ISSN: 2687-6043
e-ISSN: 2687-6035
https://dergipark.org.tr/en/pub/wie

Volume 4, Issue 1
2022
pp. 1-15

Wood Industry and Engineering
International Scientific Journal

OPTIMIZATION OF MECHANICAL PROPERTIES OF HYBRID BIOCOMPOSITE FROM STERCULIA SETIGERA DELILE FIBRE AND PTEROCARPUS ERINACEUS WOOD DUST EPOXY

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Citation

Tahir N.M., Alhaji A.U., Abdullahi I. Optimization of Mechanical Properties of Hybrid Biocomposite from Sterculia Setigera Delile Fibre and Pterocarpus Erinaceus Wood Dust Epoxy. ***Wood Industry and Engineering****. 2022; 4(1): 1-15.*

Keywords

Sterculia setigera delile Fibre
Pterocarpus erinaceus Wood Dust
Alkaline Treatment
Epoxy Matrix
Taguchi Method
ANOVA
Fibre Angular Orientation
Thermal Stability

Paper Type

Research Article

Article History

Received: 31/12/2021
Accepted: 10/02/2022

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Abstract

Synthetic fibres have been used for the production of high strength composite material of low density for various aerospace and automotive applications. The problem with synthetic fibres includes high energy consumption during processing, high cost, non-biodegradability and environmental pollution during production and disposal. Natural fibre reinforced composites have been explored as potential replacement for synthetic fibres. The research explores the use of wood fibre reinforcement such as *Sterculia Setigera delile* fibre (SSD) sourced from a durable inner tree bark and *Pterocarpus erinaceus* (PTE) wood dust from high quality wood for the production of a hybrid composite material with epoxy as the matrix. The aim is to produce a novel hybrid material with high tensile, flexural and compressive strength, low density and high thermal stability. Taguchi method was used for the design of experiment and the optimization of factors affecting the tensile, flexural and compression strength of the composite. The factors include alkaline treatment (hot, cold and untreated), SSD fibre content (2.5, 5, 7.5, 10, 12.5) wt.%, *Pterocarpus erinacues* wood dust content (0, 2.5, 5, 7.5, 10) wt.% and fibre angular orientation (0, 15, 30, 45, 90°). The result showed that the optimum composite parameters consist of 5% cold alkaline treated 5% SSD fibre with 7.5% PTE wood dust at 0-degree orientation. The thermal stability of the composite was also improved by the addition of the reinforcements. Factors such as fibre angular orientation and alkaline treatment were significant factors. The optimized composite improved the tensile strength of the composite when compared to the epoxy matrix by 105.9% and also improved the flexural strength by 94.91%. The optimized composite has a lower density (1.093g/cm^3) when compared to carbon-epoxy composite (1.6g/cm^3) and S-glass fibre epoxy composite (1.9g/cm^3). The optimized composite would have better biodegradability, lighter weight means lower energy consumption and cost when used in aerospace and automobile components.

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1. Introduction

Natural fibres are a renewable source of reinforcements that are used to improve the mechanical and thermal properties of matrices. This type of fibre is strong, low density, inexpensive and renewable. natural fibres are materials that are currently used as possible replacement for synthetic fibres. The automotive and aircraft industry has been developing interior components using mainly, hemp fibre, flax, sisal fibre and bioresin systems. The high specific properties and low cost make them attractive for various applications (Sanjay et al., 2016). The reinforcements are explored as potential replacement for synthetic fibres. Synthetic fibre production leads to high energy consumption and environmental pollution. It is known to have high cost, hazardous to workers processing it and non-biodegradability. This research involves the investigation of the effect of hybridization of *Sterculia setigera delile* fibre and *Pterocarpus erinaceus* wood dust epoxy composite. *Sterculia setigera delile* is a savannah tree widespread in tropical Africa and is known by its English name Karaya gum tree. It is a hardwood species and is known in Nigeria with local names such as Hausa-Kukuki, and Fulani- Bo'boli. The tree is found in open savannah woodland often characterized with rocky hills (Adelakun et al., 2014). The tree is used for medicinal purposes. It is used by the Fulani's as a saddle on their cows for load carrying and it is known to have good durability which is the reason it is explored as a potential composite reinforcement. *Pterocarpus erinaceus* is a highly-priced wood used for furniture's and belongs to the Fabaceae family. It is known to have one of the best mechanical properties and durability in Africa. It is known with many names such as African Rosewood, African Kino and Senegal Rosewood. It has been over-exploited for its wood by China and India. *Pterocarpus erinaceus* is classified as medium-long and medium fibre hardwood. It is suitable for paper and pulp production. The mechanical test showed that it provided high mechanical properties (Anthonio and Antwi-Boasiako, 2017). *Pterocarpus erinaceus* wood dust could be used for the reinforcement of epoxy matrix. The mechanical properties of *Pterocarpus erinaceus* would be explored and could be combined with other reinforcement mentioned to make composites. It would be an effective use of wood dust. The research involves the hybridization of *Sterculia setigera delile* fibre and *Pterocarpus erinaceus* wood dust and epoxy matrix. Hybridization is known to improve the mechanical properties of composite materials (Hanan et al., 2018; Mehra et al., 2021). This research is focused on the fabrication and optimization of the mechanical properties of hybrid fibre epoxy composite. The tensile, flexural and compressive strength of the composite was optimized using the Taguchi method. Taguchi method was used for the design of experiment and was analyzed 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. In this research, a novel bio-composite material of low density and good mechanical properties was produced as a potential replacement for synthetic fibres. Its material properties can be used by researchers for simulating components in the aerospace, automotive industry and also in the furniture industry as a potential use of wood dust.

2. Materials and Methods

Taguchi method was used for the design of experiment using Minitab software. The factors considered in the design of experiment include alkaline treatment, SSD fibre Content, *PTE* filler content and fibre angular orientation. The hand lay-up process was used for the fabrication of the composites. Materials used for the manufacturing of the composite include epoxy from EPOCHEM with a density of 1.13 g/cm^3 and hardener from EPOCHEM with a density of 1.04 g/cm^3 purchased from Epoxy Olisev Nigeria. *Sterculia setigera delile* wood bark was obtained from the tree, subjected to drying for 11 days and retting process for 11 days before manual extraction. The wood dust from *Pterocarpus erinacues* was obtained from the wood mill and a sieve of 425 µm was used to attain fine wood dust. The untreated fibre has a density of 1.1924 g/cm^3, hot alkaline treated fibre 1.184 g/cm^3, cold Alkaline treated fibre, 1g/cm^3. The untreated, hot alkaline treated and cold alkaline treated *PTE* wood dust have densities of 0.8, 0.74, 0.75g/cm^3 respectively. The dried fibres were placed on a paper with different fibre angular orientations. The fibres were then placed inside the mould. A mixture of epoxy, matrix and wood dust were thoroughly mixed and spread inside the mould and was subjected to compression using a manual press of a pressure of 23.29 MPa. For the hot alkaline treated fibre, the fibres are subjected to 5% hot alkaline treatment at 95^{o}C for 1 hour. The 5% cold alkaline treatment was conducted for 1 hour by putting the fibres in the alkaline solution for 1 hour. The factors and levels are shown in Table 2. The structure in which the experiments were performed is shown in Table 3. Tensile, flexural and compression test were performed using ASTM standard ASTM D3039, ASTM D790 and ASTM D695. The results were then recorded. The results were transformed into Signal to Noise ratio.

For the larger the better, the formula is shown in equation:

$$S/N = -10 * log(\sum(1/y^2)/n \tag{1}$$

Where y is the experimental result for the given factor level combination and n is the number of responses and n is the number of responses in factor level combinations (Trehan et al., 2013).

Table 1: Design Summary showing the type of orthogonal array, number of factors and number of experiments

Design Summary	
Taguchi Array	L25 (5^4)
Factors	4
Runs	25

Table 2: Design of Experiment data for the Factors affecting the Hybrid Composite Performance and the Levels

No	Contributing Factor	Level 1	Level 2	Level 3	Level 4	Level 5
1	Alkaline treatment	Without	5% Hot Alkaline treated reinforcements	5% Cold Alkaline treated reinforcement	Without	5% Hot Alkaline treated reinforcements
2	SSD Fibre Content (%)	2.5	5	7.5	10	12.5
3	*Pterocarpus erinaceus* filler content (%)	0	2.5	5	7.5	10
4	Fibre Angular Orientation (Degrees)	0	15	30	45	90

Table 3: Orthogonal Table Designed using Taguchi method and Minitab software

Alkaline Treatment (NaOH)	SSD Fibre Content (wt.%)	PTE Filler Content (wt.%)	Fibre Orientation (Degrees)
Without	2.5	0.0	0
Without	5.0	2.5	15
Without	7.5	5.0	30
Without	10.0	7.5	45
Without	12.5	10.0	90
Hot	2.5	2.5	30
Hot	5.0	5.0	45
Hot	7.5	7.5	90
Hot	10.0	10.0	0
Hot	12.5	0.0	15
Cold	2.5	5.0	90
Cold	5.0	7.5	0
Cold	7.5	10.0	15
Cold	10.0	0.0	30
Cold	12.5	2.5	45
Without	2.5	7.5	15
Without	5.0	10.0	30
Without	7.5	0.0	45
Without	10.0	2.5	90
Without	12.5	5.0	0
Hot	2.5	10.0	45
Hot	5.0	0.0	90
Hot	7.5	2.5	0
Hot	10.0	5.0	15
Hot	12.5	7.5	30

Figure 1: Fibre placed at 30° angular orientation

Figure 2: SSD fibre/PTE wood dust epoxy composite fibre placed at 0° angular orientation

3. Results and Discussion

3.1. Tensile Strength

The tensile test is based on ASTM D3039 (Standard Test Method of Polymer Matrix Composite). For the tensile strength the result in Table 4 shows that the hot alkaline treated 10% fibre with 10% *PTE* wood dust at 0-degree orientation has a tensile strength of 25.82 MPa and a Signal to Noise 28.10, cold alkaline treated 5% fibre and 7.5% PTE wood dust at 0-degree orientation has a tensile strength of 26.90 MPa and Signal to Noise of 28.51 and finally the hot alkaline treated 7.5% fibre and 2.5% *PTE* wood dust at 0-degree has a tensile strength of 28.46 and Signal to Noise ratio of 29.00. The result from Table 4 has clearly shown that alkaline treatment and fibre orientation of 0-degree has a significant impact on the tensile strength of the composite. The ranking table has shown that the fibre orientation has the highest effect on the tensile strength with a delta of 12.21, this is followed by the SSD fibre content of 2.71 and then the alkaline treatment of 2.31. Analysis of variance is a statistical tool used by researchers to know the extent factors influence to the outcome of the experiments and interactions, confidence value and test of significance. 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. Table 5 shows that fibre orientation has a p-value of 0.000 indicating it as the most significant factor. The p-value 0.000(fibre orientation), 0.239(alkaline treatment), 0.533(SSD fibre content) and *PTE* fibre content shows the significance of these factors on the tensile strength with fibre orientation being the highest at 95% confidence interval. The F-value shows that the fibre orientation has a F-value of 15.62 on the tensile strength followed by the alkaline treatment of 1.65, *SSD* fibre content 0.84 and *PTE* wood dust 0.31 (Trehan et al., 2013; Roy, 2010). The tensile strength of the epoxy was 13.82 MPa. The hybrid composite reinforcement's addition increased the tensile strength of the epoxy by 105.9%. Literatures have shown that fibre orientation is significant in improving the tensile strength of composite. The specimens fail by tensile rupture of fibre followed by debonding along the fibre matrix interface (Mallick, 2007). Fibres oriented at one direction give high stiffness and strength in that direction (Kaw, 2006). Parallel alignment of fibres to the direction of load application improves the mechanical properties of the

composite (Varadaraju & Srinivasan, 2019). When fibre is arranged in the direction of the load, the load is transferred to fibre which resists the load thereby improving the composite resistance to failure and the mechanical properties of the composite. Lasikun et al. (2018) researched on the effect of fibre orientation on the tensile and impact properties of zalacca midrib fiber /HDPE composites. Fibres arranged at 0, 15, 30, 45, 60, 75 and 90˚ to produce composites. The tensile and impact strength result showed a decline in strength from 0˚ to 90˚ with 0˚ being the highest tensile and impact strength. Hossain et al. (2013) studied the effect of fibre orientation on tensile strength of Jute-Epoxy composite the result showed that jute fibre arranged at 0 degree orientation has the highest tensile strength. Similar result was observed by Chanamala et al. (2019) that studied the effect of fiber orientation on dynamic mechanical properties of PALF hybridized with basalt reinforced epoxy composites. Ammar et al. (2019) also obtained similar result investigating the effect of Sugar Palm Fibre Reinforced Vinyl Ester Composites at Different Fibre Arrangements on the Mechanical Properties of the composite.
The reason for improvement of tensile properties as a result of Alkaline treatment is that Alkaline treatment removes natural fats, wax, surface debris, pectin, lignin and other impurities of the surface resulting to rougher surface of the fibre thus revealing chemically reactive functional groups like hydroxyl groups and other reactive functional groups on the surface. Sodium hydroxide also reacts with accessible –OH groups reducing the fibres affinity to moisture absorption. The surface of the fibre becoming rough increases the surface area of available interaction with the resin. Good bonding between the fibre and resin improves the load carrying capacity of the composite giving better mechanical properties (Kamath & Bennehalli, 2021; Benyahia et al., 2013).

Table 4: Tensile Strength Result for the hybrid composite with *SSD* fibre and *PTE* filler reinforcement

Alkaline Treatment (NaOH)	SSD Fibre Content (wt.%)	PTE Filler Content (wt.%)	Fibre Orientation (Deg.)	Tensile Strength (MPa)					S/N Ratio
				1	2	3	4	Mean	
Without	2.5	0.0	0	26.92	18.71	25.04	15.47	21.54	26.02
Without	5.0	2.5	15	19.66	11.19	17.70	8.98	14.38	21.84
Without	7.5	5.0	30	7.30	10.55	12.20	12.12	10.54	19.86
Without	10.0	7.5	45	7.21	6.99	7.58	11.10	8.22	17.88
Without	12.5	10.0	90	2.29	2.66	4.21	2.94	3.03	9.00
Hot	2.5	2.5	30	12.38	10.96	9.52	12.38	11.31	20.91
Hot	5.0	5.0	45	12.41	9.68	14.64	7.426	11.04	20.00
Hot	7.5	7.5	90	7.12	6.83	4.64	8.16	6.69	15.91
Hot	**10.0**	**10.0**	**0**	**22.15**	**29.52**	**25.21**	**26.38**	**25.82**	**28.10**
Hot	12.5	0.0	15	11.74	17.51	17.95	25.51	18.18	24.21
Cold	2.5	5.0	90	10.29	9.57	9.46	4.46	8.445	16.89
Cold	**5.0**	**7.5**	**0**	**26.01**	**23.76**	**28.50**	**29.33**	**26.90**	**28.51**
Cold	7.5	10.0	15	25.7	29.70	26.28	22.56	26.06	28.20
Cold	10.0	0.0	30	10.96	10.05	16.67	15.05	13.18	21.83
Cold	12.5	2.5	45	10.02	9.88	5.26	9.19	8.59	17.68
Without	2.5	7.5	15	18.12	18.69	22.16	18.64	19.40	25.68
Without	5.0	10.0	30	25.97	15.54	26.43	19.64	21.90	26.18
Without	7.5	0.0	45	6.87	7.57	8.89	10.48	8.45	18.21
Without	10.0	2.5	90	5.70	7.39	9.79	15.25	9.53	17.97
Without	12.5	5.0	0	23.73	16.77	14.41	20.92	18.96	25.08
Hot	2.5	10.0	45	10.78	17.29	15.23	19.02	15.58	23.23
Hot	5.0	0.0	90	5.43	5.89	6.64	7.62	6.40	15.91
Hot	**7.5**	**2.5**	**0**	**31.48**	**29.44**	**25.55**	**27.36**	**28.46**	**29.00**
Hot	10.0	5.0	15	32.39	20.92	24.34	23.54	25.30	27.74
Hot	12.5	7.5	30	15.23	21.01	24.04	11.52	17.95	24.02
Epoxy				11.98	11.92	15.44	16.64	13.99	22.63

Table 5: Rankings of factors affecting Tensile Strength of Hybrid-Biocomposite using Signal to Noise ratio (Larger is better)

Level	Alkaline treatment	*SSD* Fibre Content (Wt.%)	*PTE* Filler Content (Wt.%)	Fibre Orientation (Deg.)
1	20.77	22.55	21.24	**27.34**
2	22.90	22.49	21.48	25.53
3	22.62	22.24	21.92	22.56
4		22.70	22.40	19.40
5		20.00	22.94	15.13
Delta	2.13	2.71	1.70	12.21
Rank	3	2	4	1

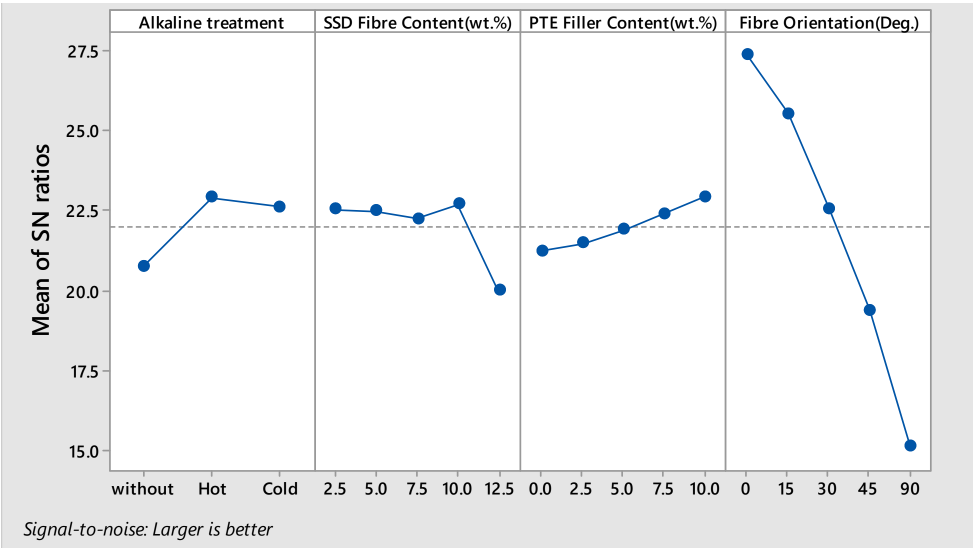

Figure 3: main effect plot for signal to noise ratio of the tensile strength of the hybrid-biocomposite

The Table 5 shows the mean effect of each parameter on the tensile strength of the hybrid-biocomposite. The result for each level of a factor was generated from the average mean effect from each level. For example, for the 0-degree fibre orientation the values were obtained from Table 4 from the signal to Noise ratio column for all values that have 0° orientation. The values used from S/N ratio table of the 0-degree orientations are 26.02, 28.10, 28.51, 25.08 and 29.00. The mean effect of the 0-degree orientation was found by finding the average of the mentioned S/N ratio values. The average value was 27.34 as highlighted in Table 5. The Main Effect plot effect for Signal to Noise Ratio of the tensile strength of the hybrid biocomposite is shown in Figure 3. The main effect plot suggests optimum factors and parameters that would give optimum performance (Roy, 2010).

Prediction of optimum tensile strength for hybrid composite

The optimum composite suggested by the main effect plot suggests that hot alkaline treated fibre with 10% SSD fibre content and 10% wood dust with 0-degree orientation would give the optimum result. In order to predict the optimum tensile strength, the ANOVA table was used to identify the significant factor which in this case is fibre orientation. The highest value of the factor was 27.34. The average value of the S/N ratio was also calculated. The two values were used in order to predict the tensile strength.

The prediction was calculated as follows:

$$EV = AVR + (A_{opt} - AVR) + (B_{opt} - AVR) + (C_{opt} - AVR) + (D_{opt} - AVR) + \ldots (nth_{opt} - AVR) \quad (2)$$

$$EV = 21.9944 + (27.34 - 21.9944) = 27.34$$

The value obtained was inserted into equation 1 to attain the tensile strength of 23.28 MPa. The predicted value is y = 23.28 MPa while the experimental value was 25.82 MPa.

Where EV = Expected Response, AVR = Average Response, A_{opt} = mean value of response at optimum setting at factor A, B_{opt} = mean value of response at optimum setting at factor B, C_{opt} = mean value of response at optimum setting at factor C (Okafor et al., 2013; Trehan et al., 2013).

Table 6: Analysis of Variance of the Tensile Strength for the Hybrid Biocomposite

Source	DF	Adj SS	Adj MS	Significance	
				F-Value	P-Value
Alkaline treatment	2	25.219	12.609	1.65	0.239
SSD Fibre Content (wt.%)	4	25.463	6.366	0.84	0.533
PTE Filler Content (wt.%)	4	9.490	2.372	0.31	0.864
Fibre Orientation (Deg.)	4	476.053	119.013	15.62	0.000
Error	10	76.198	7.620		
Total	24	612.422			

The P-value shows the significance of the parameter at 95% Confidence level, a P-value of 0.05 or less shows that a factor is highly significant on the performance of the composite and the F-value shows the level significance of each factor. The higher the F-Value the higher the significance of the factor when compared to other factors.

3.2. Flexural Strength

The flexural test was based on ASTM D790, the standard test method for flexural properties of unreinforced and reinforced plastic. For the flexural strength of the hybrid composite, Table 7 has shown that the cold alkaline treated fibre with 5% *SSD* fibre and 7.5% *PTE* filler content with 0-degree fibre orientation has the maximum flexural strength of 77.39 MPa with an S/N Ratio of 37.40. The table has also shown that hot and cold alkaline treatment improved the flexural strength of the hybrid composite and the angle of orientation was the key to improved performance of the composite. Ranking Table 8 has shown that for the S/N ratio fibre orientation has the highest effect on the flexural strength (3.92) followed by alkaline treatment (1.90), *PTE* wood dust (1.27) and *SSD* fibre (0.95). The fibre orientation has a p-value of 0.000 and alkaline treatment with a value of 0.006. The larger the F-value the more significant a factor is, fibre orientation has an F-value of 17.52, followed by alkaline treatment (8.81), *PTE* filler (0.281) and *SSD* fibre (0.352) (Roy, 2010). The fibre orientation resulted in improved resistance against flexural loading loaded in its 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.

Prediction of flexural strength for hybrid composite

The main effect plot for flexural strength of hybrid composite suggested that cold alkaline treated fibre with 5% *SSD* fibre and 7.5% *PTE* wood dust at 0-degree orientation would give the optimum result. The prediction was calculated as follows:

$$EV = 33.0816 + (34.01 - 33.0816) + (34.98 - 33.0816) = 35.9084$$

The value obtained was inserted in equation 1 in order to attain the predicted optimum flexural strength of 62.43 MPa. Predicted y = 62.43 MPa, Experimental result, y=77.38 MPa.

Table 7: Flexural Strength Result for the hybrid composite with *SSD* fibre and *PTE* filler reinforcement with Epoxy Matrix

Alkaline Treatment (NaOH)	*SSD* Fibre Content (wt.%)	*PTE* Filler Content (wt.%)	Fibre Orientation (Deg.)	Flexural Strength (MPa)					S/N
				1	2	3	4	Mean	
Without	2.5	0.0	0	32.76	57.11	63.06	72.49	56.36	33.77
Without	5.0	2.5	15	44.56	60.45	53.07	52.69	52.69	34.28
Without	7.5	5.0	30	45.44	45.75	39.10	45.08	43.84	32.78
Without	10.0	7.5	45	35.17	33.77	27.76	46.46	35.79	30.65
Without	12.5	10.0	90	41.48	25.64	30.80	45.46	35.85	30.41
Hot	2.5	2.5	30	47.80	42.31	40.44	42.49	43.26	32.67
Hot	5.0	5.0	45	34.90	42.60	43.25	39.86	40.15	31.97
Hot	7.5	7.5	90	54.85	37.10	40.69	32.79	41.36	31.88
Hot	10.0	10.0	0	61.24	51.10	69.64	57.35	59.83	35.38
Hot	12.5	0.0	15	69.04	45.79	59.84	43.37	54.51	34.27
Cold	2.5	5.0	90	47.43	44.65	46.71	40.63	44.86	32.99
Cold	**5.0**	**7.5**	**0**	**76.43**	**64.12**	**68.45**	**100.5**	**77.38**	**37.40**
Cold	7.5	10.0	15	38.26	43.95	64.99	67.99	53.80	33.84
Cold	10.0	0.0	30	45.68	46.67	44.22	60.49	49.27	33.66
Cold	12.5	2.5	45	48.77	52.15	32.36	38.50	42.95	32.19
Without	2.5	7.5	15	67.91	50.48	57.38	60.84	59.15	35.29
Without	5.0	10.0	30	54.29	48.11	37.67	43.94	46.00	33.02
Without	7.5	0.0	45	37.68	20.53	33.83	41.67	33.43	29.46
Without	10.0	2.5	90	27.90	24.67	33.39	23.98	27.49	28.57
Without	12.5	5.0	0	57.76	37.42	69.83	34.82	49.96	32.92
Hot	2.5	10.0	45	42.25	50.81	47.45	43.62	46.03	33.19
Hot	5.0	0.0	90	64.22	55.87	36.82	25.15	45.52	31.42
Hot	7.5	2.5	0	72.70	56.98	49.67	63.78	60.78	35.42
Hot	10.0	5.0	15	50.30	69.43	84.98	59.36	66.02	35.91
Hot	12.5	7.5	30	51.74	40.70	50.62	54.32	49.35	33.70
Epoxy				38.53	44.14	28.97	47.15	39.70	31.50

Table 8: Rankings of factors that influences Flexural Strength of Hybrid-Biocomposite using Signal to Noise ratio (Larger is better)

Level	Alkaline treatment (NaOH)	*SSD* Fibre Content (wt. %)	*PTE* Filler Content (wt. %)	Fibre Orientation(Deg.)
1	32.11	33.58	32.52	34.98
2	33.58	33.62	32.63	34.72
3	34.01	32.68	33.32	33.17
4		32.83	33.79	31.49
5		32.70	33.17	31.05
Delta	1.90	0.95	1.27	3.92
Rank	2	4	3	1

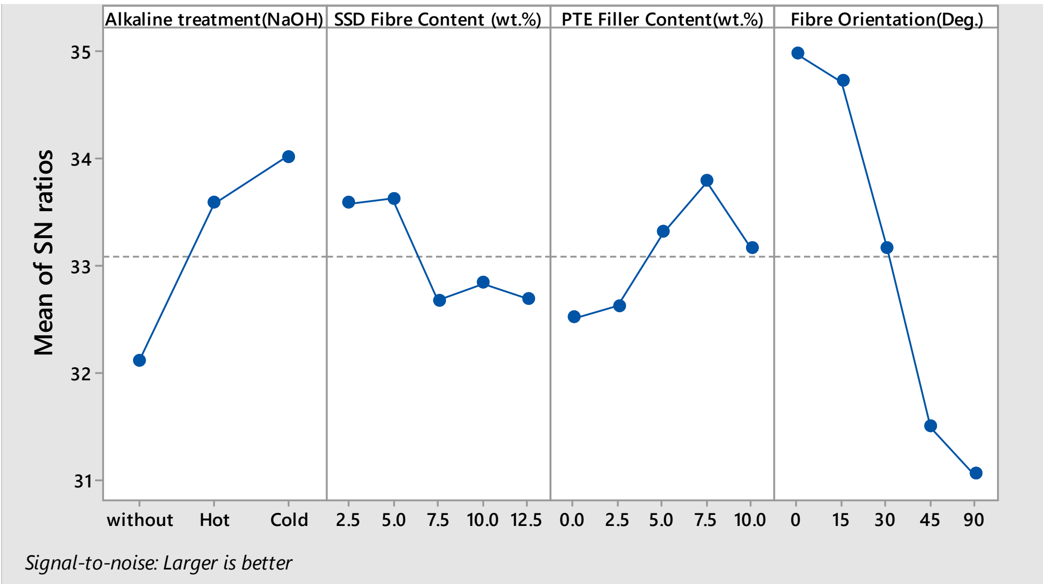

Figure 4: Main effect plot for the signal to noise ratio of factors affecting the flexural strength of the hybrid composite

Table 9: Analysis of Variance of Signal to Noise ratio of hybrid composite

Source	DF	Adj SS	Adj MS	Significant	
				F-Value	P-Value
Alkaline treatment (NaOH)	2	16.218	8.1091	8.81	0.006
SSD Fibre Content (wt. %)	4	4.595	1.1488	1.25	0.352
PTE Filler Content (wt. %)	4	5.427	1.3568	1.47	0.281
Fibre Orientation (Deg.)	4	64.536	16.1341	17.52	0.000
Error	10	9.207	0.9207		
Total	24	99.984			

The Analysis of Variance Table shows that the fibre orientation with a p-value of 0.000 and alkaline treatment with a p value of 0.006 are the most significant factors.

3.3. Compression Strength

The Compressive test was conducted based on ASTM D695. The compressive strength values in Table 10 for the hybrid composite has shown that the cold alkaline treated fibre with 5% *SSD* fibre and 7.5% *PTE* wood dust at a 0˚ orientation had a mean value of 51.39 MPa with an S/N Ratio 34.12. The hot alkaline treated fibre with 10% *SSD* fibre 5% *PTE* wood dust at 15º angular orientation had a mean value of 48.09 MPa with an S/N ratio of 33.40. The ranking Table 11 for the S/N ratio of hybrid composite shows that fibre orientation led to the highest change in the mean effect of compressive strength (2.28), followed by *SSD* fibre (2.10), *PTE* filler content (1.78) and then alkaline treatment. The analysis of variance has shown that all the factors are significant to the compressive strength. The fibre orientation had a p-value of 0.041, *SSD* fibre content (0.044). The two results were at 95% confidence interval. Alkaline treatment has a p-value of 0.070 and the *PTE* wood dust (0.084). For the compressive strength, fibre content, alkaline treatment and *PTE* wood dust were essential in resisting the compressive forces. The main plot graph suggests that the Hot Alkaline treated fibre at 5% SSD fibre and 5% wood dust at the 0º orientation would give the optimum result. The predicted response result found was 52.92 MPa while the confirmation/experimental test had a mean value of 44.62 MPa. The Epoxy matrix had a compressive strength of 53.31 MPa. The compressive strength of the composite was based on ASTM D695-15, the standard test method for compressive properties of rigid plastics.

Table 10: Compressive Strength of hybrid composite with *SSD* fibre and *PTE* filler reinforcement with Epoxy Matrix

Alkaline Treatment (NaOH)	*SSD* Fibre Content (wt.%)	*PTE* Filler Content (wt.%)	Fibre Orientation (Deg.)	Compressive Strength (MPa)					S/N Ratio
				1	2	3	4	Mean	
Without	2.5	0.0	0	55.61	45.81	50.05	40.74	48.05	33.46
Without	5.0	2.5	15	39.76	38.83	37.92	38.50	38.75	31.76
Without	7.5	5.0	30	42.63	33.40	43.08	55.71	43.71	32.39
Without	10.0	7.5	45	36.56	34.84	37.35	39.67	37.10	31.36
Without	12.5	10.0	90	40.53	29.10	43.27	28.55	35.36	30.52
Hot	2.5	2.5	30	35.42	40.67	29.70	47.20	38.25	31.27
Hot	5.0	5.0	45	55.53	49.07	45.53	41.69	47.96	33.47
Hot	7.5	7.5	90	48.39	55.93	46.21	39.54	47.52	33.34
Hot	10.0	10.0	0	43.81	44.54	42.31	44.55	43.80	32.82
Hot	12.5	0.0	15	60.90	48.88	42.53	38.36	47.67	33.19
Cold	2.5	5.0	90	53.37	46.59	47.70	45.73	48.35	33.64
Cold	**5.0**	**7.5**	**0**	**55.85**	**59.29**	**50.25**	**47.59**	**53.25**	**34.43**
Cold	7.5	10.0	15	40.44	47.30	49.76	40.32	44.46	32.85
Cold	10.0	0.0	30	25.20	29.29	24.53	24.42	25.86	28.18
Cold	12.5	2.5	45	29.56	31.41	32.23	23.76	29.24	29.13
Without	2.5	7.5	15	51.94	46.04	52.92	37.32	47.06	33.19
Without	5.0	10.0	30	50.35	46.90	45.76	49.34	48.09	33.62
Without	7.5	0.0	45	20.64	30.79	38.95	23.57	28.49	28.34
Without	10.0	2.5	90	32.66	35.05	25.27	36.89	32.47	29.94
Without	12.5	5.0	0	38.10	51.46	41.61	34.34	41.38	32.05
Hot	2.5	10.0	45	46.79	45.42	43.71	47.13	45.76	33.20
Hot	5.0	0.0	90	50.57	42.40	44.47	40.88	44.58	32.90
Hot	7.5	2.5	0	57.73	47.48	53.28	47.05	51.39	34.12
Hot	10.0	5.0	15	47.63	42.45	42.60	59.66	48.09	33.40
Hot	12.5	7.5	30	53.96	29.73	30.77	42.12	39.14	31.11
Epoxy				**53.25**	**59.46**	**44.85**	**55.53**	**53.27**	**34.39**

Table 11: Rankings of factors that influence Compressive strength of the Hybrid composite using Signal to Noise ratio (Larger is better)

Level	Alkaline treatment	SSD Fibre Content (Wt.%)	PTE Filler Content (Wt.%)	Fibre Orientation (Deg.)
1	31.66	32.95	31.21	33.38
2	32.88	33.24	31.25	32.88
3	31.64	32.21	32.99	31.32
4		31.14	32.69	31.10
5		31.20	32.60	32.07
Delta	1.24	2.10	1.78	2.28
Rank	4	2	3	1

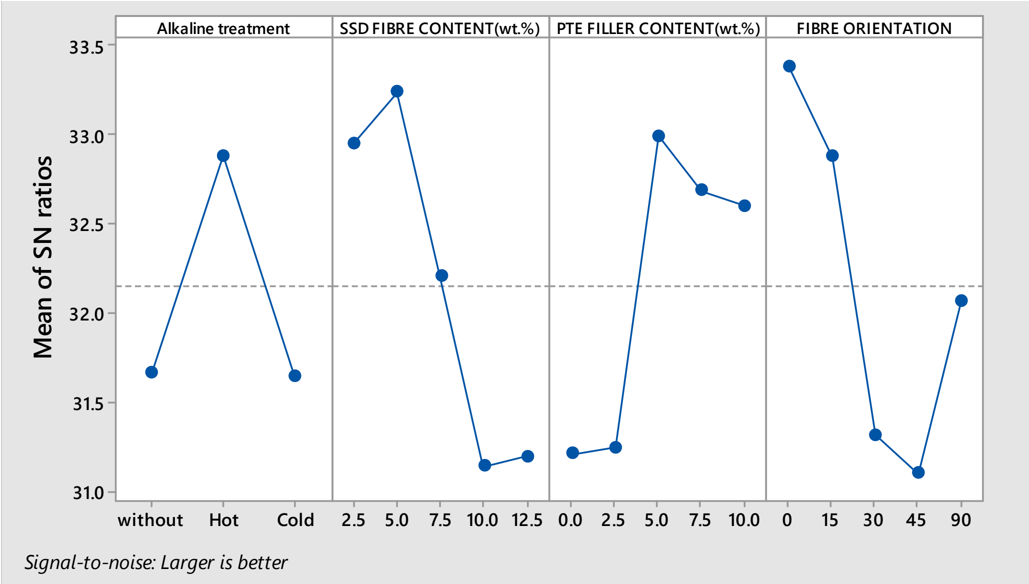

Figure 5: Main Effect plot for S/N ratio for the compressive strength of Hybrid composite

Table 11 shows that fibre orientation has the highest effect on the compressive strength of the hybrid composite. This is observed through its ranking. The main effect plot for the signal to noise ratio of the compressive strength of the hybrid biocomposite shown in Figure 5 suggests that hot alkaline treated fibre, with 5% reinforcement, 5% *PTE* wood dust and 0-degree orientation would give the optimized performance.

Table 12: Analysis of Variance for the compressive strength of Hybrid composite

Source	DF	Adj SS	Adj MS	Significance	
				F-Value	P-Value
Alkaline treatment	2	9.010	4.505	3.50	0.070
SSD Fibre Content (wt.%)	4	18.753	4.688	3.65	0.044
PTE Filler Content (wt.%)	4	14.472	3.618	2.81	0.084
Fibre Orientation	4	19.228	4.807	3.74	0.041
Error	10	12.856	1.286		
Total	24	74.318			

The ANOVA table shows that fibre orientation is still the most significant factor with a p-value of 0.041 followed by SSD fibre content with a p-value of 0.044. The alkaline treatment with a p-value (0.070) and *PTE* filler content (0.084) still affects the compressive strength.

Prediction of optimum compressive strength of hybrid composite

The predicted value of y=52.92 MPa was obtained for the compression strength and a confirmation test was performed in which an experimental value of 44.62 MPa was achieved. The result for the confirmation experiment was for the Hot Alkaline Treated 5% *SSD* fibre and 5% *PTE* Wood 0 degree orientation. This is lower than some of the results achieved in Table 10.

Table 13: Compression Strength of Hot Alkaline Treated 5% SSD fibre and 5% PTE Wood 0 Degree orientation

Force (N)	b (mm)	t (mm)	Compression Strength (MPa)
5719	12.94	9.16	48.24
5130	12.66	7.76	52.20
7182	12.90	11.54	48.24
4362	12.39	9.39	37.53
4942	11.48	11.67	36.90
			Average: 44.62

3.4. Thermogravimetric Analysis

The results for the thermogravimetric analysis for the epoxy matrix, cold alkaline treated 5% *SSD* fibre with 7.5% *PTE* wood dust composite. The tests were performed using Perkin Elmer TGA 4000. The specimens were subjected to heat from 30° to 950°C at a rate of 10°C/min.

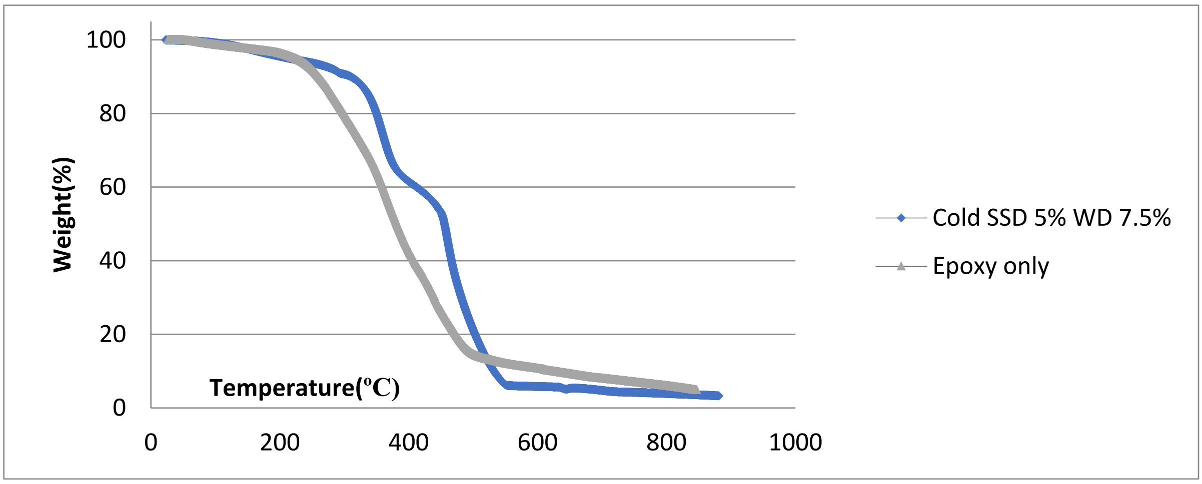

Figure 6: Thermogravimetric analyses of 5% cold alkaline treated fibre with 7.5% PTE wood dust and epoxy matrix

The onset temperature for the Cold Alkaline treated composite material is at 335°C. The two Derivative Thermogravimetric (DTG) Peaks (Inflection Points) may represent two decomposition processes. The first inflection point was at 412.22 °C , the second inflection point was at 464.49° and the end temperature of the cold Alkaline treated composite was at 540°C. The onset temperature for the Epoxy matrix was at 249°C. The inflection temperature of the Epoxy occurred at about 365.16°C and an end temperature of 497°C. Sutrisno, Rahayu, & Adhika (2019) reported that the maximum thermal degradation peak of epoxy occurs at about 350°C which is similar to the experimental result. The results have shown that the Cold Alkaline treated 5% SSD fibre and 7.5% PTE wood dust improved the thermal stability of the Epoxy by increasing its onset temperature from 249°C to 335°C. The thermal degradation peak of Epoxy was attained at a temperature of 365.16°C while the thermal degradation peak for the Cold Alkaline treated 5% SSD fibre and 7.5% PTE wood dust was attained at 412.22°C. This showed that the reinforcements improved the thermal stability of Epoxy. This is due to the high cellulose content of the fibre and wood dust reinforcements which improved the thermal stability of the composite. The reinforced composite has higher maximum degradation peaks than matrix such as Polyester (385°), however matrices such as High Density Polyethylene (HDPE) (515°C), vinyl ester (419°C), Polypropylene (PP) (431°C) and Polyurethane (420°C) have higher main peak thermal degradation. This is due to the nature of the matrix.

The thermal behaviour for both untreated and treated (Silane and methanol) aspen wood fibre reinforced composites with polypropylene (PP) or maleated polypropylene (MAPP) matrices has been studied by Monteiro et al. (2012). The 20 wt.% untreated fibre/PP composite was associated with the onset range of 307°C-453°C and a peak 476°C while the 20wt.% A1100 silane treated wood fibre/PP composite had an onset range 325°C-447°C and a peak of 471°C. The neat PP had an onset temperature of 459°C and a peak around 470˚C (Monteiro et al., 2012). Lei et al. (2007) studied the thermal stability of 30 wt. % pine wood fiber reinforcing recyled high density polyethylene (RHDPE) by TGA analysis. Wood fibre composites was treated with two active coupling agents: a maleated polyethylene (MAPE) and Titanium derived mixture (TDM) of chemical agents. The onset degradation temperature for the neat RHDPE occurs at 441˚C and the maximum degradation rate of about 471°C. The introduction of 30 wt.% wood fibre another intermediate decomposition peak, onset, stages I and II were respectively found: Pure fibre/RHDPE 262, 353 and 469˚C, 1.2% MAPE coupled fibre/RHDPE with 263, 353˚C and 469˚C and 0.9% TDM coupled fibre/RHDPE with 260˚C, 349˚C and 468˚C. The coupling agents seems to have little influence on the thermal degradation of the composite.

In summary the results have shown that the fibre reinforcement in the examined literatures did not have significant improvement in thermal stability, however the cold Alkanine treated 5% SSD fibre and 7.5% PTE wood dust improved the thermal stability of the composite. The use of treated 5% SSD fibre and 7.5% PTE wood dust to reinforce the matrices mentioned could lead to improved thermal stability.

4. Conclusion

Composites of various compositions of fibre content, wood filler content, alkaline treatment and fibre orientation were designed using Taguchi design of experiment tool and fabricated. Novel composite materials have been produced. The composites were subjected to tensile, flexural and compressive tests. The result showed that fibre angular orientation was the most significant factor affecting the mechanical properties of composite and essential in improving the properties. In addition, alkaline treatment was also significant in improving the mechanical properties of the composite. Results showed that for the hybrid composite the 5% NaOH cold alkaline treated 5% SSD fibre with 7.5% *PTE* wood dust have consistently given high Tensile, flexural and compressive strength (26.90 MPa, 77.38 MPa and 51.39) respectively. Results also showed that the addition of wood fibre and wood dust in epoxy improved the thermal stability of the composite. The use of natural reinforcements means lower production costs. The optimized composite produced has a lower density of 1.093 g/cm^3 while carbon-epoxy composite 1.6 g/cm^3 and S-glass fibre composite 1.9 g/cm^3. The hybrid natural reinforced composite would be essential in the aerospace and automotive industry since weight is among the most important factors in the industry. Low weight means lower fuel consumption of aerospace and automotive vehicles; lower weight means lower cost, lower energy usage and lower emission of greenhouse gas. An effective use of wood dust for composite material has successfully been used as a supporting reinforcement. The material properties achieved would be used for finite element simulation purpose for various applications to identify areas of application of the material.

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