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Fabrication, Characterization and Analysis of a Plantain Fiber Reinforced Composite Anti-Crash Helmet

Chinedum Ogonna Mgbemena[1*], Chika Edith Mgbemena[2] and Emmanuel Chuka Chinwuko[3]
[1]Department of Mechanical Engineering, Federal University of Petroleum Resources, Effurun, Nigeria
[2]Department of Industrial/Production Engineering, Nnamdi Azikiwe University, Awka, Nigeria
[3]Department of Industrial/Production Engineering, Nnamdi Azikiwe University, Awka, Nigeria
[*]CorrespondingAuthor's E-mail: mgbemena.ogonna@fupre.edu.ng

Abstract
The use of natural and synthetic fibres as fillers in reinforced hybrid composite materials are rapidly advancing in the field of engineering and technology due to its tailored properties. Presently, natural fibres are better alternatives in terms of biodegradability, low cost, high strength, water resistance and antistatic nature when compared to conventional materials. Many industries recognise the advantages of components and products which are designed and produced from fibre reinforced composite materials instead of metals. Therefore, this study aims to develop a crash helmet using Plantain Fibre Reinforced Composite (PFRC) material and to evaluate properties such as compressive strength, impact energy strength, water absorption rate and the electrical conductivity by subjecting the developed samples of the PFRC to each of the tests. A crash helmet was developed by hand lay-up method using Plaster of Paris (POP) as the mould. From the experimental results, it is evident that the PFRC exhibited superior properties and can be used as alternatives compared to conventional materials in this application

Keywords: Composites, Crashworthiness, Helmet, Plantain fibres, Polyester

1. Introduction

A crash helmet is a protective gear worn on the head in order to protect or reduce head injury. It is mainly used in sporting activities, military, in manufacturing and construction sites (Hopkins & Hopkins 1985; Liu et al. 2008; Kresnak 2011; Darling 2014; Meng et al. 2018). Most helmets are made from plastics, which may be reinforced with fibres such as aramids. All helmets attempt to protect the user's head by absorbing mechanical energy and protecting against penetration (Chang, Ho & Chang 2003). Their structure and protective capacity are altered in high-energy impacts. Beside their energy-absorption capability, their volume and weight are also an important issue since higher volumes and weight increase the injury risk for the user's head and neck. Neurosurgeons invented anatomical helmets adapted to the inner head structure at the end of the 20th century (Darling 2014).

The use of plastics in the manufacturing of helmets is prevalent globally but recent studies show that reinforced composite materials are highly desirable and more advantageous over conventional materials(Biagiotti, Puglia and Kenny 2004, Debnath, Nguong and Lee 2014, Pickering, Efendy and Le 2016, Ghaffar 2017, Kumar 2017, McGregor et al. 2017, Bar, Alagirusamy and Das 2018). The use of reinforced composite materials is applied in many fields of study such as the automobiles, textiles, building constructions, aeronautical, sports Composites are lightweight, durable and stiff materials made from two or more constituents with significantly different physical or chemical properties that when combined, produce a material with characteristics different from the individual component(Mgbemena & Mgbemena 2017).

Head injuries during cycling, mountaineering and construction activities could be catastrophic, and fatal. Anti-crash helmets are developed to help mitigate this problem. In this present research, PFRC were fabricated, characterised and analysed to ascertain its suitability as an alternate material for anti-crash helmets.

2.0 Material and methods

2.1 Materials- The plantain fibres used in this study were extracted from pseudostems obtained from a local plantation at Agbarho, Delta State, Nigeria. The Polyester resins,methyl-ethyl-ketone peroxide in Dimethyl Phthalate (which acts as the catalytic hardener,)cobalt naphthenate (which acts as the accelerator) and grease (which acts as the mould release agent) were obtained from local suppliers at Onitsha, Anambra State, Nigeria.

2.2 Methods.

2.2.1Fibre extraction and Retting- The plantain pseudostems were retted in water for 30 days and washed with clean water to remove the lignin and other cellulosic materials from the fibres.

2.2.2 Alkali treatment-The retted fibres were soaked in 10% sodium hydroxide (NaOH) solution for 4 hours and after that washed properly and sundried for five days.

$$FIBERCELL - OH + NaOH \rightarrow FIBER - O^{-} + Na^{+} + H_2O \qquad (1)$$

Equation (1) is the chemical equation describing the alkali treatment.

2.3 Mould preparation and Fabrication

The pattern used for this work was the desired type of crash helmet purchased from the local market. The POP was used as the mould used for this study. The traditional method of Hand lay-up was employed in fabricating the crash helmet. The fabricated helmet is then allowed to cure for about 2-3 hours and then dismantled from the mould.

Figure 1. Images of the fabricated helmet

2.4 Characterisations of the Crash helmet

The developed PFRC samples were subjected to the following characterisations to determine their mechanical and antistatic properties: water absorption, impact, compressive and electrical conductivity tests.

2.4.1 Water absorption test

The water absorption test was conducted according to ASTM D570 to determine the amount of water absorbed by the PFRC under specified conditions. The PFRC samples were initially oven-dried and cooled in a desiccator. The dried samples were weighed and immersed in water at a temperature of 23°C for 24 hours. The PFRC sample was removed from the water, dried with a lint-free cloth, re-weighed and the new weight recorded (ASTM 1998). Thedata sheds light on the performance of the materials in water or humid environments. Water absorption is expressed as an increase in weight per cent.

$$\%\, water absorption = \left[\frac{wetweig\ ht - dryweig\ ht}{dryweig\ ht}\right] \times 100 \qquad (2)$$

2.4.2Compression test

The compressive strength of the PFRC sample was determined according to ASTM D695. The dimension of the specimen is a block-sized shape of 12.7 x 12.7 x 25.4mm. A hydraulic compression testing machine (Modal-DM/TG) was used for this test. A progressive load at a rate of 0.5 MPa/s was applied to the sample until the sample failed.

2.4.3 Impact test

The Charpy impact test was conducted on the PFRC sample according to ASTM D256. The dimension of the test sample was 38mm by 3mm, and it was v-notched (2mm) deep with the aid of a triangular file, the samples were prepared at ambient temperature. The impact strength of the specimen was determined using the formula:

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

Where I is the impact strength (KJ/m^2);K is the Energy required to break the specimen or energy absorbed by the specimen(J);A is the area of the cross-section (m^2)

2.4.4 Electrical conductivity test

The electrical conductivity test was conducted to ascertain the conductivity and resistivity of the PFRC to electric current. The best materials chosen for this application should be antistatic. The antistatic material is a material that does not permit the building up of static electric current charges or static electricity in it. The electrical conductivity of the PFRC was conducted on parallel plates of two copper cylinders with holes to attach cables connected to the Keithley 6220 DC source and the Keithley 2182A nano voltmeter.

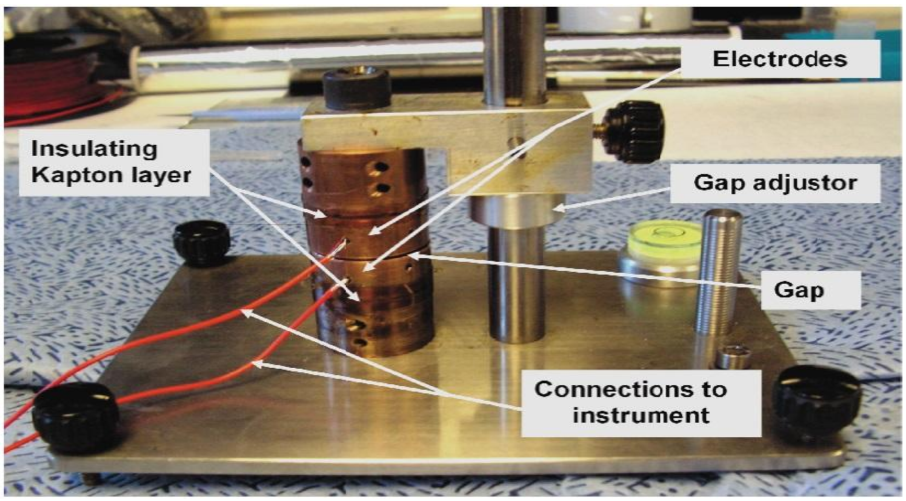


Figure 2. DC Parallel plate cell for electrical conductivity measurement

2.5 Static Analysisof the PFRC Crash Helmet

A CAD model of the crash helmet was developed in SolidWorks, and its performance under compressive forces of 30KN, 35KN and 40KN evaluated using SolidWorks.

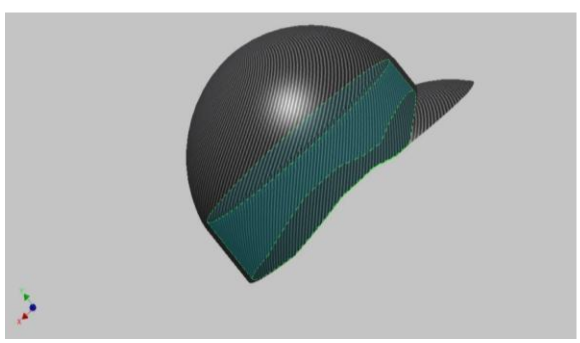


Figure 3. A CAD model of the crash helmet

3. Results and discussion

The following results were obtained for the characterisations and the analysis conducted on the PFRC crash helmet. Table 1 is a summary of the results obtained for the characterisations conducted on the PFRC samples.

Table 1. Summary of the Mechanical and Electrical Properties of the PFR Composites

Mechanical Properties	**Values**	
Impact Energy (Joules)	0.08	0.12
Impact strengths (kJ/m)	1.0	1.1
	Mean strength	1.05
Average impact value (%)	4.88	
Stress, σ	8.0Mpa	
Axial stain,	0.1939	
Transverse strain	-0.03878	
Modulus, E	41.3Mpa	
Poisson's ratio, ν	-0.2	
Density, ρ	2402kg/m^3	
Electrical Properties		
Resistance, Ω	9.83E6	
Resistivity, R	8.38E8	
Conductivity, S/mm	1.19E-9	

3.1Water absorption test

The percentage of water absorbed by the PFRC sample is 7.4% after 24 hours. The result obtained show that the PFRC, when coated with an appropriate paint, will not absorb water and is best suited for crash helmet application. Table 2 is the result obtained for the water absorption test.

Table 2. Water absorption test result

Description	**Dry**	**Wet**
Weight (g)	88	94.512
% water absorption (%)	7.4	

3.2 Compression Test

The compression test was conducted on the PFRC samples. The material failed on the application of a 40KN load. The result of the mechanical properties of the PFRC is shown in Table 1.

3.3 Charpy Impact Test

The Charpy impact test conducted for two PFRC samples with areas of 0.000114m^2 subjected to energies of 0.08 J and 0.12 J is displayed in Table 1. The mean strength of the PFRC sample is 1.05 KJ/m^2

3.4 Electrical conductivity test

Table 3 shows the result obtained for the Electrical conductivity of the PFRC samples. The result indicates that the materials are antistatic and will not accumulate static charges when exposed to air. Therefore, it is safe for use in atmospheric conditions.

Table 3. D.C conductivity test result for plantain fibre sample

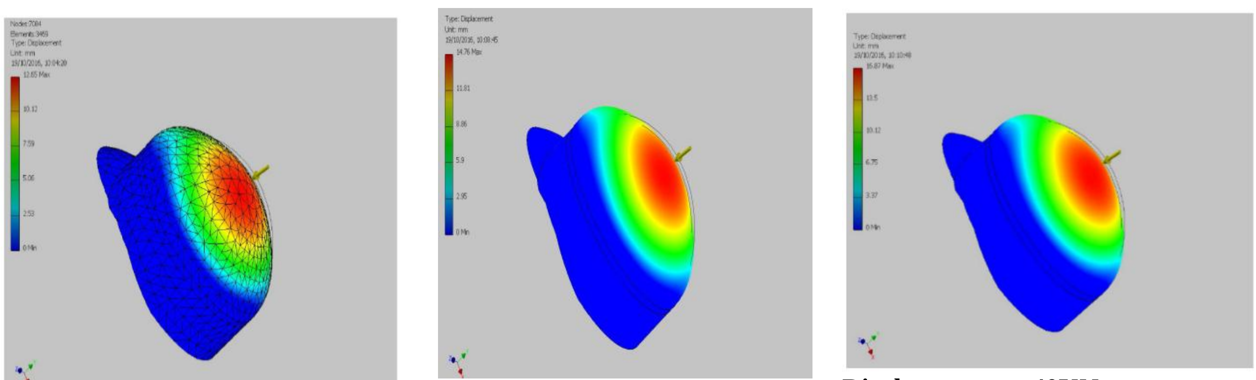
Sample	**Resistance Ω**	**Resistivity Ωmm**	**Conductivity S/mm**	**Sample area mm^2**	**Sample thickness**	**Current Method**
Plantain	9.83E6	8.38E8	1.19E-9	728.78	8.55	DC

3.5 Static Analysis of the PFRC Crash Helmet

The performance of the fabricated crash helmet was determined using SolidWorks software. The compressive forces of 30KN, 35KN and 40KN were applied to the PFRC crash helmet and the results presented in Table 4.

Table 4. Summary of the Performance Responses of the PFRC Crash Helmet

Force	30KN		35KN		40KN	
Name	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Volume	273747.3 mm^3		273747.3 mm^3		273747.3 mm^3	
Mass	0.006199		0.006199		0.006199	
Von Mises Stress (MPa)	0.000076614	42.9482	0.000089383	50.1063	0.00010215	57.2643
1st principal stress (MPa)	-3.6408	30.7922	-4.2476	35.9242	-4.8544	41.0562
3rd principal stress (MPa)	-44.5965	14.5951	-52.0293	17.0276	-59.462	19.4601
Displacement (mm)	0	12.6531	0	14.7619	0	16.8708
Yield strength	56.3 MPa					
Ultimate Compressive strength	***130 MPa***					



Displacement at 30KN **Displacement at 35KN** **Displacement at 40KN**

Figure 4. Summary of the Displacements of the PFRC Crash helmets at various loading

Table 5. Comparative analysis of various helmet materials with the developed helmet

Helmet material	Von Mises stress (N/mm^2)	References
S-glass epoxy composite	194.4	(Ram & Bajpai, 2017)
Polypropylene	4.4 E-13	(Rajasekar, Ashokkumar & NarayananL, 2015)
Acrylonitrile Butadiene Styrene	37.291	
Plantain fibre reinforced composite	**57.26**	Results obtained from this study

4. Conclusion

This study concludes as follows:

1. The PFRC developed can be used as a suitable alternative for conventional materials such as Acrylonitrile Butadiene Styrene (ABS) and Polypropylene for anti-crash helmets production, as highlighted in Table 5.
2. The PFRC has low water absorption capacity and can repel water on the application of an appropriate coating.
3. The PFRC is antistatic and is safe to use for anti-crash helmets.
4. The Crash helmet developed from PFRC can withstand loads from 0 KN to 35KN
5. The yield strength of the PFRC was obtained in this study as 56.3MPa.

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