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Optimization and Analysis of Mechanical Properties (Tensile Strength) in a developed Plantain Hybrid Fibre Reinforced Composite (PHFRC)

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ABSTRACT
Plantain fibres, which are obtained from the Pseudostems(PS) and Empty Fruit Bunch(EFB) of the plantain plant, are abundant and underutilized agro-waste. When combined with a suitable matrice, they form a hybrid composite that is lightweight, mechanically strong, and sustainable. This paper demonstrates the development, optimization, and analyses of the properties of PHFRCs while highlighting their environmental benefits and challenges. Results from optimization process gives PHFRC sample Tensile strength of $72.782\ x\ 10^6 N/m^2$ *at factor levels of hybrid ratio (40/60), Volume fraction (5%), and Aspect ratio (30) while comparative analyses, utilizing Global Safety standards, between developed composite and thermoplastic material, displayed stress and deformation responses.*

Keywords: *plantain fibres, hybrid composites, reinforced composites, optimization, biodegradability, environmental impact, mechanical properties, agricultural wastes, tensile strength*

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I. INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Sustainability has become a central concern for Nigeria and industries as they respond to the pressing need to reduce environmental impacts. The increasing global demand for sustainable materials is driven by factors such as the depletion of natural resources, pollution, and climate change (Shah, 2013). In response to these issues, researchers have turned their attention to **natural fibre-reinforced composites(NFRCs) like PHFRCs,** which offer a promising alternative to conventional synthetic materials (Joshi *et al*., 2004; Faruk *et al*., 2012).

Among the natural fibres being studied, **plantain fibre** stands out due to its availability and mechanical properties (Ramesh, 2016). Plantain hybrid fibre reinforced composites (PHFRCs) are formed by reinforcing a polymer matrix with plantain fibres, leading to improved strength, durability, and sustainability. This paper explores the development of specimens of PHFRCs, optimization of a Mechanical property, and Characterisation based on Stress and Deformation analyses of the composite.

The aim is to present PHFRC as a considerable alternative for relevant Engineering applications.

II. LITERATURE REVIEW

1I.1Natural Fibre Reinforced Composites (NFRCs) and Sustainability

Natural fibre composites are increasingly recognized as a sustainable alternative to conventional materials such as **glass fibre-reinforced composites** and **thermoplastics** (Shah, 2013). Natural fibres such as jute, sisal, flax, and hemp have been extensively studied for their mechanical properties and environmental benefits. These fibres offer unique combination of low density, biodegradability, renewability, and relatively good mechanical performance (Faruk *et al*., 2012). As industries shift toward more sustainable practices, the demand for NFRCs has grown, particularly in sectors like automotive, construction, and consumer goods, where lightweight and durable materials are essential (Joshi *et al*., 2004).

II.2 Plantain Fibre: A Sustainable Reinforcement Material

Plantain (Musa paradisiaca), commonly grown in tropical regions, is an important food crop. However, the **pseudostem and empty fruit bunch** of the plant, which remain after harvesting the fruit, are often discarded as agricultural wastes (Ramesh, 2016). Studies have shown that the fibres extracted from these possess excellent mechanical properties, including high tensile strength and flexibility, making them suitable for use as reinforcement in polymer composites (Neto*et al*., 2015). Plantain fibres also have the advantage of being renewable, biodegradable, and abundant, making them a sustainable option for the production of composites (Mwaikambo & Ansell, 2002).

Plantain empty fruit bunch fibres and Plantain pseudo stem fibres in hybrid were utilised in this study as reinforcement in a polyester matrix. This was to thoroughly utilize these would have been Agro-waste products in an attempt to promote a circular economy.

II.2.1 Alkali Treatment (Mercerization)

Alkali treatment increases amorphous cellulose at the expense of crystalline cellulose. Natural fibres absorb moisture due to hydroxyl groups in amorphous regions of cellulose, hemicellulose and lignin (Kabir, 2012) . The following reaction occurs:

Fibre–OH + NaOH → Fibre–O–Na + H2O (1.0)

Hydroxyl groups (-OH) are replaced by alkalized groups (Na-O-H), removing water molecules (H-OH) from the fibre structure. The remaining alkalized groups (Na-O-) react with the fibre cell wall.Fibres are treated with 5-25% sodium hydroxide solutions for hours(Remzi, 2010), removing hydrogen bonding in the network structure. Proper saturation and washing are crucial.

This treatment significantly impacts the mechanical properties of natural fibres, particularly strength and stiffness. The treated plantain hybrid fibre composites structure is expected to be improved by controlling three factors namely; fibre ratio,volume fraction, aspect ratio and it is believed that the plantain hybrid fibre composites structure will certainly be enhanced for suitability of purpose.

II.3 Application of Taguchi Design of Experiments in compositesParameters optimization

The Taguchi technique is recognised as a potent tool for designing high-quality systems (Chauhan *et al*., 2009). An orderly approach to data collection, analysis, and interpretation is provided by the Taguchi method of experimentation to meet study objectives. Maximum information can be obtained from a specific amount of experimentation in the design of experiments. The performance characteristics can be optimised through the setting of design parameters, and the sensitivity of system performance to variation sources can be reduced by Taguchi

11.4.Finite Element Method (FEM) and application in Composite Modeling and Analysis

The Finite Element Method (FEM) is a numerical method of structural analysis (Jovanovic and Filipovic, 2005). It involves the physical discretisation of a continuum, dividing the domain into a finite number of small, simple shapes called 'finite elements'. These elements are connected by nodes to form the original structure.One objective of this current research is to apply FEM in analysing the deformation and stress distributions of Plantain hybrid fibre reinforced composites. This is being done to investigate their potential utility in the production of Industrial items.

III. METHODOLOGY

III.1 Plantain Fibre Extraction

The extraction of plantain fibres from the pseudostem/empty fruit bunch involves several steps. The **retting** process is commonly used, where the pseudostem/empty fruit bunches are soaked in water for a specific period to break down the plant material, allowing the fibres to be separated from the non-fibrous material (Mwaikambo & Ansell, 2002). After retting, the fibres are cleaned, dried, and treated to enhance their compatibility with the polymer matrix. **Alkaline treatment** using sodium hydroxide is one of the most widely used methods to improve the surface roughness of the fibres, increasing their interfacial bonding with the polymer matrix (Mohanty *et al.*, 2001).

Figure 3.1 Plantain EFB(Left) & PS(Right)

The fibre modification process aims to accomplish several objectives: cleanse the fibre surface, chemically alter its properties, inhibit moisture absorption, and enhance surface roughness. These modifications contribute to the overall improvement of fibre characteristics and composite performance.

Figure 3.2 Treated Plantain Fibres (Left, EFB & Right, PS)

III.2 Optimization of Process Variables

III.2.1 Application of Taguchi Robust Design: Orthogonal array

Taguchi design, employed in this research, is utilized to create the experimental layout, analyze each parameter's impact, and determine the optimal level for identified parameters. This method aims to reduce process variation through robust experimental design. The primary goal is to produce high-quality products at low cost for manufacturers. Taguchi design uses an orthogonal array to study the entire parameter space with minimal experiments (Chukwunyelu *et al.*, 2020), thus reducing time and cost in experimental research. An orthogonal array provides more reliable factor effect estimates with fewer experiments compared to traditional methods.

The selection of an appropriate array depends on the number of factors and their identified levels. Each column in the orthogonal array represents a parameter and its setting levels for each experiment, while each row represents an experiment with the levels of various parameters.

This study focuses on hybrid fibre ratio, volume fraction, and aspect ratio of hybrid (EFB/PS) reinforcement materials (fibres) as process parameters affecting the mechanical (tensile) properties of plantain hybrid fibre reinforced polyester composites. Each parameter is examined at three levels to investigate the non-linear effects of the process parameters. Table 3.1 presents the selected process parameters and their corresponding levels.

Table 3.1: Process parameters and their levels selected for the preparation of specimen

Code	**Parameters**	**Levels**			**Units**
		1	**2**	**3**	
A	**Hybrid Fibre Ratio (EFB/PS)**	40/60	50/50	60/40	-
B	**Volume Fraction**	5	15	25	%
C	**Aspect ratio**	10	20	30	mm/mm

Table 3.2: Applicable Taguchi Standard Orthogonal array L9 (3^3)

Number of Experiments	**Parameters**		
	Hybrid Fibre Ratio (A)	**Volume Fraction (B)**	**Aspect Ratio (C)**
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

The signal-to-noise ratio quantifies the sensitivity of the investigated quality to uncontrollable factors (error) in the experiment. A higher ratio is always preferred, as it results in reduced product variance around the target value. To conduct ratio analysis, the mean square deviation for "the-larger-the-better" quality characteristic and ratio were computed using the relevant equations (Raju,*et al.*, 2012; Okafor, *et al.*, 2013):

$$MSD = \frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2} \qquad (3.0)$$

$$S/N = -10Log_{10}(MSD)` \qquad (3.1)$$

III.2.2 Analysis of Means and Analysis of Variance

The Taguchi design data analysis involves analysis of means (ANOM) and analysis of variance (ANOVA), as outlined by Raju *et al.,(*2012). ANOM determines each variable's direct effects, with a parameter level's effect being the deviation it causes from the overall mean response (Raju *et al.*, 2012). The S/N ratio for each process parameter level is calculated by averaging the S/N ratios when the parameter is at that level. ANOM helps identify optimal factor combinations. ANOVA, conversely, determines the parameters' relative importance in terms of percentage (%) contribution to the response. It's also needed to determine the error variance for effects and variance of prediction error. This is done by separating the total variability of S/N ratio, measured by sum of squared deviations from the total mean S/N ratio, into contributions by each design parameter and the error. Percentage (%) contribution defines a parameter's relative power to reduce variation. A parameter with high percentage (%) contribution and small variation has significant control over the response.

III.3 Verification of Experiments

After determining the optimal levels of process parameters for each mechanical and thermal property, the next phase involves predicting and validating the performance characteristic using these optimal design parameters. The predicted optimum value of the S/N ratio for the response is calculated using the following equation (Raju *et al.*, 2012):

$$\eta_{opt} = m + \sum_{j=1}^{k_1}\left[\left(m_{i,j}\right)_{max} - m\right] \qquad (3.2)$$

Where, m is the overall mean of S/N ratio; $\left(m_{i,j}\right)_{max}$ is the S/N ratio of optimum level of i of factor j, and k_1 is the number of main design parameter that affect the response.

The prediction error will be assessed to confirm the optimal process parameter combination and additive model for variable effects. Validation tests were performed at ideal parameter levels for mechanical property of treated plantain hybrid fibre-reinforced polyester composites.

III.4 Analysis of Displacement and Stress Distributions in Composite Modeling

III.4.1 Finite Element Analysis (FEA) and application

Finite element analysis was employed to assess stress distribution within plantain hybrid fibre-reinforced polyester composites. The method involved dividing specimens into triangular subregions(meshing) to determine internal stress at each point.

III.5 Safety Helmet Standard

The official standard for industrial safety helmets is **EN 397**. This specification outlines **mandatory** criteria for: impact absorption, penetration resistance, flame retardancy, chin strap attachment, and labeling.The standard stipulates:

"... Industrial safety helmets are primarily designed to safeguard the wearer against falling objects and resultant brain trauma and skull fractures ..."

Additionally:

"... industrial safety helmet headgear, henceforth referred to as a "helmet", principally intended to shield the upper portion of a wearer's head from injury caused by falling objects ..."

Essentially, these helmets are designed to protect stationary users from predominantly overhead hazards.

Testing.

Testing protocol utilized in this study is as follows:

- *Shock absorption*

A 5kg striker (with a hemispherical surface) is released onto the helmet from a 1m height. The maximum transmitted force must not surpass 5kN.

III.5Composite Fabrication Techniques

The fabrication technique employed in this research, based on open moulding, is Hand Lay-up processing, as the reinforcement is manually positioned. While this method requires minimal capital investment, it is labour-intensive. This technique allows for the precise control of the composite's mechanical properties and shape, making PHFRCs adaptable to various industrial applications.

Figure 3.3 Test Specimen Production using the manual Contacting (Open) Molding hand lay up Process

Table 3.3: Densities of Reinforcing fibres and matrix

Fibres/matrix	**Densities (g/cm^3)**	**Sources**
Plantain Empty Fruit Bunch fibre	0.354151	Okafor, E.C. (2014)
Plantain Pseudo Stem fibre	0.381966	Okafor, E.C. (2014)
Polyester resin	1.025	MohdNurazzi *et al.*, (2017)

IV. RESULTS AND DISCUSSIONS

IV.1 Scanning Electron Microscopy (SEM) for plantain hybrid fibres reinforced composite

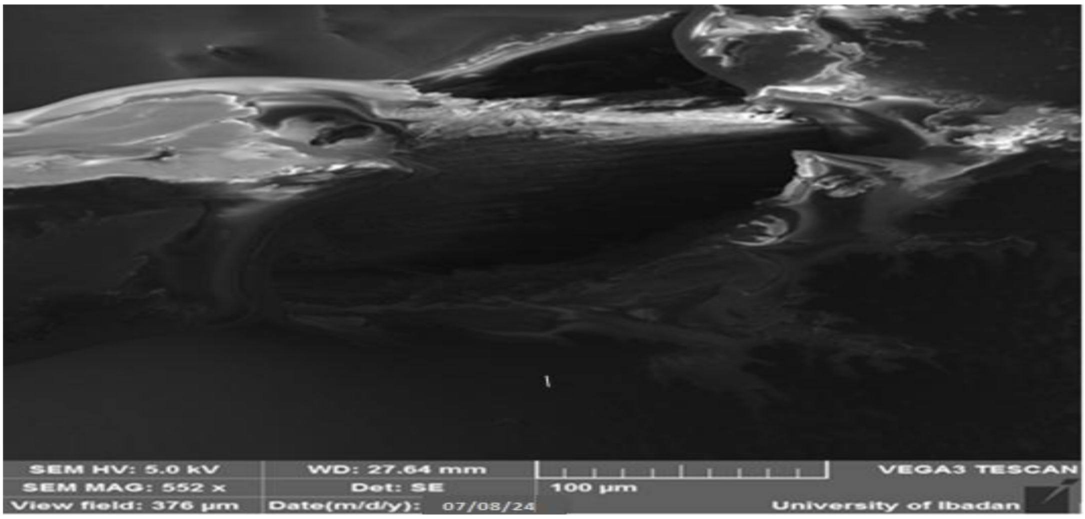


Figure3.4: Treated Plantain hybrid fibres and the polyester matrix in a sample

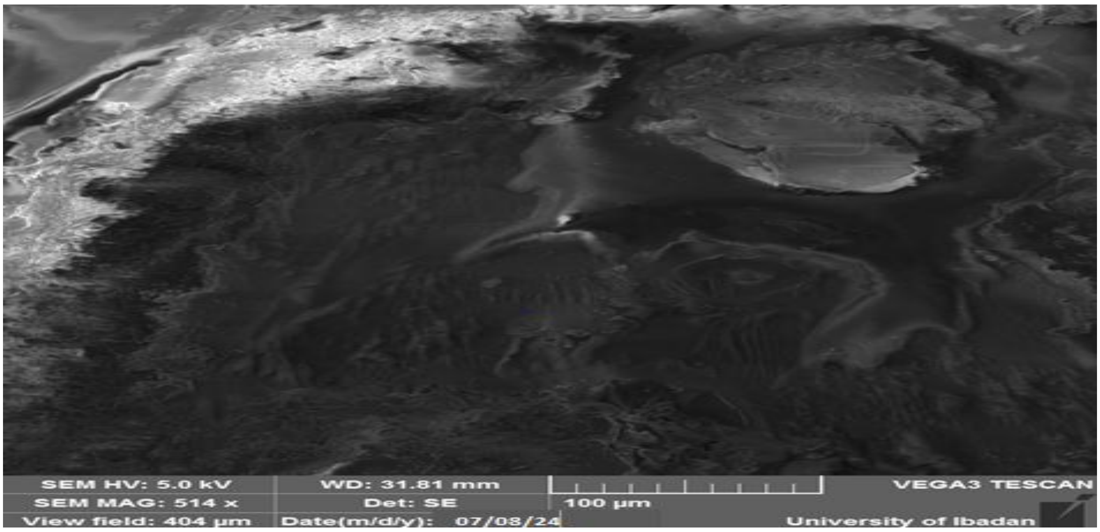


Figure3.5: Deformed treated plantain hybrid fibres and the polyester matrix in a sample

Table 3.4: Experimental design matrix for Tensile test of Treated Plantain Hybrid fibre reinforced polyester composite (ASTM-638)

No of Exp.	**Hybrid Fibre Ratio (A)**	**Volume Fraction (B)**	**Aspect Ratio (C)**	**Replicates of Tensile response $x\,10^6$ (N/m^2)**			**Mean ultimate Tensile response $x\,10^6$ (N/m^2)**	**S/N Ratio**
				Trial				
				1	**2**	**3**		
1	40/60	5	10	73.16	74.18	74.09	73.81	37.3623
2	40/60	15	20	70.05	65.93	62.32	66.10	36.4040
3	40/60	25	30	64.21	64.61	64.39	64.40	36.1777
4	50/50	5	20	61.81	64.04	63.15	63.00	35.9868
5	50/50	15	30	67.02	67.00	67.62	67.21	36.5487
6	50/50	25	10	63.50	63.33	63.35	63.40	36.0418
7	60/40	5	30	72.34	71.92	72.09	72.11	37.1599
8	60/40	15	10	62.46	64.93	62.98	63.46	36.0500
9	60/40	25	20	65.24	65.18	65.83	64.42	36.1804

Table 3.5: Response Table for SN ratio and Mean Tensile strength of Treated Plantain Hybrid composites based on Larger is better quality characteristics

Response	**Signal –to- Noise Ratios**				**Means**		
Level	**A: Hybrid Fibre Ratio**$(-)$	**B: Volume Fraction** (%)	**C: Aspect Ratio mm/mm**		**A: Hybrid Fibre Ratio** $(-)$	**B: Volume Fraction** (%)	**C: Aspect Ratio mm/mm**
1	36.65	36.84	36.48		68.10	69.64	66.89
2	36.19	36.33	36.19		64.54	65.59	64.51
3	36.46	36.13	36.63		66.66	64.07	67.91
Delta	0.46	0.70	0.44		3.57	5.57	3.40
Rank	2	1	3		2	1	3

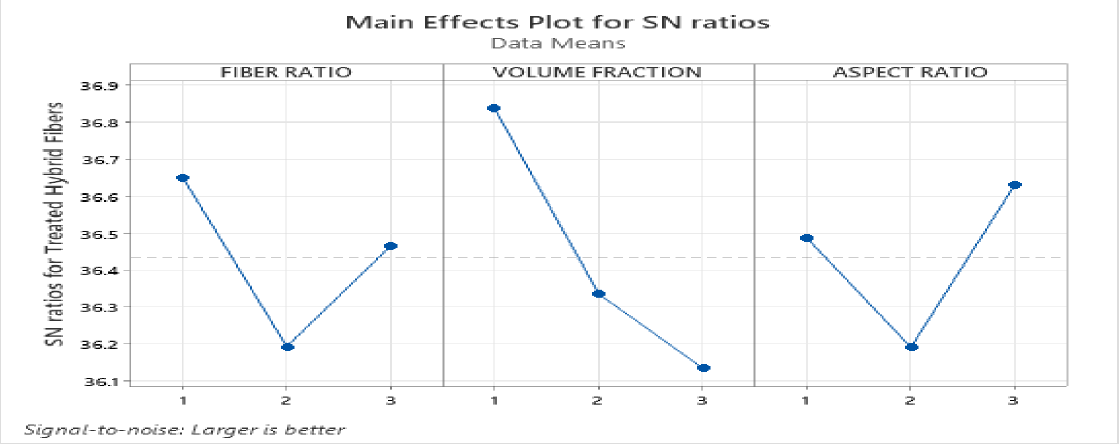


Figure 3.6: Response graph of S/N ratio for Tensile strength of Treated Plantain Hybrid fibre reinforced composite

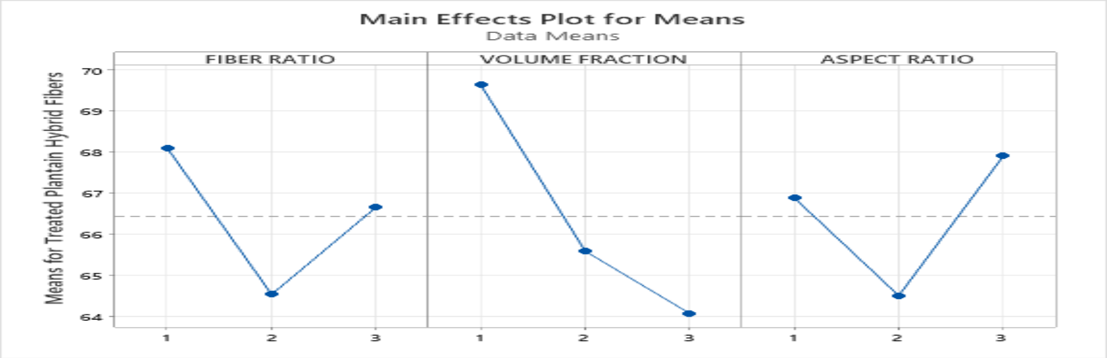


Figure 3.7: Response graph of Means for Tensile strength of Treated Plantain Hybrid hybrid fibre reinforced composite

Table 3.6: Summary of ANOVA on S/N for Tensile strength of Treated Plantain Hybrid fibre reinforced composite

Source	Degree of freedom	Sum of squares	Mean square	F-Ratio	% contribution
Hybrid Fibre Ratio (A)	2	0.3151	0.1575	0.50	15.49
Volume Fraction (B)	2	0.7867	0.3934	1.24	38.68
Aspect Ratio (C)	2	0.2995	0.1498	0.47	14.72
Residual Error	2	0.6327	0.3163		31.11
Total	8	2.0340			100

IV.2 Estimation of expected responses based on optimum settings

The predicted outcome is calculated using the optimal control factor settings from the main effects plots. By utilizing the signal-to-noise ratio response table and the mean response table (Okafor, 2014), the expected response model is expressed in the equation below

$$ER = AVR + \left(A_{opt} - AVR\right) + \left(B_{opt} - AVR\right) + \left(C_{opt} - AVR\right) + \ldots + \left(n_{opt}^{th} - AVR\right) \quad (4.1)$$

Where, ER = expected response, AVR = average response, Aopt = mean response value at factor A's optimal setting, Bopt = mean response value at factor B's optimal setting, and Copt = mean response value at factor C's optimal setting.

$$ER_{TREATED\ (Tensile)} = 66.434 + (68.1033 - 66.434) + (69.6400 - 66.434) + (67.9067 - 66.434)x\ 10^{6}$$
$$= 72.782\ x\ 10^{6} N/m^{2}$$

Table 3.7: Optimum setting of control factors and expected optimum Tensile strength of composites

Composite/property	Control factors	Optimum levels	Optimum settings	Expected optimum values
TREATED /Tensile	A	1	40/60	$72.782\ x\ 10^{6} N/m^{2}$
	B	1	5%	
	C	3	30	

IV.3Finite Element Analysis of Plantain Hybrid Fibre Reinforced Composite Industrial Helmet using *Ansys*.

Industrial helmets, commonly used by engineering personnel in workshops, serve as a case study. Models of industrial helmets were utilized to analyze displacement and stress distributions in both the developed material and standard in-use material, adhering to official industrial safety helmet specifications.

The optimal design characteristics of the developed composite material, as previously established, provided the specifications for Finite Element Method (FEM) analysis.

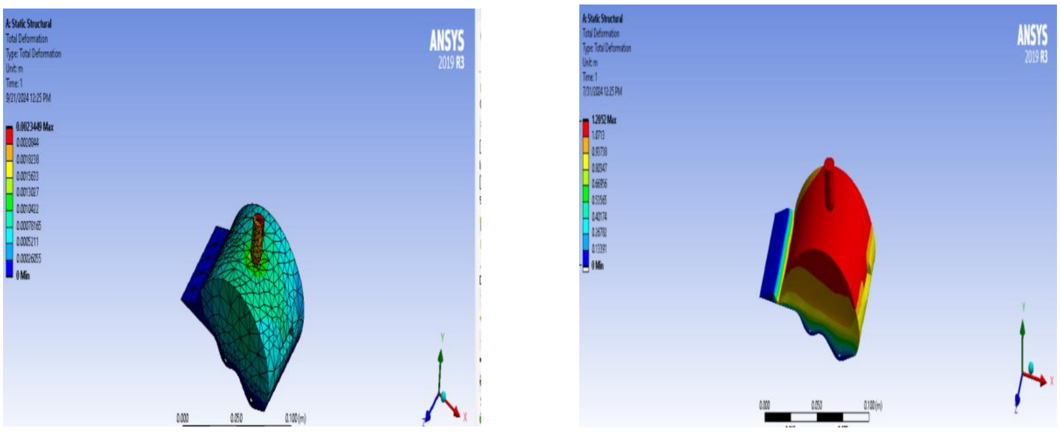
The solid model of the industrial helmet was examined. Three-dimensional geometric models (Fig.3.8) of the helmet materials were created using the graphical interface of **Ansys®.**

Figure 3.8

Table 3.8: Properties of optimized developed composite material and standard thermoplastic material

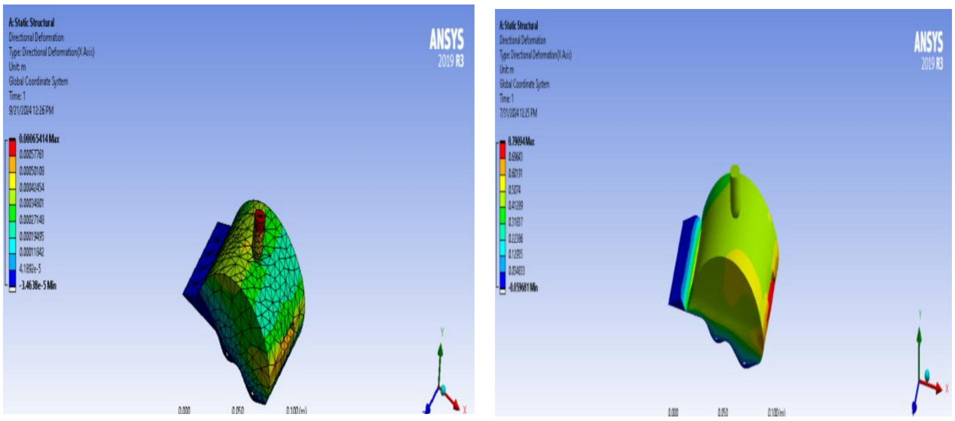
Material Properties	Composite Material	Thermoplastic Material (Source: MATWEB)
Yield Strength (MPa)	65.50	40
Young's Modulus(MPa)	51.8×10^3	3.5×10^3
Poisson's Ratio	0.381	0.4
Density (Kg/m^3)	1761.117	1050

Shock absorption analysis



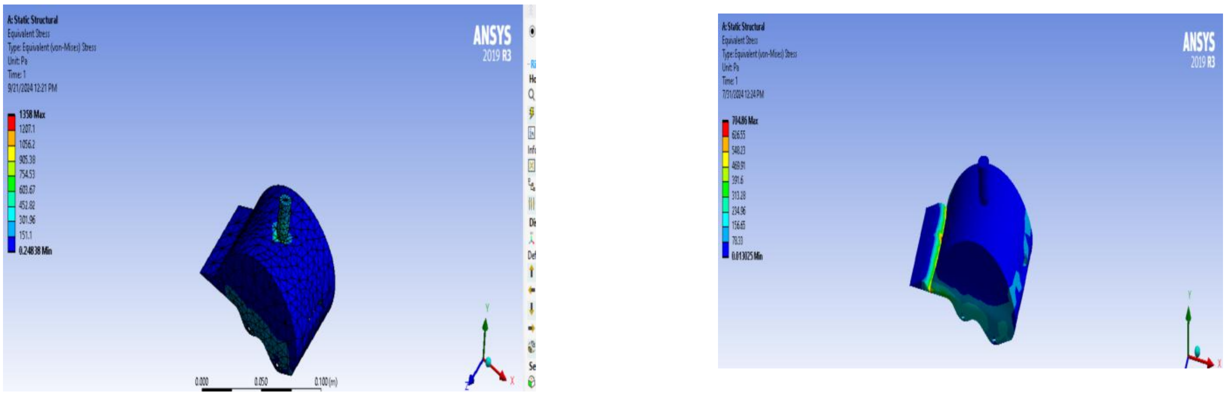
(a) **(b)**

Figure 3.9: Total Deformation of (a) Developed composite and (b) Thermoplastic Materials



(a) **(b)**

Figure3.10: Directional Deformation of (a) Developed composite and (b) Thermoplastic Materials



(a) (b)

Figure 3.11: Equivalent (Von-Mises) Stress of (a) Developed composite and (b) Thermoplastic Materials

- **Developed composite materials**

The highest Von Mises stress as seen from figure 3.11a, is 1358Pain the developed composite model. The maximum total deformation is seen tobe 0.0023449m at $1sec$(figure 3.9a) while the maximum directional deformation is shown to be0.00065414m at $1sec$(figure 3.10a)

- **Thermoplastic materials**

The highest Von Mises stress, from figure 3.11b, is 704.86Pa. The maximum total deformation of the model is found to measure 1.2052m at $1\,sec$(figure 3.9). The maximum directional deformation is 0.79094m at $1sec$(figure 3.10)

IV.4 Results Implications

One of the key properties of plantain fibre composites is theirtensile strength. Studies have shown that plantain fibre-reinforced composites can exhibit tensile strengths comparable to those of synthetic fibre-reinforced composites when optimized for fibre content and matrix compatibility (Bledzki & Gassan, 1999). The result of this study revealed an 80% increase in the tensile strength of the PHFRC sample over that of Thermoplastic.

The deformation characteristics at 5kg mass dropped shows considerable less in the developed PHFRC than in the Thermoplastic model, showing the influence of a larger elastic modulus in PHFRCs.

The combination of a larger Tensile strength and a lower deformation rate could enhance the choice of PHRFCs in Industrial Safety Helmet design as it would arrest rupture or penetration of pointed fallen objects unto the Helmets.

It can be argued that the very lower deformation value in PHFRCs, coupled with their considerable higher Elastic Modulus,create a situation where transmitted Load forces extend beyond the deformation distance.This may then pose a Safety concern. Further study on PHFRCs impact and other property characteristics is needed to verify or debunked this argument.

V. CONCLUSION

The development of **Plantain Hybrid Fibre Reinforced Composites (PHFRCs)** represents an important advancement in the pursuit of sustainability for Nigeria. By combining plantain fibres, an abundant agricultural waste product, with polymer matrices, PHFRCs offer a renewable, biodegradable, and environmentally friendly alternative to conventional materials. Their mechanical performance, sustainability benefits, and wide range of applications make them an attractive option for industries looking to reduce their environmental impact.

The advantage of this study reflects not only the potential benefits of using PHFRCs, as a sustainable material, but also insight on efficient use of optimized process parameters for controlled quality in the response parameter (Tensile strength). This response quality optimization can be extended to other relevant properties too (e.g Impact, Surface Roughness, Flexural strength. The above could enhance Product quality and shorten lead times for Manufacturers.

However, challenges remain in ensuring consistent fibre quality in PHFRCs, improving fibre-matrix adhesion, and reducing production costs. Further research is needed to optimize fibre treatment processes, develop new hybridization strategies (Ezechukwu,V.C, 2024), and explore the full potential of plantain fibre composites. Additionally, comprehensive **life cycle assessments** (LCAs) of PHFRCs will be critical in demonstrating their environmental advantages over traditional materials.

Asindustries continue to prioritize sustainability, PHFRCs could play a pivotal role in reducing reliance on non-renewable resources, lowering carbon emissions, and minimizing waste generation. PHFRCs represent a promising development in the search for better design material alternatives.

REFERNCES:

[1] Shah, D. U. (2013). Natural fibre composites: Comprehensive review on structure–property relationships. Journal of Polymer Science Part B: Polymer Physics, 51(24), 1627-1640. doi:10.1002/polb.23340

[2] Joshi, S. V., Drzal, L. T., Mohanty, A. K., & Arora, S. (2004). Are natural fiber composites environmentally superior to glass fiber reinforced composites? Composites Part A: Applied Science and Manufacturing, 35(3), 371-376. doi:10.1016/j.compositesa.2003.09.016

[3] Holbery, J., & Houston, D. (2006). Natural-fiber-reinforced polymer composites in automotive applications. JOM, 58(11), 80-86. doi:10.1007/s11837-006-0234-2

[4] Faruk, O., Bledzki, A. K., Fink, H. P., & Sain, M. (2012). Biocomposites reinforced with natural fibers: 2000–2010. Progress in Polymer Science, 37(11), 1552-1596. doi:10.1016/j.progpolymsci.2012.04.003

[5] Ramesh, M. (2016). Plant fibre composites: Sustainable and renewable green materials. Renewable and Sustainable Energy Reviews, 79, 558-584. doi:10.1016/j.rser.2016.11.115

[6] Neto, R. A., Marconcini, J. M., Lotti, C., Mattoso, L. H. C., & Tavares, M. I. B. (2015). Plantain pseudostem fibers characterization and poly (lactic acid) composites applications. Journal of Applied Polymer Science, 132(35), 42547. doi:10.1002/app.42547

[7] Mwaikambo, L. Y., & Ansell, M. P. (2002). Chemical modification of hemp, sisal, jute, and kapok fibers by alkalization.Journal of Applied Polymer Science, 84(12), 2222-2234. doi:10.1002/app.10460

[8] Mohanty, A. K., Misra, M., & Drzal, L. T. (2001). Surface modifications of natural fibers and performance of the resulting biocomposites: An overview. Composite Interfaces, 8(5), 313-343. doi:10.1163/156855401753255422

[9] Bajpai, P., & Kumar, A. (2018). Green composites from natural fibers and biodegradable polymers. In P. Bajpai (Ed.), Biomass Conversion: The Interface of Biotechnology, Chemistry and Materials Science (pp. 63-87). Springer. doi:10.1007/978-981-10-7652-2_4

[10] Bledzki, A. K., & Gassan, J. (1999). Composites reinforced with cellulose-based fibres. Progress in Polymer Science, 24(2), 221-274. doi:10.1016/S0079-6700(98)00018-5

[11] Jovanovic, M. and Filipovic, Z. (2005).Applying of Software Packages CATIA in Prediction of Possible Damages to Real Aircraft Construction.Flight test center, Belgrade, Serbian.

[12] Ihueze C. C., Okafor E. C. and Ujam A. J. (2012). Optimization of Tensile Strengths Response of Plantain Fibres Reinforced Polyester Composites (PFRP) Applying Taguchi Robust Design. Innovative Systems Design and Engineering. 3(7), 64-76.

[13] Chukwunyelu C. E., Enibe S. O. and Metu C. S., (2020). Comparative Analysis on Thermal Strength of Coir/Empty Plantain Fruit Bunch and Coir/Pseudo Stem Plantain Hybrid Fibres Reinforced Polyester Matrix Composites.Journal of Engineering and Applied Sciences, Volume 17, Number 1, 137-151

[14] Okafor, E. C. (2014). Optimal Design and Characterization of Plantain Fibre Reinforced Polyester Matrices. Department Of Industrial/Production Engineering, Nnamdi Azikiwe University, Awka.

[15] Okafor E. C., Ihueze C. C., and Nwigbo S C. (2013). Optimization of Hardness Strengths Response of Plantain Fibres Reinforced Polyester Matrix Composites (PFRP) Applying Taguchi Robust Design. International Journal of Engineering, Vol. 26, No.1, pp. 1-11.

[16] Remzi, G. (2010). Examining the effects of mercerization process applied under different conditions to dimensional stability. Scientific Research and Essays 5(6), 560-571.

[17] Chauhan S.R., Kumar Anoop , and Singh I., (2009). Study on the friction and sliding wear behavior of woven S-glass fibre reinforced vinylester composite manufactured with different comonomers. J. Mater. Sci., 44, 6338-6347.

[18] Ezechukwu, V, C. (2024). Hybridization Effect on Thermo-mechanical Behaviour of Epoxy/breadfruit Seed Shell Ash Particles and Momordica Angustisepala Fiber Composites for High- temperature Devices Application. Proceedings of the IRE. Volume 7. 2456-8880. https://www.irejournals.com/formatedpaper/1705783.pdf

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