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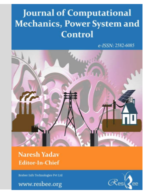

Effects of Chemical Treatment Parameters on the Flexural Strength Properties of Banana Stem Fibre Reinforced Epoxy Composites

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Abstract: Natural fiber-reinforced composites offer a sustainable alternative to synthetic fibers, utilizing agricultural waste materials for their production. However, the hydrophilic nature of natural fibers limits their use in composites. This study investigates the surface treatment of banana stem fibers with a $NaOH + Na_2SO_3$ mixture to enhance their compatibility with an epoxy matrix. Various experimental parameters, including soaking time, concentration, and temperature, were investigated at levels of 1h, 2h, 3h, 4h, 5h, 2%, 4%, 6%, 8%, 10%, and 25°C, 40°C, 50°C, 60°C, 70°C respectively. The Taguchi method is employed to optimize treatment parameters for improved flexural strength. Analysis of variance (ANOVA) was utilized to determine the effects of these parameters on the flexural strengthof BSF in the composite. Results indicate that a soaking time of 3 hours, concentration of 8%, and temperature of 25°C yield the highest flexural strength, with a 14.86% improvement over untreated fibers. The Taguchi analysis reveals the significant impact of soaking time and concentration on flexural strength, with concentration playing the most critical role. Regression analysis generates predictive equations for flexural strength, indicating that the quadratic model provides a better fit than the linear model. A confirmation test validates the predicted optimal conditions. This research demonstrates the effectiveness of the $NaOH + Na_2SO_3$ treatment in enhancing the mechanical properties of banana stem fiber-reinforced epoxy composites, offering insights for sustainable composite material development.

Keywords: Natural Fiber, Banana Stem Fiber, Surface Treatment, Taguchi Method, Flexural Strength, Epoxy Resin.

Nomenclature

Abbreviation	Expansion
BSF	Banana Stem Fiber
NaOH	Sodium Hydroxide
Na_2SO_3	Sodium Sulfite
S/N	Signal-to-Noise
ANOVA	Analysis of Variance
ASTM	American Society for Testing and Materials
MPa	Megapascal
NaOH	Sodium Hydroxide
Na_2SO_3	Sodium Sulfite
FTIS	Fourier Transformed Infrared Spectrometry
SEM	Scanning Electron Microscopy

1. Introduction

Composite materials are created by combining two or more materials to achieve a synergistic effect. The main components of a composite material are the matrix and the reinforcement. The matrix bonds the reinforcement, providing shape and desired properties, and can be either thermoplastic or thermo set. There has been increasing research interest in natural fiber-reinforced composites due to their availability, lightweight nature, eco-friendliness, recyclability, and low cost [1]. These composites offer a way to utilize agricultural waste materials. Natural fibers have shown potential as substitutes for synthetic fibers, which include nylon, rayon, polyester, plastic, acrylic, and glass [2]. Despite the advantages of synthetic fibers, they have drawbacks such as high processing labor, non-biodegradability, high cost, and relatively heavier weight.

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One major disadvantage of natural fibers is their hydrophilic nature, which limits their use as reinforcement material in composites [3]. To overcome this, various chemical modifications such as mercerization, benzoylation, acetylation, and esterification are adopted. However, the incompatibility of banana fiber with the matrix and its poor moisture resistance often limit its potential use. To enhance the compatibility of banana fiber with the matrix, physical or chemical methods are used. Chemical treatment of natural fibers used in composites has significantly increased their tensile strength, flexural strength, and impact strength.

In that process, treatment time, temperature, and concentration are the most important factors influencing natural fiber interfacial strength [3]. NaOH is a popular and inexpensive fiber surface treatment reagent that exposes fibrils and gives fibers a rough surface topography [4]. The soaking time and concentration of alkali are the major factors that determine the mechanical properties of coir–polyester composites [5] [6].The tensile strength and elastic modulus of banana stem fibre-reinforced natural rubber composite increased with 4% NaOH and 2% Na_2SO_3 mixture [7]. The surface treatments with a mixture of NaOH and any other chemical together [6] [8] [9], resulted in a better interfacial adhesion between fiber and matrix, which had a significant effect on the mechanical properties of the composite.

In this paper, Initially, banana stem fibers, NaOH, Na_2SO_3, and epoxy resin are collected. Then they used Surface Treatment for enhanced compatibility with the epoxy matrix. Then soaking time, concentration, and temperature levels using the Taguchi method (1-5 hours, 2-10%, 25-70°C) are investigated. Then using ANOVA optimal conditions (3 hours soaking time, 8% concentration, 25°C temperature) are determined for the highest flexural strength improvement. Finally, concentration is identified as enhancing flexural strength. The main contributions of the papers are listed below

- Investigated the surface treatment of banana stem fibers with a NaOH + Na_2SO_3 mixture to enhance compatibility with an epoxy matrix.
- Explored various experimental parameters (soaking time, concentration, temperature) using the Taguchi method to optimize treatment parameters for improved flexural strength.
- Utilized ANOVA to determine the effects of treatment parameters on flexural strength, highlighting the optimal conditions for enhanced mechanical properties.
- Revealed the significant impact of soaking time and concentration on flexural strength, with a focus on the critical role of concentration in enhancing the properties of the composites.
- Provided predictive equations for flexural strength using regression analysis, showcasing the effectiveness of the NaOH + Na_2SO_3 treatment in improving mechanical properties.

The study's findings contribute to sustainable material development using natural fibers, showcasing the potential of NaOH + Na_2SO_3 treatment in enhancing composite mechanical properties.

The rest of the paper is organized as follows: Section 2 represents the Literature review. Section 3 explained Taguchi's designs. Section 4 covers Materials and methods. Section 5 covers the Results and discussion. Section 6 coveys the advantages and disadvantages and section 7 concludes the manuscript.

2. Literature Review

The review indicates that NaOH treatment significantly enhances the mechanical properties of banana fiber-reinforced polymer composites. The improvement in properties was influenced by the concentration of NaOH, treatment duration, temperature, and fiber orientation. Overall, NaOH-treated fibers exhibit better tensile, flexural, and water resistance properties, making them more suitable for various composite applications. It had established that NaOH was the most common and economical fiber surface treatment reagent which reveals the fibrils and gives fibers a rough surface topography [10][11]. Bismarck*et al.,*[12] concluded that alkali treatment increases the compatibility of non-polar polymer interface with natural fibers. The reaction of NaOH with cellulose is shown in Eq. 1 [13][14].

$$Fibre - OH + NaOHFibre - O^{-}Na^{+} - H_2O + (Surfaceimpurities) \tag{1}$$

Ezema *et al.*,[7] studied the effect of surface treatment and fiber orientation on the tensile and morphological properties of banana stem fiber-reinforced natural rubber composites using a mixture of 4% NaOH and 2% Na_2SO_3. The result shows that the tensile and elastic modulus increased from initial untreated of 3.12MPa and 84.30MPa to 4.03MPa and 147.34MPa respectively. There were higher values of properties in the 0^0fiberorientation than in the $45^0$and 90^0 directions.

Oka for *et al.,* [15] used NaOH in the surface modification of BSF. The composite was produced using a hand-layup moulding technique using polyester resin as the matrix. The composite was fabricated under a 30% mass fraction of the fiber and was treated with variable temperatures of 30^0C, 45^0C, 60^0C, 75^0C, and 90^0C. The results showed slight improvement in the tensile strength from 17.39 to 18.05 MPa and an increase in the tensile modulus from 1149.35 to 3519.68N/mm^2 as compared to untreated fibers.

Venkateshwaran *et al.,*[16] studied the effect of alkali (NaOH) of various concentrations (0.5%, 1%, 2%, 5%,10%, 15%) on the mechanical behavior of banana/epoxy composite. From the experimental results obtained, it was found that 1% NaOH-treated fiber gave the maximum mechanical properties of the banana fiber-reinforced epoxy composite. Water absorption studies show that 2% NaOH treated composite had 6.72% moisture absorption while untreated showed a 7.9% increase in water absorption after 288days. The SEM image analysis shows that the alkali concentrations hada significant effect on the mechanical and surface roughness of the fiber.

Bin Bakri *et al.,*[17] studied the effect of NaOH and fiber loading on the processing and characterization of banana fiber/epoxy composite. 5% of NaOH and different fiber loading ranging from 5wt% to 20wt% were used in the experiment. The results obtained show that the amount of fiber, density, and structure affect the mechanical properties of the fiber/epoxy composite. Treatment with 5% NaOH results in superior properties when compared with untreated fiber composite. The results also showed that an increase in the amount of fiber had decreased the tensile and yield strengths of banana fiber/epoxy composites until at a certain amount of fiber, they started to bounce back. The optimum amount of fiber was at 5wt %, followed by 20wt %, 10wt % and 15wt %.

Rajesh*et al.,*[18] studied the influence of surface pre-treatment with NaOH on banana/sisal natural fiber-reinforced hybrid polymer composite. The flexural modulus and free vibration behavior of the composite were investigated. 50wt% of the fibers were treated with 1% NaOH solution. From the experimental results, it was found that chemical treatment increases the flexural modulus of the material and also increases the stiffness of the composite.

Alavudeen *et al.,*[8] studied the effect of weaving patterns and random orientation on the mechanical properties of banana/kenaf fiber-reinforced hybrid polyester composites. Hand lay-up method with two different weaving patterns, namely, plain and twill type were used in the experiment. The plain type showed improved tensile properties compared to the twill type in all the fabricated composites. Furthermore, the maximum increase in mechanical strength was observed in the plain-woven hybrid composites rather than in randomly oriented composites. NaOH and SLS of various concentrations were used for the pre-treatment of the fibers. It was found that the maximum increase in mechanical strength was observed in the plain-woven hybrid composites rather than in randomly oriented composites. This indicates minimum stress development at the interface of composites due to the distribution of load transfer along the fiber direction.

Merlini *et al.,*[19] carried out a study to evaluate the influence of fiber volume fraction, fiber length, and NaOH treatment on the mechanical and thermal properties of short random banana fiber-reinforced polyurethane derived from castor oil. The banana fibers were chemically modified through contact with 10 wt.% sodium hydroxide solutions for 1 h and characterized through FTIR, SEM, tensile strength, and density measurements. The tensile strength and Young's modulus increased with increasing fibervolume fraction and length for the untreated and treated banana fiber polyurethane composites.

Abd Rahman *et al.,*[20] carried out a study that compared the flexural property of banana fiber-reinforced epoxy composites produced via vacuum infusion and hand layup processes. Banana fibers were treated with NaOH solution for 1 hour before being dried in the oven for 24 hours at 100°C. An aluminum vacuum infusion mold was manufactured per the standard flexural test specimen of 127mm x 12.7mm x 3.2mm. The highest flexural strength of 136.27 MPa was achieved by specimens made by vacuum infusion process with 40% volume fraction and 63mm fiber length while for the hand layup process.The highest flexural strength was only 80.71 MPa with equal fibre content and fibre length. At both fiber lengths, using vacuum infusion resulted in an increase in flexural strength in the range of 31.4 to 107.9% over hand layup.

Jannah*et al.,*[21] studied the effects of chemical surface modification on the properties of woven banana-reinforced unsaturated polyester composites. Treatment was done using 1% NaOH. A vacuum bagging technique was used to prepare the woven fiber-reinforced unsaturated polyester composites with four different volume percentages of fibers (5wt%, 10wt%, 15wt%, and 20wt%). The effects of fibersurface treatments and fiber loading on the impact, flexural, and water absorption properties of the composites were investigated. Treatment with NaOH resulted in improved mechanical and water absorption properties of the composites.

Fu and Lauke[22]explained changes in the fiber orientation and fiber length will result in different behavior on the tensile and yield strength of composites.

Dai *et al.,*[23] concluded that increasing the fiber weight ratio decreased the tensile strength due to changes in the structure of fibers.

Ezema *et al.,*[7] studied the effect of surface treatment and fiber orientation on the tensile and morphological properties of banana stem fiber-reinforced natural rubber composites using a mixture of 4% NaOH and 2% Na_2SO_3. The result showedthat the tensile and elastic modulus increased from initial untreated of 3.12MPa and 84.30MPa to 4.03MPa and 147.34MPa respectively. There were higher values of properties in the 0^0fiberorientation than in the45^0 and 90^0 directions.

2.1 Review Table

The results summary of the review of related work on the treatment of banana fiber-reinforced polymer composite is represented in Table 1.

Table 1. *Summary of the review ofrelated work*

Source	Type of fiber	Treatment Agent used	Agent Conc. %	Soaking Time (h)	Soaking Temp.	Max. Tensile Strength (MPa)	Max. Flexural Strength (MPa)	Max. Impact Strength J/m^2	Max. water absorption/ Method and type of Polymer Used
[7]	Banana Stem	NaOH & Na_2SO_3	4% NaOH & 2% Na_2SO_3	24hrs	*Room Temp.*	4.03MPa at 4% NaOH & 2% Na_2SO_3	-	-	Compression Moulding/ Natural rubber
[16]	Banana Stem	NaOH	0.5% 1%, 2%, 5%,10%15%	0.5hr	*Room Temp*	33.6MPa at 1% NaOH	69.03Mpa at 1% NaOH	-	2% NaOH for 288hrs /Hand-layup/ Epoxy
[8]	Banana stem/Kenaf Hybrid	NaOH/ sodium lauryl sulphate (SLS)	5% 10% 15%	2hrs 4hrs 6hrs 8hrs	*Room Temp*	139 MPa at 5% for 2hrs	172.2 MPa at 10% for 2hrs	28 kJ/m^2at 10% for 2hrs	Hand-layup/ Polyester
[17]	Banana Stem	NaOH	5%	24hrs	*Room Temp*	25MPa at 5wt% of the fibre	-	-	Compression Moulding/ Epoxy
[18]	Banana stem/Sisal Hybrid	NaOH	1%	24hrs	*Room Temp*	25.6MPa	-	-	Compression Moulding/ Polyester
[19]	Banana stem	NaOH	5%	Ihr	23^0C	268.9 MPa	-	-	Hand-layup and Compression moulding/ castor oil polyurethane
[20]	Banana Stem	NaOH	5%	2hrs	*Room Temp*	_	136.27 MPa for Vacuum infusion method and 80.71 MPa for Hand-lay up	_	Hand-layup and Vacuum Infusion /Epoxy
[21]	Banana Stem	NaOH	1% 3% 5%	0.333h (20min)	*Room Temp*	443MPa at 1% NaOH	-	-	Vacuum bagging/ Polyester

2.2 Research Gap

From the literature, NaOH treatment significantly enhances the mechanical properties of banana fiber-reinforced polymer composites, but the specific optimal conditions for treatment in terms of concentration, duration, and temperature are not extensively explored [10-14]. While NaOH-treated fibers are known to exhibit improved tensile, flexural, and water resistance properties, there is a lack of detailed investigation on the influence of soaking time, concentration, and temperature on the flexural strength properties of composites and finally, the compatibility enhancement between non-polar polymer interfaces and natural fibers due to alkali treatment, although acknowledged, requires further in-depth analysis to determine the full extent of this effect.

3. Taguchi Designs

Genichi Taguchi, known for his work in Engineering and Statistics developed the Taguchi method which is applied to improve the quality of manufactured products. This approach includes the concept of a loss function and experiments using an outer array. The main goal of Taguchi designs is to reduce variance within a sample group or population while maintaining the mean at a desired level[24]. This is achieved by optimizing the signal-to-noise ratio, where the signal represents key factors that impact the quality of the output response in an experiment. The Taguchi design has proven to be an effective method for optimizing natural fiber composites[25] [26]. By carefully altering critical parameters and assessing their impacts, researchers were able to greatly improve the mechanical performance, durability, and overall material qualities of these composites. The Taguchi method's versatility and efficacy make it a useful approach to the production of sophisticated natural fiber composites, opening the path for their widespread application in a variety of industries[27].In this study, treatment time, concentration of the chemicals, and bath temperature are considered signals, while the response is the flexural strength and water absorption. In Taguchi designs, the S/N ratio is calculated for each combination of factor levels. For cases where a larger S/N ratio is better, Equation 2 is used to calculate it[24].

$$S / N = -10\log_{10} \frac{1}{n}\left(\sum_{i=1}^{n} \frac{1}{\mu^2}\right) \tag{2}$$

Where μ is the responses for the given factor level combination,$n$is the number of responses in the factor level combination, and $S$is the standard deviation.

4. Materials and Methods

The main materials used in this study were banana stem fiber, sodium hydroxide, sodium sulphite, and epoxy resin. Additionally, we used other materials like distilled water, petroleum jelly, rollers, clamps, a hand brush, pliers, paper tape, a nose mask, a measuring cylinder, a weighing balance, gloves, scissors, transparent containers, a knife, a test tube, a beaker, a water bath, and a stopwatch.

4.1 Fibre Surface Treatment

Table 2 presents the temperatures, soaking times, and concentrations of the $NaOH + Na_2SO_3$ mixture used in this study. The experimental design covered optimal treatment ranges based on the literature. The Taguchi L_{25} (5^3) orthogonal array was employed.
The fibers were separated into two groups: Untreated and Treated. Untreated samples were washed with distilled water and then dried at 60°C for 48 hours. Treated fibers were immersed in various concentrations of the $NaOH + Na_2SO_3$ mixture. A water bath apparatus (Fig. 1) was used, with fibers first immersed in a beaker of the chemical solution before being transferred to the water bath at the designated temperature. The water bath ensured a constant temperature for the samples. A stopwatch regulated the immersion time. After treatment, fibers were washed with distilled water and dried at 60°C for 48 hours.

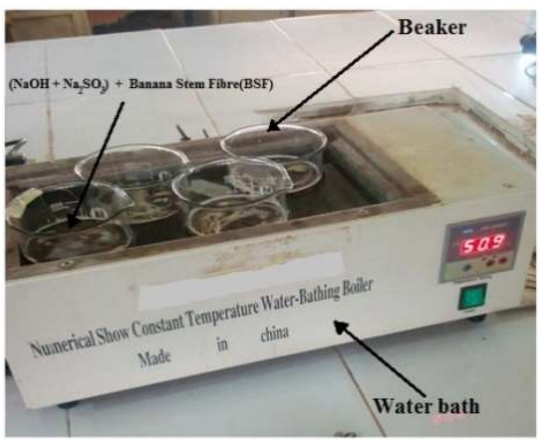

Fig. 1. *Experimental setup for banana fiber surface treatment*

Table 2. *SelectedBSF treatment parameters and their corresponding levels used in Taguchi analysis.*

Factors	Level 1	Level 2	Level 3	Level 4	Level 5
Soaking time (hrs)	1	2	3	4	5
Concentration (%)	2	4	6	8	10
Temperature (°C)	Room Temperature(25)	40	50	60	70

4.2 Composite Fabrication

The epoxy was mixed with the following specification of the manufacturer, which is 2:1 for parts A and B respectively. The molds used for fabricating the samples were prepared based on flat test specimen dimensions and tolerances per the standard of ASTM E8 and a hand-layup technique was used to laminate the composite. The composite was prepared with a 30% volume percentage of the fiber under unidirectional loading of the fiber. Equation 3was utilized for calculating the volume percentage of the fiber used [21]. Samples were prepared for both treated and untreated fibers. Based on the literature, the prepared samples were left to cure at room temperature for 24hours [15][16][45][46][47][48] before it was removed from the mold for cutting.

$$V_f = \frac{\left(\frac{W_f}{\rho_f}\right)}{\left[\left(\frac{W_f}{\rho_f}\right) + \left(\frac{W_m}{\rho_m}\right)\right]} \tag{3}$$

Where V_f is the fiber volume fraction (%), $W_m$and $W_f$are the weights of matrix and fiber, ρ_m and ρ_f are the densities (g/cm^2) of the matrix and fiber respectively.

5. Results and Discussion

5.1 Flexural Strength.

The flexural strength of each experimental run of the Taguchi L_{25}, the orthogonal array was conducted in a universal testing machine and the bending strength at peak was recorded. It was further used in the analysis.

5.2 Taguchi Analysis of the Flexural Strength.

The Taguchi experimental matrix, flexural strength responses, and S/N ratio for the twenty-five experimental runs are presented in Table 3. Minitab 18 statistical software was used for the analysis of the results.

Table 3. *Taguchi L_{25} experimental matrix and response values for flexural strength.*

TrialNo	Soaking Time (hrs)	Concentration of NaOH + Na_2SO_3 (%)	Soaking Temperature (°C)	Flexural Strength (MPa)	S/N Ratio for Flexural Strength	Standardized Residuals
1	1	2	25	102.79	40.24	0.51
2	1	4	40	103.78	40.32	0.57
3	1	6	50	98.76	39.89	0.22
4	1	8	60	99.87	39.99	-0.72
5	1	10	70	88.74	38.96	-0.57
6	2	2	40	92.74	39.35	-0.87
7	2	4	50	94.75	39.53	-0.01
8	2	6	60	98.79	39.89	1.05
9	2	8	70	100.78	40.07	0.47
10	2	10	25	84.71	38.56	-0.63
11	3	2	50	98.79	39.89	0.11
12	3	4	60	96.76	39.71	-1.54
13	3	6	70	103.79	40.32	0.51
14	3	8	25	100.74	40.06	-1.35
15	3	10	40	98.77	39.89	2.25
16	4	2	60	97.76	39.80	0.68
17	4	4	70	98.72	39.89	0.03
18	4	6	25	99.77	39.98	0.51
19	4	8	40	100.72	40.07	0.35
20	4	10	50	78.69	37.92	-1.57
21	5	2	70	89.73	39.06	-0.43
22	5	4	25	96.76	39.71	0.95
23	5	6	40	83.72	38.45	-2.29
24	5	8	50	95.46	39.50	1.25
25	5	10	60	81.72	38.25	0.52
Untreated	-	-	-	**91.38**	-	-
Confirmation Test	3	8	25	**104.96**	-	-

Table 4. *Flexural strength response Table for S/N Ratios (Larger is better)*

Level	Soaking Time(hr)	Concentration (%)	Temperature°C
1	39.88	39.67	**39.71**
2	39.48	39.83	39.62
3	**39.98**	39.71	39.37
4	39.53	**39.96**	39.53
5	39.01	38.72	39.66
Delta	0.96	1.24	0.34
Rank	2	1	3

The optimal treatment parameters were determined using the larger the better S/N ratio in Equation 2, aiming for optimal flexural strength properties of the fiber. For each treatment parameter level, the S/N ratio was calculated based on the Taguchi method's S/N analysis.

The impact of each control factor (soaking time, temperature, and concentration) on the flexural strength of BSF in a reinforced epoxy composite was analyzed using the S/N response Table 4. It is generated through Taguchi techniques and presents the optimal levels of the control factors for flexural strength. It also includes rank information based on delta statistics, indicating the relative effects of each factor on the response. Delta statistics are calculated as the difference between the highest and lowest averages for the chosen factor.

The control factor levels in Table 4are visually represented in graph form in Fig. 2, facilitating the determination of optimal treatment parameters. The best level for each control factor was determined based on the highest S/N ratio level. Consequently, the optimal levels and S/N ratios for the factors contributing to the best flexural strength were identified as Soaking time (Level 3, S/N 39.98), Concentration (Level 4, S/N = 39.96), and Temperature (Level 1, S/N = 39.71).

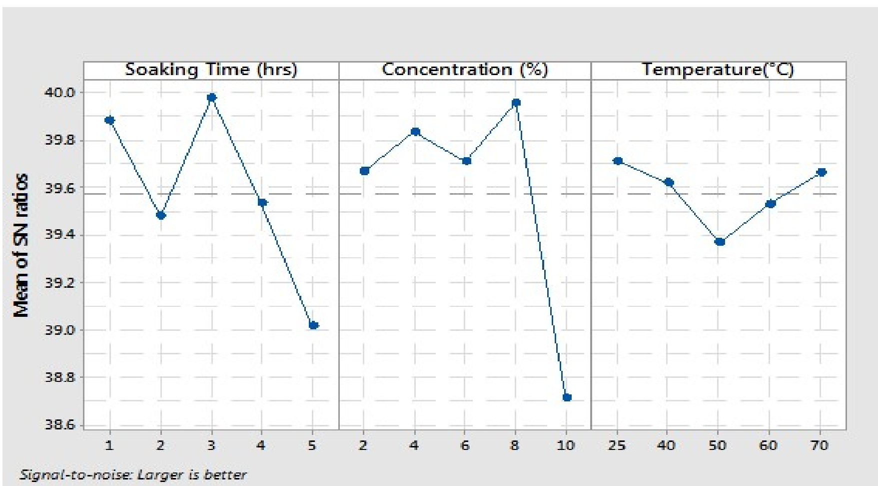

Fig. 2. *Effect of BSF treatment parameters on S/N ratio for flexural strength.*

5.3 ANOVA of the Flexural Strength

ANOVA was employed to assess the significance of the treatment parameters on the flexural strength. The ANOVA results are presented in Table 5. This analysis was conducted at a significance level of 5%, determined by comparing the F-values associated with each treatment parameter. The F-ratio served as a measure of the treatment parameter's significance on the flexural strength, at the specified significance level.

Table 5. *Analysis of variance results for flexural strength*

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Soaking Time (hrs)	4	333.74	**28.11%**	333.74	83.44	3.59	**0.038**
Concentration (%)	4	533.39	**44.92%**	533.39	133.35	5.73	**0.008**
Temperature(°C)	4	41.02	**3.45%**	41.02	10.26	0.44	**0.777**
Error	12	279.27	**23.52%**	279.27	23.27		
Total	24	1187.42	100.00%				

Model Summary S = 4.82418 R-sq = 76.48% R-sq(adj) = 52.96%

From the results in Table 5, it is evident that soaking time and concentration significantly impact the flexural strength of the BSF in a reinforced epoxy composite, as indicated by the P-values. The analysis also reveals that concentration plays the most critical role in the surface treatment of BSF, contributing

44.92%, followed by soaking time at 28.11%. In contrast, temperature's impact is less significant, contributing only 3.45%, as reflected in its P-value exceeding the 5% significance level. The model summary's R-squared value indicates that soaking time, concentration, and temperature collectively explain 76.48% of the total variation in the flexural strength response of the BSF in a reinforced epoxy composite. This implies that 23.52% of the variation is attributable to other unconsidered factors such as fiber direction, fiber weight, and fiber volume. The residual plots depicted in Fig. 3, confirm that the ANOVA assumptions are met. The normal probability plot of the residuals indicates a near-linear distribution, suggesting normality. Additionally, the residuals versus observation order plot shows no discernible pattern or trend, indicating independence among residuals. Finally, the residuals versus fitted value plot demonstrates that the residuals exhibit constant variance and are randomly distributed.

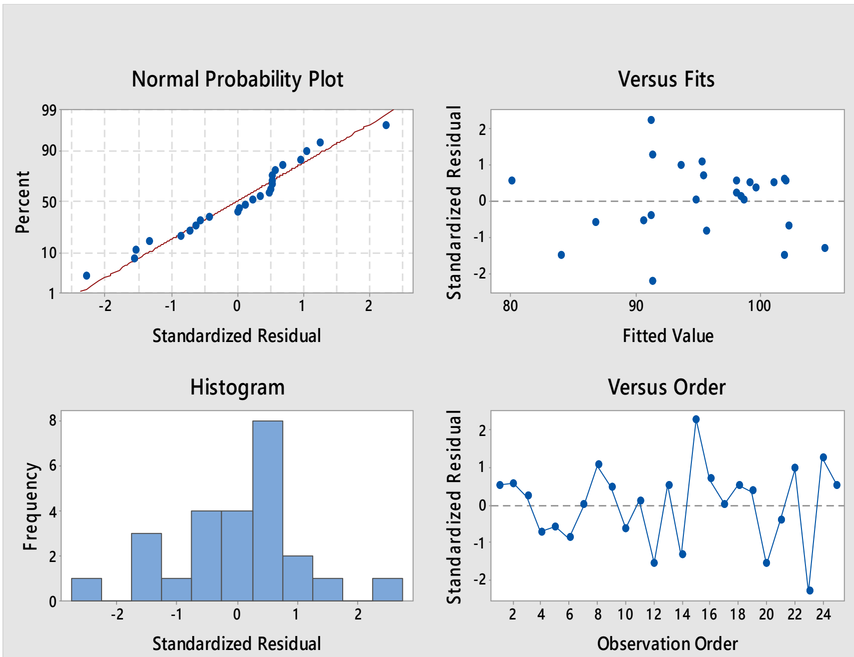

Fig. 3. *Residual plots for flexural strength*

5.4 Regression Analysis of the Flexural Strength Response

Regression analysis was conducted in other to obtain a predictive equation for the flexural strength under the influence of the independent variables, soaking time, concentration, and temperature only. These predictive equations were made for both multiple linear and quadratic regression models and were both conducted with Minitab 18 statistical software. The predictive equation which was obtained by the linear regression model and a quadratic regression model is shown in Equations 3, 4, and 5 respectively.

$$Y = 106.792 - 1.703X_1 - 0.895X_2 - 0.0205377X_3 \quad (3)$$

R-sq = 27.78% R-sq(adj) = 17.46%

$$Y = 93.43 - 1.783X_1 + 4.62X_2 + 0.000012X_1^2 - 0.461X_2^2 \quad (4)$$

R-sq = 27.78% R-sq(adj) = 17.46%

$$Y = 93.43 - 1.783X_1 + 4.62X_2 + 0.000012X_1^2 - 0.461X_2^2 \quad (5)$$

R-sq = 47.56% R-sq(adj) = 39.89%

Where Y = Flexural Strength (MPa), X_1 = Soaking Time (hrs), X_2 = Concentration (%), and X_3 = Soaking Temperature (°C)

The R-sq values for both the linear and quadratic regression models are 27.78% and 47.56% respectively. This means that 27.78% of the total variation in flexural strength is predicted by the linear regression model while 47.56% of the variation in flexural strength is predicted by the quadratic regression model. The low R-sq value in both the linear and quadratic models developed is due to other factors that affect the flexural strength which is not added in the model such as fiber direction, weight, volume, etc. In Fig. 4 and 5 the actual experimental test responses are compared with the predicted responses for both linear and quadratic regression models respectively.

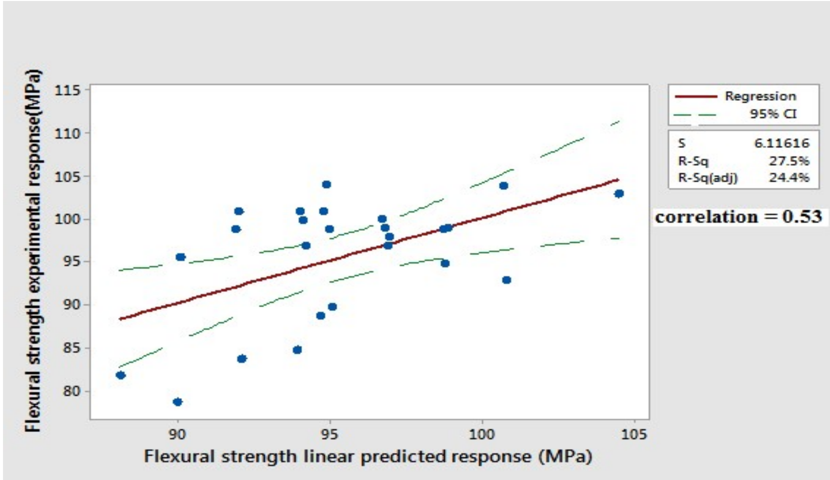

Fig. 4. *Comparison of the experimental results with the predicted linear regression model for flexural strength*

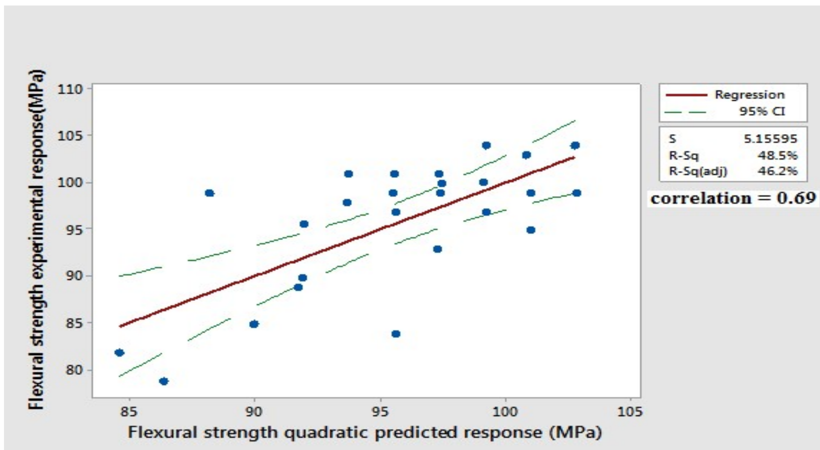

Fig. 5. *Comparison of the experimental results with the predicted quadratic regression model for flexural strength*

The graphs in Fig. 4 and 5 show that the quadratic regression model predicts more accurately than the linear regression model. This is supported by the higher R-squared adjusted value of the quadratic regression model compared to the linear regression model. Therefore, the quadratic regression model is better at estimating how the treatment parameters affect the flexural strength of the banana stem fiber in a reinforced epoxy composite. The quadratic regression model also correlates well with the experimental results, as indicated by a correlation coefficient of 0.69.

5.5 Confirmation Experiment for Flexural Strength

Based on the Taguchi analysis results, it is identified that the optimal conditions for treating the BSF in a reinforced epoxy composite are a soaking time of 3 hours, concentration of 8%, and temperature of 25°C. This prediction was verified through a confirmation test. Here, a new composite was molded as per the predicted results while maintaining the necessary composite molding conditions. Four samples were prepared for the confirmation test and the average value of the flexural strength was taken. The result showed a higher flexural strength of 104.96MPa. When compared to the untreated 91.38MPa, it shows that there is a 14.86% increase in the flexural strength, hence there is an improvement in the flexural strength of the BSF after treatment.

6. Advantages and Disadvantages

Advantages

- The chemical treatment with NaOH + Na_2SO_3 mixture significantly improved the flexural strength of banana stem fiber-reinforced epoxy composites.
- Optimal treatment conditions were identified as 3 hours soaking time, 8% concentration, and 25°C temperature, resulting in a 14.86% increase in flexural strength compared to untreated fibers.
- The Taguchi analysis highlighted the importance of soaking time and concentration in enhancing flexural strength, with concentration being the most critical factor.
- ANOVA results confirmed that concentration and soaking time significantly influenced flexural strength, with contributions of 61.7% and 21.3% respectively.
- The study's findings contribute to sustainable material development using natural fibers, showcasing the potential of NaOH + Na_2SO_3 treatment in enhancing composite mechanical properties.

Disadvantages

- Natural fibers like banana stem fibers are hydrophilic, limiting their use in composites due to their tendency to absorb moisture.
- The study focuses on the flexural strength properties but does not extensively cover other mechanical properties like tensile strength and impact strength, which are also crucial in assessing the overall performance of composites, and does not delve into the environmental impact or sustainability aspects of using chemical treatments on banana stem fibers for composite materials.
- The research paper primarily emphasizes the use of a NaOH + Na_2SO_3 mixture for surface treatment, but it does not explore or compare the effectiveness of other chemical treatments commonly used in improving the mechanical properties of natural fibers in composites like mercerization, benzoylation, acetylation, and esterification
- The paper could benefit from a more detailed discussion on the economic feasibility and scalability of implementing the optimized treatment parameters in large-scale production processes for banana stem fiber-reinforced epoxy composites.

7. Conclusion

This study explored the effects of chemical treatment parameters on the flexural strength of BSF-reinforced epoxy composites. The experimental results demonstrated that the chemical treatment significantly improved the flexural strength of the composites. The optimal conditions were identified as a soaking time of 3 hours, a NaOH + Na_2SO_3 concentration of 8%, and a treatment temperature of 25°C. Under these conditions, the treated fibers exhibited a 14.86% improvement in flexural strength compared to untreated fibers, highlighting the effectiveness of the chemical treatment process. The Taguchi analysis provided valuable insights into the relative importance of the treatment parameters. The ANOVA results further confirmed that concentration and soaking time significantly influenced the flexural strength, with contributions of 61.7% and 21.3% respectively. The regression analysis supported the experimental findings, indicating that the quadratic model better predicted flexural strength than the linear model.

This research highlights the potential of NaOH + Na_2SO_3 treatment in enhancing the mechanical properties of natural fiber composites. By improving the interfacial adhesion between the hydrophilic banana stem fibers and the hydrophobic epoxy matrix, the treated fibers can better reinforce the composite material, leading to superior mechanical performance.

The study's findings contribute to the broader field of sustainable material development. Utilizing agricultural waste materials like banana stem fibers not only addresses environmental concerns but also offers a cost-effective and renewable alternative to synthetic fibers. The successful enhancement of BSF through chemical treatment paves the way for its wider application in various composite materials, potentially replacing more traditional and less eco-friendly options.

Future research should explore the long-term durability and environmental impact of these treated composites. Additionally, investigating other natural fibers and different chemical treatment methods could further expand the applicability and performance of natural fiber-reinforced composites. Overall, this study provides a solid foundation for developing high-performance, sustainable composite materials from natural fibers.

Compliance with Ethical Standards

Conflicts of interest: Authors declared that they have no conflict of interest.

Human participants: The conducted research follows the ethical standards and the authors ensured that they have not conducted any studies with human participants or animals.

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