Analysis and Application of Natural Fiber Reinforced Polyester Composites to Automobile Fender

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Abstract – In Nigeria, little attention has been given to the analyses and applications of natural fibers for automobile body parts production. Hence in this work, an attempt is made to evaluate the compressive and impact strength of plantain fiber reinforced polyester composites (PFRC) and to develop an automobile fender using plantain fiber reinforced polyester composites. The PFRC automobile fender was constructed using the hand lay-up technique. The method adopted to achieve the PFRC fender involved fiber extraction, fiber surface treatment, laminates development for impact and compressive test experiment and the development of automobile fender. Experimental investigations for compressive and impact tests were carried out on the laminates which were prepared according to the ASTM D256 and ASTM D1621 standards, respectively. The impact strength result of the PFRC with volume fraction 0.25 and 0.3 was 12.22J/m² and 12.83J/m², respectively. The compressive strength, shear stress and resultant stress results of PFRC laminates with volume fraction 0.25 and 0.3 were 62.52MPa, 31.26MPa, 69.99MPa and 68.98MPa, 34.49MPa, 77.12MPa, respectively. From the results, it was observed that the strength of the plantain fiber reinforced polyester composites depend on the fiber volume fraction. The constructed automobile fender was simulated in a Solidworks software environment and was found that the edges, especially the circular part of the automobile fender have high stress concentrations. The production of the automobile fender using PFRC was done at low cost.

Keywords: Plantain fiber, polyester, volume fraction, automobile fender, product development
I. Introduction
The state of the art in material technology advocates for environmental-friendly materials for engineering applications. In recent times, advances in natural fibers syntheses have made the application of these materials suitable for automobile parts and body work. Plantain fibers possess moderately high specific strength and stiffness and can be used as reinforcement in polymeric matrix to make useful composite materials. Natural fibers have been used due to their advantages such as low density, low cost, acceptable specific strength to weight ratio, and biodegradability [1, 2]. In Nigeria, there are abundant natural fibers that could be obtained from plant, such as plantain, bamboo, raffia, coir fibers, etc. An attempt had been made by several researchers to optimize some mechanical properties such as tensile strength, impact strength, flexural and hardness of plantain fiber as reinforcement in polymer composites [3 - 8]. However, little attention has been given to the application of plantain fibers for automobile body parts production, especially in Nigeria.

II. Materials and Methods
Materials Selection. The materials employed in this study include plantain pseudostem fibers, polyester resins, accelerator (Cobalt naphthenate), catalyst (Methyl ethyl ketone peroxide), inorganic filler (Calcium trioxocarbonate IV), release agent (wax), sodium hydroxide, and mold. Plantain pseudostems were locally sourced from fully matured plantain plantation, located at Agbarho, Delta state, Nigeria. The resins and other chemicals were purchased at Warri main market, Delta State, Nigeria. The fibers form the reinforcement in the composites. Methyl Ethyl Ketone Peroxide (MEKP) was used as a catalyst while cobalt naphthenate was used as an accelerator. The release agent was debonding wax. The inorganic filler was calcium trioxocarbonate (IV).

Equipment/Tools. The equipment/tools used includes; Paintbrush, Pair of scissors, Hand gloves, rollers, grinding and filing machine.

Methods. The method adopted includes; the extraction and treatment (Mercerization) of plantain fibers, experimental analysis of the impact and compressive strength.

Extraction and Treatment of PFRC. The plantain pseudo stems were soaked in water for a period of four weeks and were manually extracted (retting method, figure 1). To remove the lignin (de-lignification), pectin and others non-fibrous materials, the plantain fibers were subjected to surface chemical modification by mercerization (soaked in NaOH solution of 5% concentration for 60 minutes) in Figure 2. Thereafter, washed with distilled water and sun-dried as shown in Figure 3 and 4.
The chemical reaction for the fiber and sodium hydroxide solution could be express as:
\[
\text{FIBER-OH} + \text{NaOH} \rightarrow \text{FIBER-O} - \text{Na}^+ + \text{H}_2\text{O}
\]  
(1)

**Volume Fraction Analysis.** Applying Archimedes principle to determine the volume fraction of the plantain fibers, we have

\[
\text{Fiber volume fraction}, \quad V_f = \frac{\text{Volume of fiber}}{\text{volume of composite}} \quad V_c
\]  
(2)

Volume of composite,
\[
V_c = V_f + V_m
\]  
(3)

Fiber weight fraction,
\[
W_f = \frac{\text{Weight of fiber}}{\text{weight of composite}} = \frac{W_f}{W_c}
\]  
(4)

Also,
\[
W_f = \frac{W_f}{W_f + W_m}
\]  
(5)

Hence, fraction of the applied force absorbed by the fibers in the composites could be expressed as;
\[
F_f = \frac{E_fV_f}{(E_fV_f + (E_mV_m)}
\]  
(8)

Stress and Strain Analysis. The force applied (load) on the composite (F_c) is shared by both the fiber and
the matrix. Let the forces on the fiber and the matrix be \( F_f \) and \( F_m \).

Therefore,

\[
F = F_f + F_m \tag{9}
\]

The strain, \( \epsilon \) is the same in the fiber (\( \epsilon_f \)) and the matrix (\( \epsilon_m \)) and is equal to the composite strain (\( \epsilon_c \)). Hence,

\[
\epsilon_c = \epsilon_f = \epsilon_m \tag{10}
\]

And let, Modulus of elasticity \( E \), of the fiber = \( E_f \) and matrix = \( E_m \). Hence,

\[
\text{Stress } \sigma = \frac{\text{Force}}{\text{Area}} = \frac{F}{A} \tag{11}
\]

\[
\text{Strain } \epsilon = \frac{\text{Change in length}}{\text{Original length}} = \frac{\Delta L}{L} \tag{12}
\]

Thus,

\[
\text{Stress } \sigma = E \times \epsilon \tag{13}
\]

Fiber stress,

\[
\sigma = E_f \times \epsilon_f \tag{14}
\]

Matrix stress,

\[
\sigma = E_m \times \epsilon_m \tag{15}
\]

Composite stress, \( \sigma_c = \sigma_f + \sigma_m \)

So,

\[
\sigma_c = (E_f \epsilon_f) + (E_m \epsilon_m) \tag{16}
\]

Shear Stress Analysis. It is expected that the fender would experience shear stress other than direct stresses such as compression, when in service. From [9], Normal stress could be expressed as;

\[
\sigma_n = \sigma \sin^2 \theta = \frac{\sigma}{2} (1 - \cos 2\theta) = \frac{\sigma}{2} - \frac{\sigma}{2} \cos 2\theta \tag{18}
\]

And shear or tangential stress;

\[
\tau = \sigma \sin \theta \cos \theta = \frac{\sigma}{2} \sin 2\theta \tag{19}
\]

From equation (18), the normal stress across the fender face will be maximum when \( \sin^2 \theta = 1 \) or \( \sin \theta = 1 \) or \( \theta = 90^\circ \), hence, the face of the fender will carry the maximum direct stresses. Similarly, from equation (19), the shear stress across the face of the fender would be maximum when \( \sin 2\theta = 1 \) or \( \sin 2\theta = 90^\circ \) or \( 270^\circ \); that is, the shear stress will be maximum on the planes inclined at \( 45^\circ \) and \( 135^\circ \). Hence,

\[
\tau_{\text{max}} = \frac{\sigma}{2} \sin 90^\circ = \frac{\sigma}{2} \times 1 = \frac{\sigma}{2} \tag{20}
\]

Therefore, the magnitudes of the shear stress is half of the compressive, hence the resultant stress, \( \sigma_R \) could be obtained from the relation;

\[
\sigma_R = \sqrt{\sigma_n^2 + \tau^2} \tag{21}
\]

Experimental Evaluation. Impact and compressive strength were evaluated.

Impact Test. The impact test specimens of plantain fiber reinforced polyester composites were prepared according to ASTM D256. The dimensions of the test samples were \( 63.5 \times 12.7 \times 3.2 \) mm and it was v-notched (2mm) deep with the aid of a triangular file, at an angle of \( 45^\circ \) with 0.25mm radius along the base. Five (5) samples each of volume fraction 0.25 and 0.3 respectively, were prepared at a curing pressure of \( 30\text{N/mm}^2 \) and \( 25^\circ \text{C} \) temperature. The test was carried out in a charpy setup using the Brooks impact testing machine. The energy required to break each sample was measured. The impact strength of the specimen was the energy absorbed per unit cross-sectional area at the notch (J/m\(^2\)) and it was determined using the formula:

\[
I = \frac{K}{A} \tag{22}
\]

where, \( I = \text{Impact strength (J/m}^2\)), \( K = \text{Energy required to break the specimen (J)} \), \( A = \text{cross-sectional area (m}^2\)).

Compressive test. The compressive test specimen was prepared according to ASTM D1621 standard. Squared specimens of dimension
5.2 cm x 5.2 cm x 25.4 mm were prepared for five (5) samples of volume fraction 0.3 and 0.4, respectively at a curing pressure of 30 N/mm$^2$ and 25$^0$C temperature. The compressive test experiment was performed using the Universal Testing Machine (UTM) which comprised of a digital load meter for reading the applied load, a dial gauge or extensometer for reading the deflection. The force and deformation data were then recorded. The expression in equation (23) was used to determine the compressive strength of the specimen:

$$\sigma_c = \frac{P_c}{A}$$  \hspace{1cm} (23)

Where, $\sigma_c$ = compressive strength, $P_c$ = load/force, $A$ = cross-section area

$$\varepsilon_c = \frac{\Delta L}{L}$$  \hspace{1cm} (24)

**Development of Auto Fender Made of Natural Composite Materials**

**Selection.** The matrix employed in the construction of fender was unsaturated polyester (mixed with cobalt naphthenate, and methyl ethyl ketone peroxide, MEKP initiator). The methyl ethyl ketone peroxide act as the catalyst or initiator, cobalt naphthenate as an accelerator, along with inorganic filler (calcium trioxocarbonate IV, CaCO$_3$) and ammonium chloride (NH$_4$Cl) as curing agent were added to the unsaturated polyester resins. Hand layup technique was employed. First, a gel coat prepared from the resin was applied on the mold and then, the matted plantain fibers were placed on the gel coat. There after a sequential impregnation of fiber – matrix (resin) ratio proportion of volume fraction 0.3 was employed until a thickness of 2.54 mm was obtained. The finished composite fender was allowed to cure at a pressure 30 N/mm$^2$ and 25$^0$Celsius, for 24 hours. Thereafter, the product was de-molded and surface finish techniques such as filing and spraying were done.

**III. Results and Discussion**

J/m$^2$. Plots of stress-strain for compression of PFRC with volume fraction 0.25 and 0.3 are shown in figure 5 to figure 14. It was observed that PFRC with volume fraction 0.25 and 0.3 had an average compressive strength of 62.52 MPa and 68.98 MPa, respectively.
Fig. 5: Sample 1, plot of stress-strain of PFRC($V_f=0.25$)

Fig. 6: Sample 2, plot of stress-strain of PFRC($V_f=0.25$)

Fig. 7: Sample 3 plot of stress-strain of PFRC($V_f=0.25$)
Fig. 8: Sample 4 plot of stress-strain of PFRC($V_i=0.25$)

Fig. 9: Sample 5 plot of stress-strain of PFRC($V_i=0.25$)

Fig. 18: Sample 6 plot of stress-strain of PFRC($V_i=0.3$)
Fig. 11: Sample 7 plot of stress-strain of PFRC($V_f=0.3$)

Fig. 12: Sample 8 plot of stress-strain of PFRC($V_f=0.3$)

Fig. 13: Sample 8 plot of stress-strain of PFRC($V_f=0.3$)
From equations 18, 20 and 21, the computed shear stress for volume fraction 0.25 and 0.3 were 31.26 MPa and 34.49 MPa, respectively. And the resultant stress for volume fraction 0.25 and 0.3 were 69.99 MPa and 77.12 MPa, respectively. The constructed fender was simulated in a Solidworks environment as shown in figure 15 and 16. It was observed that the edges of the fender have high-stress concentrations, especially the circular part. It means that more reinforcement is required in this region of the fender in order to withstand shocks and impact load. And for the displacement pattern, the facial part of the fender experiences larger displacement. Hence when fibers are evenly distributed in the matrix, it would help to accommodate induced stresses.
Figure 17 shows the orthographic drawing of the automobile fender using first angle projection. The surface area of the fender is $4156.74 \text{ mm}^2 (0.0042 \text{ m}^2)$. The automobile fender constructed from plantain fiber reinforced polyester composites is shown in figure 18.

Figure 17: Orthographic drawing of the automobile fender using first angle projection
Fig 18: Finished product of automobile fender developed from plantain fiber reinforced polyester composites

IV. Conclusion
From this work, the suitability of plantain fiber reinforced composites for use in automobile body work application is promising. The major challenge with plantain fibers reinforced with the polymer is the incompatibility between the hydrophilic plantain fibers and the hydrophobic polymer resins. This leads to undesirable properties of the composites. It has been observed that the modification of plantain fibers through chemical treatment tend to improve the adhesion between plantain fibers and resins, and also, improve the strength of the PFRC. Hence, further work should be done on plantain fiber extraction process, plantain fiber surface modification and its application to automobile body parts.

References


