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Original Research Article

Development of Automobile Bumper Fascia from Plantain Fibre-Reinforced Polyester Composites

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Abstract

Applying natural fibre-reinforced polymer composites for automobile body parts has not gained much attention in Nigeria. Natural fibres appear to be a good alternative to non-biodegradable synthetic fibres. This work aimed to develop natural fibres obtained from plantain pseudo-stem for reinforcement with polyester composites for automobile bumper fascia application. The plantain fibres were manually extracted and treated using the mercerization process. Compressive and impact tests were carried out on the laminates which were prepared according to the ASTM D695 and ASTM D256 standards, respectively. The plantain fibre-reinforced composite automobile bumper was then constructed using the hand lay-up technique. Laminates with volume fractions 0.3 and 0.4 are produced and analysed for impact and compression tests. From the experimental results, it was observed that the Impact strength for a volume fraction 0.3 and 0.4 was 12.22 kJ/m^2 and 13.83 kJ/m^2, respectively and compressive strength for a volume fraction 0.3 and 0.4 was $65.3x10^3 kN/mm^2$ and $67.4x10^3 kN/mm^2$, respectively. The study shows that plantain fibre-reinforced polyester composites could be an alternate candidate for automotive bumper fascia.

Keywords: Plantain fibres, polyester resin, Impact strength, Compressive strength, Bumper fascia.

1.0 INTRODUCTION

In recent years the development of biodegradable fibres as an alternative source to synthetic fibre is gaining more attention due to environmental concerns for non-biodegradable materials. Over the years, synthetic fibre-reinforced polymeric material has been an excellent alternative for metals due to its lightweight, low density, adequate strength-to-weight ratio, and corrosion-resistant properties [1-3], which make such material a suitable candidate for application in the automobile and aerospace industries. Because of their low cost, biodegradability properties after life-cycle usage, etc., natural fibres have been an attractive alternative source to synthetic fibres. In recent times, developments in natural fibres syntheses have improved their application as a suitable material for automobile parts and bodywork [1]. However, the ability of natural fibres to compete optimally as synthetic fibres such as carbon, aramid, glass fibres, etc., has shown some drawbacks, due to natural fibres' hydrophilic characteristics, wettability and poor compatibility with matrix. Studies on strengthening and improving the performance of natural fibres are still ongoing [4-10]. Advances in the syntheses, characterizations, and performance evaluations of natural fibre-reinforced composites and their applications have gained more attention because of their prospects. For instance [11], reviewed the characteristics of natural fibre composite on automobile body parts and revealed that natural fibres have advantages and that epoxy served to increase the material properties of natural fibre. Natural fibre-epoxy used in crashworthiness design serves as an absorption energy tool. Natural Fibre Polymer Composites (NFPCs) in the automobile and construction industry and other applications have been reviewed and had been observed that chemical treatment of the natural fibre improved adhesion between the fibre surface and the polymer matrix which ultimately enhanced physico-mechanical and thermochemical properties of the NFPCs [12]. Attempts have also been made to study the possibility of replacing glass fibres with natural fibres and the mechanical properties of these natural fibres such as sisal, hemp, coir, kenaf and jute reinforced in polypropylene composites appeared to compete favourably with the corresponding properties of glass fibre polypropylene composites [13-17]. In terms of composites application to bumper, [18] designed, analyzed and characterized car bumper using glass fibre reinforced with Aluminium and observed that the damage size was greater in laminates with poor interfacial adhesion compared to that of laminates with strong adhesion between aluminium and glass layers. Several investigations have been made on natural fibres composite materials properties [19–24]. The hardness, impact, flexural, and compressive properties of plantain fibre laminates have been studied by 25-28. In Nigeria, there are abundant natural fibres that could be obtained from plants, such as plantain, bamboo, raffia, coir fibres, etc [1], and are being extracted through the method of retting or machines [1, 29]. Literature has shown that a lot of work has been done on natural fibres reinforcement in polymeric materials and its applications. However, it is observed that limited work has been done on the application of plantain fibres as reinforcement in polyester for automobile bumper fascia development. Hence, this work seeks to develop automobile bumper fascia from plantain fibre reinforced polyester composites.

2.0 MATERIALS AND METHODS

2.1. Materials

Materials used are plantain pseudo-stems which were locally sourced from fully matured plantain plantation, located at Ugbomro, Delta state, Nigeria; and the resins/matrix along with other chemicals were purchased at Warri main market, Delta State, Nigeria. The fibres 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).

2.1.1. Reinforcements- Plantain Pseudo-stem fibre

The role of the plantain pseudo-stem fibres is to reinforce the composite material, with the goal of increasing the resin/matrix's mechanical properties.

2.1.2. Matrix- Polyester resin

The matrix is a polyol 344-TA thixotropic unsaturated polyester resin with high reactivity and medium viscosity. Because of its high heat resistance, it is widely used in the automotive industry. Polyester is a compound which belongs to the group of polymer derivatives. It is a polymer whose monomers are linked together by ester bonds. The polyester resin forms the matrix of the composite. To improve the reaction rate, an accelerator and a catalyst are added to the original matrix material.

2.1.3. Accelerator

The accelerator used in this work is cobalt naphthenate. The accelerator act to activate the resin at a lower temperature.

2.1.4. Catalyst

The catalyst is a chemical compound that speeds up the chemical reaction of the unsaturated polyester from liquid to solid state when mixed with the accelerator. The catalyst used here is methyl-ethyl ketone peroxide (MEKP).

2.1.5. Release agent

The release agent aids the removal of the laminate after undergoing the curing process by constituting barrier against adhesion to the mould surface.

2.1.6 Tools

The tools that were used in the course of this study include; Paintbrush used for the application of resin and release agent. Pair of scissors used for the cutting of the fibres load to the require shape and size before formation of laminate and product. Rubber hand gloves used to prevent direct contact of hand and the resin. Rollers for proper consolidation and impregnation of the fibres in order to remove air-trapped from the laminate mould and product.

2.2 Methods

2.2.1. Extraction of Plantain Pseudo stem Fibre (PFRC)

The matured plantain pseudo stems were cut to seize and soaked in water for a period of four weeks and were manually extracted using retting method as shown in figure 1, to remove the lignin, pectin and others nonfibrous materials. Thereafter, it was subjected to surface chemical modification by mercerization (soaked in NaOH solution of 5% concentration for 60 minutes). Thereafter, it was washed with distilled water and sun-dried as shown in Figure 2.

Fig 1: Retting process of plantain pseudo stem

Fig 2: Dried fibre of plantain pseudo-stem

The treated fibres were then sun dried for 24 hours to remove free water [1]. The reaction between the fibre and sodium hydroxide solution could be expressed as:

FIBRE-OH +NaOH →FIBRE-O-Na^+ + H_2O …… (1)

2.2.2. Laminate Composite Preparation Process

After the fibre had been reduced to its fibrous form, the plantain fibres were then chopped to appropriate sizes before they were combined with the polyester resin using the hand lay-up techniques. Horizontal random directional arrangements of the fibres were matted using the polyester resin as matrix. They were arranged to according to ASTM D695 for the compressive specimens and ASTM D256 for the impact specimen.

2.2.3 Development of Automobile Bumper from Plantain fibre reinforced Composites

Mould of a Volkswagen golf 2 model bumper shape was constructed with wooden material. The matrix was prepared from unsaturated polyester mixed with the hardener/accelerator- cobalt naphthenate and a catalyst -methyl ethyl ketone peroxide MEKP. The MEKP acts as the catalyst or initiator, as well as inorganic filler (calcium trioxocarbonate IV, $CaCo_3$) and ammonium chloride (NH_4Cl) as curing agents were equally added [1]. The prepared matrix is then weighed/measured and poured on the mould proportionately along with the weighed/measured treated fibres according to the determined volume fraction. A roller was used to permeate the fibres with the matrix for uniformly distributed composites until the required thickness was attained. After the PFRC was cured/solidified for 24 hours in open air. Thereafter, the composite bumper was de-moulded and surface-finished and sprayed. Hand layup technique was employed. First, a gel coat prepared from the resin was applied to the mould and then, the matted plantain fibres were placed on the gel coat. Thereafter, a sequential impregnation of fibre–matrix (resin) ratio proportion of volume fraction 0.4 was employed until a thickness was obtained. The finished composite fender was allowed to cure at a pressure of 30 N/mm^2 and 25^0 Celsius, for 24 hours. Thereafter, the product was de-moulded and surface finish techniques such as filing and spraying were done.

2.3 Experimental Set-up

2.3.1 Compressive test:

The compressive test specimen was prepared as per the ASTM D695 [30]. The compressive test was performed using the Universal testing machine (UTM) which comprised a digital load meter for reading the applied load, and a dial gauge or extensometer for reading the deflection. The compressive test involved mounting the specimen on the machine and gradually subjecting it to a compressive loading, which was applied via a hand pump until it fractured. The compression force was recorded as a function of displacement. The following formula was used to determine the compressive strength of the specimen:

$$\sigma_c = \frac{P}{A} \quad \ldots\ldots (2)$$

Where: σ_c= compressive strength (N/m^2); P= Force of compression (N); A= Area of cross-section (m^2)

2.3.2 Impact test:

The impact test specimens were prepared according to ASTM 256 [30]. The test was carried out in a Charpy setup using the Brooks impact testing machine. During the testing process, the specimen was loaded in the impact testing machine by placing it horizontally between the parallel sample holders which act as clamps, and then the pendulum was allowed to strike the specimen from the back of the notch until it fractured and the energy required to break the material was measured easily. The energy measured was in joules. The impact strength of the specimen was determined using the expression:

$$I = \frac{K}{A} \quad \ldots\ldots (3)$$

Where:
I= Impact strength (KJ/m^2); K= Energy required to break the specimen (J); A= Area

2.3.3 Design for stress

Stress – Strain Analysis

The force applied (load) on the composite F_c [1] is shared by both the fibre and the matrix. The forces on the fibre and the matrix are denoted as F_F and F_M.

Therefore,
Force on composite = force on fibre + force on matrix

$$F_C = F_F + F_M \quad \ldots\ldots (4)$$

The strain ϵ is the same in the fibre (ϵ_F) and the matrix (ϵ_M) and is equal to the composite strain (ϵ_C).
That is, Strain in composite = strain in fibre = strain in matrix, $\epsilon_C = \epsilon_F = \epsilon_M$ …… (5)

And the modulus of elasticity E, of the fibre E_F and matrix E_M is;

$$\text{Modulus } E = \frac{\text{stress}}{\text{strain}} = \frac{\sigma}{\epsilon} \quad \ldots\ldots (6)$$

And

$$\text{Stress} = \frac{\text{Force}}{\text{Area}} = \frac{F}{A} \quad \ldots\ldots (7)$$

$$\text{Strain} = \frac{\text{change in length}}{\text{original length}} = \frac{\Delta L}{L} \quad \ldots\ldots (8)$$

From equations 6,7,8, we have

$$\text{Modulus } E = \frac{F}{A} \times \frac{\Delta L}{L} \quad \ldots\ldots (9)$$

$$\text{Hence, Modulus } E = \frac{\text{Stress}}{\text{Strain}} = \frac{\sigma}{\epsilon} \quad \ldots\ldots (10)$$

Thus:

$$\text{Stress } \sigma = E \cdot \epsilon \quad \ldots\ldots (11)$$

Therefore;

$$\text{Fibre stress } \sigma_F = E_F \cdot \epsilon_F \quad \ldots\ldots (12)$$

$$\text{Matrix stress } \sigma_M = E_M \cdot \epsilon_M \quad \ldots\ldots (13)$$

$$\text{Composite stress } \sigma_c = \sigma_F + \sigma_M \quad \ldots\ldots (14)$$

Hence,

$$\sigma_c = (E_F \cdot \epsilon_F) + (E_M \cdot \epsilon_M) \quad \ldots\ldots (15)$$

$$E_C \cdot \epsilon_M = (E_F \cdot \epsilon_M) + (E_M \cdot \epsilon_M) \quad \ldots\ldots (16)$$

2.3.4 Fibre Volume Fraction Analysis

From Archimedes principle, the volume fraction of the fibres could be expressed as;

$$\text{Fibre volume fraction, } V_F = \frac{\text{Volume of fibre}}{\text{volume of composite}} = \frac{V_f}{V_c} \quad \ldots\ldots (17)$$

$$V_c = V_f + V_m \quad \ldots\ldots (18)$$

Where V_f= volume fraction of fibre, V_f = volume of fibre, V_C = volume of composite
V_M = Volume of matrix

More so,

$$\text{Fibre weight fraction } W_F = \frac{\text{Weight of fibre}}{\text{weight of composite}} = \frac{W_F}{W_C} = \frac{W_F}{W_F + W_M} \quad \ldots\ldots (19)$$

$$W_F = \rho_F \cdot v_F \quad \ldots\ldots (20)$$

$$W_c = \rho_c \cdot V_c \quad \ldots\ldots (21)$$

Where ρ = density, v = volume, subscript F, C refer to fibre and composite respectively. Hence, fraction of the applied force which can be taken by the fibre in the composite is given,

$$F_F = \frac{E_F \cdot V_F}{(E_F \cdot V_F) + (E_M \cdot V_M)} \quad \ldots\ldots (22)$$

2.3.5 Shear Stress Analysis

When two principal stresses (tensile stress and compressive stress) act on a body, they are accompanied by shear stresses. This accompanying shear stress is maximum at failure. Normal stress is given as:

$$\sigma_n = \sigma sin^2\theta \quad \ldots\ldots (23)$$

And it is also equal to the following expression

$$= \frac{\sigma}{2}(1 - \cos 2\theta) = \frac{\sigma}{2} - \frac{\sigma}{2}\cos 2\theta \quad \ldots\ldots (24)$$

While the shear or tangential stress is given as:

$$\tau = \sigma \sin\theta \cos\theta = \frac{\sigma}{2}\sin 2\theta \quad \ldots\ldots (25)$$

From equation 23 above, the normal stress across the bumper face will be maximum when $sin^2\theta$ =1 or $\sin\theta = 1, where\ \theta = 90°$. Hence, the bumper face will carry the maximum direct stress. Similarly, the shear stress across the face will be maximum when $\sin 2\theta = 1$ or $\sin 2\theta = 90°\ or\ 270°$. This means the shear stress will be maximum on the planes inclined at 45^0 and 135^0 with the line of action of the compressive and shear stress when θ is equal to 45^0

$$\tau_{max} = \frac{\sigma}{2} sin\, 90° = \frac{\sigma}{2} \times 1 = \frac{\sigma}{2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (26)$$

Thus, the magnitudes of maximum shear stress are half of the compressive, hence the resultant stress may be found out from the relation:

$$\sigma_R = \sqrt{{\sigma_n}^2 + \tau^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (27)$$

Where: $\sigma_n =$ Normal stress, $\sigma =$ Direct (compressive) stress, $\sigma_R =$ Resultant stress, $\sigma_1 =$ Principal stress $\tau_{max} =$ Maximum shear stress, $\tau =$ Shear stress or tangential stress

2.4 Simulation of the Bumper

The performance of the automobile bumper made of plantain fibre-reinforced polyester composite was simulated using SolidWorks software, with the assumption that the bumper was fixed and the applied forces were on the entire surface of the bumper fascia.

3.0 RESULTS AND DISCUSSION

3.1 Experimental Results

The impact strength of the plantain fibre-reinforced composites with volume fractions 0.3 and 0.4 gave average impact strength of 12.22 kJ/m^2 and 13.83 kJ/m^2 as shown in figures 5 and 6. The Impact test result shows that the strength of the plantain fibre-reinforced composite depends on the volume fraction.

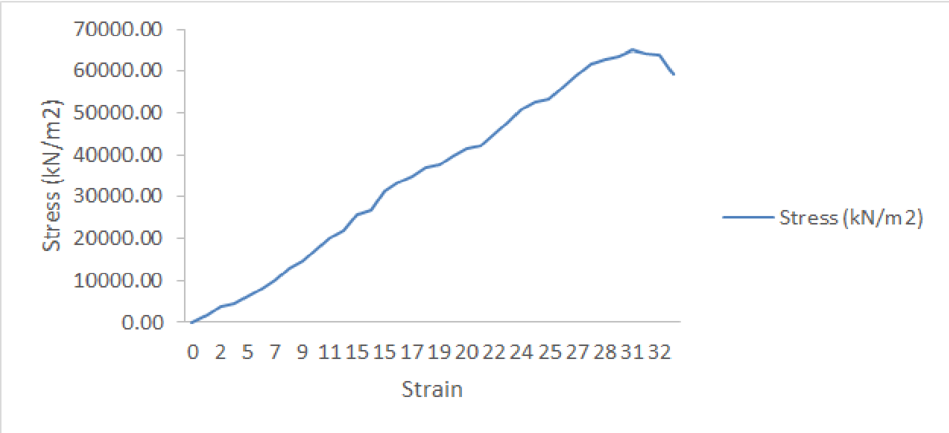

Figure 3: Stress-Strain plot for Compressive Test with volume Fraction = 0.3

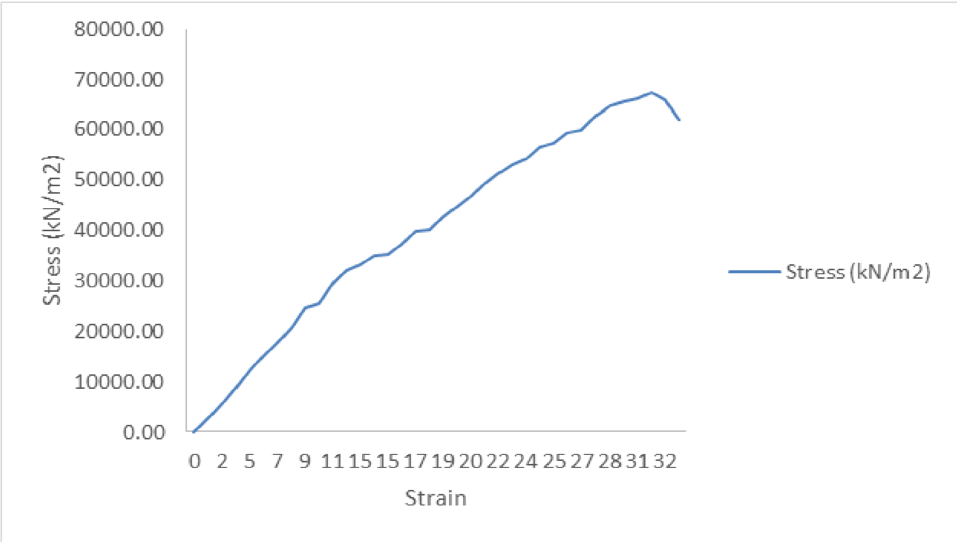

Figure 4: Stress-Strain plot for Compressive Test with volume Fraction = 0.4

4.3 Simulation Results of the Bumper Facia

The performance of the automobile bumper was simulated using Solid Works software. It was assumed that the bumper was fixed at all edges and the force was applied on the entire surface of the bumper. A compressive force of 40kN was applied on the surface and simulated; the results of von Mises stress and resultant displacement obtained for volume fraction 0.45

were shown in Figures 5 and 6, respectively. Figure 5 depicts the stress distribution on the surface of the bumper. The different colours on the bumper indicate various stress levels. The edges and the middle of the bumper are observed to have high-stress concentrations. The minimum and maximum stress are 1254.36 N/m^2 and 4.07211×10^8 N/m^2, respectively. More so, we can see that the stress distribution pattern on the bumper is random; hence the fibre in the matrix was randomly distributed to accommodate this stress distribution pattern and the displacement. It was observed in Figure 6, that the displacement of the bumper is least at the edges, while the centre of the bumper experiences the highest displacement of 102.811 mm. Figure 7 is the fabricated bumper fascia.

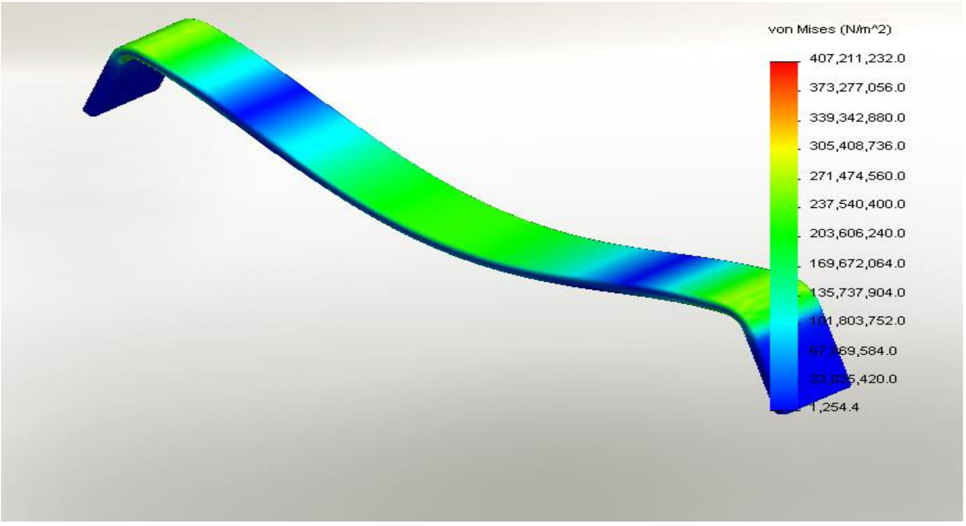

Figure 5: Von Mises Stress Distribution of Bumper for a volume fraction of 0.4

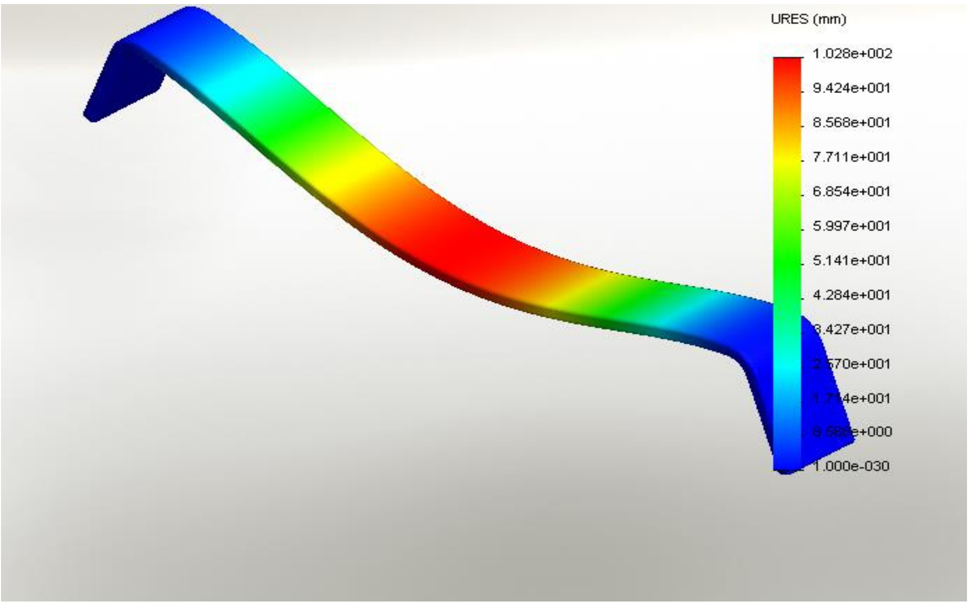

Fig 6: Resultant Displacement of Bumper for a volume fraction of 0.4

Fig 7: Fabricated Bumper Fascia

CONCLUSION

This study has shown that plantain fibre reinforced polyester composites could be used as alternate candidate for automotive bumper fascia. From the experimental results, it was observed that the Impact strength for a volume fraction 0.3 and 0.4 was 12.22 kJ/m^2 and 13.83 kJ/m^2, respectively and compressive strength for a volume fraction 0.3 and 0.4 was $65.3x10^3$ kN/mm^2 and $67.4x10^3$ kN/mm^2, respectively.

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