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Study and Characterization of Flexural and Tensile Properties of Hybrid Bamboo/Sisal Fiber Reinforced Epoxy Composite

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Abstract

Bamboo and Sisal fibers are among the most common used reinforcement materials in the fabrication of new natural fiber based composite materials. In this work, an attempt is made to fabricate, characterize and analyze the mechanical property of hybrid sisal/bamboo fibers reinforced epoxy matrix composite. The fibers were manually extracted from sisal and bamboo plants. After extraction, bamboo and sisal fibers were chemically treated with 8% and 5% sodium hydroxide respectively, to remove the extra lignin and hemicelluloses so that the bond and interfacial, shear strength of the fibres can be improved. The experiment was conducted based on Taguchi experimental method by considering weight fraction of hybrid sisal/bamboo fibers, fibers orientation and curing temperature as basic parameters which affect product strength. Hand lay-up and compression techniques were employed in the fabrication of the experimental composite. The tensile and flexural strength tests of the experimental hybrid sisal/bamboo fiber reinforced epoxy matrix composites were determined by taking samples as per the ASTM standard. The result revealed that, the bamboo–sisal fiber reinforced epoxy composites fabricated with 25/25% weight fraction of sisal to bamboo fibers, fibers stacked unidirectional and cured at 25°C demonstrate a high tensile and bending strength.

Keywords: Hybrid sisal-bamboo fibers; Flexural and tensile strength; Taguchi method

Introduction

Currently, the need for a material with light weight and high performance is increasing for energy saving in various industries and engineering application. The synthetic fiber-reinforced polymers matrix composite materials are preferred in different application due their lightweight, high stiffness, and the ratio of specific strength to weight [1]. However, they have some drawbacks including high production cost and pollute the environment during production and rejection period.

Recently, materials researchers tilted to natural fiber reinforced composite as an alternative to synthetic fiber-reinforced composite for environment- friendly products [2]. The natural fiber materials such as: sisal, bamboo jute, flax, kenaf, banana, etc. are inherently low density, environmentally friendly and low-cost materials. In various research works, authors have used single natural plant fibers as reinforcement of polymer-based composite. Still, the mechanical performances of these natural fiber based composites are lagging behind to synthetic fiber base composite such as carbon and glass fiber-reinforced polymer. Some researchers have used hybrid fibers as reinforcement to improve the mechanical properties over single reinforcement. According to Navjot [3], the mechanical behaviour of hybrid sisal/hemp fiber reinforced HDPE composite is superior to single fiber-reinforced composite. Akash et al. [4] found higher tensile strength from characterized hybrid sisal/coir fiber reinforced epoxy composite. Therefore, to achieve high mechanical strength, it requires hybridizing of fibers in natural fibers based composite materials.

The bamboo and sisal fibers are great attention of most researchers' while they are advantageous over manmade fibers such as carbon and glass fibers. Bamboo fibers are extracted mechanically, chemically or by combining both processes from bamboo plants which are abundantly available plant in the world [5]. The mechanical characteristics of bamboo fibers are near to synthetic fibers. But, the factors such as orientation, fiber length and amount of treatment influence the mechanical strength of bamboo fiber [5,6]. The mechanical performance of bamboo fibers vary between types of species and through their culms. Roslan et al. [7] state that, the Dendrocalamus Asper (DA) species of bamboo plants have the best physical and mechanical characters and high tensile strength obtained from the bottom portion of all bamboo species.

Although, the sisal fibers, extracted by retting, decortications (mechanically) or by scraping process from Agave Sisalana (sisal plant) leaf which has cultivated in countries like Haiti, East Africa, Brazil Indonesia and India [8].This fiber is durable and ductile.

Both bamboo and sisal fibers are naturally compacted with cellulose and pectin materials. These materials have the behavior to absorb the moisture and decrease compatibility of fibers with a matrix which is the root cause to decrease the mechanical performance status of the composite. Due to eliminate this disadvantage, most researchers treat the fibers with varies acids and alkali chemicals to increase interface bonding of fibers and matrix [9]. NaOH is the common alkali treatment which various researchers have been used with different percentage.

Hence this study was conducted to investigate the tensile and three point bending tests on the specimen of various composite material made of epoxy resin as matrix and hybrid sisal-bamboo fibers as a reinforcement element, fabricated by hand layup and compression mold.

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Materials and Experimental Methods

Reinforcement materials

In composite materials, reinforcement (fibers), are used to increase the stiffness and strength. For this investigation, the sisal fibers have extracted by retting and scrapping process from the sisal plant leave (Agave sisalana). While, bamboo fibers are mechanically extracted from bamboo plant (Dendrocalamus asper) species in African bamboo industry Addis Ababa, Ethiopia. Both plants are demographically collected from town Ambo, Ethiopia. Both bamboo and sisal fibers have been treated with 8% and 5% of NaOH respectively to improve interfacing fiber to a matrix.

Matrix material

In this experiment, epoxy resin and catalyst (hardener) with a brand name ("SYSTEM # 2000 EPOXY") and ("SYSTEM # 2060 HARDENER"), respectively are obtained from KADISCO paint industry Town Addis Ababa, Ethiopia which is manufactured with fiber Glast development Corporation Company was used.

Extraction of fibers

Extraction of bamboo fiber: The bamboo culms are banded and crushed by using circular banding and crushing machine respectively. The bamboo culms prepared with 180 cm are divided into four slabs culms by using a circular hack-saw machine. Then the liquid forms and the thinner layer exoderm of the inner bamboo Culm have been removed during the crushing process and remaining parts have cleaved in a longitudinal direction. Then the crashed bamboo Culms is dried to the sun for three weeks. The prepared bamboo strips are waiting in water for one day in order to make soften slab of bamboo Culm. Then the bamboo Culm strips are beaten at slow uniform impact load by using rubber hammer in up to get single fiber. The resulting fiber bundle is combed using steel wire comb. The process of beating and combing is repeated until individual fibers are separated.

Extraction of sisal fiber: The strongest part of sisal plant leaf had cut out from the original sisal plant. Then shortening the leaf of sisal plants by trimming both ends. The scraping process is conducted by a sharp knife and the wood table had used to guide up the leaves during scraping. The single fibers had identified by washing the extracted fibers with pure water. Finally, the sisal fibers have been dried for five days for alkali treatment.

Bamboo and sisal fibers alkali treatment

The 5% and 8% concentration of NaOH alkali solution have been used to treat bamboo and sisal fiber respectively. The fibers are soaked at room temperature in NaOH solution for 4 and 8 hours for bamboo and sisal fiber respectively. Then, the fiber washed many times with fresh water in order to reduce reactivity with environment. Finally, these fibers dried in sunlight for four days.

Experimental design

The mechanical cheracters of composites materials influenced by many factors such as the amount of composite content and fabrication process. Hence, the experimental study has been performed on the hybrid sisal-bamboo fibers reinforced composite fabricated with various fiber stacking orientation, various fibers values and various curing temperature. The details of selected parameters, which influence the tensile and flexural strength, have been presented in Table 1.

Taguchi design of experiment: Taguchi experimental design is the appropriate design as it is used for various product quality control, product development, and process optimization and uses the minimum number of runs. It is a group of fractional factorial designs concentrated on the estimation of the main effect. For this study, four factors of fiber reinforcement and three levels (runs) for each factor were considered for composite preparation. According to Taguchi design approach the product quality (signal) to uncontrollable factors (noise) should be high.

The following steps are the Taguchi design of experiment procedure [10]:

1) Define the problem and noise factors
2) Identify design parameters that influence product properties.
3) Determine control parameters, response variables, and their levels.
4) Select the orthogonal array.
5) Conduct experiments.
6) Analysis final result and predict the effect of level.

Define the problem and noise factors: To recognize the influence of natural fibers values and fabrication process on tensile and bending strength of Hybrid sisal/Bamboo fibers reinforced epoxy composite materials.

Identify design parameters that influence product properties: The fiber orientation, fibers weight percentage and socking temperature during compression molding are considered as design factors that affect the characters of composite material.

Determine control parameters with their runs and response variables: The tensile and three point bending (flexural) strength tests was chosen as a response variable for the investigation. Control parameters are the variables which influence the result of the process or the product. The factors listed in Table 1 were chosen as control parameter with their levels.

Select orthogonal array: Taguchi representation for the orthogonal arrays is; La (b^c), where a is the value experimental runs, b is the value of levels for each factor, and c is value of variables. Seral levels of factors are used in orthogonal arrays. In this investigation, the factors are listed with their levels in Table 2 depending on L9 orthogonal arrays

Preparation of composite and specimen

The nine composite materials, used for this investigation were prepared with hand layup process and compression molding technique at various curing temperature. The composite prepared with six plies of

Factors affect composite properties	Levels of factors and values		
	Level 1	Level 2	Level 3
Sisal fiber (wt%)	25	20	15
Bamboo fiber (wt%)	25	20	15
Plies orientation (°)	[0, 0, 0, 0, 0, 0]	[90, 90, 90, 90, 90, 90]	[0, 90, 90, 0, 0, 90]
Curing temperature (°C)	25	40	55

Table 1: The levels and values of factors which affect the tensile and flexural strength.

HSBFREC. No. ????	Sisal volume fraction (%)	Bamboo volume fraction (%)	The orientation of fiber plies	The curing temperature (°C)
1	25	25	$[0_S, 0_B, 0_S, 0_B, 0_S, 0_B,]$	25
2	25	20	$[90_B, 90_S, 90_B, 90_S, 90_B, 90_S]$	40
3	25	15	$[0_S, 90_B, 90_S, 0_B, 0_S, 90_B]$	55
4	20	25	$[90_B, 90_S, 90_B, 90_S, 90_B, 90_S]$	55
5	20	20	$[0_S, 90_B, 90_S, 0_B, 0_S, 90_B]$	25
6	20	15	$[0_S, 0_B, 0_S, 0_B, 0_S, 0_B]$	40
7	15	25	$[0_S, 90_B, 90_S, 0_B, 0_S, 90_B]$	40
8	15	20	$[0_S, 0_B, 0_S, 0_B, 0_S, 0_B]$	55
9	15	15	$[90_B, 90_S, 90_B, 90_S, 90_B, 90_S]$	25

Table 2: Orthogonal arrays for the design of the experiment.

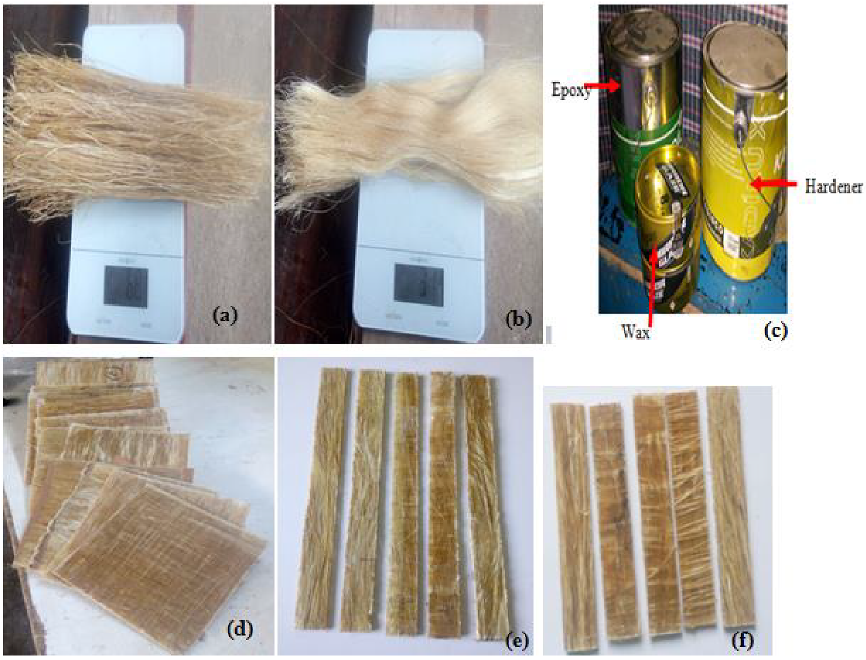

Figure 1: Materials and prepared samples for tensile and flexural test.

fibers depend on the parameters presented in Table 1. The 2:1 Epoxy resin to catalyst (hardener) chemicals ware mixed well and painted on the plies layer by layer to bind the fibers. At first, the aluminum foam was placed over the steel plate to prepare the good and clean surface of the composite. Then the wax painted on the surface of aluminum foam used for releasing at the end of curing time. After that, the epoxy resin spread on the painted wax. The fibers is over placed one by one and painted up to the last layer. Then the prepared samples were allowed to compress. Compression molding machine was used to develop 5 Mpa pressure (Figure 1).

Specimen tests: The tensile and three points bending (flexural) test was investigated on three specimens to evaluate the strength of each composite. The investigations were conducted on UTM at 0.5 mm/min cross-head speed of the machine for both tensile and flexural load.

Tensile test: The Characterizing tensile strength of HSBFREC was conducted with UTM according to (ASTM D3039) material tests. The geometry of the specimen was 3 x 20 x 220 mm and gauge length is 120 mm. During the test, the specimens were placed in the grips of UTM and axial load is applied at both ends of the specimen. Stress-strain curves, ultimate tensile strength were recorded by a machine and elastic modulus was determined from the linear part of stress-strain diagram. The specimen under tensile test and fracture mode is presented in Figure 2.

Flexural test: The bending (Flexural strength) is the ability of materials to resist familiarity under an applied load. This test is performed as per (ASTM D790) standard using UTM. The prepared dimension of the specimen is 123 x 20 x 3.2 mm and the support span-to-depth ratio is 32:1 and the support span length is 102.4 mm. The loading arrangement and failure mode is presented in Figure 3.

Result and Discussion

Evaluation of tensile strength

The Tensile strength has been evaluated for nine different HSBFREC. For each composite five similar specimens are tested. Figure 4a display the average values of stress-strain curves of tensile strength for all composites during tensile test. Figure 4b present the comparison of ultimate tensile strength for all investigated hybrid bamboo/sisal reinforced epoxy composite.

The Orientation of fiber plies, the weight percentage of fibers and also the composite curing temperature play a great effect on composite under tensile load. For example from Figure 4b the composite type

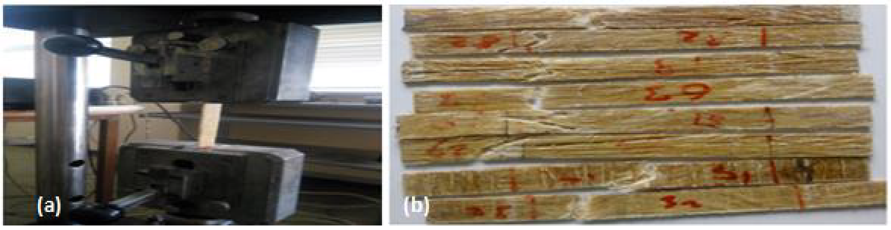

Figure 2: (a) Fixture of tensile test and (b) failure mode of samples after the test.

Figure 3: (a) Fixture of the three point (flexural) test before loaded (b) fixture of flexural test after loaded (c) fracture mode of specimen.

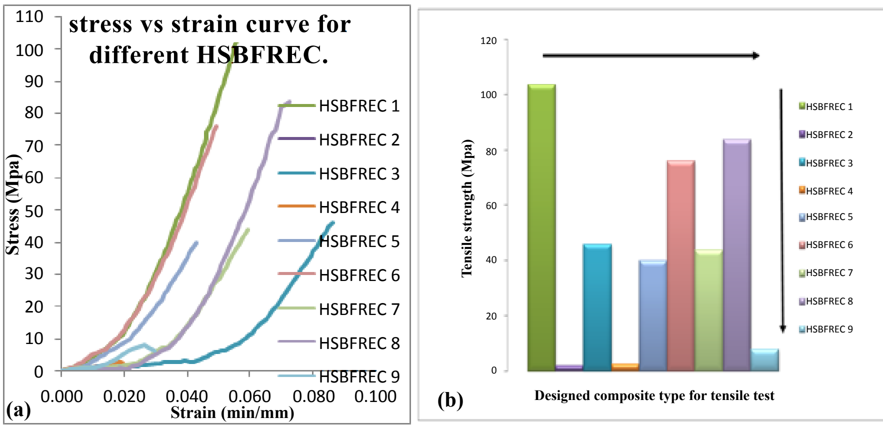

Figure 4: (a) the average value of stress-strain curve for the tensile test (b) the average value of Tensile strength of all HSBFREC.

HSBFREC 1 is fabricated from (25% sisal fiber, 25% bamboo fiber, 50% epoxy weight fraction), cured at 25°C and fibers stack-oriented [$0_S/0_B/0_S/0_B/0_S/0_B$] is recording the maximum ultimate tensile strength (103.611 Mpa) compared to others composites. The ultimate tensile strength of HSBFREC becomes very low, while all orientations of laminated fibers are perpendicular to the applied load. From Figure 4b the ultimate strength and elastic modulus of (HSBFREC 2, HSBFREC 4, and HSBFREC 9) are, become very low due to the orientation of fibers are perpendicular to the applied load.

When the orientation of HSBFREC is laminated with both transverse and longitudinal direction to the applied tensile load, the result of ultimate strength become medium compared to unidirectional oriented composite. For example, Figure 4b display that, the ultimate tensile and tensile modulus values of (HSBFREC 3, 5 and 7) are (45.75, 39.7778 and 43.61 Mpa) respectively which are the medium strength compared to other results.

Evaluation of flexural test

The three-point bending test was conducted using the universal testing machine (wp310 universal material tester 50 kN) to measures the force required to bend a specimen under a three-point loading situation. The specimens prepared according to ASTM standard (D790-2010) and the span length was 102.5 mm as presented in Figure 5.

The values of specimen dimension, the maximum load and the ultimate strength value of the testing specimen are displayed to an integrated computer as per Figure 5.

Under three points bending in Figure 5, the load P is applied at mid-span of a rectangular specimen of span L between two rollers, the highest flexural strength is determined by:

$$\sigma_b = \frac{M_b}{W} \tag{1}$$

Then the maximum bending moment is then found as;

$$M_b = \frac{Fl}{4} \tag{2}$$

The resistance of moment corresponding to bending with the region of elastic deformations is calculated as

$$W = \frac{bh^2}{6} \tag{3}$$

where σ_b: Ultimate bending strength; M_b: Maximum Bending moment; W: The reistance of moment; *F*: Maximum Applied Load; *l*: Span

Length; b: Width of the specimen; h: Thickness of specimen.

Figure 5b display result of pick flexural strength for various HSBFREC.

The combination of bamboo and sisal fiber reinforced epoxy composite give the better flexural strength, under bending load. Figure 5b the HSBFREC 1 is fabricated with 25%/25% wt% of sisal/bamboo, Orientation $[0_S/0_B/0_S/0_B/0_S/0_B]$ and curing temperature (25°C) give better flexural strength under bending load. Due to the fiber orientation is along the specimen length, the flexural strength of HSBFREC increase. Figure 5b shows, that the ultimate bending value of (HSBFREC 2, 4, 9) are (15.013, 7.51 and 15.01 Mpa) respectively is very low doe to fibers plies are perpendicular to span length. Figure 5b shows, that (HSBFREC 3, 5, 7) designed with the fiber orientation of fiber $[0_S/90_B/90_S/0_B/0_S/90_B]$ have medium values (60.5, 57.556 and 77.576 Mpa respectively) compared to others. From (HSBFREC 3, 5, 7) the HSBFREC 7, have more strength due to the decrement of bamboo fibers weight fraction. This indicates the sisal fiber play vital role to increase the bending strength of HSBFREC. Regarding curing temperature, the 25°C have the best curing of HSBFREC while increasing temperature has decreased the flexibility of fibers. The comparison bending strength result of (HSBFREC 2, 4, 9) regarding curing temperature ensures the decrement of fiber flexibility due to increasing temperature.

Now, we have to find the ratio of Signal to Noise for all combination of tensile and bending strength tabulated in Table 3. The three functions have been postulated by Taguchi are:

1. Smaller the better,
2. Larger the better,
3. Nominal the best.

In this experimental, the larger better is selected to determine the compression, tensile hardness and flexural performance of prepared composite specimens. The signal to noise (S/N) ratio for large better types of the objective function is calculated as follows:

$$\eta = -10log_{10}\frac{1}{y^2}; \tag{4}$$

Where y is the value of ultimate strength.

The S/N ratio values for each experiment are computed by using the MINITAB version 18.0 software. The computed S/N ratio from MINITAB software is presented in Tables 3 and 4.

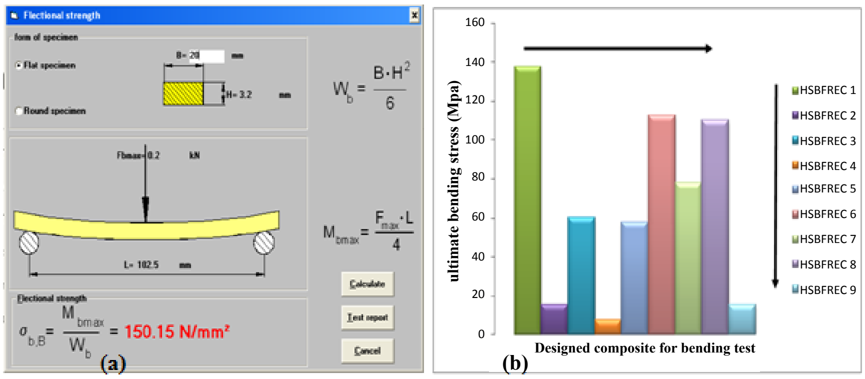

Figure 5: (a) the three-point bending test nomenclature with wp310 UTM (b) flexural strength of all HSBFREC.

Composite type	Tensile modulus (Mpa)	Tensile strength (Mpa)	S/N ratio values for tensile strength	Flexural strength (Mpa)	S/N ratio values for flexural strength
HSBFREC 1	3065.539	103.611	40.3	137.633	42.77
HSBFREC 2	243.9024	1.845	5.32	15.013	23.53
HSBFREC 3	1444.44	45.75	33.2	60.05	35.57
HSBFREC 4	384.6154	2.5	7.95	7.51	17.51
HSBFREC 5	1628.319	39.7778	32	57.556	35.2
HSBFREC 6	2077.419	75.9444	37.6	112.45	41.01
HSBFREC 7	1539.267	43.6111	32.79	77.576	37.79
HSBFREC 8	2077.419	83.55556	38.43	110.1	40.8
HSBFREC 9	612.2449	7.583333	17.6	15.01	23.52

Table 3: S/N ratios values for ultimate bending and tensile strength.

Factors		Level 1	Level 2	Level 3	Max-Min	Rank
Sisal Volume fraction%	For tensile	26.27	25.85	29.6	3.75	4
	For flexural	33.95	31.24	34.03	2.79	3
Bamboo volume fraction%	For tensile	27.01	25.25	29.46	4.21	3
	For flexural	32.69	33.17	33.36	0.67	4
Fiber orientation	For tensile	38.77	10.29	32.66	28.48	1
	For flexural	41.52	21.52	36.18	20	1
Curing temperature	For tensile	29.96	25.23	26.52	4.73	2
	For flexural	33.83	34.11	31.29	2.82	2

Table 4: The Response values of the control factors at each level for both ultimate tensile and flexural strength.

From Figure 6a and 6b it is seen that a large SN ratio was recorded for bamboo and sisal fibers of weight fraction level 3 (15% and 15%) respectively. and also the Figure 6c and 6d reveal that the large SN ratio was seen for fiber orientation and curing temperature at level $1[0_S/0_B/0_S/0_B/0_S/0_B]$ and 25°C respectively.

From Figure 7a and 7b it is seen that a large SN ratio was recorded for bamboo and sisal fibers of the mass fraction at level 3 (15% and 15%) respectively and also the Figure 7c and 7d, reveal that the large SN ratio was seen for fiber orientation and curing temperature at level $1[0_S/0_B/0_S/0_B/0_S/0_B]$ and level 2 (40°C) respectively.

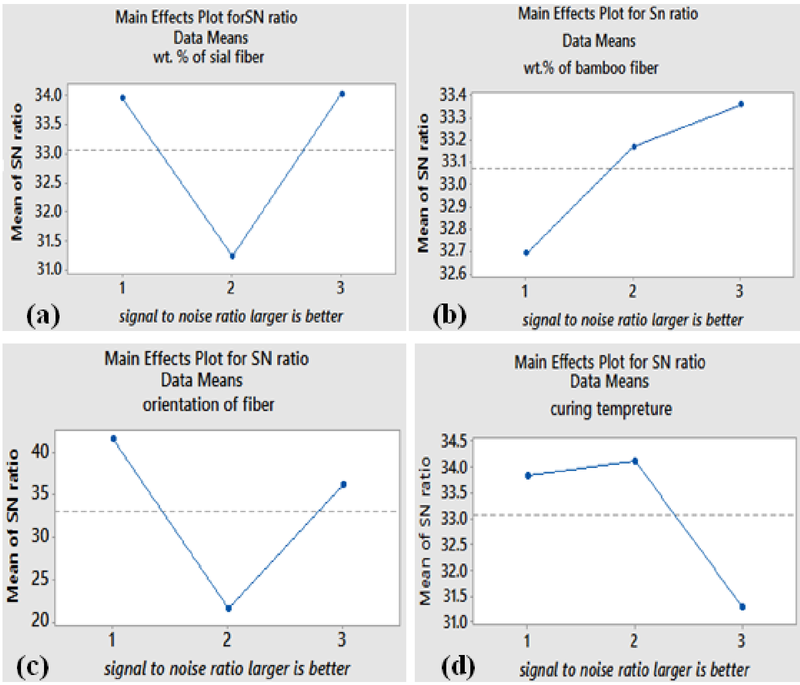

Figure 6: Mean effects curve for SN ratios under tensile strength.

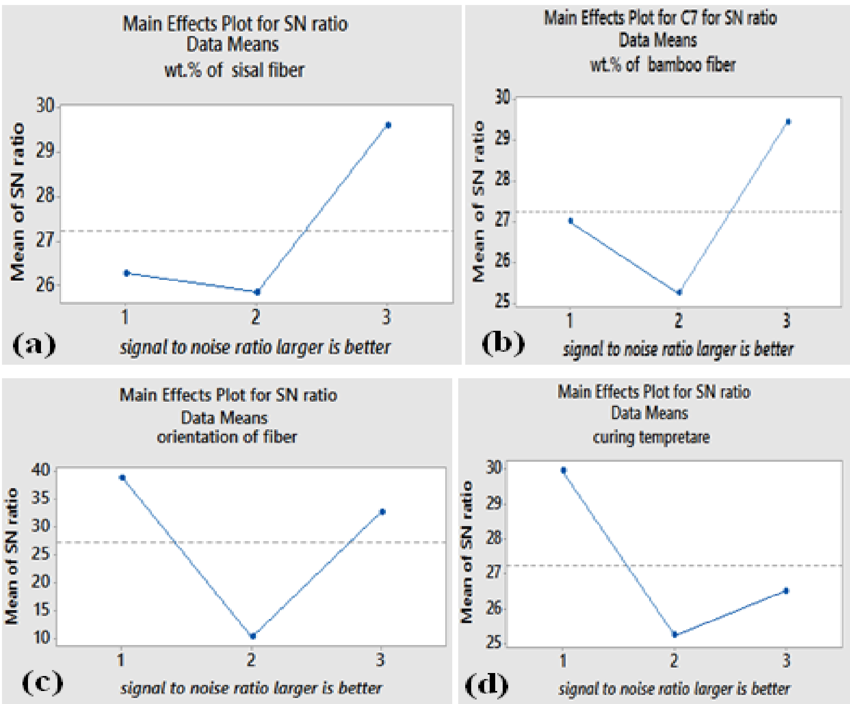

Figure 7: Mean effects curve for SN ratios under flexural strength.

Conclusion

The bamboo and sisal fibers are extracted mechanically and manually from bamboo and sisal plants respectively. Alkaline treatment was carried out for both sisal and bamboo 8% and 5% NaOH concentration respectively to remove lignin, cellulose, and other fats. Next to that the sisal/bamboo hybridized fibers epoxy composite material was fabricated and characterized the mechanical properties specifically tensile and bending strength by using laboratory experiment. Based on the result data obtained from experimentally investigated tensile and flexural tests, few points recognized as follows: the hybridized sisal/Bamboo fibers reinforced epoxy matrix composite material fabricated at 25° consolidation temperature with 25/25% sisal to bamboo fibers, 50% epoxy weight fraction and oriented fibers with $[0_S0_B0_S0_B0_S0_B]$ record the maximum values of tensile and bending strength (103.611 and 137.633 Mpa) respectively. The result observed from S/N curve means value reveals that fibers stack $[0_S0_B0_S0_B0_S0_B]$ and curing temperature (25°C) have played a great role to increase tensile and flexural strength. From the experimental testing result, henceforth, can conclude that the unidirectional bamboo/sisal fiber reinforced epoxy matrix composite material have significantly good mechanical properties, along with the inherent advantages being environmental friendly, cost effectiveness, low specific to weight ratio and so on for various application.

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