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RESEARCH ARTICLE

Optimization of the mechanical properties of SterculiaSetigeraDelile fibre epoxy composite using Taguchi methodology

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Abstract

SterculiaSetigeraDelile fibres potential has not been explored as a means to improve the mechanical properties of Epoxy Matrix. The study focuses on the optimization of factors affecting the mechanical properties (Tensile, flexural and compression) of SterculiaSetigeraDelile fibre-Epoxy composite using Taguchi method. The factors include Hot Alkaline treatment of fibres, fibres placed at angular orientation (0°, 30°, 45° and 90°.), and fibre percentages (5, 10, 15, and 20%). Taguchi method was used for the design of experiment and the results were analysed using Analysis of Variance (ANOVA). The results showed that fibre angular orientation was the most significant factor with a p-value of 0.000. The optimized fibre reinforced composite improved the tensile strength of the Epoxy by 72%, while the fibre reinforcement improved the flexural strength of the Epoxy matrix by 89% and the compression strength of the Epoxy matrix was improved by only 6% due to the fact that the matrix plays a major role in compression strength. Thermogravimetric analysis was done for both the optimum composite which was the Hot Alkaline treated 10% fibre-epoxy composite and the pure Epoxy matrix material. The results were compared and showed that the addition of fibres in epoxy matrix improved the thermal stability of composites. The material produced was of low density and could be explored for applications in the aerospace industry.

1. Introduction

Natural fibres are agricultural plants that are grown in different parts of the world. They are commonly used for ropes, clothing, carpets, and bags. The main component of natural fibre is cellulose dispersed in an amorphous matrix of lignin and hemicellulose. Natural fibre has a cellulose content of a range 60 to 80wt. %, the cellulose content is among the most important component of natural fibre. The hemicellulose content is between 5-20%. The moisture content in fibres can be up to 20%. Natural fibre composites are used in the automotive industry in doors, inner panels, seat back and roof inner panel [1]. The properties of natural fibres depend on the nature of plant, the area or location the plant is grown in, the age of plant and the fibre extraction method.

1.1 SterculiaSetigeraDelile Tree

SterculiaSetigeraDelile is known by its English name Karaya Gum Tree is a multipurpose savannah tree that spreads in savannah area of tropical Africa. It is classified under the genus Sterculia and the family Malvaceae[2]. SterculiaSetigeraDelile is a multipurpose woody species known in sub-Saharan Africa for medicinal and dietary use [3]. The leaf is known to treat malaria, asthma, Bronchitis, tooth ache and diarrhea. SterculiaSetigeraDelile is known as medium/long fibre hardwood species. SterculiaSetigeraDelile are among the underutilized plants in Nigeria with medium/long fibre characteristics of a mean fibre length of 2.41mm [4]. The mean fiber length is regarded as long fiber wood species in accordance to the classification of Bublitz [2]. The fibre obtained from the inner bark is used for rope making and cloth [2, 5]. In Togo, SterculiaSetigeraDelile is used to make a rope called lignale. The rope is used to ferment a sorghum based local beer. Wood quality studies have been carried out to ascertain its suitability for paper making. All the derived indices showed that it is suitable for writing and printing papers. SterculiaSetigeraDelile fibre has not been explored in making fibre epoxy composite.

This research is focused on the fabrication and optimization of the mechanical properties of SterculiaSetigeraDelile fibre Epoxy composite. The tensile, flexural and compressive strength of the composite were optimized using Taguchi method. Taguchi method was used for the design of experiment and the results were analysed using Analysis of Variance (ANOVA). The experiments were carried out to understand the relationship among controllable parameters and identify the significant parameters that influence the properties of the composite.

2. Materials and methods

Materials used for the manufacturing of the composite include Epoxy from EPOCHEM with a density of 1.13g/cm3 and Hardener from EPOCHEM with a density of 1.04g/cm3 purchased from Epoxy Olisev Nigeria. The SterculiaSetigeraDelile tree in which the fibres were extracted was obtained from Rano local government. The tree bark was obtained by cutting the region required and subjecting the bark to beating to separate it from the tree. The obtained tree bark was subjected to beating to expose the fibres from the tree bark. The beaten tree bark was subjected to drying for 11 days and retting for another 11 days to obtain the fibres by manual extraction.

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The fibres were then dried in the sun. The density of the fibres were found using Archimedes principle and using Canola Oil as the fluid [6].The fibre density of the untreated fibre was 1.193g/cm3 and density of Hot Alkaline treated fibre was 1.184g/cm3. The handlayup method was used for the manufacture of the composites. The hand layup method is one of the most common and simple manufacturing method. It involves the placement of fibres in the mould and matrix spread on the fibres. The SSD fibres were placed in a mould, epoxy resin/Hardener was then added and forced into the reinforcement using rollers.

2.1 Fibre Treatment

Fibres were subjected to Hot Alkaline treatment. Firstly distilled water was heated to 95°C. The hot distilled water of 900ml was used to dilute 5g of Sodium Hydroxide pellets; hot water at 95°C was then added until 1000ml was reached. Fibres were then put in a metal container, the hot alkaline solution was added and the temperature of 95°C was maintained for 1hr using a digital electric hot plate. After then the hot alkaline water used to treat the fibres was poured out. Drops of acetic acid was added to the fibres and water was used to wash the fibres. 5% concentration Hot Alkaline treated fibres were obtained.

2.2 Fibre Arrangement

In this research work, the fibres were manually arranged at different angular orientations with the aid of a plane sheet. The plane sheet contains different angular orientations drawn with the aid of a pencil. The Paper was divided into different lengths and sections as shown in Figure 1. The fibres were arranged manually on the plane sheet using UHU adhesive gum glue. The ratio percentage was calculated for each fibre weight to be placed at each section of the paper.

2.3 Calculation of Density of composite and fibre, Epoxy and Hardener weight

$$\rho_{composite} = \frac{m_c}{V_c} \quad (1)$$

$$\rho_T = \frac{\rho_E \rho_H \rho_f}{a\rho_H \rho_f + b\rho_E \rho_f + c\rho_E \rho_H} \quad (2)$$

Where: m_E : mass of epoxy in grams, m_H : mass of Hardener in grams, m_f is the mass of the fibre, V_E : Volume of Epoxy, V_H : Volume of Hardener, V_f : Volume of fibre, ρ_E : density of Epoxy, g/cm3, ρ_H : density of Hardener, ρ_f : Density of fibre and ρ_T : Density of composite a : % mass of Epoxy, b : % mass of Hardener, c : % mass of fibre

For a given fibre percentage, treatment and angular orientation the density of the composite was found using equation 2. For example for a 10% Hot Alkaline treated fibre at 0° orientation the density was calculated using the equation 2. ρ_E : Density of Epoxy – 1.13g/cm^3, ρ_H : density of Hardener – 1.04g/cm^3, ρ_f : Density of fibre- 1.184, The ratio of Epoxy to Hardener ratio of 2:1.

$\therefore 100 - (10) = 90\%$

The mass percentage of Epoxy $\therefore \frac{2}{3} \times 90 = 60\%$ while for the Hardener the percentage is found using $\frac{1}{3} \times 90 = 30\%$

$$\rho_T = \frac{1.13 \times 1.04 \times 1.184}{\frac{60}{100} \times 1.04 \times 1.184 + \frac{30}{100} \times 1.13 \times 1.184 + \frac{10}{100} \times 1.13 \times 1.04}$$

$= 1.1063 g/cm^3$

The dimension of the mould for the tensile and flexural strength specimen is 20cm x 10.5cm x 5cm. For a thickness of specimen 0.35cm.

$\therefore V_c = 20 \times 10.5 \times 0.35 = 73.5 cm^3$,

$m_T = \rho_c V_c$, $m_T = 1.1063 \times 73.5 = 81.31 g$

$m_E = \frac{60}{100} \times 81.31 = 48.786 g$

$m_H = \frac{30}{100} \times 81.31 = 24.393 g$, $m_f = \frac{10}{100} \times 81.31 = 8.131 g$

Table 1. Theoretical Density of the SSD fibre reinforced epoxy composite

Treatment	SSD fibre content wt.%	Fibre Orientation (Deg.)	Density of Composite (g/cm^3)
With	5	0	1.102287
With	10	30	1.106285
With	15	45	1.110313
With	20	90	1.114370
Without	5	30	1.102685
Without	10	0	1.107087
Without	15	90	1.111524
Without	20	45	1.115997
With	5	45	1.102287
With	10	90	1.106285
With	15	0	1.110313
With	20	30	1.114370
Without	5	90	1.102685
Without	10	45	1.107087
Without	15	30	1.111524
Without	20	0	1.115997

For the 10% SSD fibre at 30° angular orientation, the mass of the fibre was distributed across the paper as shown in Figure 1. The paper was divided into 17 sections with a distance of 0.8cm each. The length of each line in the paper was measured and the total lengths of the lines were found. The total mass of the fibre was divided by the total length of fibre creating a ratio of TM: TL ratio. The length of line of each section times the TM: TL ratio gives the mass for the small section in the paper. Table 2 shows the ratios and mass calculation for each section in order to have balanced distribution of masses. Table 2 shows the mass distribution of fibres on the paper. A total mass of 8.131grams is seen in the table after the mass distribution using the given method. The method provides a systematic method for fibre distribution for researchers.

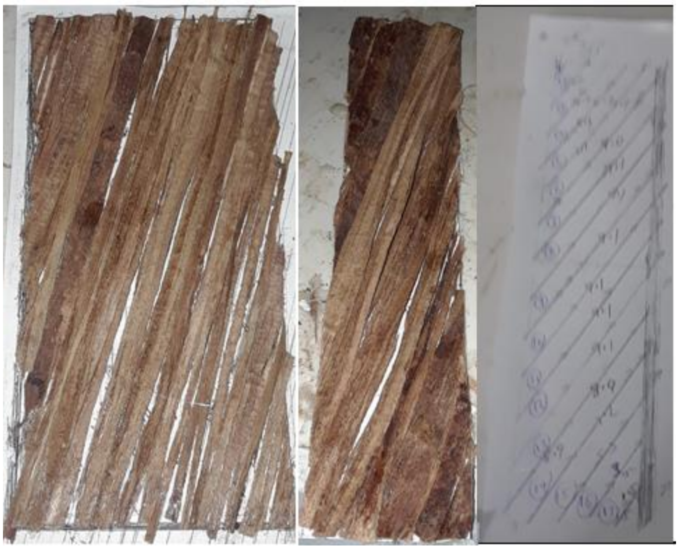

Figure 1. (a) Fibre placed on the paper at angular orientation for tensile and flexural composite production (b) Fibre placed on the paper for compression test specimen (c) Paper with drawn angular orientation for fibre placement

Table 2. Distribution of mass of SSD fibre

S.No	Length of section on paper (cm)	Total mass of fibre/ Total length (TW:TL)	Mass of fibre at section (g) (length of section) × (TW:TL ratio)
1	0.8	0.072665	0.058132
2	2.6	0.072665	0.188929
3	4.4	0.072665	0.319725
4	6.2	0.072665	0.450522
5	7.9	0.072665	0.574052
6	9.0	0.072665	0.653984
7	9.1	0.072665	0.661250
8	9.1	0.072665	0.661250
9	9.1	0.072665	0.661250
10	9.1	0.072665	0.661250
11	9.1	0.072665	0.661250
12	9.1	0.072665	0.661250
13	8.9	0.072665	0.646717
14	7.2	0.072665	0.523187
15	5.3	0.072665	0.385124
16	3.5	0.072665	0.254327
17	1.5	0.072665	0.108997
Total Length	111.9	Total	8.131198

2.4 Mould and Composite Production

The mould used in this research was fabricated with dimensions 200mm x 105mm x 50mm. The steel plates used for the mould was of 10mm thickness. The plate thickness was critical in ensuring that the mould plate doesn't deform during welding in production. Plates of at least 2 to 3mm thickness were initially produced, deformation of the mould plates occurred during welding. This led to the selection of the 10mm plate. The mould was firstly cleaned properly and releasing agent wax was spread on the mould for easy demoulding of the composite. The fibre already glued on a paper with known fibre percentage was brought and the back of the paper was removed to expose the fibres. The fibres were then placed into the mould. A mixture of epoxy and hardener of calculated percentages was poured with even distribution into the mould as shown in Figure 2. The mixture was spread evenly across the fibres. After 1.5 hour the cover of the mould was placed on the fibres to ensure the spreading of the mixture. After 2.5 hours of curing a manual press was used to produce compression of 23.29MPa on the composite and to ensure even distribution of the matrix mixture.

Figure 2. Fibre placed in the mould and a mixture of Epoxy/Hardener spread evenly on the fibres

Figure 3. SSD fibre-epoxy composite produced at 0-degree and 90-degree orientation

Figure 4. Specimens cut for mechanical testing

2.5 Taguchi Experimental Model

Taguchi experimental design is a powerful analysis tool for modelling and analysing the influence of control parameters on performance output. The tensile strength, flexural strength and compressive strength test on composites were carried out under different operating conditions considering three parameters, namely alkaline treatment, fibre percentage (%) and fibre orientation as listed in Table 3 in accordance to L16 orthogonal array. The impacts of these parameters were studied using the L16 arrays and the tests were conducted per the experimental design. The experimental observations are further transformed into signal to noise(S/N) ratios. The Signal to Noise ratio can be expressed using the "Larger the Better" characteristic and calculated using the equation [7]:

$$S/N = -10 * \log(\sum(1/y^2)/n \quad (3)$$

y= responses for the given factor level combination and n= number of responses in the factor level combination [8].

Taguchi method was used for the Design of experiment (DOE), because it reduces the number of iterations and was also used to optimize the known parameters. Taguchi L16 array was selected for the experimentation. This was done using the software MINITAB 16 specifically used for DOE. The Taguchi L16 arrays with factors and level are shown in Table 3. The composite specimens were produced as per ASTM standards, ASTM D3039 for tensile strength with a sample size of 200mm x 20mm x 3.5mm and ASTM D790 for flexural strength with a sample size of 200 mm x 15mm by 3.2 mm and ASTM D695 for compression strength with a sample size of 12.7mm by 12.7mm by 50.8mm and all test conducted at a rate of 2mm/min.

Table 3. Design of Experiment data for the Factors affecting the SSD fibre-epoxy Composite Performance and their Levels.

S.No	Contributing Factors	Level 1	Level 2	Level 3	Level 4
1	Alkaline treatment	With	Without	With	Without
2	SSD fibre (%)	5	10	15	20
3	Fibre Orientation (Deg.)	0	30	45	90

Table 4.Orthogonal Table Designed using Taguchi method and Minitab software

Treatment	SSD fibre content wt.%	Fibre Orientation (Deg.)
With	5	0
With	10	30
With	15	45
With	20	90
Without	5	30
Without	10	0
Without	15	90
Without	20	45
With	5	45
With	10	90
With	15	0
With	20	30
Without	5	90
Without	10	45
Without	15	30
Without	20	0

3. Results and discussion

3.1 Tensile Strength

Table 5 shows the tensile strength of the composites reinforced with SSD fibre and Epoxy as Matrix. The table shows that fibres arranged at 0-degree orientation have the highest Tensile strength with the untreated 10% SSD fibre at 0-degree orientation having a mean of 23.45MPa, Hot Alkaline treated 15% fibre arranged at 0-degree orientation having a mean of 24.86MPa and Untreated 20% fibre having a mean of 24.08MPa. The Ranking table 6 for the SSD fibre-epoxy composite shows that the Fibre orientation has the highest effect on the tensile properties with a Delta of 11.13, followed by fibre percentage (1.70) and alkaline treatment (0.75). The Analysis of variance table 7 shows that the angle of orientation of the fibre reinforcement is the most significant factor that affects the tensile strength with a p-value of 0.000. This is followed by fibre percentage with a p-value 0.73 which is higher than the 0.05(95%) confidence interval. The fibre orientation has an F-value of 21.97. The p-value suggests the significance of a factor on desired characteristic. The principle behind significance value is that the p-value should not be less than 0.05(considering confidence of 95%). The larger the F-value the more significant a factor is. Literatures have shown that fibre orientation in the direction of the load applied is significant in improving the tensile strength by resisting the load. Fibre oriented at one direction gives high stiffness and strength in that direction. The Figure 5 has shown that fibre oriented at 0-degree which is the direction of the load applied produced the highest tensile strength composites [1]. The main effect plot for Signal to Noise Ratio of the Tensile Strength of the SSD Fibre/Epoxy composite is shown in Figure 5. The main effect plot suggests the optimum factors and parameters that would give the optimum tensile strength. Researchers such as Lasikun et al.(2013), Hossain et al.(2013) and Ammar et al. (2019) studied the effect of fibre orientation of various fibres on the mechanical properties of composite, the results showed that fibres placed at 0-degee orientation has the highest tensile strength [9-11].

Prediction of the composite with optimum Tensile Strength

The optimum composite suggested by the main effect plot suggests that untreated fibre with 20% SSD fibre content and 0-degree orientation would give the optimum result. The prediction was calculated as follows using the optimum factors value from the ranking table 6:

The prediction was calculated as follows:

$$EV = AVR + (A_{opt} - AVR) + (B_{opt} - AVR) + (C_{opt} - AVR) + (D_{opt} - AVR) + \ldots(nth_{opt} - AVR)$$

$$EV = 19.401 + (26.40 - 19.401) = 26.40$$

$$y^2 = \frac{1}{10^{-\frac{EV}{10}}}, \quad y^2 = \frac{1}{10^{-\frac{26.40}{10}}} = 436.52, \quad y=20.89\text{MPa}$$

Predicted optimum y= 20.89 MPa while the actual experimental value was 24.075MPa.

Where EV = Expected Response, AVR = Average Response, Aopt = mean value of response at optimum setting at factor A, Bopt = mean value of response at optimum setting at factor B, Copt = mean value of response at optimum setting at factor C [12]. The tensile strength of the optimum composite which is the untreated 20% SSD fibre at 0^o orientation had a tensile strength of 24.08MPa compared to the Epoxy material with a tensile strength of 13.99MPa. The reinforcement improved the tensile strength of Epoxy by 72%. The tensile Strength result in table 5 shows some fluctuations in the results. This could be due to the non-uniformity of the natural fibres giving varying tensile strength and also the manual production of the composites using handlayup method leading to variation in results.

Table 5. Tensile Strength Result for composite with *SSD* fibre reinforcement with Epoxy Matrix

Treatment	SSD fibre wt.%	Fibre orientation(Deg.)	Tensile Strength (MPa)					
			1	2	3	4	Mean	S/N Ratio
With	5	0	13.14	19.98	16.79	17.42	16.83	24.22
With	10	30	17.52	11.21	13.13	7.99	12.4625	20.88
With	15	45	11.07	8.58	8.77	12.92	10.3350	19.92
With	20	90	5.78	8.44	8.22	4.84	6.8200	15.96
Without	5	30	15.05	14.46	11.76	8.84	12.5275	21.36
Without	10	0	25.42	22.70	22.85	22.85	23.4550	27.38
Without	15	90	4.85	5.98	3.52	5.88	5.0575	13.47
Without	20	45	9.19	9.43	10.90	8.62	9.5350	19.49
With	5	45	9.34	4.07	5.46	3.89	5.690	13.68
With	10	90	7	4.05	4.42	6.54	5.5025	14.09
With	15	0	31.06	21.22	17.86	29.30	24.8600	27.24
With	20	30	11.16	11.92	20.02	9.38	13.1200	21.41
Without	5	90	6.54	9.23	7.05	8.34	7.79	17.59
Without	10	45	5.65	7.17	8.39	3.97	6.2950	14.93
Without	15	30	12.72	18.13	10.32	15.16	14.0825	22.41
Without	20	0	24.80	34.45	17.11	19.94	24.0750	26.78

Table 6. Rankings of factors affecting Tensile Strength of SSD fibre/Epoxy composite using Signal to Noise ratio (Larger is better)

Level	Alkaline Treatment	*SSD* Fibre (%)	Fibre Orientation (Deg.)
1	19.67	19.21	26.40
2	20.43	19.32	21.51
3		20.76	17.01
4		20.91	15.28
Delta	0.75	1.70	11.13
Rank	3	2	1

Table 7. Analysis of Variance of the Signal to Noise ratio of Tensile Strength of SSD fibre-epoxy composite

Source	DF	Adj SS	Adj MS	Significant	
				F-Value	P-Value
Alkaline Treatment	1	2.267	2.267	0.50	0.499
SSD Fibre (%)	3	9.888	3.296	0.73	0.563
Fibre Orientation (Deg.)	3	298.191	99.397	21.97	0.000
Error	8	36.197	4.525		
Total	15	346.543			

3.2 Flexural Strength

The flexural test was based on ASTM D790, the standard test method for flexural properties of unreinforced and reinforced plastic. Table 8 shows the flexural strengths of the SSD fibre-epoxy composite. The design of experiment tool Taguchi method was used for the experimental design, it showed how the experiments were arranged and conducted. For the SSD fibre-epoxy composite result in table 8, the untreated 10% SSD fibre content at 0-degree fibre orientations had a mean value of 63.38MPa with an S/N ratio 36.01. The 15% Hot Alkaline treated SSD fibre at 0º orientation had a mean value of 56.09MPa with an S/N ratio of 34.40. The 5% Hot Alkaline treated SSD fibre at 0º had a mean value 50.31MPa with S/N ratio of 33.75. The result shows and strengthens the fact that Fibre orientation at 0-degree gives improved flexural strength. This is due to fact that fibres' being placed in the direction of the load improves resistance against flexural loading in the direction and the alkaline treatment removed impurities and oils from the natural fibre improving the bonding between the fibre and the matrix thereby improving the flexural strength. The ranking table 9 for the SSD fibre-epoxy composite shows that fibre orientation has the highest impact on the flexural strength with a delta of 6.75, SSD fibre (1.76) and alkaline treatment (1.63). The ANOVA table 10 shows the fibre orientation has the highest p-value of 0.012 followed by alkaline treatment (0.157) and then SSD fibre content (0.650). The most significant factors are fibre orientation and alkaline treatment. Fibre orientation had an F-value of 7.08, Alkaline treatment (2.44) and fibre content (0.57) [12].The most significant factor that affected the flexural strength of the SSD fibre/Epoxy composite with a p-value of 0.012 at a 95% confidence level was the fibre orientation.

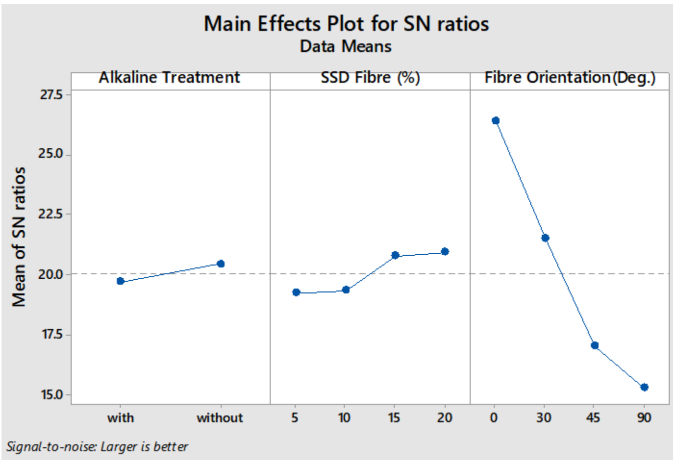

Figure 5. Main effect Plot for the Signal to Noise Ratio of factors affecting the Tensile Strength of the *SSD* fibre-epoxy composite

Prediction of flexural strength for SSD fibre-Epoxy composite using Taguchi Method

The main effect plot for flexural strength of SSD fibre epoxy composite suggested that the Hot Alkaline treated fibre with 10% SSD fibre at 0-degree orientation would give the optimum result. The data of most significant parameters suggested by the

ANOVA was obtained from the ranking table 9. The values were used to predict the optimum flexural strength.

$$EV = 30.489 + (34.09 - 30.489) = 34.09$$

$$y^2 = \frac{1}{10^{-\frac{EV}{10}}}, \quad y^2 = \frac{1}{10^{-\frac{34.09}{10}}} = 2564.484$$

y=50.64MPa, Predicted result, y=50.64MPa, Experimental result, y =74.90MPa. The optimised flexural strength was achieved using Hot Alkaline treated 10% SSD fibre at 0º orientation.

Sachudhanandan and Lakshmanaswamy (2019) studied the effect of fibre orientation on the mechanical properties of ramie fibre epoxy composite. The composite of 0/0º orientation had the highest maximum flexural strength with a value of 82.36MPa [13]. Abd-Ali and Madeh (2016) studied the effect of fibre orientation on the mechanical behaviour of car bumper composite using glass fibre polymeric matrix. The result showed that the 0-degree angle of orientation had the highest flexural strength. This is similar to the result achieved through experimentation for the SSD fibre composite [14].

However, Prasath, Arumugaprabu, Amuthakkannan and Manikandan (2019) studied the effect of fibre orientation on flax fibre reinforced polyester composite. The result showed that 90-degree angular orientation gave the maximum flexural strength of 34.78MPa [15].

The flexural strength result for the SSD fibre-epoxy composite is similar to the work by Kumar et al.(2014) that optimized the mechanical properties of epoxy based sundi wood dust based green composite using Taguchi method[16]. The maximum flexural strength result was obtained at 10% wt. filler which is similar to the Hot Alkaline treated 10% wt. SSD fibre. The p-value for the filler content for the work by Kumar et al. (2014) was 0.004 showing that the factor was highly significant in affecting the flexural strength. The minimum flexural strength was at 15% filler wt. Bankoti et al. (2017) optimized walnut epoxy composite using Taguchi method. The result was similar to the result by Kumar et al. (2014) which showed that the 10% filler content gave the optimum flexural strength. The filler loading had a p-value of 0 and an F-value of 57.91[16][17].

In summary fibre orientation, Alkaline treatment and fibre percentage are key in improving flexural strength of natural fibre composite materials for applications.

Table 8. Flexural Strength of the *SSD* fibre/ Epoxy Matrix composite with varying fibre percentage, angular orientation and alkaline treatment

Treatment	SSD fibre wt.%	Fibre Orientation (Deg.)	Flexural Strength (MPa)					
			1	2	3	4	Mean	S/N Ratio
With	5	0	54.03	59.350	47.82	40.07	50.3175	33.75
With	10	30	37.62	55.160	62.21	31.67	46.6650	32.42
With	15	45	67.23	35.520	51.88	53.76	52.0975	33.64
With	20	90	27.68	22.630	12.37	22.98	21.4150	25.34
Without	5	30	25.47	30.035	24.42	29.14	27.2662	28.61
Without	10	0	58.83	67.250	63.76	63.67	63.3775	36.01
Without	15	90	29.78	19.230	25.87	29.42	26.0750	27.90
Without	20	45	20.35	26.600	19.77	41.23	26.9875	27.59
With	5	45	28.83	52.010	33.16	28.35	35.5875	30.31
With	10	90	24.00	23.500	25.67	24.54	24.4275	27.74
With	15	0	67.28	47.860	41.67	67.55	56.0900	34.40
With	20	30	36.45	39.530	60.48	48.66	46.2800	32.83
Without	5	90	32.29	25.400	37.29	19.55	28.6325	28.35
Without	10	45	24.35	27.430	30.65	29.35	27.9450	28.83
Without	15	30	30.64	23.730	26.30	21.40	25.5175	27.91
Without	20	0	62.59	29.030	53.90	40.07	46.3975	32.20

Table 9. Rankings of factors that influence Flexural Strength of the SSD fibre epoxy composite using Signal to Noise ratio (Larger is better)

Level	Alkaline Treatment (NaOH)	*SSD* Fibre Content (%)	Fibre Orientation (Deg.)
1	31.30	30.26	34.09
2	29.68	31.25	30.44
3		30.96	30.09
4		29.49	27.34
Delta	1.63	1.76	6.75
Rank	3	2	1

Table 10. Analysis of Variance for Signal to Noise Ratio of the Flexural Strength of the *SSD* fibre/Epoxy composite.

Source	DF	Adj SS	Adj MS	Significant	
				F-Value	P-Value
Alkaline Treatment	1	10.596	10.596	2.44	0.157
Fibre Content (%)	3	7.435	2.478	0.57	0.650
Fibre Orientation (Deg.)	3	92.289	30.763	7.08	0.012
Error	8	34.745	4.343		
Total	15	145.066			

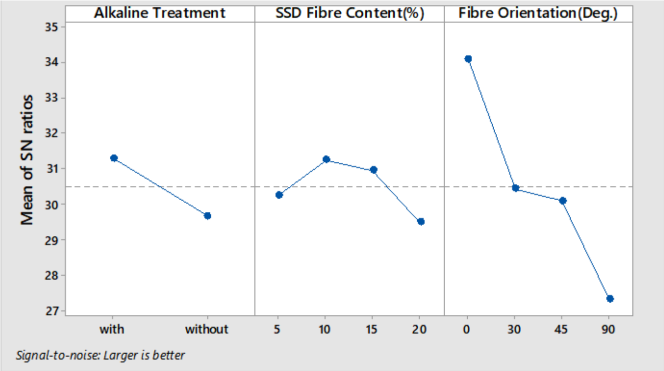

Figure 6. Signal to Noise ratio for the Flexural Strength of SSD fibre-Epoxy composite

3.3 Compression Strength of the SSD fibre epoxy composite

Table 11 shows the compression strength of the *SSD* fibre epoxy composites. The result shows that the Hot Alkaline treated 15% SSD fibre at 0-degree orientation has the highest mean value of 51.98MPa with an S/N ratio of 34.16. The Ranking table 12 of the S/N ratio has shown that fibre orientation led to the maximum change in compressive strength (1.96), this is followed by *SSD* fibre (%) (1.60) and then Alkaline treatment (0.43). The fibre orientation has a p-value of 0.292, *SSD* fibre content (0.513) and Alkaline treatment (0.598). The factors do not have a 95% confidence interval. However, the mean effect plot graph shows that the optimum composite would be found using Hot Alkaline treated fibre with 10% SSD fibre at 0º orientation. The predicted response value was 51.68MPa and the actual confirmation test value was 56.45MPa. The result was higher than the compressive strength of the Epoxy matrix specimen (53.31MPa) by 3.14MPa.

Prediction of compressive strength of SSD fibre epoxy composite

$$31.742 + (33.15 - 31.742) + (32.38 - 31.742)$$
$$+ (31.95 - 31.742) = 34.266$$

$$y^2 = \frac{1}{10^{-\frac{34.266}{10}}} = 2670.546,$$

y= 51.68MPa.

The confirmation test for the optimum composite combination confirmed the suggestion from the Taguchi method that Hot Alkaline treatment 10% SSD fibre with 0-degree orientation would give optimum strength.

Das and Biswas (2016) studied the effect of length of fibre and fibre content on the compressive strength of coir-fibre epoxy composite. The result showed that the compressive strength increased with fibre loading. The maximum compressive strength of 8.32MPa was observed for composite with 12mm fibre length and 15wt. % Coir fibre content. At 20wt. % there was a reduction in compressive strength. There is a similar trend observed for the hot alkaline treated 15% SSD fibre at 0º orientation which achieved a compressive strength of 51.98MPa [18].

For the SSD fibre-epoxy composite Hot Alkaline treated 10% SSD fibre at 0-degree orientation achieved the maximum compressive strength (56.45MPa) as suggested by the Taguchi method, however with an increased fibre content led to reduction in compressive strength.

Parida, Dash and Das (2015) studied the effect of fibre treatment and fibre loading on the mechanical properties of luffa-Resorcinol composites. The result showed that (1:5) ratio of treated fibre to matrix achieved the maximum compressive strength of 81.0MPa. The matrix had an Ultimate compressive strength of 76.68MPa. The result showed that the addition of Luffa cylindrica in resorcinal-formaldehyde (RF) matrix improved the compressive strength. However with higher content of fibre led to agglomeration. Therefore for each natural fibre composite, researchers need to investigate the percentage at which fibre agglomeration is achieved [19].

Table 11. Compression Strength for SSD fibre Epoxy composite with varying fibre percentage, fibre orientation and alkaline treatment

Treatment	SSD fibre content wt. %	Fibre Orientation (Deg.)	Compressive Strength (MPa) 1	2	3	4	Mean	S/N Ratio
With	5	0	45.920	45.61	46.430	45.020	45.7450	33.21
With	10	30	32.880	42.80	34.940	40.320	37.7350	31.39
With	15	45	29.930	34.73	37.570	41.613	35.9607	30.94
With	20	90	32.46	25.08	27.83	24.38	27.4375	28.61
Without	5	30	27.93	37.87	37.226	40.43	35.86	30.82
Without	10	0	45.910	41.77	34.840	47.370	42.47	32.37
Without	15	90	38.81	34.51	42.71	32.23	37.07	31.23
Without	20	45	28.840	32.46	19.930	42.750	30.99	28.85
With	5	45	35.350	47.64	38.730	41.830	40.89	32.08
With	10	90	43.90	41.64	38.91	44.09	42.14	32.46
With	15	0	54.534	50.78	43.800	58.80	51.98	34.16
With	20	30	42.270	51.30	39.340	44.090	44.25	32.80
Without	5	90	41.530	39.87	43.190	44.530	42.28	32.50
Without	10	45	46.240	55.45	46.860	40.070	47.16	33.30
Without	15	30	32.870	32.78	31.360	33.560	32.64	30.27
Without	20	0	41.730	47.56	48.120	40.390	44.45	32.88

Table 12. Ranking of factors that influence the Compressive strength of SSD fibre-epoxy composite using Signal to Noise ratio (Larger is better

Level	Alkaline Treatment	Fibre content (%)	Fibre Orientation (Deg.)
1	31.95	32.15	33.15
2	31.53	32.38	31.32
3		31.65	31.29
4		30.78	31.20
Delta	0.43	1.60	1.96
Rank	3	2	1

Table 13. Analysis of Variance for the SSD fibre-epoxy composite compressive strength

Source	DF	Adj SS	Adj MS	Significant	
				F-Value	P-Value
Alkaline Treatment	1	0.7274	0.7274	0.30	0.598
Fibre (%)	3	6.0107	2.0036	0.83	0.513
Angle	3	10.7000	3.5667	1.48	0.292
Error	8	19.2722	2.4090		
Total	15	36.7103			

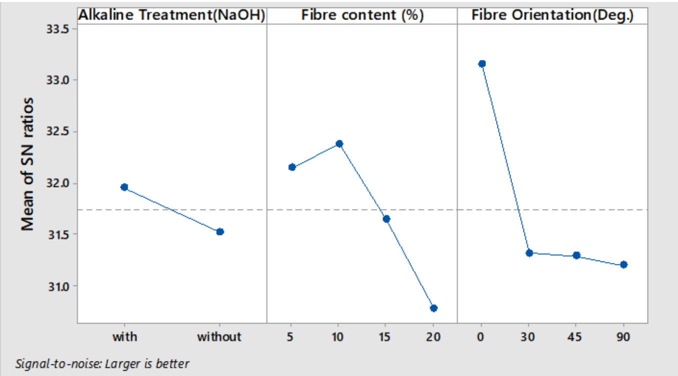

Figure 7. Main effect plot for S/N ratio for the compressive strength of the SSD fibre/Epoxy composite

Figure 8 and Figure 9 shows the fracture specimen of first, the Hot Alkaline treated 5% SSD fibre at 0-degree orientation and the untreated 10% SSD fibre at 45-degree orientation.

Table 14. Confirmation test result of the Compressive strength of the Hot Alkaline treatment 10% SSD fibre with 0 degree orientation with optimum strength

Force (N)	B (mm)	T (mm)	Compressive Strength (MPa)
6361	11.47	9.82	56.47
7121	12.12	11.55	50.13
5135	10.67	9.35	51.47
6253	11.45	11.00	49.65
10210	12.85	10.66	74.54
			Average: 56.45

3.4 Thermogravimetric Analysis

Thermogravimetric analysis was performed using Perkin Elmer TGA4000. The Thermogravimetric analysis graph shows the stability of the composites in response to an increase in temperature. The thermal evaluation was conducted through TGA under an inert atmosphere. The effect of the reinforcement on the degradation temperature, mass loss rate and the residual mass was considered. The Graph showed that the addition of reinforcement 10 % Hot Alkaline treated fibre improved the thermal performance of the Epoxy. The heating rate was 10°C/min starting from 30°C to 950°C. Table 15 has shown that the addition of the treated SSD fibres improved the degradation temperature. The Table 15 has shown that initially, the Weight (%) of the composites are the same. At the weight (%) of about 80%, the temperature for the thermal degradation of Epoxy was at 294.1°C and Hot Alkaline treated fibre at 316.56°C. At the Weight (%) of 60%, for the Epoxy the temperature was 356.56°C and for the Hot Alkaline treated fibre composite the temperature was 375.84°C. The result at 80% weight has shown that at the percentage weight Epoxy has the lowest temperature for thermal degradation (294.1°C), this is followed by Hot Alkaline treated fibre (316.56°C). At 40% weight the Epoxy has a thermal degradation temperature of 403.18°C and the Hot Alkaline treated fibre (481.27°C). The reinforced composite had a higher thermal degradation temperature than the Epoxy matrix composite (403.18°C). The improved thermal Stability of the fibre reinforced composite is as a result of the fibre treated composite has high cellulose content which is essential for thermal stability, the treatment removed the Hydroxyl group from the surface of the fibre improving its stability.

Figure 8. Fractures specimens of Hot Alkaline treated 5% SSD fibre at 0-degree Orientation

Figure 9. Fractures specimens of untreated treated 10% SSD fibre at 45-degree Orientation

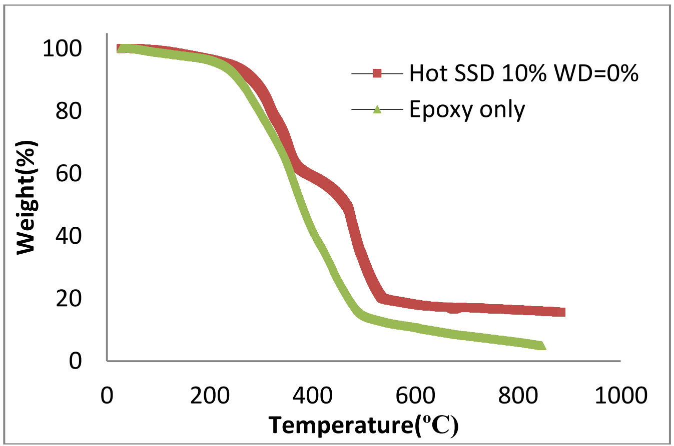

Figure 10. Thermograph for the 10 % Hot Alkaline treated fibre with 0% wood dust and Epoxy matrix

Thermal decomposition natural fibre composite involves the emission of volatile components, weight loss, and weight loss due to hemicellulose and cellulose degradation [20]. There are three stage weight loss associated with the TG curve. The first stage is up to 200°C, which corresponds to a maximum weight loss of 10% at about 200°C, the second stage with more than 70%wt. of loss up to about 500°C and the final stage extends to ending test temperature to about 800°C [21]. The first stage is associated with loss of moisture and highly volatile extractives from the fibre, the second stage is due to decomposition of hemicellulose due to chemical change and cellulose due to cellulose breakdown as temperature increases. In this stage, volatile hydrocarbons were released as a result of the decomposition of cellulose, hemicellulose and some of the lignin fibre. The third degradation phase represents the temperature in which heavy fraction mainly lignin degrades [22].

Table 15. Thermal Decomposition of composite against temperature

Weight (%)	Epoxy (°C)	Hot Alkaline treated 10% SSD fibre at 0° (°C)
100.082	238.08	238.08
93.479	238.08	238.08
81.518	294.1	316.56
61.434	356.56	375.84
41.429	403.18	481.27
20.023	473.16	538.05

4. Conclusions

Taguchi method has been used for the Design of Experiment and the optimization of tensile, flexural and compressive strength of SterculiaSetigeraDelile fibre Epoxy composite. The method was successfully used to improve the mechanical properties of the composite. The results showed that fibre orientation was the most significant parameter in improving the tensile, flexural and compressive strength with 0-degree being the best angular orientation. This was followed by alkaline treatment. The 10% Hot Alkaline treated fibre at 0-degree orientation had consistently high tensile, flexural and compression strength. The 10% Hot Alkaline reinforcement of the fibre epoxy composite improved the thermal stability of the Epoxy. The Epoxy material has a melting point at 367.25°C while the 10% Hot Alkaline reinforcement composite has a melting point at 479.81°C which showed an increase in the melting point. The composite can be used for interiors of automobiles.

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Author contributions

Nasir Mohammed Tahir: Production of composites, testing of composite materials, writing of paper

Adamu Umar Alhaji: Conceptualization, identification of new material, extraction method, review and editing of paper, data analysis

Ibrahim Abdullahi: Conceptualization, data analysis, supervision, review and editing, funding acquisition

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