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Improvement of the Mechanical Properties of *Hibiscus Esculentus* (Okra) Fiber Reinforced Polymer Composite

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Abstract

Natural fiber and their composites are the emerging trends in material science. They are speedily gaining grounds in the replacement of synthetic reinforcements. This is due to their low density, high specific mechanical strength, ultimate availability and disposability and less processing requirements. Most plant based fibers have become centers of research. This work is based on Okra fiber. Okra fiber was used as reinforcement in vinyl ester polymer matrix. Okra fiber was chemically treated using NaOH to clean fiber surface, modify the surface to increase the surface roughness and in general enhance bond strength between fiber and matrix. Reinforcement of the matrix using Okra fiber increases mechanical properties of the composite. But for optimal result, certain parameters were considered and varied. The two parameters considered were: fiber length, and proportion or volume fraction. Different variations of fiber length considered were: 10mm, 30mm and 50mm while the different fiber volume fractions considered are 10%, 30% and 50%. This work has analyzed how these parameters can be best combined for optimum values of tensile properties of the composite. The tensile strength of composite was highest at fiber length of 50mm and volume fraction of 10% at ultimate tensile strength of 214MPa.

1. Introduction

We find composites everywhere around us. Composite is a material system

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composed of two or more physically distinct phases whose combination produces synergistic effect and aggregate properties that are different from those of its constituents. Many materials existing in nature, such as bones in the human body, wood and bamboo in the forest, derive their superb mechanical properties by combining two or more macroscopic components or constituents.

A composite in this respect is a compound formed between a polymer and a fibrous material. These polymer composite products have good mechanical properties per unit weight, are durable and their technologies allow the manufacture of complex and rare shapes. In recent times natural fibers have been used as reinforcement for polymer composite creation. Natural fibers are derived from plants, animals and mineral sources. Plant fibers are widely used for composite fabrication. The properties of these fibers depend on the nature of the plant, locality in which it is grown and age (Joseph et al. [3], Khandal et al. [4] and Kuchinda et al. [5]). Natural fibers are fast displacing glass and other industrial fibers due to its low specificity, high specific strength and stiffness. It has renewability source advantage over glass fiber as well as cost effectiveness. Furthermore, reduction of wear of tooling, healthier working condition and no skin irritation coupled with thermal recycling and acoustic insulating properties are inevitable.

Nevertheless, to fabricate a polymer composite with good mechanical properties, control parameters; fiber length and volume fraction of reinforcement material (natural fiber) play significant role (Mohanty et al. [8]). In this work the chosen fiber length and volume fraction are 10mm, 30mm, 50mm, and 10%, 30% 50%, respectively.

Also previous studies have proved the importance of chemically treating the plant fiber that will be used as reinforcement in composite fabrication. According to the work of Xing et al. [2], proper chemical treatment will reduce moisture sensitivity, biological decay and optimize fiber matrix interface thus enabling perfect bonding strength.

Mattoso et al. [6], Martins and Joekes [7] also opined that by treating the fibers with suitable chemicals, the reinforcing efficiency of the fibers in the composite and the interfacial adhesion between fibers and most polymers is established.

Ray and Sarkar [9] investigated the changes occurring in jute fibers after 5% NaOH solution treatment was done. He ascertained that the tenacity and modulus of fiber improved by 45% and 79%, respectively.

In this work, the Okra fiber used as reinforcement was treated with NaOH.

Natural fiber has become a huge attraction for researchers as it can be used to create composite raw materials for the manufacturing of products in a wide range of industries such as building and construction, automotive, electrical, domestic items etc.

A possible route for broadening the number of species from which plant fibers are extracted to be employed for massive composite creation would be turning to local fibers. One of these locally available plants is the Okra Plant.

Okra Fiber

Okra fiber is a natural plant fiber extracted from the bark of the Okra plant, a plant of the Malvaceae family, known botanically as *Hibiscus esculentus*. They are not dissimilar chemically from plants such as pineapple, whose fibers found some use as reinforcement in composites. The color of Okra fiber is quite variable, from whitish to yellowish, depending on the action of UV radiation, a fact which generates some concern on the effect of solar exposure on them [1].

2. Materials and Method

2.1. *Sample collection*

The Okra stem was harvested in an Okra farm located in Umuoma, a village in Uli, Latitude 5.7833 and Longitude 6.8667, Ihiala Local Government Area of Anambra State.

2.2. *Methodology*

For the purpose of analyzing and optimization of the tensile test results of fabricated composite samples, response surface methodology (RSM) was employed. A second order quadratic model is used:

$$\hat{Y} = a_0 + a_1X_1 + a_2X_2 + a_3X_1X_2 + a_4X_1^2 + a_5X_2^2 + E \quad (1)$$

where:

$\hat{Y}$ = Response, X_1 = fiber length (fl) (mm), X_2 = fiber volume fraction (vf) (%), a_0, a_1, a_2, a_3, a_4 and a_5 are constants, and E = error observed in the response.

2.3. *Reagents*

The major chemicals used are NaOH for chemical treatment of fiber and vinyl ester as polymer matrix base for the composite.

2.4. *Sample preparation*

The central part of the Okra stem was removed and kept under water to allow microbial degradation. Within 15-25 days, the stems degraded appreciably to allow fiber extraction. The fibers were isolated from the degraded stems by washing with detergent, rinsed in clean water and allowed to dry under the sun, then kept in moisture proof container. Afterwards fiber was chopped into lengths of 10mm, 30mm and 50mm.

2.5. *Chemical treatment of fiber*

The Okra fibers are chemically treated with sodium hydroxide (NaOH). The fibers were dipped into 2% solution of NaOH, for an hour under constant stirring and allowed for 24hrs at room temperature and then dried in open air for 6-7 days.

2.6. *Mould preparation fiber laying and impregnation*

The mould is waxed for easy removal of composite. By simple hand lay-up technique, the fiber is soaked into the vinyl ester resin in the mould for different volume fractions: 10%, 30% and 50%. Composite was allowed to cure.

2.7. *Sample characterization*

The composite samples were separated accordingly to have nine (9) samples with fiber proportion as follows:

Table 1. Sample characterization.

Fiber length (mm)	10	10	10	30	30	30	50	50	50
Volume Fraction (%)	10	30	50	10	30	50	10	30	50

2.8. *Tensile test*

The tensile properties were ascertained using a Hounsfield Monsanto Universal Tensometer Machine at a constant rate of traverse of the moving grip of 5mm min^{-1} for randomly oriented fiber composites (ASTMD638-99) and 20mm/min for oriented fiber composites (ASTM 05083). The test specimens were rectangular in shape with dimensions $(100 \times 19 \times 3.2)$ mm for randomly oriented fiber composites.

3. Results and Discussion

The results of the tensile test on the Okra fiber reinforced polymer composite are as shown on the table.

Table 2. Okra tensile test analysis.

Fiber Length (mm)	Volume Fraction (%)	Tensile st. (MPa)	Modulus (MPa)	Toughness	Ultimate el. (mm)
10	10	32.89	2.4024	0.4118	1.88
10	30	74.01	6.6654	0.5399	1.41
10	50	143.91	11.0936	1.4782	1.88
30	10	143.9	12.5941	1.7176	2.50
30	30	143.91	10.7110	0.7075	0.94
30	50	197.37	8.5054	4.6616	4.38
50	10	209.7	17.140	3.0489	2.81
50	30	193.26	6.5285	1.7213	2.18
50	50	98.68	5.1034	0.5167	1.41

Table 3. Response surface model table for tensile strength analysis.

Variables	Coefficients	Std. Error	t-stat	P-value	F-stat
Constant	-119.8828	63.1746	-1.8976	0.154	SSE=2583.9
Fiber Length (mm)	11.7013	3.3556	3.4871	0.0398	DFE=3
Volume Frac. (%)	4.5066	3.3556	1.3430	0.2718	DFR=5
Fiber Length*Vol. Frac.	-0.1388	0.0367	-3.7829	0.0324	SSR=25927
Fiber Length^2	-0.0908	0.0519	-1.7501	0.1784	F=6.0203
Volume Frac.^2	0.0017	0.0519	0.0328	0.9759	P-val =0.085205
	R^2 =0.9094	Adj.R^2 =0.7583			

Table 4. Analysis of variance for tensile strength

Source	Sum Sq.	d.f.	Mean Sq.	F	Prob>F
X1	13124	2	6562	1.76	0.2829
X2	477.4	2	238.72	0.06	0.9389
Error	14909.4	4	3727.34		
Total	28510.8	8			

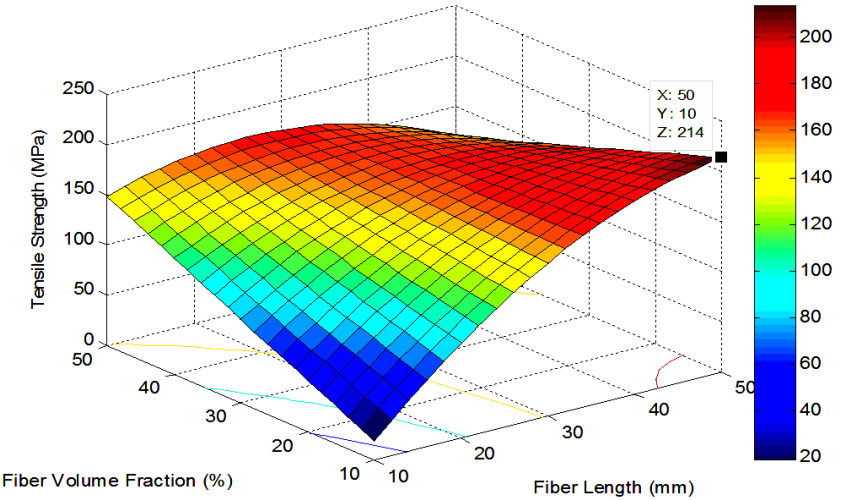

Figure 1. Surface plot and analysis of variance for tensile strength.

Table 5. Response surface model table for modulus of elasticity analysis.

Variables	**Coefficients**	**Std. Error**	**t-stat**	**P-value**	**F-stat**
Constant	-4.4752	4.2152	-1.0617	0.3663	SSE=11.503
Fiber Length (mm)	0.8276	0.2239	3.6964	0.0344	DFE=3
Volume Frac. (%)	0.101	0.2239	0.451	0.6826	DFR=5
Fiber Length*Vol. Frac.	-0.013	0.0024	-5.2926	0.0132	SSR=145.49
Fiber Length^2	-0.0061	0.0035	-1.7679	0.1752	F=7.5886
Volume Frac.^2	0.0038	0.0035	1.0868	0.3566	P-val =0.06296
	R^2 = 0.9267	Adj.R^2 =0.8046			

Table 6. Analysis of variance for modulus of elasticity

Source	Sum Sq.	d.f.	Mean Sq.	F	Prob>F
X1	24.342	2	12.1709	0.41	0.689
X2	13.74	2	6.8701	0.23	0.8036
Error	118.914	4	29.7285		
Total	156.996	8			

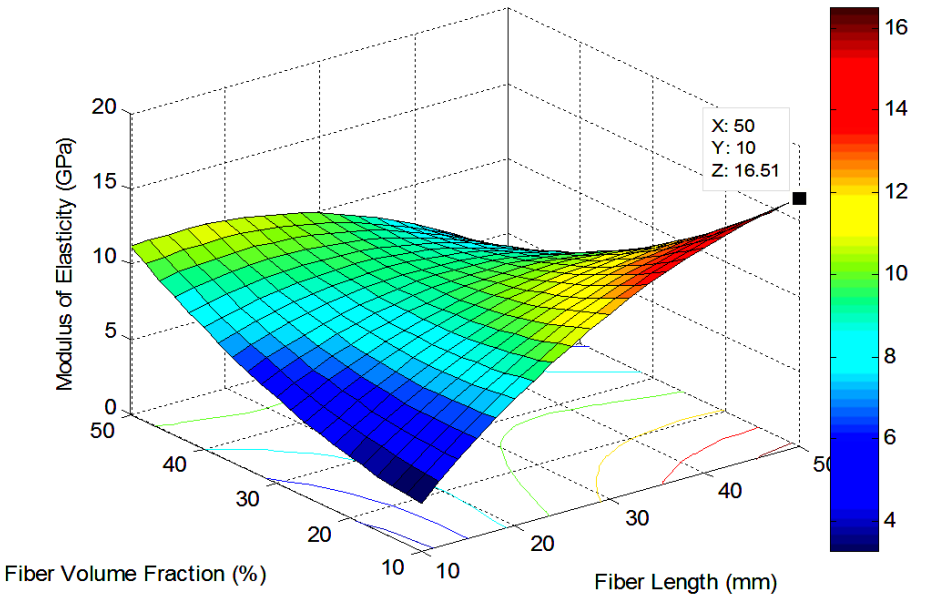

Figure 2. Surface plot and analysis of variance for modulus of elasticity (MOE).

Table 7. Response surface model table for toughness analysis.

Variables	**Coefficients**	**Std. Error**	**t-stat**	**P-value**	**F-stat**
Constant	-1.6107	3.2393	-0.4973	0.6532	SSE=6.7935
Fiber Length (mm)	0.2527	0.1721	1.4687	0.2382	DFE=3
Volume Frac. (%)	-0.0676	0.1721	-0.3931	0.7205	DFR=5
Fiber Length*Vol. Frac.	-0.0022	0.0019	-1.1957	0.3177	SSR=9.2102
Fiber Length^2	-0.0027	0.0027	-1.0113	0.3864	F=0.81345
Volume Frac.^2	0.0025	0.0027	0.9237	0.4238	P-val =0.60922
	R^2 = 0.5755	Adj.R^2 =-0.1320			

Table 8. Analysis of variance for toughness.

Source	Sum Sq.	d.f.	Mean Sq.	F	Prob>F
X1	3.6764	2	1.8382	0.73	0.5355
X2	2.2964	2	1.14818	0.46	0.6621
Error	10.031	4	2.50774		
Total	16.0037	8			

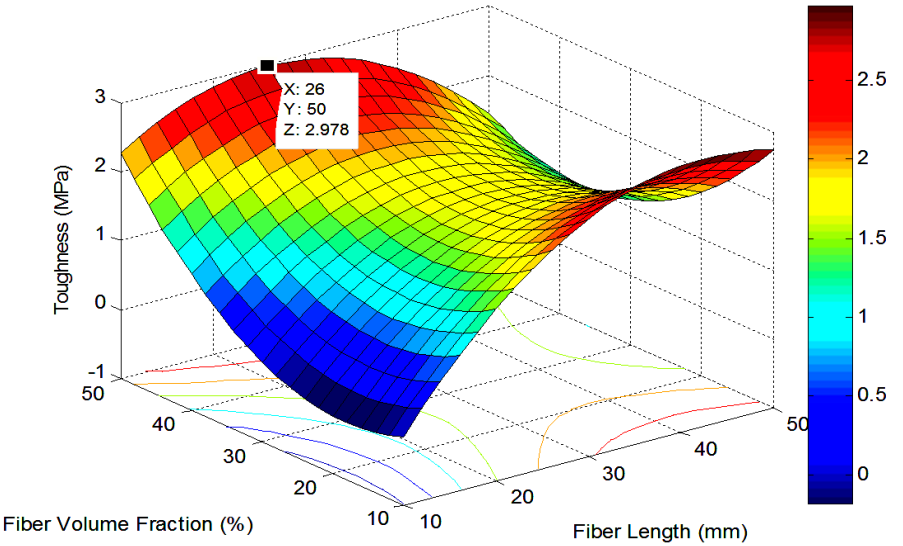

Figure 3. Surface plot and analysis of variance for toughness.

Table 9. Response surface model table for ultimate elongation analysis.

Variables	**Coefficients**	**Std. Error**	**t-stat**	**P-value**	**F-stat**
Constant	1.396	2.6849	0.5199	0.6390	SSE=4.6671
Fiber Length (mm)	0.1383	0.1426	0.9694	0.4038	DFE=3
Volume Frac. (%)	-0.1148	0.1426	-0.8046	0.4799	DFR=5
Fiber Length*Vol. Frac.	-0.0009	0.0016	-0.5612	0.6138	SSR=3.5697
Fiber Length^2	-0.0017	0.0022	-0.7691	0.4978	F=0.45892
Volume Frac.^2	0.0024	0.0022	1.0960	0.3532	P-val =0.79115
	$R^2 = 0.4334$	Adj.R^2 =-0.5110			

Table 10. Analysis of variance for ultimate elongation of fiber.

Source	Sum Sq.	d.f.	Mean Sq.	F	Prob>F
X1	1.17242	2	0.58621	0.45	0.6638
X2	1.90729	2	0.95364	0.74	0.5329
Error	5.15711	4	1.28928		
Total	8.23682	8			

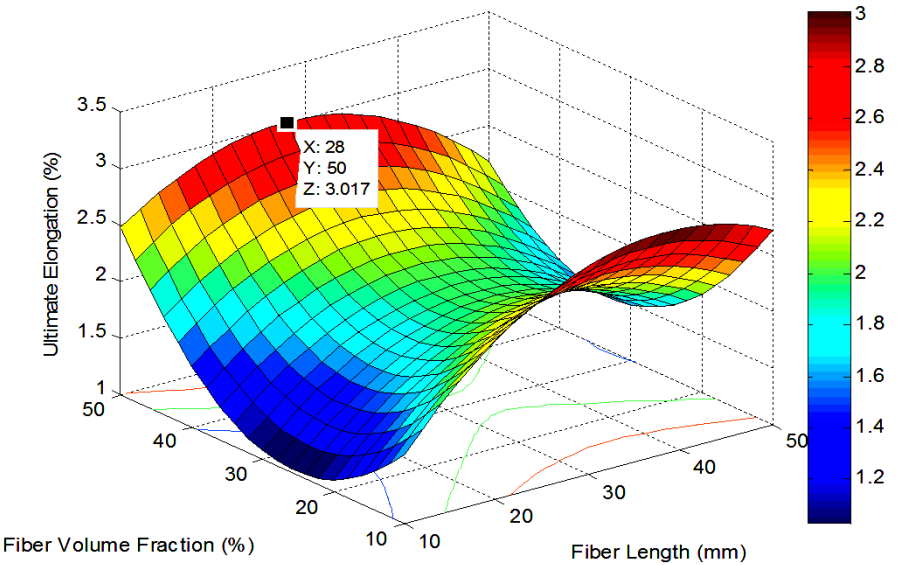

Figure 4. Surface plot and analysis of variance for ultimate elongation analysis.

Response surface methodology was used to analyze the influence of the variables viz.: fiber length and volume fraction on the mechanical properties of the Okra fiber reinforced polymer composite. Based on the value of the adjusted R^2 value the 'quadratic model' fits best for the analysis of the extent of variation/variability in the experiment. The model is stated below:

$$Y(x) = C_0 + C_1x_1 + C_2X_2 + C_3x_1x_2 + C_4x_1^2 + C_5x_2^2 + \cdots + E. \quad (2)$$

On application of the above stated model and from analysis using response surface methodology, according to Figure 1, tensile strength is highest at Fl = 50mm, Vf = 10%. Ultimate tensile strength is 214MPa with ultimate elongation of 2.81mm. While virgin vinyl ester resin has an ultimate tensile strength in the range of 22-26Mpa and a mean value of 23.98Mpa, after reinforcement using Okra fiber, there is significant improvement in the tensile strength. This is about 900% increment as compared to unreinforced vinyl ester. According to the tensile strength analysis Table 3, R^2 which has value 0.9094 depicts that the model is accurate and can be said to explain up to 90% of observation in experimental data.

Also from Table 4, T-Stat value of fiber length and fiber length * vol. fraction is ≥ 2. This shows that the two variables have significant effect on the tensile property of the

composite. That is to say in varying the two parameters, the tensile strength of the composite can be improved or decreased.

The P-value for fiber length and fiber volume fraction is 0.03. This shows the model is adequate enough with above 90% confidence level and that the variables: fiber length, interaction between fiber length and volume fraction has significant influence on the tensile strength of the composite. The contour lines under the graph in Figure 1 are the region where the tensile strength is the same even though the fiber length and volume fraction may be changing.

Modulus of Elasticity: The analysis shows R^2 value of 0.9267. This means that the model is accurate and explains 93% of observation in the experimental data as regards modulus of elasticity. The variables; fiber length and interaction between fiber length and volume fraction is significant as depicted by the T-stat values and P-values. According to the surface plot in Figure 2, the modulus of elasticity is highest at Fl = 50, Vf = 10. Modulus of Elasticity = 16.5.

Toughness Analysis: As can be seen in Table 3, from T-stat and P-value, none of the parameters: Fl, Vf and Fl*Vf are significant and does not determine the toughness. This also explains poor R^2 value of 0.575.

Elongation analysis from Table 9 changes in fiber length and volume fraction has no significant effect on the composite elongation hence low value of R^2 of 0.4334.

4. Conclusions

The Okra fiber reinforced polymer composite has good tensile strength and this mechanical property can be affected by the fiber length of individual fiber used for each sample. The volume fraction of the fiber in the composite sample can also affect tensile strength of the composite.

The tensile strength of the composite increases linearly with fiber lengths up to 50mm and volume fractions of 10%. With ultimate tensile strength of 214 MPa, alternative to other raw materials for production of items that includes window blinds, desktops, automotive interiors etc. growing Okra plant and investing on its fiber extraction can also burst good employment opportunity.

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