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Prediction of the Best Tensile and Flexural Strength of Natural Fiber Reinforced Epoxy Resin Based Composite Using Taguchi Method

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Abstract

The evolution of human civilization is based on interest in research for new things. Natural fiber reinforced polymer matrix composites have got a considerable interest in the exploration of new light weight bio-degradable durable materials because of the good properties and superior advantages of natural fiber over synthetic fibers. Tensile and flexural strengths are exceptionally vital mechanical properties that must be optimized to get improved NFC (Natural fiber composite). This paper represents a study of improving tensile and flexural strength of sponge gourd, coir, and jute fibers reinforced epoxy resin-based composites. Taguchi method is used to design the experiments and four different control factors, wt% ratio of resin and hardener, wt% of resin and hardener, wt% ratio of sponge gourd and jute, wt% ratio of sponge gourd and coir, were optimized by using this method which was validated by confirmation tests. Maximum tensile and flexural strength was found 31.19 MPa and 137.32 MPa. The percentages of contribution of each predefined control factors are explored by Analysis of Variance (ANOVA). The combined effects of any two control factors on mechanical properties were analyzed using contour plots. At last, a mathematical model, relates an association between mechanical properties and control factors, was formulated by Regression analysis.

Keywords
Natural fiber-reinforced composites, Tensile and Flexural strength, Taguchi analysis, ANOVA analysis, Regression analysis.

1. Introduction
Natural fibers are not synthetic or manmade and are collected from various animal and plant resources. Fiber-reinforced composites got considerable attention in numerous applications because of the improved characteristics and superior advantages of natural fiber over artificial fibers in term of its high durability, electrical resistance, corrosion resistance, comparatively low weight, little cost, renewable resources, being abundant, good comparative mechanical properties such as flexural, impact, and tensile strength, good surface quality, flexibility during processing, biodegradability, and negligible health threats (Mohammed et al. 2015). At present, the focus of the researcher's attention is centered to the improvement of NFC to meet the demand of a new era utilizing the superior advantages of natural fibers over artificial ones. NFC's are gaining wider consideration in current years in various applications including structural, automobile, roof and wall panel, container, protective vest, etc. Natural fiber composites, with their exclusive and wide range of variability in characteristics, can alter the use of synthetic fiber composites in the way of searching new alternative engineered material (Ticoalu, Aravinthan, and Cardona 2010). In a new engineered composite, natural fibers have been accepted as good potential reinforcements (Kabir et al. 2012).
Sponge gourd-epoxy based NFC's have been fabricated by the hand lay-up method. Both chemically treated and untreated Sponge gourd fibers for 12 hrs and 24 hrs in different fiber loading (5%, 10%, 15%, 20%, and 25%) was used. Tensile and flexural strength are varied from 35-75 MPa and 40-85 MPa respectively with different percentages of fiber reinforcement (Ichetaonye et al. 2015). Another epoxy resin-based chemically treated sponge gourd-glass fiber natural composite was fabricated. Sponge gourd fibers were treated with 2% NaOH solution by volume for 1 hr. Maximum tensile strength 17.97 MPa was tested for composite with sponge gourd fiber (5 gms) and glass fiber (15 gms) and maximum flexural strength 106.67 MPa was found for composite with luffa fiber (15gms) and glass fiber (5 gms) (Sreeramulu and Ramesh 2018). Viviane A. Escocio et al. studied the structural and mechanical properties of agro-residue of sponge gourd and high density polyethylene (HDPE) composites. HDPE was collected from natural resources and the blending of sponge gourd scrap was used at different weight percentages (10, 20, 30, and 40%). The flexural, tensile, and impact strength of these composites with different compositions are 28.4-35.8 MPa, 19.2-20.8 MPa, and 25.5-34.7 J/m respectively (Escocio et al. 2015). Polypropylenes based coir fiber reinforced composites were made-up with different weight percentages by Nadir Ayrilmis et al. for automotive interior applications. Mechanical, physical, and inflammability characteristics of these composite panels were tested. Coir fiber, at four different weight percentages, was used with the polypropylene powder and a coupling agent, 3 wt % maleic anhydrides grafted polypropylene (MAPP) powder. The flexural strength, tensile strength, and hardness of the composites improved with the increment of weight percentages of the coir fiber up to 60%. The tensile and flexural strengths of these composites were found 13.2-17.8 N/mm^2 and 24.3-30.6 N/mm^2 respectively (Ayrilmis et al. 2011).
Fairuz I. Romli et al. also explored the consequence of fiber loading on the tensile property of epoxy based coir fiber reinforced composite. The conventional hand lay-up technique is used for fabricating the composites. Maximum tensile strength (8.25 MPa) was found for 15% fiber loading with 48 hours curing (Romli et al. 2012). Another epoxy resin based sisal and coir natural fibers composite was fabricated by Girisha. C et al. Washed and dried sisal fibers and coir were treated with 10% NaOH solution. Tensile and flexural strengths are 39 MPa and 47 MPa respectively for 20 wt% fibers reinforcement (Girisha, Sanjeevamurthy, and Srinivas 2012). Ajith Gopinatha et al. investigated two types of jute fiber reinforced composites made of epoxy and polyester resins ASTM standards. The mechanical properties of both NFC were tested and compared. The tensile property for jute-epoxy and jute-polyester NFC was observed 12.46 MPa and 9.23 MPa respectively. The 5% NaOH, by volume, treatment showed a better result than 10% NaOH treatment (Gopinath, Kumar, and Elayaperumal 2014). The compression molding technique was used to fabricate polypropylene matrix based short jute fiber reinforced composite. Mechanical properties such as tensile strength, tensile modulus, elongation at break, flexural strength, flexural modulus, impact strength, and hardness of the composites were found 32 N/mm^2, 850 N/mm^2, 12%, 38 N/mm^2, 1685 N/mm^2, 18,000 J/m^2, and 96 shore-A respectively (Khan et al. 2012).
Thermosetting epoxy resin based bidirectional jute fiber mat strengthen NFC was developed by Vivek Mishra et al. Hand lay-up method was used for fabrication and fiber loading varied from zero to 48% by weight. Improvement of mechanical properties was explored with the increment in fiber loading. The maximum tensile strength, tensile modulus, and impact strength were found 110 MPa, 4.45 GPa, and 4.875 J respectively (Mishra and Biswas 2013). Md. Rafiquzzaman et al. investigated a hybrid polymer composite where jute and glass fiber was used as natural and synthetic fiber respectively and as polymer matrix epoxy resin and hardener were used. The hand lay-up method was

used for fabrication where the maximum flexural, tensile, and impact strength were found 107.89 MPa, 89.56 MPa, and 265.87 J/m^2 for composite with 10% jute and 30% glass fiber by weight (Rafiquzzaman, Islam, et al. 2016). P. Prabaharan Grcaeraj et al. studied the tensile property of jute fiber strengthened polymer composites. The design of the experiment (DOE) was developed by the Taguchi method. The effect of different control factors was explored and the best combinations of these control factors were recommended by using the Taguchi method (Graceraj and Venkatachalam 2015). Sailesh and Shanjeevi (Sailesh and Shanjeevi 2014) fabricated a hybrid composite using bamboo, banana, and glass fiber. The Taguchi method was used in this study for predicting the combination of optimum process parameters for maximum hardness property. However, from the best of the author's knowledge, no natural composite had been made yet by using sponge gourd, coir, and jute. Taguchi method, being a simple, efficient, and systematic approach to optimize designs for performance, quality, and cost, is used in many engineering applications.
The objective of this research is to fabricate epoxy resin based sponge gourd, coir, and jute fiber reinforced natural composites and to explore the tensile and flexural strength. Taguchi method was applied to understand the effect of different control factors on output mechanical properties and to explore the optimal combination of control factors for each mechanical property. The confirmation tests were performed by using these optimum combinations. Lastly, the percentage of contributions of control factors on mechanical properties was determined by ANOVA and mathematical models, relate control factors with output mechanical properties, was developed by Regression analysis.

2. Materials and Methods

In this work, sponge gourd, coir, and jute were used for reinforcement in the composite. They are easily available and cheap in Bangladesh. Sponge gourd is a fruit of *Luffa cylindrica.* The size of this fruit is around 0.3 meters long which is similar to a cucumber in shape and size (Tanobe et al. 2005). Now a days, Sponge gourd fibers are used in different natural or hybrid composites fabrication (Ichetaonye et al. 2015)(Escocio et al. 2015)(Gafur and Mina 2018)(Boynard, Monteiro, and d'Almeida 2003). Biodegradable coir fiber is abundant in nature and showed upgraded resistance to degradation in salty environment and excellent interfacial adhesion. High lignin content increases the lifespan of coir fiber considerably compared to natural fibers of other types (Hill and Abdul Khalil 2000). Coir fibers have been used with both thermosetting and thermoplastic resin for producing NFC or hybrid composites by different researchers (Ayrilmis et al. 2011)(Romli et al. 2012)(Bhagat, Prasad, and Srivastava 2017). Jute fiber is a type of bast fiber that contains mainly lignin and cellulose (lignocellulose). It is a long, flexible, glossy fiber that is used to produce strong threads, cloth, bag, etc. Two types of jutes are cultivated in Bangladesh. They are white jute (Corchorus capsularis) and tossa jute (Corchorus olitorius) ("Jute - Wikipedia," n.d.). White jute is used in this research. A wide variety of NFC has been developed by using jute fibers with different types of resins (Gopinath, Kumar, and Elayaperumal 2014)(Khan et al. 2012)(Mishra and Biswas 2013)(Rafiquzzaman, Islam, et al. 2016)(Graceraj and Venkatachalam 2015)(Rafiquzzaman, Rahman, et al. 2016). Collected natural fibers were cleaned properly and cut into small pieces (15 mm to 20 mm) by using a shredder machine. Chemical treatment was performed using a caustic solution (5 % NaOH by volume). The epoxy resin (Araldite AW 106) was used as the matrix material and hardener (Hardener HV 953 IN) was used to provide more strength and improve the interfacial adhesion to the composites. The composites were manufactured by the hand lay-up process. The fabricated composites were cut using a Jig saw machine to obtain the specimen for mechanical testing as per the ASTM D3039/3039M and ASTM D790 standards for tensile and flexural strength test respectively. Figure 1 shows the flexural and tensile strength sample.

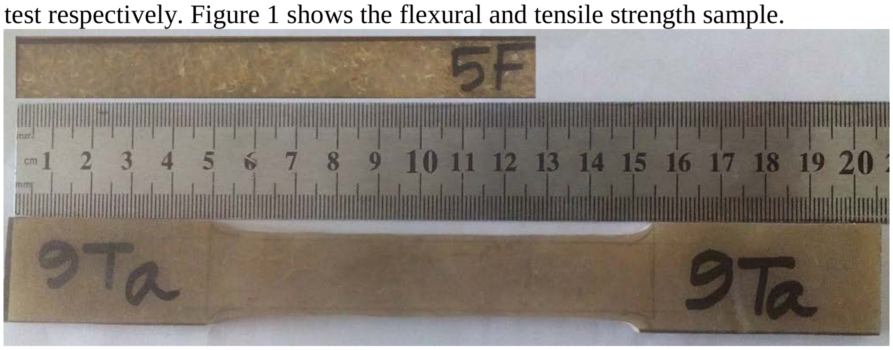

Figure 1. Specimens for Flexural and Tensile test.

2.1 Taguchi Method

The Taguchi method is an excellent combination of both statistical and mathematical techniques. It is popular as a proficient and powerful tool for the optimization of control factors or process parameters. Orthogonal arrays (OA) and signal-to-noise (S/N) ratio are the major tools in the Taguchi method (Ghani, Choudhury, and Hassan 2004). The larger is better, nominal is best, and the smaller is better are three basic categories of S/N ratio. The objective function described in this investigation is the maximization of mechanical properties. So, larger is better S/N ratio is considered in this study. These characteristics can be calculated using the expression shown in equation (1).

$$\eta(dB) = -10\log_{10}\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2} \quad (1)$$

Where, y_i is the i^{th} value of the response variable. Taguchi experimental design of experiments suggests L9 orthogonal array, where 9 experiments are sufficient to optimize the parameters. Four factors i.e., weight percentage ratio of resin and hardener (A), weight percentage of resin and hardener in composite (B), weight percentage ratio of sponge gourd and jute (C), and weight percentage ratio of sponge gourd and coir (D), each at three levels is considered in this study. The influences of four factors were studied using L9 (3^4) orthogonal design. The levels of control factors are shown in table 1.

Table 1. Levels of the variables used in the experiment.

Control factors	Levels		
	1	2	3
Wt% ratio of resin & hardener, A	1.50	1.25	1.00
Wt% of resin & hardener in composite, B	91	88	85
Wt% ratio of sponge gourd & jute, C	0.33	1.00	3.00
Wt% ratio of sponge gourd & coir, D	0.33	1.00	3.00

Table 2 shows the Taguchi (L9) orthogonal array. In table 2, each column stands for a test parameter and a row provides a test condition which is the combination of parameter levels. The experimental results or outputs obtained from the tests were converted into S/N ratio. The S/N ratios serve as the objective functions for optimization and help in the analysis of data and optimum results prediction (Bement 1989).

3. Results and Discussion

3.1 Tensile and Flexural Strength

Table 2 shows the DOE by using Taguchi L9 orthogonal array with tensile and flexural strength values. Experiment no. 8 gives the maximum S/N ratio tensile strength (29.28), where wt% ratio of resin and hardener, wt% of resin and hardener in composite, wt% ratio of sponge gourd and jute, and wt% ratio of sponge gourd and coir are 1.00, 88, 0.33 and 3.00 respectively. On the other hand, experiment no. 1 reveals the minimum S/N ratio of tensile strength value (17.43), where wt% ratio of resin and hardener, wt% of resin and hardener in composite, wt% ratio of sponge gourd and jute, and wt% ratio of sponge gourd and coir are 1.50, 91, 0.33 and 0.33 respectively.

For flexural strength, experiment no. 9 gives the maximum S/N ratio of flexural strength (42.75), where wt% ratio of resin and hardener, wt% of resin and hardener in composite, wt% ratio of sponge gourd and jute, and wt% ratio of sponge gourd and coir are 1.00, 85, 1.00, and 0.33 respectively. On the other hand, experiment no. 1 reveals the minimum SN ratios of flexural strength (36.26), where wt% ratio of resin and hardener, wt% of resin and hardener in composite, wt% ratio of sponge gourd and jute, and wt% ratio of sponge gourd and coir are 1.50, 91, 0.33, and 0.33 respectively.

Table 2. Taguchi experimental design using L9 orthogonal array with responses of natural composite.

Expt. No.	A	B (%)	C	D	Tensile strength (MPa)	S/N Ratio (dB)	Flexural strength (MPa)	S/N Ratio (dB)
1	1.50	91	0.33	0.33	7.435	17.43	65.017	36.26
2	1.50	88	1.00	1.00	8.535	18.62	66.103	36.40
3	1.50	85	3.00	3.00	11.560	21.26	78.008	37.84
4	1.25	91	1.00	3.00	8.920	19.01	70.026	36.91
5	1.25	88	3.00	0.33	7.815	17.86	69.133	36.79
6	1.25	85	0.33	1.00	8.535	18.62	74.175	37.41
7	1.00	91	3.00	1.00	22.330	26.98	112.360	41.01
8	1.00	88	0.33	3.00	29.095	29.28	116.595	41.33
9	1.00	85	1.00	0.33	28.595	29.13	137.321	42.75

3.2 Taguchi Analysis for Tensile Strength

From table 3 and figure 2, it is seen that variations of tensile property are very small for the factor wt% ratio of sponge gourd and jute, and very low response is observed in case of 0.33 level value. The high variation comes from wt% ratio of resin and hardener in the composite. So, wt% ratio of resin and hardener should be the key factor to improve of tensile strength. The highest desired response was found from 1.00 wt% ratio of resin and hardener. Wt% of resin and hardener in the composite is the second important control factor for the improvement of tensile strength. Tensile strength was increased with decreasing values of wt% of resin and hardener decreases.

Table 3. Response table for signal to noise ratio of tensile strength at various levels of input parameters.

Level	Wt% ratio of resin & hardener, A	Wt% of resin & hardener, B	Wt% ratio of sponge g. & jute, C	Wt% ratio of sponge g. & coir, D
1	**28.46**	**23.00**	21.78	21.47
2	18.50	21.92	**22.25**	21.41
3	19.10	21.14	22.03	**23.18**
Delta	9.96	1.87	0.48	1.77
Rank	1	2	4	3

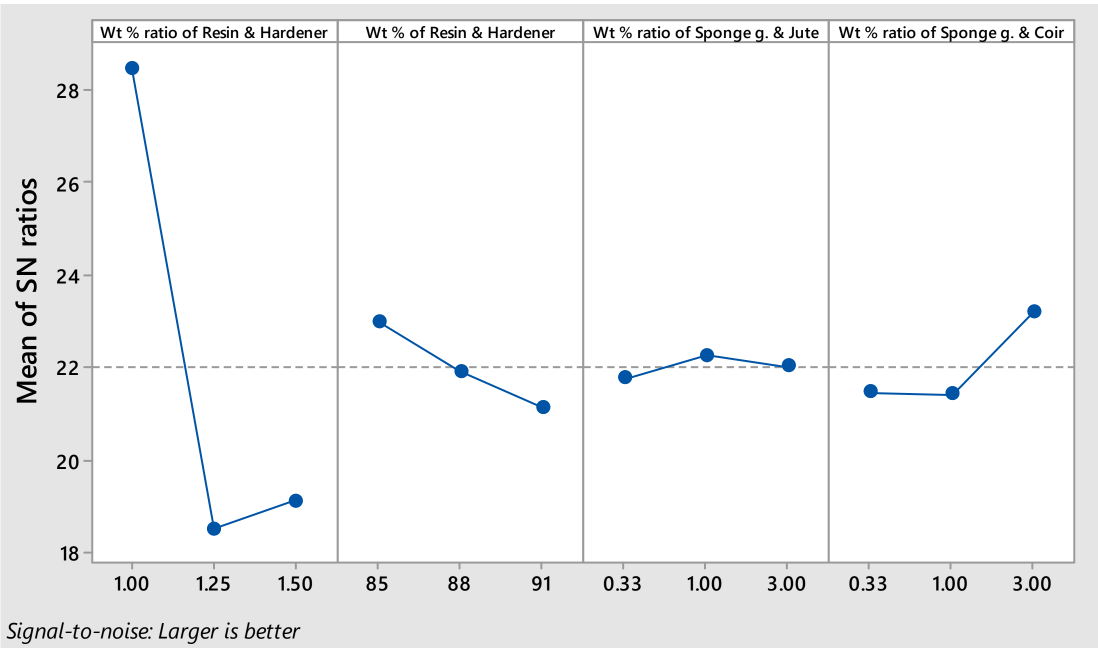

Figure 2. Main effect plots for S/N ratio values of tensile strength.

3.2.1 Confirmation Experiment for Tensile Strength

The optimal control factor combination for maximum tensile strength is $A_{1.00}$, B_{85}, $C_{1.00}$, $D_{3.00}$, which did not correspond to any experiment in the orthogonal array. The predicted S/N ratio for maximum tensile strength is given by equation (2).

$$\text{Tensile Strength (Predicted)} = \eta_{A(1.00)} + \eta_{B(85)} + \eta_{C(1.00)} + \eta_{D(3.00)} - 3\eta_m \quad (2)$$
$$= 28.46 + 23.00 + 22.25 + 23.18 - 3(22.02)$$
$$= 30.83.$$

Where A_i, B_i, C_i, and D_i are the values of S/N ratio at their i^{th} levels respectively, and η_m is the overall mean. The confirmation experiments were carried out in three different samples with the control factors set at their optimal levels. The predicted and experimental values of S/N ratio for tensile strength are 30.83 and 29.88 respectively where the percentage of error is only 3.08%.

3.3 Taguchi Analysis for Flexural Strength

From table 4 and figure 3, the variations of wt % ratio of sponge gourd & jute showed very little effect on the flexural property. The large variation comes from wt% ratio of resin and hardener. So, wt% ratio of resin and hardener should be the main factor for the improvement of flexural strength. The highest value of flexural strength was found from 1.00 wt% ratio of resin and hardener in the composite. The flexural strength of these composites was decreased with an increase of wt% ratio of resin and hardener. Very poor results are obtained in case of 1.50 wt% ratio of resin and hardener. Wt% of resin & hardener is the second important choice to improve the flexural strength of these composites. For, 85% resin & hardener in composite, it gives a better result. Wt% ratio of sponge gourd & coir is the third important option for the improvement of flexural strength. A good response was found for 3.00 value of wt % ratio of sponge gourd & coir.

Table 4. Response table for SN ratios of flexural strength at various levels of input parameters.

Level	Wt% ratio of resin & hardener, A	Wt% of resin & hardener, B (%)	Wt% ratio of sponge g. & jute, C	Wt % ratio of sponge g. & coir, D
1	**41.71**	**39.34**	38.33	38.61
2	37.02	38.17	**38.70**	38.26
3	36.83	38.06	38.54	**38.69**
Delta	4.88	1.28	0.37	0.43
Rank	1	2	4	3

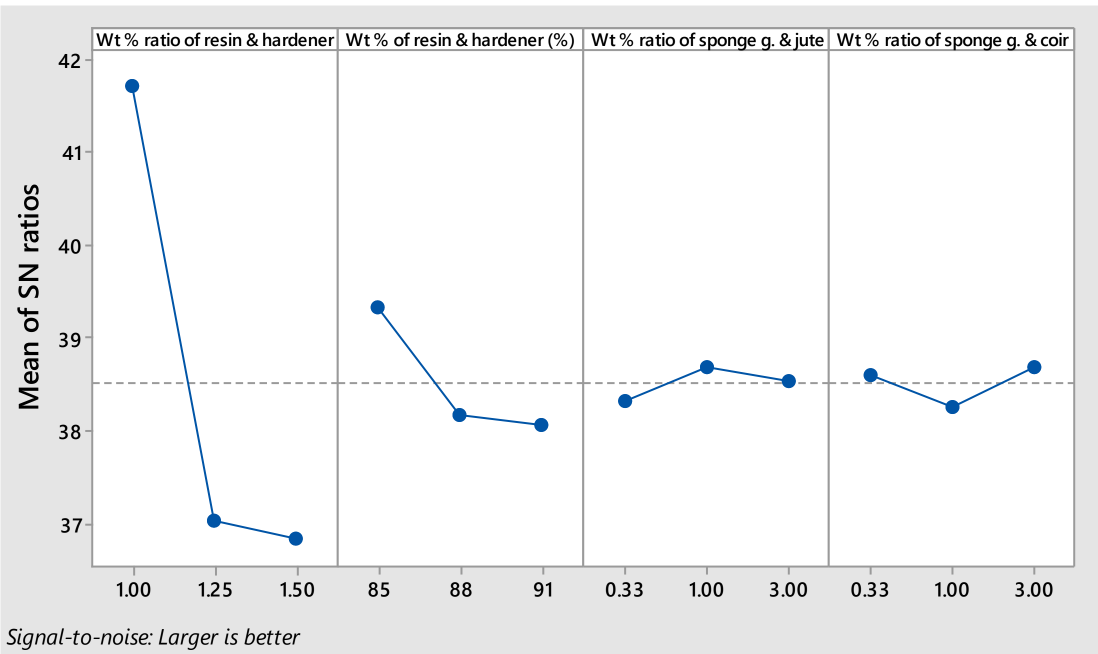

Figure 3. Main effect plots for S/N ratios of flexural strength.

3.3.1 Confirmation Test for Flexural Strength

The optimal control factor combination for maximum flexural strength is $A_{1.00}$, B_{85}, $C_{1.00}$, $D_{3.00}$, which did not correspond to any experiment in the orthogonal array. The predicted maximum flexural strength is given by the following equation (3).

$$\text{Flexural Strength (Predicted)} = \eta_{A(1.00)} + \eta_{B(85)} + \eta_{C(1.00)} + \eta_{D(3.00)} - 3\eta_m \quad (3)$$
$$= 41.71 + 39.34 + 38.70 + 38.69 - 3(38.522)$$
$$= 42.88.$$

Where A_i, B_i, C_i, and D_i are the values of S/N ratio at their i^{th} levels respectively, and η_m is the overall mean. The confirmation experiments were carried out in three different samples with the control factors set at their optimal levels. The predicted and experimental values of S/N ratio for flexural strength are 42.88 and 42.35 respectively where the percentage of error is only 1.24%.

3.4 ANOVA (Analysis of variance)

F Statistic that is broadly applied for ANOVA analysis based on the F probabilistic distribution. To decide on accepting or rejecting the null hypothesis, F statistic is used. F test result consists of F value and F critical value. The value that is calculated from experimental data is known as F value and the value that is obtained from the F distribution table is defined as F critical. Generally, the null hypothesis is rejected when the calculated F value is larger than the F critical value. During the F test result, p-value is an important consideration and it is determined by the F statistic. The value of p indicates the probability that the results could have happened by chance.
The degree of freedom (DF) is a term that explains the amount of information uses in an experiment. The total DF is determined by the number of observations carried out in the designed experiment. Variation of different components of the model is measured by Adjusted sums of squares (Adj SS) and how much varied a component is determined by Adjusted mean squares (Adj MS). This variation determination considers all other terms present in the model and no matter what order they were entered. Between the Adj SS and Adj MS, Adj MS only considers the DF. Minitab separates the sums of squares in ANOVA analysis result into different components that describe the variation due to different sources.

3.4.1 ANOVA for Tensile Strength

The percentage of contribution shows how much a source contributes to total variation. From this one-way ANOVA analysis shown in Table 5, the maximum percentage of contribution was found 85.65 for wt% ratio of resin and hardener. The F value should always be used along with the p-value in deciding whether the results are significant enough to reject the null hypothesis. No relation between the term and the response is indicated by the null hypothesis. Usually, a significance level is denoted by as α and in this study significance level of 0.05 has been used due to the value 0.05 works well. From F-distribution table (Gooch 2011), for numerator 1 (as DF=1 for wt% of resin & hardener) and denominator 4 (as DF=4 for error), critical value F=7.71. The F statistic just compares the joint effect of all the variables together. To put it simply, reject the null hypothesis only if the significance level is larger than the p-value. In this study, the calculated F-value corresponding to the maximum percentage of contribution is 9.72 which is larger than the critical F-value. So, the p-value is 0.036 or 3.6% which is smaller than the significance level of 0.05 that indicates the assumption is very close to the critical zone for this factor. Similarly, the minimum percentage of contribution was found 0.517 for wt% ratio of sponge gourd and Jute. Here, the calculated F-value is 0.06 which is less than 7.71. So, p-value is 0.82 or 82% which is greater than the significance level of 0.05 that indicates the high probability of accepting the null hypothesis. In this analysis, the combinational effects of factors that are not considered, contribute 8.81% as an error.

Table 5. ANOVA analysis for tensile strength at 95% confidence level.

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Percentage of contribution
Wt % ratio of Resin & Hardener, A	1	459.200	459.200	9.72	0.036	85.65
Wt % of Resin & Hardener, B	1	16.683	16.683	0.35	0.584	3.11
Wt % ratio of Sponge g. & Jute, C	1	2.774	2.774	0.06	0.820	0.517
Wt % ratio of Sponge g. & Coir, D	1	10.244	10.244	0.22	0.666	1.91
Error	4	189.039	47.260			8.81
Total	8	677.940				100

3.4.2 ANOVA for Flexural Strength

From the one way ANOVA table (table 6), the maximum percentage of contribution was found 86.22 for wt% ratio of resin & hardener. In this study, calculated F-value is 11.54 which is larger than critical F-value ($F_{critical}$=7.71, for numerator 1 and denominator 4 from F distribution table (Gooch 2011) with 0.05 significance level). So, P-value is 0.027 or 2.7% which is less than 5% that indicates the assumption is very close to the critical zone of rejecting the null hypothesis. Similarly, the minimum percentage of contribution was found 0.0095 for wt% ratio of sponge gourd & jute. Here, the calculated F-value is 0.0013 which is less than 7.71. So, P-value is 0.973 or 97.3% which is greater than 5% that indicates the high probability of accepting the assumptions statistically. In this analysis, the combinational effects of factors that are not considered in this study, contribute 7.47% as an error.

3.5 Contour plots analysis

A Contour Plot is used to determine where a maximum or minimum response expected from the process. It is especially useful for situations where a maximum or minimum response is projected within or close to the data range as a contour area. Contour plots are very helpful to explore the combined influences of different control factors on output characteristics.

Table 6. ANOVA analysis for Flexural strength at 95% Confidence Level.

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Percentage of contribution
Wt % ratio of Resin & Hardener, A	1	4158.30	4158.30	11.54	0.027	86.22
Wt % of Resin & Hardener, B	1	303.03	303.03	0.84	0.411	6.28
Wt % ratio of Sponge g. & Jute, C	1	0.46	0.46	0.0013	0.973	0.0095
Wt % ratio of Sponge g. & Coir, D	1	0.69	0.69	0.0019	0.967	0.0143
Error	4	1441.58	360.40			7.47
Total	8	5904.05	4822.88			100

3.5.1 Contour plots analysis for Tensile Strength

Figure 4 reveals the contour plots of the tensile strength of the natural composite. Actually, wt% of resin and hardener doesn't affect largely for the tensile strength. The wt% ratio of resin and hardener ranges from 1.0 to near 1.2, shows the contour surface of better result, tensile strength value higher than 25 MPa. But, an increase in wt% ratio of resin and hardener indicates the lower tensile strength contour. The contour surface for wt% ratio of sponge gourd & jute with wt% ratio of resin & hardener is practically similar to the contour surface of wt% of resin & hardener with wt% ratio of resin & hardener. The contour surface for wt% ratio of sponge gourd & coir with wt% ratio of resin and hardener reveals that the tensile strength doesn't depend on the wt% ratio of sponge gourd & coir largely. With increasing wt% ratio of resin and hardener, the value of tensile strength decreases. Lower wt% ratio of sponge gourd & jute with lower wt% of resin & hardener shows the higher tensile strength contour surface. On the other hand, a higher wt% ratio of sponge gourd & coir along with lower wt% of resin and hardener gives the better contour surface for tensile strength. The contour surface for wt% ratio of sponge gourd & coir with wt% ratio of sponge gourd & jute is approximately similar to the contour surface of wt% ratio of sponge gourd & coir with wt% of resin & hardener.

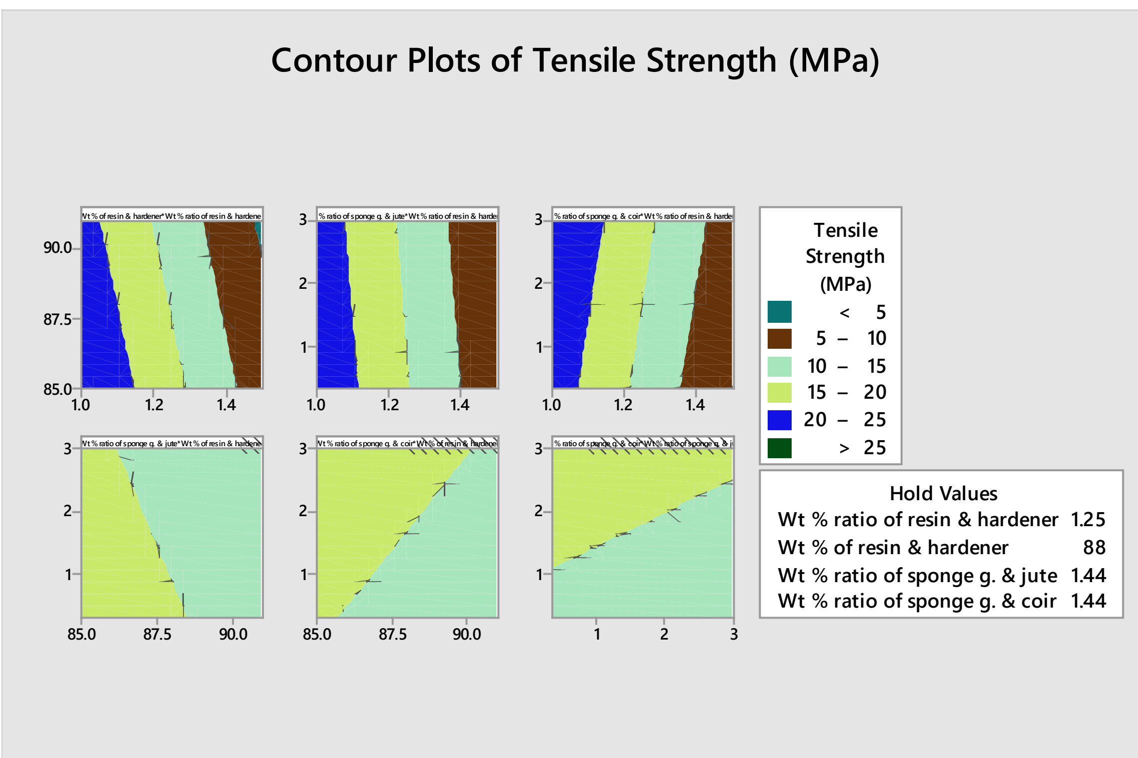

Figure 4. Contour plots for tensile strength.

3.5.2 Contour plots analysis for Flexural Strength

Figure 5 represents the contour plots of flexural strength for the natural composite. In 1st contour plot, if the value of wt% of resin and hardener ranges from 85 to 89 and the value of wt% ratio of resin and hardener ranges from 1.0 to 1.1, then it shows improved contour surface with flexural strength above 110 MPa. Increasing values of both control factors reduce the flexural strength. 2nd and 3rd plots are almost identical. In both plots, flexural strength decreases with increasing values of wt% ratio of resin and hardener. But very little influence on flexural strength was found for wt% ratio of sponge gourd & jute and wt% ratio of sponge gourd & coir in 2nd and 3rd plot respectively. With the increasing value of wt% of resin and hardener, flexural strength is reduced. But the variation of wt% ratio of sponge gourd & jute has very little effect on flexural strength. Almost the same response was found for the contour plot of wt% ratio of sponge gourd & coir with wt% of resin & hardener.

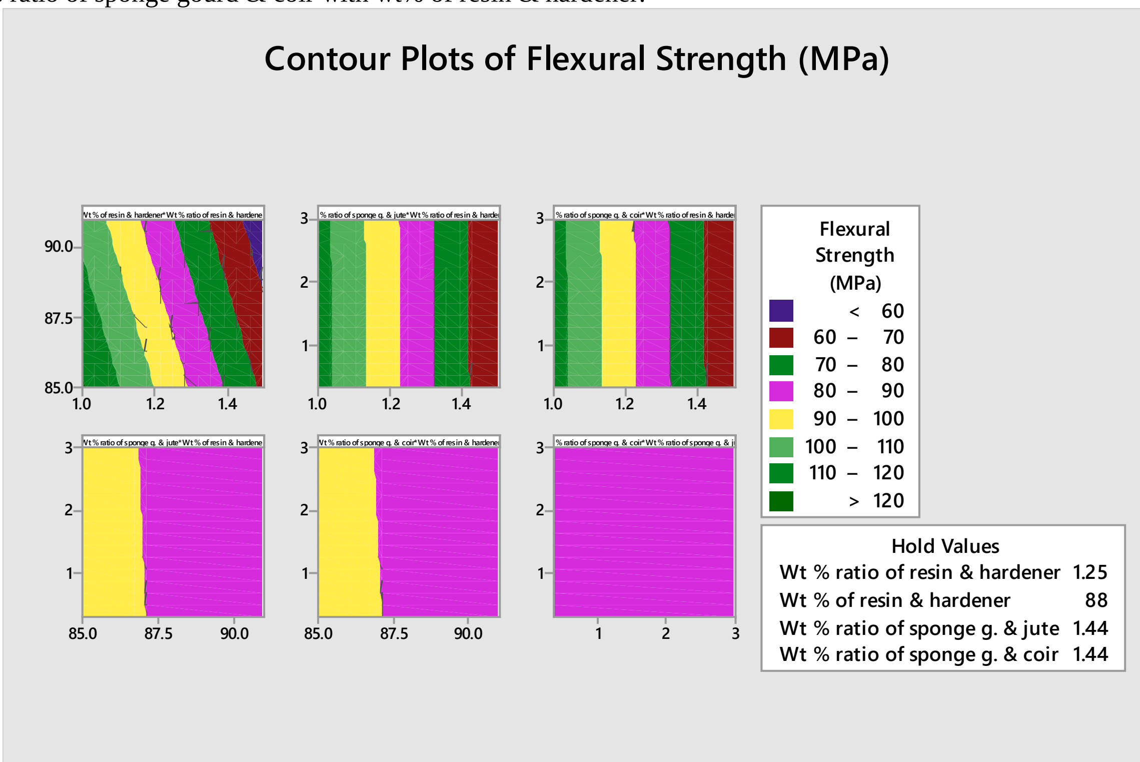

Figure 5. Contour plots of flexural strength.

3.6 Regression Analysis

The regression equation represents a mathematical model that relates control factors with output properties. In this study, regression analysis was performed using MINITAB 19 software. The feature of the regression equation was developed by providing input and output parameters from the Taguchi L9 OA. The regression equation of tensile and flexural strength is shown in equation (4) and (5) respectively.

$$\text{Tensile strength (MPa)} = 106.8 - 35.0A - 0.556B - 0.49C + 0.94D \tag{4}$$

$$\text{Flexural strength (MPa)} = 428 - 105.3A - 2.37B - 0.20C - 0.24D \tag{5}$$

Figure 6 shows the comparison between experimental and predicted values tensile and flexural strength values. The figure shows the nature of the two lines for tensile strength practically almost similar. The experimental tensile strength values for the experiment no. 1, 2, 3, 7, 8, and 9 almost match with the predicted value. For flexural strength, the nature of the two lines essentially nearly comparable. The experimental flexural strength values for the experiment no. 2, 7, and 8 are almost matched with predicted values. The experimental flexural strength values for the experiment no. 1, 3, and 4 are much closed with predicted values.

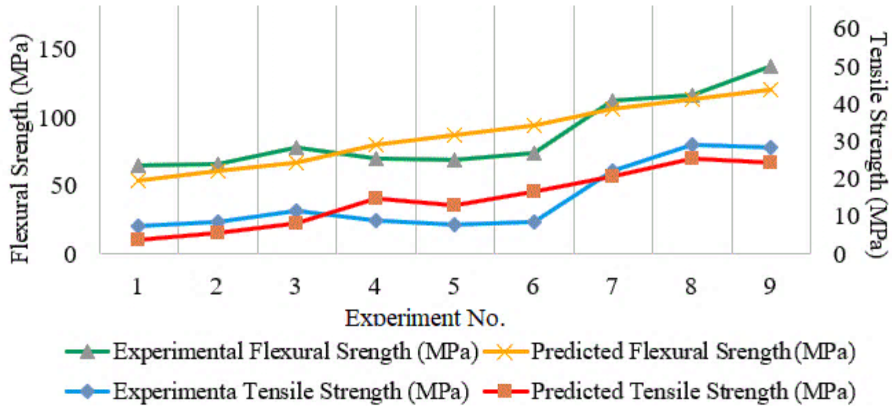

Figure 6. Comparison between experimental and predicted values of tensile and flexural strength.

4. Conclusions

The present study reveals that the sponge gourd, coir, and jute fiber reinforced epoxy composites exhibited improved mechanical properties and found to have the adequate potential for different applications. The following conclusions are drawn regarding the above discussion:

1. The combination of wt% ratio of resin and hardener 1.00, wt% of resin and hardener 85, wt% ratio of sponge gourd and jute 1.00, and wt% ratio of sponge gourd and coir 3.00 was obtained as the optimum setting to achieve both maximum tensile and flexural strength.
2. Confirmation experiments were carried out with the optimum settings on three different samples that showed almost the same mechanical properties with predicted values. The percentage of errors were only 3.08 % and 1.24% for tensile and flexural strength respectively.
3. From the ANOVA table, maximum and minimum contribution on both tensile and flexural strength were found for wt% ratio of resin and hardener, and wt % ratio of sponge gourd and jute respectively.
4. Contour plots are very helpful to explore the combined influences of different control factors on mechanical characteristics. The regression equations showed a very close resemblance between predicted and experimental values.

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