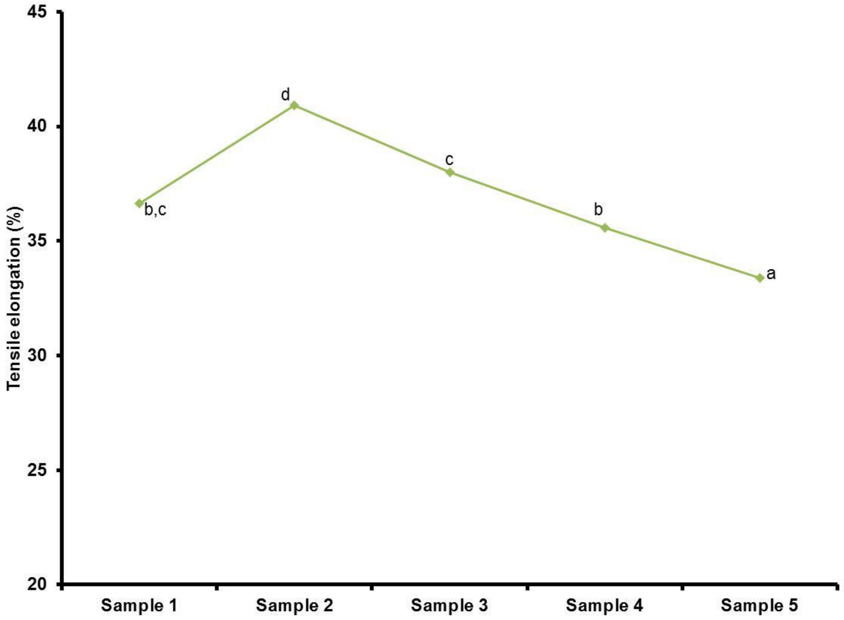
Table 2: Effect of filler volume on the tensile strength and elongation of the hybridize composite

Parameter		Sum of Squares	Df	Mean Square	F	p-value
TS	Between Groups	2749.561	4	687.390	96.15	6.14E-08*
	Within Groups	71.495	10	7.149		
	Total	2821.056	14			
TE	Between Groups	94.154	4	23.538	16.22	2.2E-04*
	Within Groups	14.510	10	1.451		
	Total	108.664	14			

TS = tensile strenght, TE = tensile elongation, * = signicant at $p \leq 0.05$



Points with the same common indicates that they exhibits no significant difference (P ≤0.05)
Figure 2: Tensile strength of the hybridized composite



Points with the same common means that they are not significant different (P ≤0.05)
Figure 3: The composite samples tensile elongation

3.2 The impact of the fillers on the flexural properties

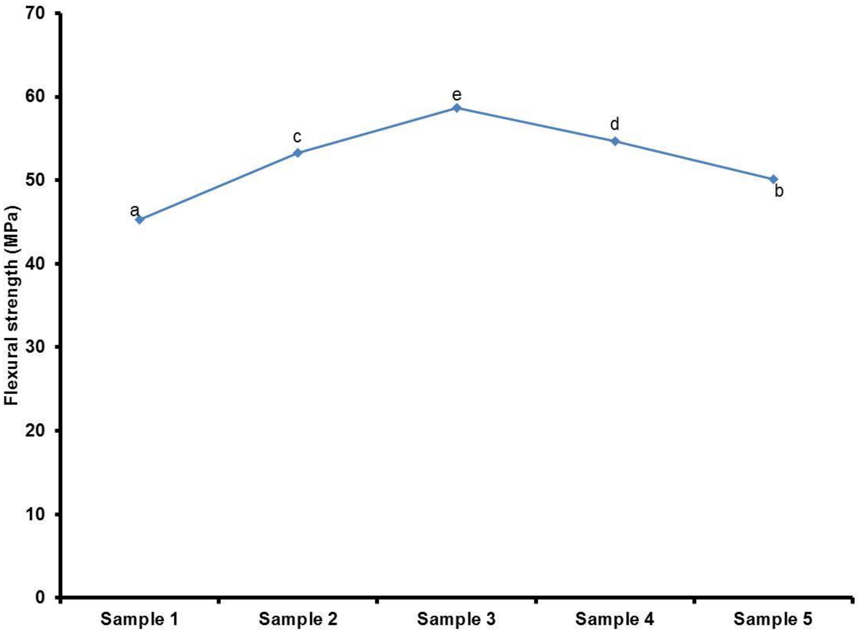
The ANOVA results presented in Table 3 revealed that fillers had significant ($P \leq 0.05$) effect on the flexural strength of the glass fiber reinforced epoxy composite. The findings from the separated means presented in Figure 4 revealed that, the flexural strength (FS) of the composite samples exhibited an uneven increase as the volume of fillers was uniformly increased from 0 to 10%. It was observed that composite samples 1, 2, 3, 4 and 5 recorded FS values of 45.3, 53.26, 58.7, 54.68, and 50.1 MPa, respectively. This is an indication that as the glass fiber volume declined from 5 to 0%, there was remarkably decline in the flexural strength of the concrete. These findings are similar to the observations made by Akpenyi-Aboh [33], where the composite flexural strength fluctuated as the fillers volume increases. Jacob [36] and Fadhil [35] research findings on the impact of groundnut shells particles on the mechanical properties indicated that, when groundnut shell powders are incorporated into composites at lower quantities, they can increase the flexural strength of composites to an appreciable level.

This study finding emphasizes the importance of reinforcing composite with natural fillers to improve its tensile and flexural properties. Devendra [19] explored the mechanical properties of composite made from glass fibers, and highlight the significant influence of integrating organic or inorganic fillers on the mechanical behavior of the composites. The major reason for the decline in the flexural strength of the composites samples as the fillers volume exceed 10% could be attributed to the poor interface bonding and fillers distribution within the matrix. Consequently, this will lead to microstructural flaws like voids, agglomerations, and clusters within the composite, thereby jeopardizing its structural integrity [37, 38].

The differences observed in the mechanical properties of these composite samples, in comparison to those manufactured by previous researchers using similar primary materials, may be attributed to several factors. These include the dynamic mechanical characteristics of biomaterials, differences in the maturity stage and variety of the agricultural materials utilized, as well as variances in the processing and storage methods of the biomaterials [35, 39-41].

Table 2: Effect of filler volume on the flexural strength of the glass fiber hybridized composite

	Sum of Squares	df	Mean Square	F	p-value
Between Groups	304.096	4	76.024	152.38	6.49E-09
Within Groups	4.989	10	0.499		
Total	309.085	14			



Points sharing the same commonality indicate a lack of significant difference (P ≤0.05)
Figure 4: Effect of filler volume on the flexural strength of glass fiber epoxy composite

4.0 Conclusion

In this study, the influence of varying volumes of organic fillers on the tensile and flexural properties of glass fiber epoxy composites was investigated. Different composite samples were produced by varying the volume of combination of groundnut shells and snail shells, mixed at a 1:1 ratio, ranging from 0% to 25%. All the composite samples were prepared and tested in accordance with ASTM procedures. The findings indicated that the quantity of organic fillers had a noteworthy impact on the mechanical properties of the composite material ($P \leq 0.05$). It was noted that the tensile strength and flexural strength of the composites exhibited a non-linear increase as the volume of fillers increased from 0 to 10%. However, further addition of fillers beyond this point led to a decline in both tensile and flexural strength. The results of this study portrayed that utilizing a combination of treated snail shells and groundnut shells as fillers could serve as promising partial replacement glass fiber in the production of high quality composite unit for industrial applications.

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