Statistical analysis of Mechanical Properties of Flax, Sisal and Hemp Fiber Reinforced Composites with Polyester and Epoxy Resin Matrices by using Taguchi Method

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Abstract: **Taguchi Method is a statistical approach to optimize the process parameters and improve the quality of components that are manufactured. In the present study, Flax-Sisal-Hemp Fiber reinforced composites were fabricated and tested for their mechanical properties. The resins used in this study are polyester and epoxy. Experiments were conducted using Taguchi L9 orthogonal array considering the three deign parameters viz. weight fraction of the Flax, weight fraction of the sisal and weight fraction of the Hemp. The experimental results were analyzed using Taguchi optimization method. Orthogonal arrays of Taguchi, the signal-to-noise (S/N) ratio, the analysis of variance (ANOVA), and regression analyses are employed. Analysis of variance (ANOVA) was carried out to obtain the significant values of tensile strength, flexural strength and impact strength at 95 % confidence level.**

Keywords: **ANOVA, Orthogonal Array, S/N Ratio, Taguchi Method.**

1. Introduction:

Recently there is focus on the development of natural fibers like jute, coir, sisal, pineapple, ramie, bamboo, banana etc., is to explore its application in low load condition. Composites, the wonder material with light-weight, high strength-to weight ratio and stiffness properties have come a long way in replacing the conventional materials like metals, woods etc. The replacement of steel with composites can save a 60-80 percentage of component weight. Use of polymer based composite materials is increasing because of their light weight, good mechanical and tribological responses [1]. However, composites encounter problems such as fiber fracture, matrix cracking and delamination. Of these, fiber fracture and matrix cracking plays an important role in laminates under tensile load [2-5]. After the composite development to meet the challenges of aerospace sector, researchers have focused to cater the needs of domestic and industrial applications. The abundant availability of natural fibers such as jute, coir, sisal, pineapple, ramie, bamboo, banana etc., has given a impetus to the development of natural fiber composites. This development is done considering the deforestation (depletion of forest resources) with an objective of returns for the cultivation of natural fibers. Composite boards have been used in development of panel and flush doors to satisfy the low cost housing needs. Other product development such as panel roofing sheets with sisal fibers and glass added to jute fiber produces large increase in mechanical properties of composites. Since natural fiber composite is being cost effective materials finds it application in building, construction industry, and packaging, automobile and storage devices. The mechanical properties of some natural fibers such as jute, sisal, and flax fibers were compared to glass fibers and it was observed that specific moduli of these fibers are comparable to or better than those of glass fibers [6].
Taguchi method of design of experiments, genetic algorithm, and artificial neural network are some of the important tools used for robust design to produce high quality products quickly and at low cost. Taguchi method based on performing evaluation or experiments to test the sensitivity of a set of response variables to a set of control parameters (or independent variables) by considering experiments in "orthogonal array" with an aim to attain the optimum setting of the control parameters. Orthogonal arrays provide a best set of well-balanced (minimum) experiments [7]. The S/N ratios, which are log functions of desired output, serve as the objective functions for optimization, help in data analysis and the prediction of the optimum results. There are three forms of S/N ratio that are of common interest for optimization of static problems. 1. Smaller-the-better, 2.Larger-the-better and 3.Nominalthe-best. Different factors affect the strength to a different degree. Analysis of variance is a better feel for the relative effect of the different factors obtained by the decomposition of variance [8, 9].
Taguchi method of analysis is uses to reduce total number of experiments. The experimental data is analyzed using Taguchi method for optimal conditions of input parameters. ANOVA carried out on experimental data to find the significant effect of the input parameters.

2. Experimental

2.1 Materials

2.1.1 Flax fiber: These fibres obtained from the stems of the plant Linum usitatissimum are used mainly to make linen. The plant has been used for fibre production since prehistoric times. Like cotton, flax fibre is a cellulose polymer, but its structure is more crystalline, making it stronger, crisper and stiffer to handle, and more easily wrinkled. Flax fibres range in length up to 90 cm, and average 12 to 16 microns in diameter. They absorb and release water quickly, making linen comfortable to wear in hot weather.

2.1.2 Sisal fiber: These fibers are obtained from Agave sisalana, a native of Mexico. The hardy plant grows well in a variety of hot climates, including dry areas unsuitable for other crops. Lustrous and creamy white, sisal fibre measures up to 1 m in length, with a diameter of 200 to 400 microns. It is a coarse, hard fibre unsuitable for textiles or fabrics. But it is strong, durable and stretchable, does not absorb moisture easily, resists saltwater deterioration, and has a fine surface texture that accepts a wide range of dyes.

2.1.3 Hemp fiber: These fibres are obtained from the bast of the plant Cannabis sativa L. It grows easily - to a height of 4 m - without agrochemicals and captures large quantities of carbon. Long, strong and durable, hemp fibres are about 70% cellulose and contain low levels of lignin (around 8-10%). The fibre diameter ranges from 16 to 50 microns. Hemp fibre conducts heat, dyes well, resists mildew, blocks ultraviolet light and has natural anti-bacterial properties. Shorter, woody core fibres ("tow") contain higher levels of lignin.

2.1.4 Polyester resin: Polyester is a category of polymers that contain the ester functional group in their main chain. Unsaturated polyesters (UPR) are thermosetting resins. They are used in the liquid state as casting materials, in sheet molding compounds, as fiberglass laminating resins and in non-metallic auto-body fillers. They are also used as the thermoset polymer matrix in pre-pregs. The hardener used for polyester resin was methyl ethyl ketone peroxide (MEKPO).

2.1.5 Epoxy resin: Epoxy resins have been widely used for coatings, electronic materials, adhesives, and matrices for fiber-reinforced composites because of their outstanding mechanical properties, high adhesion strength, good heat resistance, and high electrical resistance. The hardener used for epoxy resin was Triethylene Tetramine (TETA).

2.2 Design of Experiments by Taguchi Method:

The design of experiments carried out with the help of Taguchi's L9 orthogonal array to reduce the number of experiments. The L9 orthogonal array contains nine rows and three columns, with 9 degrees of freedom (df) to treat one for Mean value and two each for the other factors. Each parameter level is set according to the L9 orthogonal array, based on Taguchi method of design. The experimental results further transferred into S/N ratio using MINITAB 17 software. The different levels of variables used in experiment listed in table 1. When response maximized (Larger-the-better), Taguchi uses the following formula for S/N ratio (η).

$$\eta = -10\,log_{10}\left(\frac{1}{n}\sum\nolimits_{i=1}^{n} {y^2}_i\right)$$

Table 1 Selected Factors and their Levels

S.NO	PARAMETER	CODE	LEVELS			UNITS
			1	**2**	**3**	
1	Weight Fraction of the FLAX	X	0	0.25	0.5	Grams
2	Weight Fraction of the SISAL	Y	0	0.25	0.5	Grams
3	Weight Fraction of the HEMP	Z	0	0.25	0.5	Grams

The most suitable orthogonal array for experimentation is L9 array as shown in Table 2. Therefore, a total nine experiments are to be carried out.

Table 2 Orthogonal Array (OA) L9

Experiment No.	Control Factors		
	X	**Y**	**Z**
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

2.3 Conducting the matrix experiment

In accordance with the above OA, experiments were conducted with their factors and their levels as mentioned in table 1. The experimental layout with the selected values of the factors is shown in Table 3. Each of the above 9 experiments were conducted 4 times (36 experiments in all) to account for the variations that may occur due to the noise factors.

Table 3 Orthogonal Array (OA) with control factors

S.NO	WEIGHT FRACTON OF THE FLAX(X)	WEIGHT FRACTION OF THE SISAL(Y)	WEIGHT FRACTION OF THE HEMP(Z)
1	0	0	0
2	0	0.25	0.25
3	0	0.5	0.5

4	0.25	0	0.25
5	0.25	0.25	0.5
6	0.25	0.5	0
7	0.5	0	0.5
8	0.5	0.25	0
9	0.5	0.5	0.25

2.4 Processing:

Many techniques are available in industries for manufacturing of composites such as compression mouldings, vacuum moulding, pultruding, and resin transfer moulding are few examples. The hand layup process of manufacturing is one of the simplest and easiest methods for manufacturing composites. A primary advantage of the hand layup technique is to fabricate very large, complex parts with reduced manufacturing times. Additional benefits are simple equipment and tooling that are relatively less expensive than other manufacturing processes. The fibers were added to the resin mixed hardener with required weight percentages. The fiber resin hardener mixture was poured in to the moulds for different testing prepared as per ASTM standards. The setting time taken by the composites was approximately 24 hours. The prepared composites were subjected to tensile, flexural and impact tests.

2.5 Tensile, Flexural and Impact tests:

An electronic tensometer used to find the tensile and flexural properties of the composite specimens. The tensile test specimens were made in accordance with ASTM-D 638M to measure the tensile properties. For flexural properties, three point bend tests performed in accordance with ASTM D790M test method. The samples tested at a crosshead speed of 1 mm/min. An Izod impact test machine used to find the impact properties of the composite specimens. The specimens were prepared in accordance with ASTM D256-97.

3. Results and Discussion

3.1. Taguchi analysis for tensile, flexural and impact strength

Experiment results for tensile strength, flexural strength, impact strength, S/N ratio for each combination parameters is calculated and shown in table 4, 5 and 6 for epoxy resin and table 10, 11 and 12 for polyester respectively. Analysis of the influence of control factors (weight fraction of flax(X), weight fraction of Sisal(Y) and weight fraction of Hemp (Z)) on the responses are obtained from the response tables of mean S/N ratio and the results are listed in table 7, 8 and 9 for epoxy and table 13, 14 and 15 for polyester respectively. The main effect plots for S/N ratio are presented in Fig. 1, 2. (a), (b) and (c) for Epoxy and polyester resin respectively.

Table 4 Experimental results of tensile strength along with S/N ratio **(epoxy resin)**

S.NO	Weight fraction of the FLAX(X)	Weight fraction of the SISAL(Y)	Weight fraction of the HEMP(Z)	TS1 (N/mm²)	TS2 (N/mm²)	TS3 (N/mm²)	TS4 (N/mm²)	S/N Ratio	MEAN (N/mm²)
1	1	1	1	21.5	22	22.5	22.8	26.9205	22.2000
2	1	2	2	32.27	32.53	32.53	33.1	30.2652	32.6075
3	1	3	3	37.6	37.87	38.4	39.2	31.6533	38.2675
4	2	1	2	24.67	24.67	25.2	25.47	27.9572	25.0025
5	2	2	3	25.6	25.6	25.87	26.14	28.2323	25.8025
6	2	3	1	25.34	25.87	26.14	26.4	28.2755	25.9375
7	3	1	3	24.27	24.27	25.07	26.14	27.9250	24.9375
8	3	2	1	35.47	35.74	36	36.8	31.1242	36.0025
9	3	3	2	48.54	48.54	49.07	50.14	33.8145	49.0725

Table 5 Experimental results of flexural strength along with S/N ratio (epoxy resin)

S.NO	Weight fraction of the FLAX(X)	Weight fraction of the SISAL(Y)	Weight fraction of the HEMP(Z)	FS1 (N/mm²)	FS2 (N/mm²)	FS3 (N/mm²)	FS4 (N/mm²)	S/N Ratio	MEAN (N/mm²)
1	1	1	1	90	91.5	91.8	92	39.2108	91.325
2	1	2	2	93.6	98.13	102.13	106.65	39.9807	100.128
3	1	3	3	136.53	140.82	145.08	149.34	43.0887	142.943
4	2	1	2	145.08	149.34	157.89	166.41	43.7527	154.680
5	2	2	3	238.95	247.47	251.76	255.99	47.8995	248.542
6	2	3	1	140.82	145.08	149.34	157.86	43.3983	148.275
7	3	1	3	226.14	230.4	238.92	247.44	47.4326	235.725
8	3	2	1	132.3	136.56	140.82	145.08	42.8255	138.690
9	3	3	2	217.62	221.88	230.4	238.92	47.1117	227.05

Table 6 Experimental results of impact strength along with S/N ratio (epoxy resin)

S.NO	Weight fraction	Weight fraction	Weight fraction	IS1	IS2	IS3	IS4	S/N	MEAN

	of the FLAX(X)	of the SISAL(Y)	of the HEMP(Z)	(J/m)	(J/m)	(J/m)	(J/m)	Ratio	(J/m)
1	1	1	1	89	89	90	90	39.0361	89.50
2	1	2	2	120	130	140	140	42.3909	132.50
3	1	3	3	180	180	190	190	45.5036	185.00
4	2	1	2	185	187	192	190	45.3339	188.50
5	2	2	3	120	128	130	132	42.0929	127.50
6	2	3	1	110	115	125	125	41.4530	118.75
7	3	1	3	95	99	105	110	40.1527	102.25
8	3	2	1	93	94	95	99	39.5700	95.25
9	3	3	2	165	170	185	185	44.8889	176.25

Table 7 Response table for S/N ratio for Tensile Strength (epoxy resin)

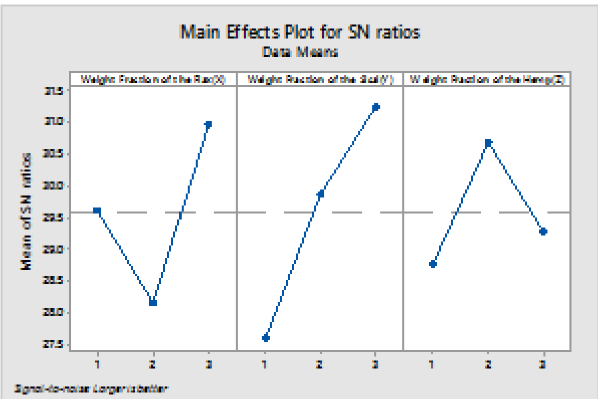
RESPONSE TABLE FOR SIGNAL TO NOISE RATIO			
LARGER IS BETTER			
LEVEL	WEIGHT FRACTON OF THE FLAX(X)	WEIGHT FRACTION OF THE SISAL(Y)	WEIGHT FRACTION OF THE HEMP(Z)
1	29.61	27.60	28.77
2	28.15	29.87	30.68
3	30.95	31.25	29.27
DELTA	2.80	3.65	1.91
RANK	2	1	3

Table 8 Response table for S/N ratio for Flexural Strength (epoxy resin)

RESPONSE TABLE FOR SIGNAL TO NOISE RATIO			
LARGER IS BETTER			
LEVEL	WEIGHT FRACTON OF THE FLAX(X)	WEIGHT FRACTION OF THE SISAL(Y)	WEIGHT FRACTION OF THE HEMP(Z)
1	40.76	43.47	41.81
2	45.02	43.57	43.62
3	45.79	44.53	46.14
DELTA	5.03	1.07	4.33
RANK	1	3	2

Table 9 Response table for S/N ratio for Impact Strength (epoxy resin)

RESPONSE TABLE FOR SIGNAL TO NOISE RATIO			
LARGER IS BETTER			
LEVEL	WEIGHT FRACTON OF THE FLAX(X)	WEIGHT FRACTION OF THE SISAL(Y)	WEIGHT FRACTION OF THE HEMP(Z)
1	42.25	41.56	40.02
2	43.02	41.35	44.26
3	14.54	43.89	42.53
DELTA	1.48	2.54	4.24
RANK	3	2	1



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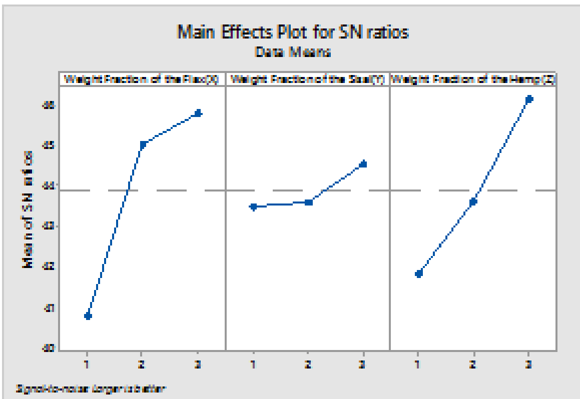

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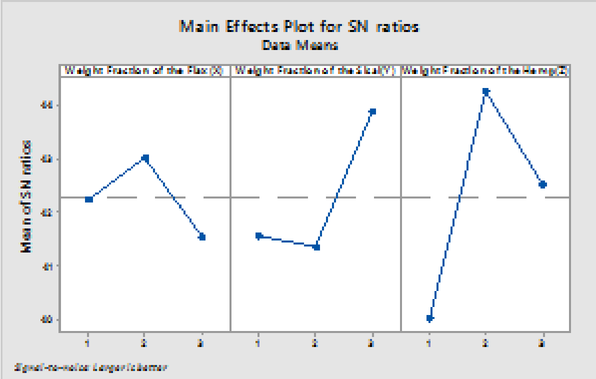

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Fig. 1 Main effects plot of S/N ratio for a) Tensile Strength b) Flexural Strength c) Impact Strength

Larger value of S/N ratios corresponds to better quality, so optimal combination of design parameters can be obtained as X3Y3Z2 for tensile strength, X2Y2Z3 for flexural strength and X1Y3Z3 for impact strength.

Table 10 Experimental results of tensile strength along with S/N ratio (Polyester resin)

S.NO	Weight fraction of the FLAX(X)	Weight fraction of the SISAL(Y)	Weight fraction of the HEMP(Z)	TS1 (N/mm²)	TS2 (N/mm²)	TS3 (N/mm²)	TS4 (N/mm²)	S/N Ratio	MEAN (N/mm²)
1	1	1	1	20	20.21	20.2	20.9	26.1581	20.3275
2	1	2	2	24.3	24.6	24.6	25.1	27.8346	24.6500
3	1	3	3	26.7	28	29.1	29.4	29.0170	28.3000
4	2	1	2	21.3	21.8	22.4	22.7	26.8603	22.0500
5	2	2	3	24.5	24.5	25.1	25.6	27.9283	24.9250
6	2	3	1	24	24.3	24.3	24.5	27.7025	24.2750
7	3	1	3	21.4	21.4	21.4	21.9	26.6576	21.5250
8	3	2	1	32.5	33.1	33.4	33.6	30.4076	33.1500
9	3	3	2	29.3	29.3	30.4	30.4	29.4945	29.8500

Table 11 Experimental results of flexural strength along with S/N ratio (polyester resin)

S.NO	Weight fraction of the FLAX(X)	Weight fraction of the SISAL(Y)	Weight fraction of the HEMP(Z)	FS1 (N/mm²)	FS2 (N/mm²)	FS3 (N/mm²)	FS4 (N/mm²)	S/N Ratio	MEAN (N/mm²)
1	1	1	1	110	112	120	122	41.2640	116.000
2	1	2	2	145	149.4	153.6	166.4	43.6941	153.600
3	1	3	3	179.4	187.7	196.26	209	45.6739	193.090
4	2	1	2	157.86	162.14	166.4	170.67	44.3000	164.267
5	2	2	3	268.8	273.06	281.6	294.4	48.9109	279.465
6	2	3	1	157.87	162.14	164.4	160.4	44.1446	161.202
7	3	1	3	179.2	183.47	189.86	195.41	45.4220	186.985
8	3	2	1	145	153.6	153.6	166.4	43.7559	154.650
9	3	3	2	221.87	221.87	230.4	230.4	47.0827	226.135

Table 12 Experimental results of impact strength along with S/N ratio (polyester resin)

S.NO	Weight fraction of the FLAX(X)	Weight fraction of the SISAL(Y)	Weight fraction of the HEMP(Z)	IS1 (J/m)	IS2 (J/m)	IS3 (J/m)	IS4 (J/m)	S/N Ratio	MEAN (J/m)
1	1	1	1	120	120	125	135	41.9085	125.00
2	1	2	2	200	204	209	210	46.2618	205.75
3	1	3	3	230	242	256	260	47.8231	247.00
4	2	1	2	215	217	217	220	46.7383	217.25
5	2	2	3	170	178	186	190	45.1297	181.00
6	2	3	1	190	190	198	200	45.7713	194.50
7	3	1	3	200	222	232	240	46.9234	223.50
8	3	2	1	110	116	124	130	41.5309	120.00

9	3	3	2	215	224	232	240	47.1274	227.75

Table 13 Response table for S/N ratio for Tensile Strength (polyester resin)

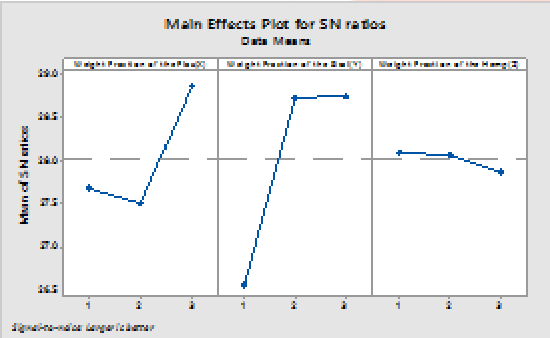
RESPONSE TABLE FOR SIGNAL TO NOISE RATIO			
LARGER IS BETTER			
LEVEL	WEIGHT FRACTON OF THE FLAX(X)	WEIGHT FRACTION OF THE SISAL(Y)	WEIGHT FRACTION OF THE HEMP(Z)
1	27.67	26.56	28.09
2	27.50	28.72	28.06
3	28.85	28.74	27.87
DELTA	1.36	2.18	0.22
RANK	2	1	3

Table 14 Response table for S/N ratio for Flexural Strength (polyester resin)

RESPONSE TABLE FOR SIGNAL TO NOISE RATIO			
LARGER IS BETTER			
LEVEL	WEIGHT FRACTON OF THE FLAX(X)	WEIGHT FRACTION OF THE SISAL(Y)	WEIGHT FRACTION OF THE HEMP(Z)
1	43.54	43.66	43.05
2	45.79	45.45	45.03
3	45.42	45.63	46.67
DELTA	2.24	1.97	3.61
RANK	2	3	1

Table 15 Response table for S/N ratio for Impact Strength (polyester resin)

RESPONSE TABLE FOR SIGNAL TO NOISE RATIO			
LARGER IS BETTER			
LEVEL	WEIGHT FRACTON OF THE FLAX(X)	WEIGHT FRACTION OF THE SISAL(Y)	WEIGHT FRACTION OF THE HEMP(Z)
1	45.33	45.19	43.07
2	45.88	44.31	46.71
3	45.19	46.91	46.63
DELTA	0.69	2.60	3.64
RANK	3	2	1



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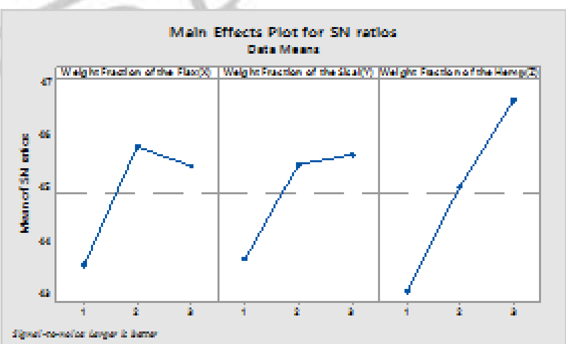

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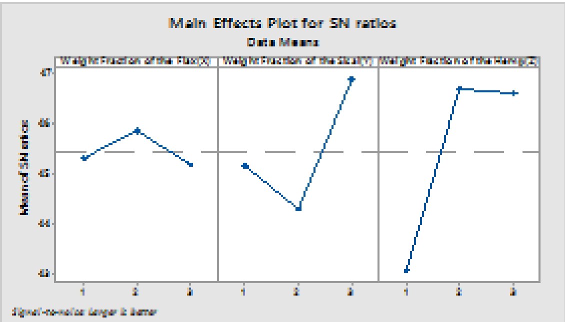

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Fig 2 Main effects plot of S/N ratio for a) Tensile Strength b) Flexural Strength c) Impact Strength

Larger value of S/N ratios corresponds to better quality, so optimal combination of design parameters can be obtained as X3Y3Z2 for tensile strength, X2Y2Z3 for flexural strength and X1Y3Z3 for impact strength.

3.2 Analysis of variance

The purpose of the statistical analysis of variance is to investigate which design parameter significantly affects strength of the composites. The analysis carried out for the level of significance of 5% (the level of confidence is 95%). Three-way ANOVA allow comparing population means when the populations classified according to three (categorical) factors (weight fraction of the flax (X), weight fraction of the sisal(Y) and weight fraction of the hemp(Z)). Analysis of variance results are listed in table 16, 17 and 18 for epoxy resin and table 19, 20 and 21 for polyester resin respectively.

Table 16 ANOVA table for tensile strength (epoxy resin)

Source of Variation	Degree of Freedom(DOF)	Sum of Squares(SS)	Variance(V)	F-value	P-Value	Percentage (%)
X	2	184.50	92.25	3.78	0.209	30.25%
Y	2	282.69	141.35	5.80	0.147*	46.36%
Z	2	93.81	46.90	1.92	0.342	15.38%
ERROR	2	48.77	24.38			7.99%
TOTAL	8	609.77				100%

***-significant**

Table 17 ANOVA table for flexural strength (epoxy resin)

Source of Variation	Degree of Freedom(DOF)	Sum of Squares(SS)	Variance(V)	F-value	P-Value	Percentage (%)
X	2	13450.6	6725.3	4.61	0.178*	49.72%
Y	2	260.3	130.2	0.09	0.918	0.009%
Z	2	10422.4	5211.2	3.57	0.219	38.52%
ERROR	2	2918.3	1459.1			10.78%
TOTAL	8	27051.6				100%

***-significant**

Table 18 ANOVA table for impact strength (epoxy resin)

Source of Variation	Degree of Freedom(DOF)	Sum of Squares(SS)	Variance(V)	F-value	P-Value	Percentage (%)
X	2	621.8	310.9	0.27	0.786	51.33%
Y	2	2904.2	1452.1	1.27	0.440	23.97%
Z	2	6302.4	3151.2	2.76	0.266*	52.02%
ERROR	2	2284.8	1142.4			18.86%
TOTAL	8	12113.2				100%

***-significant**

From ANOVA it can conclude that the weight fraction of the flax (X) is significant for flexural strength, weight fraction of the sisal (Y) is significant for tensile strength and weight fraction of the hemp (Z) is significant for impact strength.

Table 19 ANOVA table for tensile strength (polyester resin)

Source of Variation	Degree of Freedom(DOF)	Sum of Squares(SS)	Variance(V)	F-value	P-Value	Percentage (%)
X	2	34.094	17.0468	1.17	0.461	23.96%
Y	2	77.496	38.7478	2.66	0.273*	54.46%
Z	2	1.522	0.7612	0.05	0.950	1.06%
ERROR	2	29.163	14.5815			20.49%
TOTAL	8	142.274				100%

***-significant**

Table 20 ANOVA table for flexural strength (polyester resin)

Source of Variation	Degree of Freedom(DOF)	Sum of Squares(SS)	Variance(V)	F-value	P-Value	Percentage (%)
X	2	3629	1814	1.23	0.448	19.88%
Y	2	3041	1521	1.03	0.492	16.66%
Z	2	8641	4320	2.94	0.254*	47.34%
ERROR	2	2941	1471			16.11%-
TOTAL	8	18252				100%

***-significant**

Table 21 ANOVA table for impact strength (polyester resin)

Source of Variation	Degree of Freedom(DOF)	Sum of Squares(SS)	Variance(V)	F-value	P-Value	Percentage (%)

X	2	81.1	40.53	0.06	0.944	0.51%
Y	2	4511.1	2255.53	3.32	0.231	28.36%
Z	2	9952.3	4976.17	7.34	0.120*	62.58%
ERROR	2	1356.7	678.36			8.53%
TOTAL	8	15901.2				100%

***-significant**

From ANOVA it can conclude that the weight fraction of the sisal (Y) is significant for tensile strength and weight fraction of the hemp (Z) is significant for impact strength and flexural strength.

3.3 Mathematical model using multiple regression analysis

Multiple regression analysis is done using the statistical software package MINITAB-17. The fitted line plots for tensile strength, flexural strength and impact strength are shown in Figure 3 (a), (b) and (c) for epoxy resin and figure 4 (a), (b) and (c) for polyester resin respectively. These graphs show trends of tensile strength, flexural strength and impact strength.
Mathematical models have been developed to evaluate the relationship between input and output parameters. The output values of tensile strength, flexural strength and impact strength have been used to construct the mathematical models. The functional relationship between dependent output parameter with the input parameters could be postulated using the following equation (1).

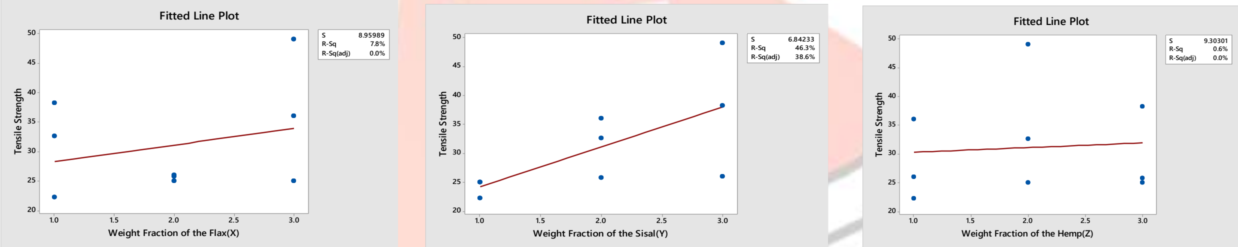
$$Z = A * (X)^a * (Y)^b * (Z)^c \qquad (1)$$

where Z is dependent output variable such as tensile strength, flexural strength and impact strength; X and Y are independent input variables such as weight fraction of the fiber and treatment respectively; a and b are the exponents of input parameters. The above nonlinear equation converted into linear form by logarithmic transformation and can write as equation (2).

$$\text{Log}(Z) = \log(A) + a*\log(X) + b*\log(Y) + c*\log(Z) \qquad (2)$$

For Epoxy resin:

As weight fraction of the flax (X) increases tensile strength and flexural strength is showing a slightly increasing trend but impact strength is showing slightly decreasing trend. As weight fraction of the sisal (Y) and weight fraction of the hemp (Z) increases tensile strength, flexural strength and impact strength is showing a slightly increasing trend.



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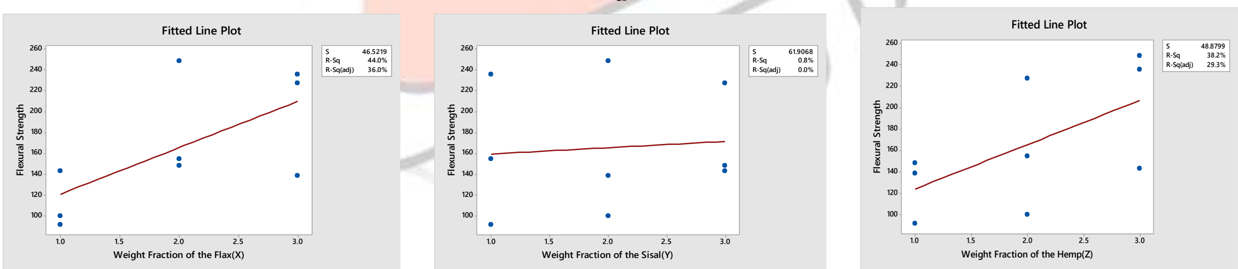

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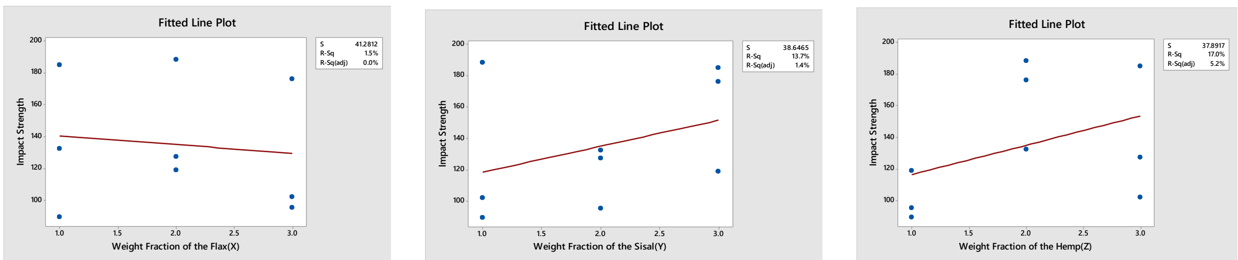

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Figure3. Fitted line plots for a) Tensile Strength b) FlexuralStrength c) Impact Strength

Minitab 17 statistical analysis software has been used to estimate the parameters of the above first order model. The data regression constants are calculated by performing multi parameter linear regression analysis which are shown in tables 22, 23 and 24 for tensile strength, flexural strength and impact strength respectively.

Table 22 Data regression constants for tensile strength

Term	Coefficient	SE Coefficient	T-Value	P-Value	VIF

Constant	1.3333	0.0796	16.74	0.000	
LOG (X)	0.100	0.162	0.61	0.567	1.00
LOG (Y)	0.381	0.162	2.35	0.066	1.00
LOG (Z)	0.081	0.162	0.50	0.640	1.00

Table 23 Data regression constants for flexural strength

Term	Coefficient	SE Coefficient	T-Value	P-Value	VIF
Constant	1.9121	0.0533	35.84	0.000	
LOG (X)	0.547	0.109	5.03	0.004	1.00
LOG (Y)	0.102	0.109	0.94	0.392	1.00
LOG (Z)	0.437	0.109	4.02	0.010	1.00

Table 24 Data regression constants for impact strength

Term	Coefficient	SE Coefficient	T-Value	P-Value	VIF
Constant	1.992	0.100	19.85	0.000	
LOG (X)	-0.053	0.205	-0.26	0.807	1.00
LOG (Y)	0.215	0.205	1.05	0.341	1.00
LOG (Z)	0.311	0.205	1.52	0.189	1.00

The equations of logarithmic transmission of tensile strength, flexural strength and impact strength are shown in (3), (4) and (5) respectively.

$$\log(\text{Tensile Strength}) = 1.3333+0.100 * \log(X) + 0.381 * \log(Y) + 0.081 * \log(Z) \quad (3)$$
$$\log(\text{Flexural Strength}) = 1.9121+0.547 * \log(X)+0.102 * \log(Y) + 0.437 * \log(Z) \quad (4)$$

$$\log(\text{Impact Strength}) = 1.992 - 0.053 * \log(X) + 0.215 * \log(Y) + 0.311 * \log(Z) \quad (5)$$

After taking antilog on both the sides for the equations (3), (4) and (5), the modified equations for tensile strength, flexural strength and impact strength are shown in (6), (7) and (8).

Table 25 Error percentage of experimental and predicted values of tensile strength

S.NO	Weight fraction of the FLAX(X)	Weight fraction of the SISAL(Y)	Weight fraction of the HEMP(Z)	Tensile strength (N/mm^2)	Predicted Tensile Strength	% Error
1	1	1	1	22.2000	21.5426	2.9612
2	1	2	2	32.6075	29.6738	8.9970
3	1	3	3	38.2675	35.7872	6.4814
4	2	1	2	25.0025	24.4221	2.3213
5	2	2	3	25.8025	32.8655	-27.3733
6	2	3	1	25.9375	35.0900	-35.2867
7	3	1	3	24.9375	26.2819	-5.3910
8	3	2	1	36.0025	31.3114	13.0299
9	3	3	2	49.0725	38.6524	21.2340

Table 26 Error percentage of experimental and predicted values of flexural strength

S.NO	Weight fraction of the FLAX(X)	Weight fraction of the SISAL(Y)	Weight fraction of the HEMP(Z)	Flexural strength (N/mm^2)	Predicted Flexural Strength	% Error
1	1	1	1	91.325	81.6770	10.5644
2	1	2	2	100.128	118.6738	-18.5221
3	1	3	3	142.943	147.6617	-3.3011
4	2	1	2	154.680	161.5523	-4.4429
5	2	2	3	248.542	206.9999	16.7143
6	2	3	1	148.275	133.4841	9.9753
7	3	1	3	235.725	240.7615	-2.1366
8	3	2	1	138.690	159.8785	-15.2776
9	3	3	2	227.05	225.5805	0.6472

Table 27 Error percentage of experimental and predicted values of impact strength

S.NO	Weight fraction of the FLAX(X)	Weight fraction of the SISAL(Y)	Weight fraction of the HEMP(Z)	Impact strength (J/m)	Predicted Impact Strength	% Error
1	1	1	1	89.50	98.1747	-9.6924
2	1	2	2	132.50	141.3648	-6.6904
3	1	3	3	185.00	174.9707	5.4212
4	2	1	2	188.50	117.3992	37.7192
5	2	2	3	127.50	154.5792	-21.2386
6	2	3	1	118.75	119.8466	-0.9234
7	3	1	3	102.25	130.3457	-27.4775
8	3	2	1	95.25	107.5062	-12.8674
9	3	3	2	176.25	145.5169	17.4372

Tensile Strength=21.5426* $X^{0.100} * Y^{0.381} * Z^{0.081}$ (6)

Flexural Strength=81.670* $X^{0.547} * Y^{0.102} * Z^{0.437}$ (7)

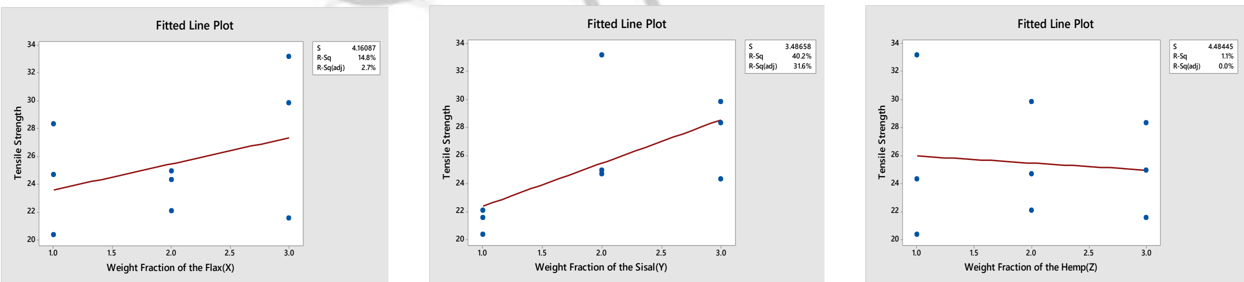
Impact Strength=98.1747* $X^{-0.053} * Y^{0.215} * Z^{0.311}$ (8)

The predicted values of tensile strength, flexural strength and impact strength calculated from equations (6), (7) and (8), which to be compared with experimental values for which error must be calculated. The predicted error percentage between predicted and measured output values at each experimental condition calculated by using the equation (9).

$$\text{Error(\%)}=\left(\frac{experimental\ value-predicted\ value}{experimental\ value}\right)*100 \quad (9)$$

Tables 25, 26 and 27 show the comparison of predicted values and experimental values of tensile strength, flexural strength and impact strength respectively along with error (%). The average errors for tensile strength, flexural strength and impact strength equations are -1.45%, -0.64% and -2.03% respectively. For tensile strength, 66.66% of the points are within 20% of the error and for flexural strength 100% of the points are within 20% of the error and impact strength, 66.66%of the points are within 20% of the error, which is acceptable.It cansee that experimental and predicted values are very close and hence the mathematical model is suitable.

For Polyester resin:
As weight fraction of the flax (X) increases tensile strength and flexural strength is showing a slightly increasing trend but impact strength is showing slightly decreasing trend. As weight fraction of the sisal (Y) and weight fraction of the hemp (Z) increases flexural strength and impact strength is showing a slightly increasing trend but tensile strength is showing slightly decreasing trend.



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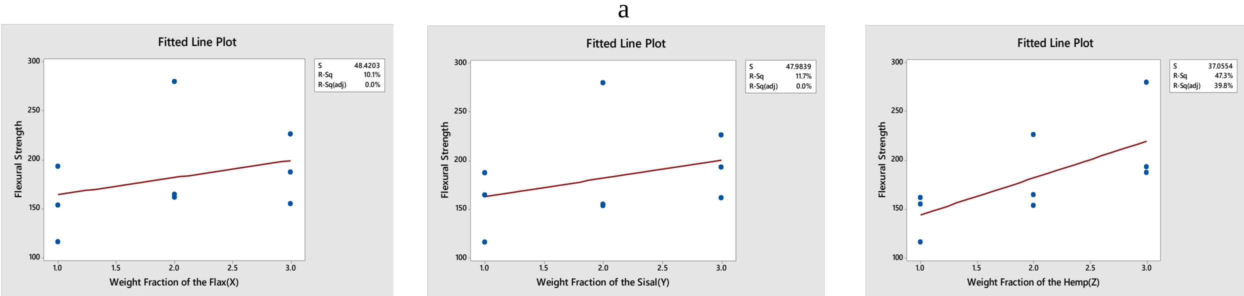

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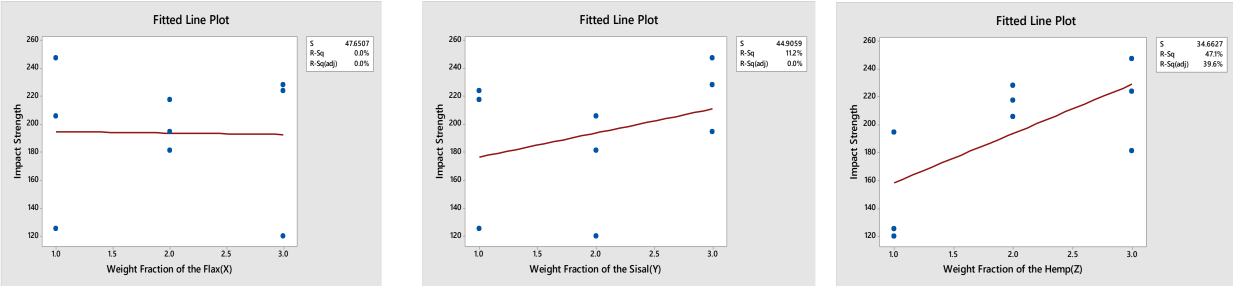

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Figure 4. Fitted line plots for a) Tensile Strength b) FlexuralStrength c) Impact Strength

Minitab 17 statistical analysis software has been used to estimate the parameters of the above first order model. The data regression constants are calculated by performing multi parameter linear regression analysis which are shown in tables 28, 29 and 30 for tensile strength, flexural strength and impact strength respective

Table 28 Data regression constants for tensile strength

Term	Coefficient	SE Coefficient	T-Value	P-Value	VIF
Constant	1.3152	0.0447	29.41	0.000	
LOG (X)	0.1070	0.0912	1.17	0.293	1.00
LOG (Y)	0.2428	0.0912	2.66	0.045	1.00
LOG (Z)	-0.0206	0.0912	-0.23	0.830	1.00

Table 29 Data regression constants for flexural strength

Term	Coefficient	SE Coefficient	T-Value	P-Value	VIF
Constant	2.0384	0.0458	44.51	0.000	
LOG (X)	0.2135	0.0934	2.29	0.071	1.00
LOG (Y)	0.2166	0.0934	2.32	0.068	1.00
LOG (Z)	0.3735	0.0934	4.00	0.010	1.00

Table 30 Data regression constants for impact strength

Term	Coefficient	SE Coefficient	T-Value	P-Value	VIF
Constant	2.1345	0.0738	28.93	0.000	
LOG (X)	-0.001	0.150	-0.01	0.995	1.00
LOG (Y)	0.144	0.150	0.96	0.383	1.00
LOG (Z)	0.398	0.150	2.65	0.046	1.00

The equations of logarithmic transmission of tensile strength, flexural strength and impact strength are shown in (10), (11) and (12) respectively.

$$\log(\text{Tensile Strength}) = 1.3152+0.1070*\log(X) + 0.2428*\log(Y) -0.0206*\log(Z) \quad (10)$$
$$\log(\text{Flexural Strength}) = 2.0384+0.2135*\log(X)+0.2166*\log(Y) + 0.3735*\log(Z) \quad (11)$$

$$\log(\text{Impact Strength}) = 2.1345 - 0.001*\log(X) + 0.144*\log(Y) + 0.398*\log(Z) \quad (12)$$

After taking antilog on both the sides for the equations (10), (11) and (12), the modified equations for tensile strength, flexural strength and impact strength are shown in (13), (14) and (15).

Table 31 Error percentage of experimental and predicted values of tensile strength

S.NO	Weight fraction of the FLAX(X)	Weight fraction of the SISAL(Y)	Weight fraction of the HEMP(Z)	Tensile strength (N/mm^2)	Predicted Tensile Strength	% Error
1	1	1	1	20.3275	20.6633	-1.6519
2	1	2	2	24.6500	24.1039	2.2154
3	1	3	3	28.3000	26.3764	6.7971
4	2	1	2	22.0500	21.9385	0.5056
5	2	2	3	24.9250	25.7437	-3.2846
6	2	3	1	24.2750	29.0572	-19.7001
7	3	1	3	21.5250	22.7207	-5.5549
8	3	2	1	33.1500	27.5005	17.0422
9	3	3	2	29.8500	29.9154	-0.2191

Table 32 Error percentage of experimental and predicted values of flexural strength

S.NO	Weight fraction of the FLAX(X)	Weight fraction of the SISAL(Y)	Weight fraction of the HEMP(Z)	Flexural strength (N/mm^2)	Predicted Flexural Strength	% Error
1	1	1	1	116.000	109.2446	5.8236
2	1	2	2	153.600	164.4514	-7.0647
3	1	3	3	193.090	208.9051	-8.1905
4	2	1	2	164.267	164.0984	0.1026
5	2	2	3	279.465	221.8593	20.612
6	2	3	1	161.202	160.6994	0.3117
7	3	1	3	186.985	208.1949	-11.3431
8	3	2	1	154.650	160.4975	-3.7811
9	3	3	2	226.135	227.0097	-0.3868

Table 33 Error percentage of experimental and predicted values of impact strength

S.NO	Weight fraction of the FLAX(X)	Weight fraction of the SISAL(Y)	Weight fraction of the HEMP(Z)	Impact strength (J/m)	Predicted Impact Strength	% Error
1	1	1	1	125.00	136.3013	-9.04104
2	1	2	2	205.75	198.4532	3.54644
3	1	3	3	247.00	247.2291	-0.09275
4	2	1	2	217.25	179.4770	17.38688
5	2	2	3	181.00	233.0459	-28.7546
6	2	3	1	194.50	159.5527	17.96776
7	3	1	3	223.50	210.8225	5.67226
8	3	2	1	120.00	150.4427	-25.3689
9	3	3	2	227.75	210.1542	7.725928

$$\text{Tensile Strength}=20.6633*X^{0.1070}*Y^{0.2428}*Z^{-0.0206} \quad (13)$$

$$\text{Flexural Strength}=109.2446*X^{0.2135}*Y^{0.2166}*Z^{0.3735} \quad (14)$$

$$\text{Impact Strength}=136.3013*X^{-0.001}*Y^{0.144}*Z^{0.398} \quad (15)$$

The predicted values of tensile strength, flexural strength and impact strength calculated from equations (13), (14) and (15), which to be compared with experimental values for which error must be calculated. The predicted error percentage between predicted and measured output values at each experimental condition calculated by using the equation (9).

Tables 31, 32 and 33 show the comparison of predicted values and experimental values of tensile strength, flexural strength and impact strength respectively along with error (%). The average errors for tensile strength, flexural strength and impact strength equations are -0.43%, -0.435% and -1.217% respectively. For tensile strength, 88.889% of the points are within 20% of the error and for flexural strength 88.889% of the points are within 20% of the error and impact strength, 77.778%of the points are within 20% of the error, which is acceptable.It cansee that experimental and predicted values are very close and hence the mathematical model is suitable.

Conclusions

The epoxy and polyester flax-hemp-sisal hybrid fiber reinforced composite specimens prepared as per ASTM standards subjected to mechanical characterization results were analyzed and compared. Optimizations of tensile, flexural and impact test parameters done with the help of Taguchi analysis. It can be concluded from S/N ratio, optimal combination of design parameters can be obtained at X3Y3Z2 composite for tensile strength,X2Y2Z3 composite for flexural and X1Y3Z3 composite for impact strength for both epoxy and polyester resins. It can be concluded from ANOVA that the weight fraction of the flax (X) is significant for flexural strength, weight fraction of the sisal (Y) is significant for tensile strength and weight fraction of the hemp (Z) is significant for impact strength for epoxy fiber reinforced composites and the weight fraction of the sisal (Y) is significant for tensile strength and weight fraction of the hemp (Z) is significant for impact strength and flexural strength for polyester fiber reinforced composites. The prediction of output parameters is obtained at X3Y3Z2 for tensile strength are 49.0725 N/mm^2 for epoxy fiber reinforced composite and 33.15N/mm^2 for polyester fiber reinforced composite. For flexural strength the predicted output parameters are obtained at X2Y2Z3 are 248.542N/mm^2 for epoxy fiber reinforced composite and 279.465 for polyester fiber reinforced composite. For Impact strength the predicted output parameters are obtained at X1Y3Z3 are 188.5J/m for epoxy composite and 247J/m for polyester composite. From the above results, it revealed that the epoxy reinforced composites exhibited better tensile and flexural properties.

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