Modelling and Optimization of the Manufacturing Parameters of a Hybrid Fiber Reinforced Polymer Composite PxGyEz

Bassey Okon Samuel (basseyokon59@gmail.com)
Ahmadu Bello University https://orcid.org/0000-0001-9104-7063
Malachy Sumaila
Ahmadu Bello University
Bashar Dan-Asabe
Ahmadu Bello University

Research Article

Keywords: Composites, Natural Fibers, Optimization, Taguchi

Posted Date: May 25th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-539135/v1

Modelling and Optimization of the Manufacturing Parameters of a Hybrid Fiber Reinforced Polymer Composite $P_xG_yE^z$

Authors:

Bassey Okon SAMUEL,*
Mechanical Engineering, Ahmadu Bello University, Zaria
basseyokon59@gmail.com

Malachy SUMAILA,
Mechanical Engineering, Ahmadu Bello University, Zaria
msumaila@abu.edu.ng

Bashar DAN-ASABE,
Mechanical Engineering, Ahmadu Bello University, Zaria
bdanasabe@abu.edu.ng

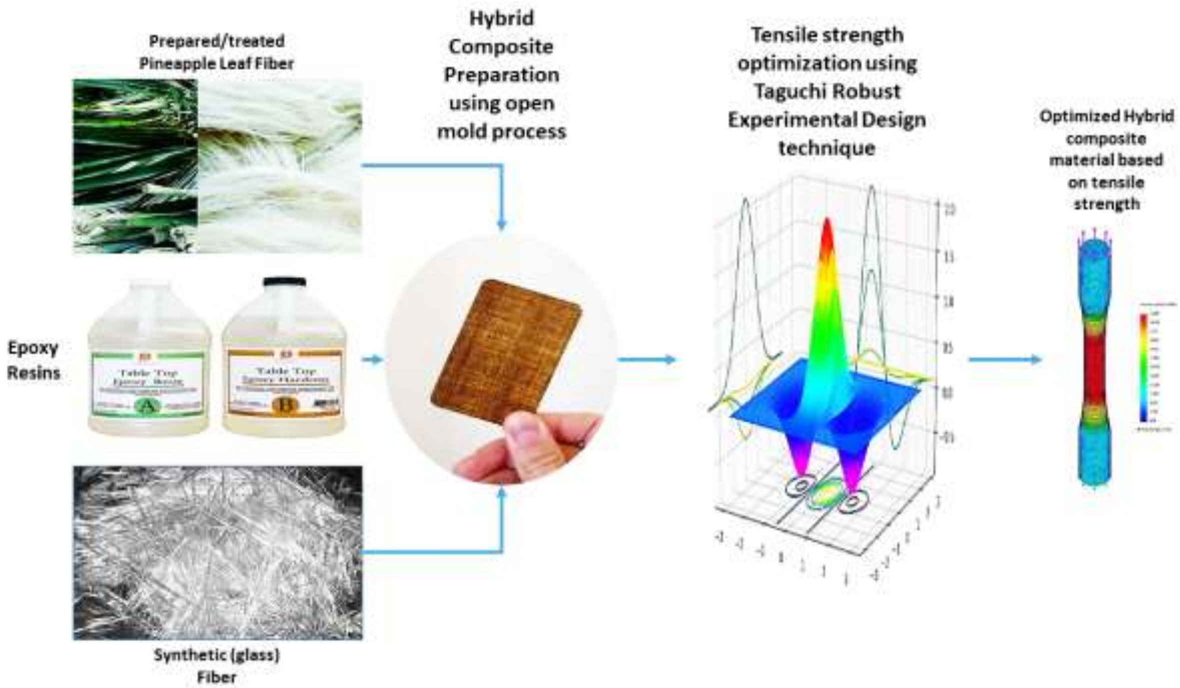
*Corresponding Author

Abstract

In this study, a Pineapple Leaf fiber (PALF)/Glass fiber Epoxy hybrid composite $P_xG_yE^z$ (with x, y, and z representing the volume fraction of pineapple leaf fiber (P), volume fraction of glass fiber (G) and fiber length respectively in Epoxy (E) matrix) was developed and its tensile properties modelled and optimized with regards to the variable parameters of x, y, and z respectively. For the quality characteristics (high tensile strength) investigated, the Minitab®19 software was used to analyze the Taguchi robust experiment design technique on the higher the better basis. The optimum combination of the control factors was found at x=10%, y=20% and z = 15mm. The optimized composite $P_{10}G_{20}E^{15}$ possessed a tensile strength of 95.3144MPa which was only a 5.9% deviation from the predicted optimum tensile strength. Analysis of variance showed that the glass fiber had the highest contribution of 50.64% to the tensile strength of $P_xG_yE^z$, PALF 15.53% and fiber length 28.84%. SEM Images of the PALF, glass fiber and fractured surface of the optimized material $P_{10}G_{20}E^{15}$ revealed the surface structure which explained their different contribution to the tensile strength of the materials. An equation for the prediction of the tensile properties of $P_xG_yE^z$ was derived from the regression model.

Key Words: Composites, Natural Fibers, Optimization, Taguchi

Graphical Abstract



1.0 Introduction

Computational modelling and Optimization

In recent times, within the past two decades, there have been an exponential growth in computational power and this is coupled with improved algorithms. Advanced design requirements have been achieved by different researchers in various field by applying these computational methods in carrying out analytical studies (Mulenga et al. 2021). The challenges in physical complexities which are normally encountered in science and engineering research have been addressed by these modelling and optimization techniques. In the field of materials, researchers have been exploring these computational techniques to optimize the mechanical characteristics of these composite materials which are reinforced with natural fibers mostly with the aim of potentially replacing the synthetic fibers because of sustainability issues and environmental aspects. Several computational modelling and optimization techniques have been developed but one that stands out is the Taguchi design of experimental technique.

Natural Fibers

The ability to tailor and enhance its properties to meet with expected performances, composite materials have increasingly found application in manufacturing and engineering. Such that with changes in its methods of preparation, constituents, features, etc., varying material behaviors or properties can be achieved to suit the intended application. Some of the properties of these composite materials such as its mechanical strength (tensile strength, flexural strength, impact strength), fracture toughness, etc. have been improved through the years so much that they could be compared with the conventional materials like steel (Kerni et al, 2020; Wang et al., 2020).

In composite materials, natural fibers have more and more been used for reinforcement and this is not far from their exceptional features like environmental compatibility, low density, high impact strength, and some of them with high tensile strength. (Venkateshwaran et al., 2012; Wang et al., 2018). Natural fibers have been improving the mechanical properties of composites, serving as reinforcements, providing strength and stiffness to the materials. These reinforcements could be in fibrous or non-fibrous (particulate) form. They are usually embedded in the matrix which serves the main purpose of holding the fibers in place and also transferring the stress from the loading point to the fibers. The durability, shape, environmental compatibility, and appearance (Omrani et al., 2016). Some well-known sources of natural fibers which have been explored for application in engineering, industrial and consumer goods applications are banana, jute, coir, sisal, and kenaf (Wang et al., 2020). Sources like pineapple leaves have hardly been explored due to the set back of non-adhesiveness of the fibers with most polymer matrix materials (which is poor interfacial interaction between fiber and matrix) even though there have been attempts to surmount this setback by the surface modification of the fibers. With current findings, natural fiber composites have exhibited lesser mechanical properties in comparison with their counterpart synthetic fiber composites. Which is the reason why hybridization is normally employed to address this challenge. In hybridization, two or more fibers, which are dissimilar, are used in a single matrix to form a single material. An example is the hybridization of synthetic fiber with natural fibers. Hybridization can also be achieved by combining varying lengths and diameters of dissimilar short fibers, this approach has substantially improved the mechanical properties of these composites developed from natural fiber sources (Vijayakumar et al., 2019). In these natural fiber composites, the material behavior can be affected by different factors. Factors like the length of the fibers, weight ratio of fiber compared with the matrix, orientation of the fiber in the composites, kind of fiber (source), methods of fabrication, methods of preparation/modification, etc. (Pappu et al., 2017; Jeyapragash et al., 2020).

$P_xG_yE^z$ Hybrid Composite

Developing materials from renewable sources with high strength to weight ratio such that the tensile performance of the material is high in respect to its weight, is a challenging task for engineers and scientists. Natural fibers from plant materials have in recent times been exploited for applications in several industries due to their low density and environmental friendliness. But pineapple leaf fibers have been under-utilized due to its hydrophobic nature (Lee et al., 2020, Rajeshkumar et al., 2020). $P_xG_yE^z$ Hybrid Composite is a proposed hybrid composite material made up of Pineapple leaf fibers (PALF) with (X% composition by volume), Glass fiber (with Y% composition by volume), all with fiber length of Zmm, in Epoxy matrix. The composite seeks to exploit the high mechanical properties of synthetic fibers while taking advantage of the low density and Eco-friendliness of natural fibers. Glass fiber, although having commendable mechanical properties is non-biodegradable and the pineapple leaf fibers, being abundantly available due to its consideration as agro waste, has a low density and is environmentally friendly.

Taguchi Optimization

The Taguchi robust experimental design technique has been an important optimization processes applied for the derivation of optimum processes or behaviors, and powerful tool for the development or design of systems with high quality using individual and combined parameters from a minimum number of experimentations or simulation trials. Being a very important optimization process, the Taguchi technique is a powerful tool for the design of systems of high quality with individual and combined parameters and yet still a minimum number of experimental runs thereby reducing the cost of resources needed for the process (Basavarajappa et al., 2007; Taguchi et al., 1987; Taguchi, 1993). As stated earlier, in designing composites, the various factors that may affect the desired properties must be detailed. The fiber length and fiber content ratio have proven to be of influence in the mechanical behaviour of the composite materials (Vijayakumar et al., 2019). This study explores the effect of the fiber content and the fiber length on the tensile property of the natural fiber composite. The optimum strength in relation to the combination of these factors was achieved by the evaluation of the tensile strength of these composites.

This study will employ the Taguchi robust design to optimize the best combination of development factors of pineapple leaf fiber, glass fiber and fiber length to achieve the optimum possible tensile strength of the $P_xG_yE^z$ hybrid composites within the constraints of these variable parameters. The software Minitab®2019 will be used for the analysis.

2.0 Experimental Methods

Fiber Preparation

The fiber was extracted from pineapple leaf using the wet retting method. The chemical treatment was carried out in line with the procedure stated in (Mittal & Chaudhary, 2018). After cleaning the cellulosic fiber and drying under the sun, the fibers were immersed in an alkali solution of 4wt% NaOH at room temperature for 24hrs and was thereafter treated with 2wt% acetic acid (CH_3COOH) solution. The pH was controlled at 7 by rinsing in distilled water. The treated fibers were then dried in an oven at 90^0C for 24hrs until the weight became constant (i.e. there was no more weight loss due to moisture loss. The glass fiber was procured directly from Steve Moore Ltd, Zaria. The fibers were then cut in appropriate lengths as needed.

Composite Preparation

The volume of the matrix (epoxy and hardener) required was calculated by multiplying the dimensions of the steel mold with the required thickness of the composite to be molded. The required amount of the epoxy and hardener was calculated by weight in the ratio of 5:1. This research will employ the double method of the stir and cast and the open mold (hand lay-up process) i.e., the fibers in the measured quantities will be dispersed in the wet epoxy matrix and stirred gently for some time. This will be done for the purpose of obtaining considerable dispersion of the chopped fibers in the polymer matrix and also to ensure wetting of the fibers. The mixture will then be directly cast in an open mold, for the manufacturing of the composites plates.

Before casting, a releasing agent (wax) was applied to the surface of the mold to enhance the easy removal after fabrication, then the mixed resin and fibers were poured into the mold. Voids were removed from the materials by the use of brushes and hand rollers and to spread the resin evenly throughout the fibers. The mold was transferred to the simple press to force all air which was between the fiber and resin out and it was left under pressure for 72hrs in other to obtain the perfect samples. Upon complete setting (hardening) of the hybrid composite, the mold was released from the press and the rough edges trimmed to the shape of the mold. Curing of the laminated hybrid composites was carried out by exposure to atmospheric conditions. Samples for the tensile test were then obtained from the cured composites by cutting to shape using a grinding machine.

Tensile Test

The Instron tensile testing machine was used to conduct the tensile test according to ASTM D638. The tensile strength, were calculated using equation:

$$Tensile\ Strenght = \frac{Load\ at\ Break}{(Original\ width)(Original\ thickness)} \quad (1)$$

Taguchi Approach to Robust Parameter Design

In this study, optimization of the tensile strength by variation of design parameters through Taguchi approach is used along with orthogonal arrays (OAs) in statistical experimental design method. Using this method enables us to observe the effects of Pineapple leaf fibers volume content, glass fiber volume content, and fiber length on the tensile strength of the hybrid composite. Table 1 shows the different factors considered and their various levels. According to Taguchi, the S/N ratio is a measure of the deviation of our measured effect from the desired values. For the analysis with regards to the SN ratio, the effects measured could be categorized into three classes which are the higher the better, the lower the better and the nominal the best. Tensile strength is regarded in the class of the higher the better implying that the higher tensile strength is more desired and corresponds to the optimal level of the process parameters. SN ratio for the Higher the better characteristics is derived from the equation (2).

$$\left(\frac{S}{N}\right)_{HTB} = -10 * log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right) \quad (2)$$

Where n represents the number of experimentations, y_i represents the response value (tensile strength) of the i^{th} experiment in the orthogonal array, $\bar{y}^2$ indicates the average, and S^2 the variance of the observed data. Also, (S/N) represents the signal to noise ratio, and acronyms HTB, stands for the Higher the Better. The Minitab® 19 software will be employed for the analysis of result, while the Origin Pro 2019b will be used for the graphical illustrations of the results.

The factors that are considered in this optimization process and their levels are presented in table1.

Table 1: Variable parameters and their levels

S/N	**Processing Factors**	**Factors Designation**	**Level**		
			1	**2**	**3**
1	PALF Volume Fraction (%)	X	10	15	20
2	Glass Fiber Volume Fraction (%)	Y	20	15	10
3	Fiber Length (mm)	Z	15	20	25

Table 1 shows the experimental design with three factors at three levels for the fabrication of the PLAF/GL Epoxy ($P_xG_yE^z$) Hybrid composite.

X: Pineapple Leaf fiber vol.% Y: Glass Fiber vol.% Z: Fiber Length mm

For the three factor three level experiment: the equation (3) gives the minimum number of experimental runs to be carried out:

$$N_{Taguchi} = 1 + N(L - 1) \tag{3}$$

Where $N_{Taguchi}$ is the minimum number of trials to be conducted; N is the number of variable parameters, while L is the number of levels for the control factors (variable parameters), and from table 1 above, NV = 3, L = 3. Therefore $N_{Taguchi} = 9$.

From the Taguchi Orthogonal array table, the 3 factor 3 level, the number of experimentations to be carried out is 9 and 27, in other to reduce the number of experiments, we go for the minimum which is nine. Minitab®19 was then used to generate table 2 where the factor combinations in the experimental runs are presented.

Table 2: The Result of Orthogonal Test L9

	Levels of parameter Settings		
Trial No.	**PALF Volume Fraction (X)**	**Glass Fiber Volume Fraction (Y)**	**Fiber Length (Z)**
1	10	20	15
2	10	15	20
3	10	10	25
4	15	20	20
5	15	15	25
6	15	10	15
7	20	20	25
8	20	15	15
9	20	10	20

Each test was replicated three times for repeatability.

3.0 Results and Discussions

The results of the tensile testes that were carried out on materials fabricated under the conditions specified by the orthogonal array of the variable parameters and their levels are presented in table 3. The mean tensile strength was observed to be 54.253MPa, and the average SN ratio was 34.2813dB.

Table 3: Results of Mean and SN Ratio of Tensile Strength of PALF/Glass Fiber Epoxy Hybrid composite

Trial No.	**Raw Data (Tensile Strength (MPa))**			**Mean (MPa)**	**S/N ratio (dB)**
1	94.3396	96.4506	95.1529	95.3144	39.5821
2	38.2212	39.4345	39.8597	39.1718	31.8553

3	50.1618	47.6190	49.3827	49.0545	33.8074
4	48.4914	46.2963	47.6190	47.4689	33.5234
5	45.3175	46.5745	46.0614	45.9845	33.2506
6	40.1235	41.6667	38.7879	40.1927	32.0718
7	73.2887	73.9796	72.3522	73.2068	37.2899
8	60.1852	58.3333	60.2121	59.5769	35.4987
9	36.7156	38.5220	39.6825	38.3067	31.6521
Mean				54.2530	34.2813

The response table for the mean and SN ratio are presented in table 4. Each are derived from averaging the measured responses of the factors at each levels. Such that:

$$S_{Pi} = \frac{\sum_{n=1}^{9} \eta_{in}}{l} \quad (4)$$

Where S_{Pi} represents the average response of factor P(X, Y, Z) at level i; n is the experiment number

η_{in} is the result of the S/N ratio or mean at level i appearing within the number of runs; l is the number of levels.

Table 4: Tensile Strength Response table (Means and S/N ratio)

Level	**PALF Content (X)**		**Glass Fiber Content (Y)**		**Fiber Length (Z)**	
	Mean	**S/N Ratio**	**Mean**	**S/N Ratio**	**Mean**	**S/N Ratio**
1	61.18	35.08	72.00	36.80	65.03	35.72
2	44.55	32.95	48.24	33.53	41.65	32.34
3	57.03	34.81	42.52	32.51	56.08	34.78
Delta	16.63	2.13	29.48	4.29	23.38	3.37
Rank	3	3	1	1	2	2

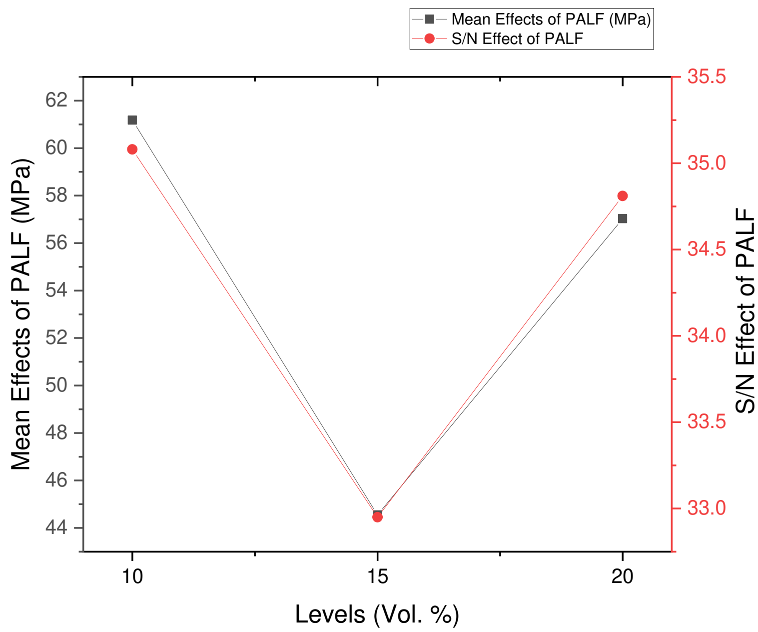


Figure1a: Graph of the effect of PALF on the Tensile Strength of $P_xG_yE^z$ (Mean and S/N)

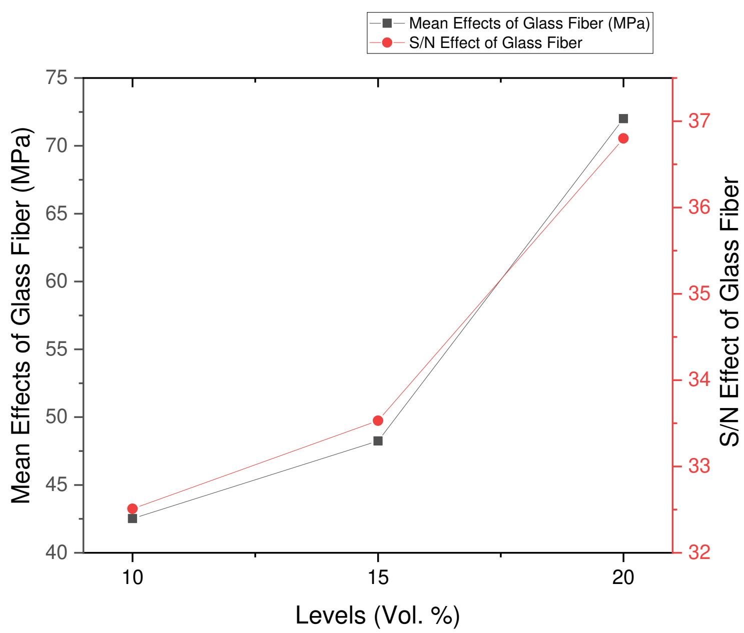


Figure 1b: Graph of the effect of Glass Fiber on the Tensile Strength of $P_xG_yE^z$ (Mean and S/N)

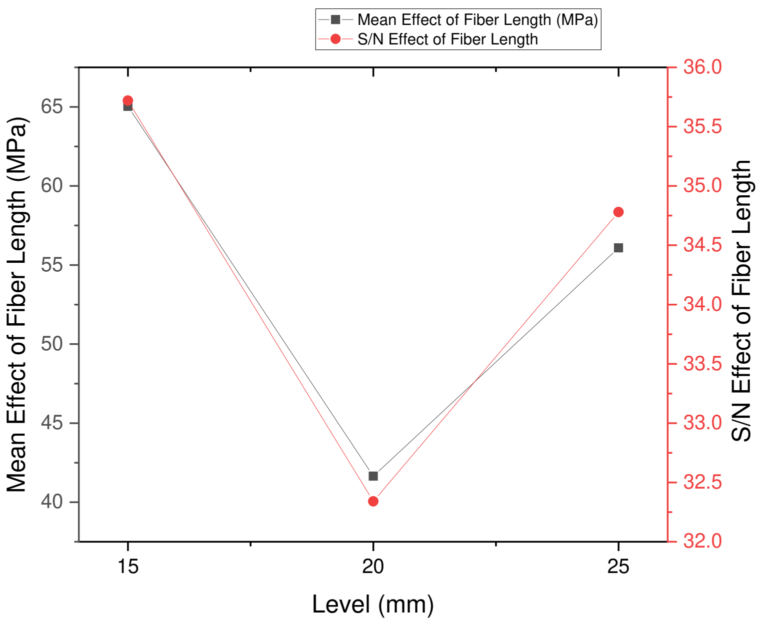


Figure 1c: Graph of the effect of Fiber Length on the Tensile Strength of $P_xG_yE^z$ (Mean and S/N)

Figure 1a shows the tensile strength of the material with varying composition by volume percent of the Pineapple leaf fiber. The tensile strength decreased upon an increase in the content of the PALF fiber. This indicates that natural fibers, like pineapple leaves fibers, due to their poor fibrillar and matrix adhesion are of little contribution to the tensile strength of the Fiber. SEM morphology in figure 2A shows the presence of non-celulosic materials on the surface of the treated pineapple leaves fiber. The observed increase after 15% volume is indicative of the increased fiber to fiber interaction, in the form of entanglement which is favorable for the tensile strength of the composite. This increased entanglement may not act favorable if it was in the context of a more brittle fiber like the glass fiber, but the entanglement is favorable in ductile materials like the pineapple leaf fiber. The peak of tensile strength with regards to the increment of PALF content by volume is at the first level (10% volume content). Figure 1b shows the positive effect of glass fiber on the tensile strength of the developed material. With considerable increase in tensile strength, it proves that synthetic fibers possesses superior tensile properties than natural fibers. This may also be as a result of good adhesion of the glass fiber with the polymer matrix. This is clearly seen in figure 2B where the epoxy materials could still be seen adhered to the surface of the glass fiber even after rupture. Also it is important to note that the steep increase in the tensile strength with an increase in the glass fiber may be attributed to the colony of the glass fiber (not entanglement which most researchers have attributed to) which increases the effect of its contribution as the colony acts as a fiber with more cross sectional area as in the case of wire ropes. This could clearly be seen in Figure 2C. The tensile strength of the composite peaks at level 1 which is 20% volume of the glass fiber in the hybrid composite. According to figure 1c which showed the effect of increasing fiber length on the tensile strength of the developed composite, it is observed that an increase in fiber length results to a reduction in tensile strength of the hybrid composite. This may not be disconnected to the fact that with an increase in surface area of fiber matrix interaction, there is a proportionate increase in possible failure points. Although the rise in tensile strength with a further increase in fiber length may not be disconnected from the possibility of fiber entanglements for the less brittle fibers which is of positive effect to the tensile strength of the material. The peak tensile strength within the observed length was at the shortest fiber length of 15mm which is at level 1. This shows that the optimal combination of the considered factors that will give the best tensile strength for the composite under study is X1Y1Z1. Which is Pineapple leaf fiber at 10% volume fiber content, glass fiber at 20% volume fiber content and 15mm fiber length. Implying that the $P_xG_yE^z$ composite possessed an optimized tensile strength at $P_{10}G_{20}E^{15}$. Figure 2C shows the fractured surface of the optimized composite. Although fiber agglomeration could be observed with the glass fiber, but the length of the glass fibers at fractured points compared with the length of the pineapple leaf fiber indicates that the glass fibers continued to bear stress even after the failure of the pineapple leaf fibers proving their superior strength.

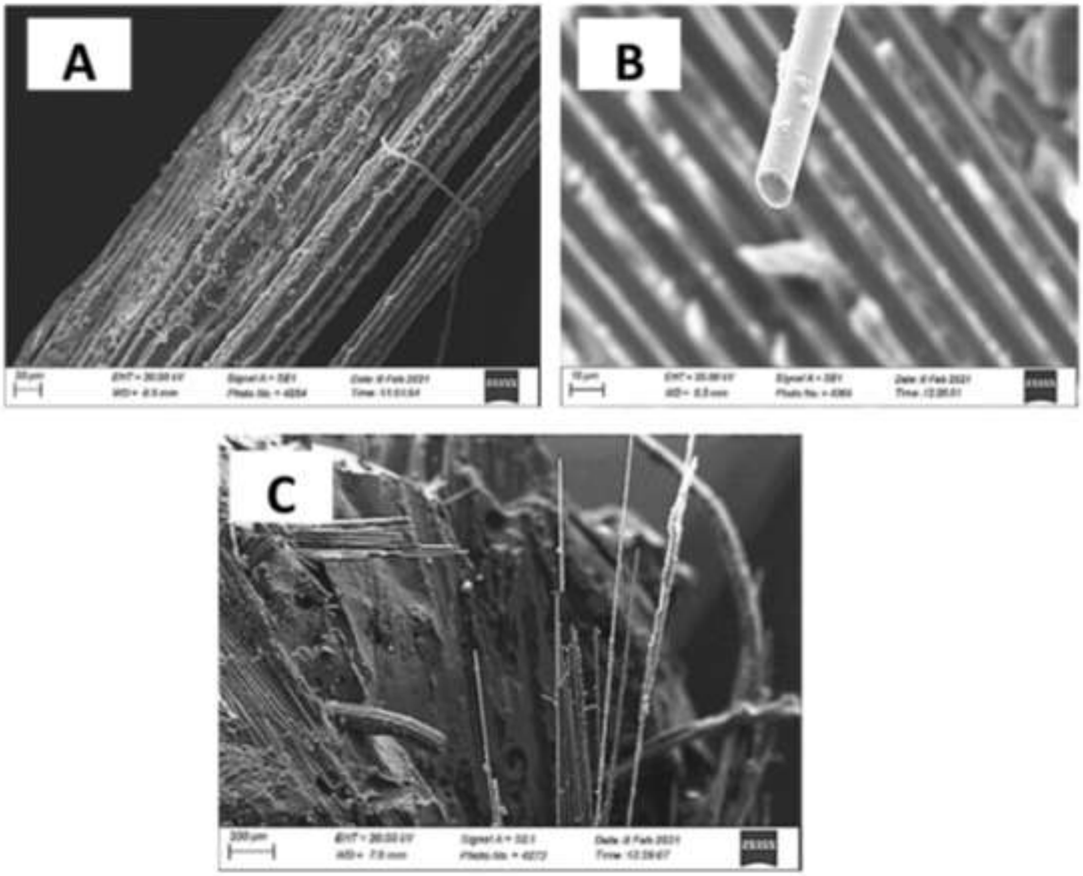


Figure 2: SEM Images of (A) Treated pineapple leaf fiber (B) Glass Fiber (C) $P_{10}G_{20}E^{15}$ fractured surface.

Analysis of Variance (ANOVA)

The analysis of variance is used to understand the level of significance of each factor (variable parameter) on the measured effect. In this situation, the anova is used to determine the level of contribution of PALF, glass fiber and fiber length to the tensile strength of the developed composite. The anova for the mean effect and the SN ratios are presented in Table 5 and 6 respectively.

Analysis of Variance for Means

Table 5: Analysis of Variance of Means for Tensile Strength of PALF/Glass Fiber Epoxy Hybrid composite.

Source	DF	Seq SS	Adj SS	Adj MS	Fishers Test: F	% Contribution (%)
A	2	449.6	449.6	224.81	3.12	15.53
B	2	1466.0	1466.0	732.98	10.18	50.64
C	2	834.9	834.9	417.45	5.80	28.84
Residual Error	2	144.0	144.0	71.99		5.00
Total	8	2894.5				

Tabulated F-ratio at 95% confident level

Analysis of Variance for SN Ratio

Table 6: Analysis of Variance of SN Ratio for Tensile Strength of PALF/Glass Fiber Epoxy Hybrid composite.

Source	DF	Seq SS	Adj SS	Adj MS	F	% Contribution (%)
A	2	8.100	8.100	4.0498	4.55	13.92
B	2	30.088	30.088	15.0441	16.91	51.72
C	2	18.206	18.206	9.1030	10.23	31.30
Residual Error	2	1.780	1.780	0.8899		3.10
Total	8	58.174				

Tabulated F-ratio at 95% confident level, DF= Degree of freedom, SS=Sum of square, MS=Mean Square

The anova shows that the glass fiber has the most significant percentage contribution to the tensile strength of the material. The Fiber length also considerably contribute to the tensile strength of the material but the PALF has the least contribution to the tensile test of the material. All these was measured at a confidence level of 0.05.

Estimating the Optimal Tensile Strength

Using the optimal settings of the control factors (X1Y1Z1), an optimal tensile strength for the hybrid material can be predicted using the expression;

$$T_{opt} = T_m + \sum_{k=1}^{k_n}[(T_{ik})_{max} - T_m] \quad (5)$$

Where: T_m = 54.2530 is the overall mean or S/N ratio obtained from table 3;

T_{ikmax} = 61.18MPa, 72.00MPa and 65.03MPa is the mean or S/N ratio at optimum level i of factor k (obtained from table 4) and k_n is the number of main design factor that affect the response (=3; PALF, glass fiber, and fiber length). T_{ikmax} is gotten from the response table of mean or S/N ratio in which for each parameter on the table, the highest value among the levels is the T_{ikmax}.

Therefore, the optimal tensile strength is:

$$T_{opt} = 54.253 + (61.18 - 54.253) + (72.00 - 54.253) + (65.03 - 54.253)$$

$$T_{opt} = 89.704MPa$$

In other to calculate a confidence interval C.I,

$$C.I = \sqrt{F_{\alpha}(1, F_e)V_e\left[\frac{1}{\eta_{eff}} + \frac{1}{\eta_{ver}}\right]} \quad (6)$$

Where; $\mathrm{C.I}$ = Confidence interval; $F_{\alpha}(1, F_e)$ = F ratio required for α; α = Risk; F_e = Error DOF; $F_{\alpha}(1, F_e) = F_{0.05}(1,2) = 18.51$ (tabulated), V_e = Error Variance (obtained from the Anova table) = 71.99 ; η_{ver} = Number of trials to run confirmation test i.e. same as number of replication for each run = 3; η_{eff} = Effective number of replications

$$\eta_{eff} = \frac{N}{1+[Total\ DOF\ of\ controlled\ factors]} \quad (7)$$

N = Total number of results = 27, Total DOF (degree of freedom) of controlled factors = 6

Therefore $\eta_{eff} = 3.85$ and C.I = ±28.11MPa

The percentage error is calculated using the expression

$$Error = \frac{Experimental\ value - Predictive\ Value}{Experimental\ Value} \quad (8)$$

Confirmation test

The $P_{10}G_{20}E^{15}$ optimized composite was fabricated using the optimized composition as obtained which is PALF fiber at 10%, glass fiber at 20% and fiber length at 15mm. Three samples were cut out for and tensile test were carried out according to the ASTM D638 tensile test procedures. The result of the tensile test is presented in table 7. The average tensile strength was found to be 95.3144 with SN Ratio of 39.5821dB.

Table 7: Observation of confirmation test (tensile strength)

	Trial Number				
	1	2	3	Average tensile Strength (MPa)	SN Ratio (dB)
1	94.3396	96.4506	95.1529	95.3144	39.5821

The obtained tensile test from the confirmatory test shows that the experimental value lie between the confidence interval range of the tensile strength such that Predictive value – C.I < Experimental value < Predictive value + C.I. Such that 61.594MPa < 95.3144MPa < 117.814MPa.

Regression Analysis

A mathematical model for the combination of PALF in volume percentage, glass fiber in volume percentage and fiber length in millimeters was gotten from the regression analysis carried out using the MINITAB® 19 statistical software used for the prediction of the tensile strength of the $P_xG_yE^z$ composite. The regression analysis model is presented in table 8.

Table 8: Regression analysis model

Predictor	Coef	SE Coef	T	P
Constant	34.15	40.86	0.84	0.441
A	-0.415	1.388	-0.30	0.777
B	2.948	1.388	2.12	0.087
C	-0.895	1.388	-0.64	0.548

S = 17.0005   R-Sq = 50.1%   R-Sq (adj) = 20.1%

The regression equation is

$$\text{Tensile strength} = 34.2 - 0.42\,A + 2.95\,B - 0.89\,C \tag{9}$$

Where A, B, C are equivalent to the factors and represents x, y, z respectively in the composite $P_xG_yE^z$. The result of the predicted tensile strength of and the experimental values of the $P_{10}G_{20}E^{15}$ which is at the optimal composition is compared in table 9.

Table 9: Results at optimal level

	Optimal Process Parameter Settings	Predictive Values (MPa)	Experimental Values (MPa)	% Error
S/N ratio (dB)	X1Y1Z1	39.0351	39.5821	1.38
Tensile strength (MPa)	X1Y1Z1	75.65	95.3144	20.63

4.0 Conclusion

A pineapple leaf fiber/Glass Fiber Epoxy hybrid composite $P_xG_yE^z$ was developed, characterized and optimized on its tensile properties. The following deductions were made:

- The tensile strength of the composite developed with the optimum composition of 10% PALF, 20% Glass fiber and 15mm fiber length was 95.3164MPa.
- Glass fiber has the highest contribution of 50.64% to the tensile strength of $P_xG_yE^z$ and Pineapple leaf fiber and the fiber length contributed 15.53% and 28.84% respectively and the cause of this variation may not be far from the fibrilar-matrix adhesion and individual mechanical properties.
- The regression equation satisfactorily predicts the tensile behavior of the $P_xG_yE^z$ composite at different combinations of its factors.

Declaration

Funding: This research did not receive any funding

Conflicts of interest/Competing interests: The author declare no conflict of interest

Availability of data and material: Not applicable

Code availability: Not applicable

Ethics approval: Not applicable

Consent to participate: Not applicable

Consent for publication: Not applicable

References

Basavarajappa, S., Chandramohan, G. and Paulo, D.J. (2007) Application of Taguchi Techniques to Study Dry Sliding Wear Behaviour of Metal Matrix Composites. Materials and Design, 28, 1393-1398. http://dx.doi.org/10.1016/j.matdes.2006.01.006

Jeyapragash, R., Srinivasan, V., Sathiyamurthy, S. (2020) Mechanical properties of natural fiber/particulate reinforced epoxy composites— A review of the literature. Mater. Today Proc. 22, 1223–1227.

Kerni, L.; Singh, S.; Patnaik, A.; Kumar, N. (2020) A review on natural fiber reinforced composites. Mater. Today: Proc. 2020, 28, 1616–1621.

Lee C.H., Khalina A., Lee S.H., Padzil F.N.M., Ainun Z.M.A. (2020) Physical, Morphological, Structural, Thermal and Mechanical Properties of Pineapple Leaf Fibers. In: Jawaid M., Asim M., Tahir P., Nasir M. (eds) Pineapple Leaf Fibers. Green Energy and Technology. Springer, Singapore. https://doi.org/10.1007/978-981-15-1416-6_6

Mittal, M., & Chaudhary, R. (2018). Development of Palf / Glass and Coir / Glass Fiber Reinforced Hybrid Epoxy Development of PALF / Glass and Coir / Glass Fiber Reinforced Hybrid Epoxy Composites. Journal of Materials Science and Surface Engineering, 6(5), 851–861. Https://Doi.Org/10.Jmsse/2348-8956/6-5.1

Mulenga, T. K., Ude, A. U., & Vivekanandhan, C. (2021). Techniques for Modelling and Optimizing the Mechanical Properties of Natural Fiber Composites: A Review. Fibers, 9(1), 6.

Nagavally, R. R. (2016). Composite Materials - History, Types, Fabrication Techniques, Advantages, and Applications. International Journal of Advances in Science Engineering and Technology, 4(3), 87–92.

Omrani, E.; Menezes, P.L.; Rohatgi, P.K. (2016) State of the art on tribological behavior of polymer matrix composites reinforced with natural fibers in the green materials world. Eng. Sci. Technol. Int. J., 19, 717–736.

Pappu, A., Thakur, V.K. (2017). Towards sustainable micro and nano composites from fly ash and natural fibers for multifunctional applications. Vacuum, 146, 375–385.

Rajeshkumar, G., Ramakrishnan, S., Pugalenthi, T., & Ravikumar, P. (2020). Performance of surface modified pineapple leaf fiber and its applications. In Pineapple leaf fibers (pp. 309-321). Springer, Singapore.

Taguchi, G. (1993) Taguchi on Robust Technology Development Methods. ASME Press, New York, 1-40. http://dx.doi.org/10.1115/1.800288.ch1

Taguchi, G. and Konishi, S. (1987) Taguchi Methods, Orthogonalarrays and Linear Graphs, Tools for Quality Engineering. American Supplier Institute, Dearborn, 35-38.

Venkateshwaran, N.; Elayaperumal, A.; Sathiya, G.K. (2012) Prediction of tensile properties of hybrid-natural fiber composites. Compos. Part B Eng., 43, 793–796.

Vijayakumar, S., Palanikumar, K. (2019) Mechanical Property Evaluation of Hybrid Reinforced Epoxy Composite. Mater. Today Proc., 16, 430–438.

Wang, C.; Zuo, Q.; Lin, T.; Anuar, N.I.S.; Salleh, K.M.; Gan, S.; Yousfani, S.H.S.; Zuo, H.; Zakaria, S. (2020) Predicting thermal conductivity and mechanical property of bamboo fibers/polypropylene nonwovens reinforced composites based on regression analysis. Int. Commun. Heat Mass Transf. 118, 104895.

Wang, K.F.; Wang, B.L. (2018) A mechanical degradation model for bidirectional natural fiber reinforced composites under hydrothermal ageing and applying in buckling and vibration analysis. Compos. Struct., 206, 594–600.

Figures

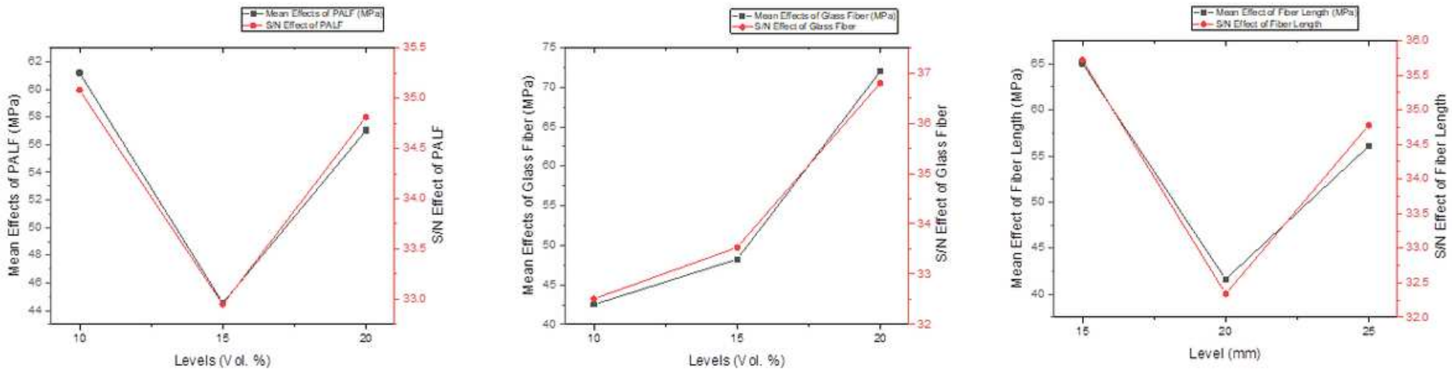


Figure 1

a: Graph of the effect of PALF on the Tensile Strength of PxGyEz (Mean and S/N) b: Graph of the effect of Glass Fiber on the Tensile Strength of PxGyEz (Mean and S/N) c: Graph of the effect of Fiber Length on the Tensile Strength of PxGyEz (Mean and S/N)

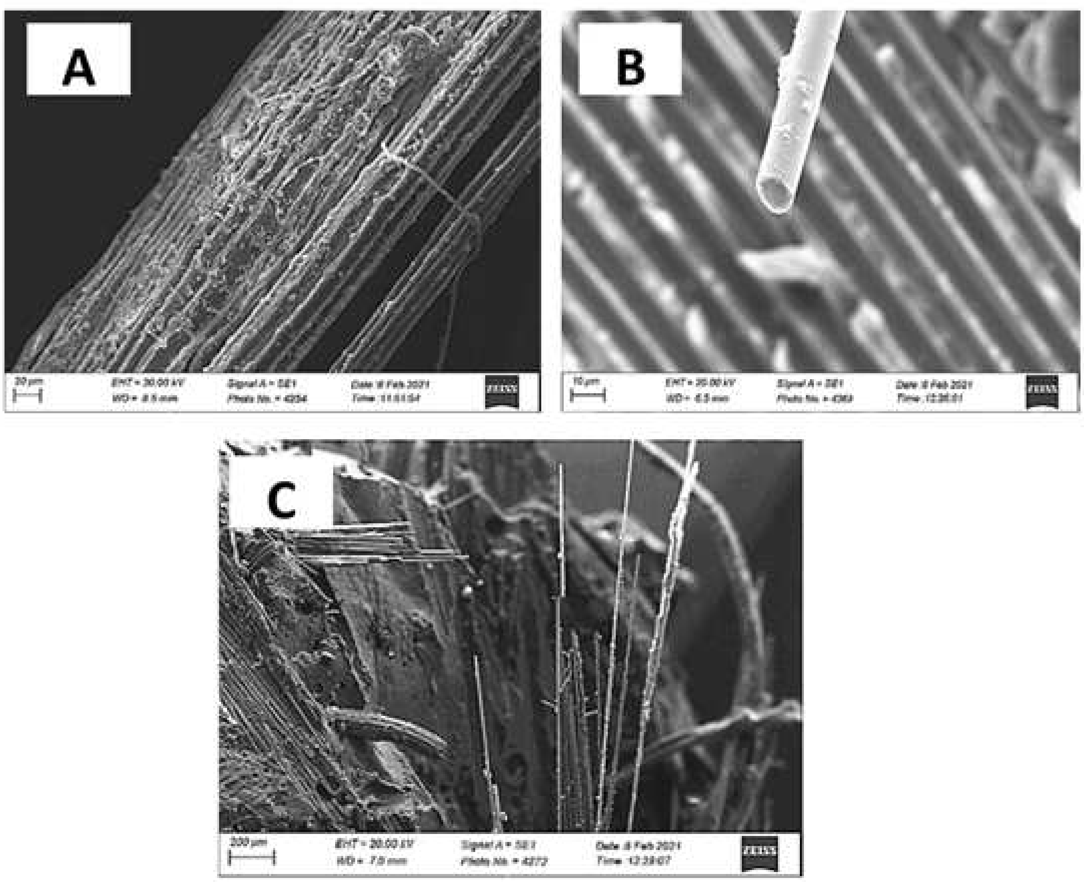


Figure 2

SEM Images of (A) Treated pineapple leaf fiber (B) Glass Fiber (C) P10G20E15 fractured surface.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- GA.png