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Research Article

Multiobjective Optimization of Mechanical Properties on Sisal-Glass Fiber-Reinforced Hybrid Composites Using Response Surface Methodology and LINGO Analysis

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The aim of this research work was to develop the optimal mechanical properties, namely, tensile strength, flexural strength, and impact strength of sisal and glass fiber-reinforced polymer hybrid composites. The sisal, in the form of short fiber, is randomly used as reinforcements for composite materials, which is rich in cellulose, economical, and easily available as well as glass fibers have low cost and have good mechanical properties. In addition, epoxy resin and hardener were for the fabrication of composites by compression molding. The selected materials are fabricated by compression molding in various concentrations on volume basics. The combination of material compositions is obtained from the design of experiments and optimum parameters determined by the Response Surface Methodology (RSM). From the investigation of mechanical properties, the sisal is the most significant factor and verified by ANOVA techniques. The multiobjective optimal levels of factors are obtained by LINGO analysis.

1. Introduction

The natural fiber is one of the most growing materials in the field of composite materials, which is available as a natural resource and has properties; there is a demand for high-performance composite materials in applications such as automotive, aircraft, and space. Natural fibers such as banana, hemp sisal, jute, flax, and coconut were used as reinforced materials on fiber composite fabrications. The wide availability of natural fibers has encouraged the progress of natural fiber components on developed composites. Hence, it should have more benefits than synthetic fiber; for example, it has a biodegradable, considerable cost, low density, and most adequate properties [1–5]. There is a relationship between the epoxy resin and carbon fiber in their mechanical properties. The effects of fiber orientations are 0, 35, 45, and 90, and the number of laminates and the type of resigning are taken as variables, but results were mainly dependent on the fiber orientation. The matrix materials such as thermoset polymer (epoxy resin) have the highest mechanical properties, and they are concluded that parameters that are taken into account are fiber orientation > number of laminates > resin type [1–9].

The experimental investigation was done on bananas and sisal hybrid composites to constrain the fiber load in the range of 0.20 to 0.50 volume fraction on fabrication. The materials are in the form of short fibers. They are randomly oriented to get increments on mechanical properties while increasing load [10]. Synthesis and mechanical properties of *Hibiscus sabdariffa* fiber with urea-formaldehyde (UF) were analyzed, and fibers that were taken into account are particle sizes, short fibers, and long fibers, and they found that UF resin has been more effective than the short fiber reinforcement [11]. The alkali-treated hollow epoxy particles were produced by water-based emulsion method along with polyester matrix composite. They examined tensile strength, tensile modulus, and flexural strength properties of the composites. Due to the interlocking of the polyester matrix into the pore regions of hollow epoxy particles, there is an increase in the mechanical, water absorption, and diffusion coefficient properties of the polyester composite [12].

The variation in the composition of epoxy resin had increasing mechanical properties of developed composites. The bio-based epoxy resin concluded that the physicomechanical and thermal properties were increased and used for manufacturing high-performance automotive and aerospace products [13]. The unidirectional orientation of developed composites had better results than random orientation sisal fiber epoxy resin for tensile and flexural properties of sisal fiber-reinforced epoxy composites [14]. The mechanical behaviors of surface-modified sisal fiber epoxy composites were analyzed, and the optimum mechanical properties were obtained at 18% NaOH-treated sisal fibers and 110% enhancement in the tensile strength. they concluded that NaOH-treated sisal-epoxy composites varied linearly with fiber fractions reaching different percentages [15].

The mechanical and water absorption properties of jute/banana fibers were investigated through layering sequence and hybridization on fabrication and concluded that tensile and flexural strength of developed composites were higher than those of distinct composites. But the layering patterns have more significant effects than the other effects on tensile, flexural, and impact properties of the composite using the ANOVA[16]. The mechanical properties of glass and jute fiber composites were analyzed, and the results showed that the optimal addition of jute fibers produces more strength on developed composites. For the evaluation of experimental results, the FEM base numerical studies were followed, and finally, they predict that incorporation of natural and synthetic fibers was improved by the strength of mechanical properties [17]. Physicomechanical properties on banana fiber-reinforced polypropylene composites were studied, and these composites are prepared by compression molding with UV-treated banana fibers being used and its mechanical properties increased significantly compared to untreated specimens. The optimum properties are obtained on 75 UV passes [18]. The alkali-treated sisal fibers with polypropylene composites were examined, and the results concluded that the treated fiber composites were improved because of their adhesion nature between the fibers and matrix; at the same time, treated fibers were damaged during the process [19].

MAPP treatment fibers were used to improve fire resistance and thermal properties of kenaf and sisal fiber-reinforced polypropylene composites. However, the impact strength of composites decreased with the addition of MAPP to the fiber because the interfacial bond strength between fiber and matrix decreased [20]. There is an effect of fiber twist on the mechanical properties of prepared composites on both unimpregnated and resin-impregnated sisal yarns. A critical fiber twist level for unimpregnated and impregnated sisal yarns was found as the tensile strengths were decreased and increased with increasing levels of fiber twists, respectively. It concluded that lower twist levels led to higher mechanical properties of composites. The experimental results are proved analytically by using Rao's model [21]. The mechanical and fracture behavior of banana fiber composites with maleic anhydride (MA) as a compatibilizer and glycerol triacetate ester (GTA) on the properties of PLA/BF composites was studied by Majhi et al.. Compatibilized biocomposites exhibited improved tensile modulus to the tune of 62% and GTA plasticized composites showed improvement in impact strength by 143% [22].

From the exhaustive literature survey, the present work is planned to be carried out by developing hybrid fiber-reinforced polymer composites with the combination of sisal fiber and epoxy matrix materials. The developed composites were investigated on mechanical properties, namely, tensile strength, flexural strength, and impact strength according to ASTM standard. The empirical models were developed through RSM for predicting the experimental value. The aim of the present work is to predict optimum levels of process parameters for tensile, flexural, and impact strength. In addition, LINGO analysis was used to determine the suitable compositions of selected materials for obtaining a quality composite specimen.

2. Experimental Setup

2.1. Materials. In experimental research work, the sisal and glass fiber were taken as reinforcement materials in the form of short and mate woven type fibers, respectively, to increase the mechanical properties of linear and lateral dimensions of the fabricated specimen and to increase the performance of flexural and impact strength. The epoxy resin is used as a matrix to obtain the desired composite specimens which are procured by local dealers [23]. Hence, to improve the bonding strength of the composite, the natural fibers have undergone 5% of NaOH alkali treatment for half an hour; finally, fibers are cleaned by water and dried at an environmental temperature for a couple of days. To increase the impact and flexural strength properties, reinforcement of sisal fibers is applied randomly between the mate-type glass fibers which are taken as constant [24]. In addition, for better adhesive properties, LY556 Epoxy Resin and Hardener Hy951 are used to mix in the ratio of 10 : 1 to speed up the curing stage in the fabrication process. Table 1 shows the designed level of factors for fabricating sample specimens [25].

2.2. Fabrication. The number of experiments and mixing compositions of a specified range of materials is obtained from the design of experiments, and it is tabulated in Table 2. The DOE is used to minimize the number of experiments through which the materials, cost, and time were reduced, and also, it produces results without any deviation.

From the above-designed experiments, different combination samples were fabricated by compression molding machine by volume fraction method. During the molding process, the setup is kept at 500 psi at 95°C for 60 minutes. The fabrication work was completed at the Kumaraguru College of Technology, Coimbatore, India.

2.3. Testing Standards. The developed composite specimens were examined according to ASTM standards. The tensile strength test was carried out on UTM in accordance with ASTM D3039 with a constant strain rate of 1.25 mm/min. At the same time, flexural moduli were determined by ASTM D790 standards as the size of specimens was taken as $125 \times 13 \times 9\,mm^3$ and the test was conducted by Lloyd instrument LR 100 kN. In addition, the impact strength of composite materials was analyzed by the impact Izod testing machine as per the ASTM D256 [24, 26]. During the result summarized and the evaluation result, the average values of each tested sample are considered to obtain a precision value.

3. Results and Discussion

The mechanical properties, namely, tensile, flexural, and impact strength of tested sample results are summarized in Table 3 and to be analyzed in the following manner.

For tensile strength, Figure 1 shows that experiment 2 has a slightly high strength (31.89 MPa) as compared to the other experiments, and the maximum strength is found in the order of $2 > 8 > 1 > 3 > 4 > 9 > 5 > 6 > 7$. The greatest tensile strength of the composite was formed in the volume % of the mean level composition of the specified range. By increasing the volume of sisal content, the same volume of epoxy resin strength of the composite drops out. (In addition, sisal content in the same volume of epoxy resin composite drops the strength.) However, the lowest strength was obtained in a high level of sisal and epoxy resin content in fabricated specimens. It is noted that volume fraction is increased in both factors endowed with very less strength (21.98 MPa) as compared to other experiments because of the variation in binding between the reinforcement with matrix materials [27, 28].

Figure 2 shows the variation of flexural strength of tested samples. It is clearly understood that the maximum and minimum strengths of flexural properties are also followed in the same trend of tensile strength and the strength order $2 > 1 > 3 > 8 > 4 > 5 > 9 > 6 > 7$. However, the variation of the maximum strength of the first two values has a high range of deviation (161.34 MPa and 134.65 MPa), and it is observed that both levels of sisal fibers were decreased. It shows that the addition of materials led to a decrease in flexural strength rapidly and the deviation is 60 MPa [29].

The mechanical properties of impact strength of examined sample results are plotted as a graph in Figure 3; while reviewing the results, the maximum range occurred in the low-level mixing composition experiment only. Hence, the consequences of impact strength entirely differ from the other tested properties and the maximum to a minimum order of experiments as $6 > 1 > 5 > 3 > 8 > 2 > 4 > 7 > 9$ [30].

3.1. ANOVA. The statistical analysis ANOVA was carried out, and it is reported in Tables 4–6. From the ANOVA, the obtained P value is less than 0.05. From the ANOVA techniques, it can be concluded that the P value is lesser than the F value; the null hypothesis can be rejected, accepting alternative hypothesis which says that there is a significant effect on layering sequence on the mechanical strength of the composite [16].

From Table 4, the model is significant for the output response of tensile strength. The epoxy resin is the most significant factor (<0.05) and sisal fiber is not much more significant factor (>0.05), and it is already observed in the experimental data, the optimum range of tensile strength is obtained (15% and 25% of sisal and epoxy resin) at the same level of sisal fiber, and tensile strength is reduced which changes the level of epoxy resin. Hence, the experimental result and ANOVA calculation are almost the same.

It can be observed from ANOVA, the model is significant for the output response of flexural strength shown in Table 5. The sisal fiber is the most significant factor (<0.05) and epoxy resin is not much more significant factor (>0.05), and it is most suitable for experimental data because the maximum flexural strength is obtained (15% and 25% of sisal and epoxy resin) at the same level of epoxy resin, and flexural strength is reduced which changes the sisal fiber content. However, sisal fiber is the most significant factor in the test.

The impact strength of the experiment proves that sisal fiber is a more significant factor when compared to epoxy resin described in Table 6. The objective of this investigation is to predict the most influencing level of factors, which affects the strength of mechanical parameters. The desirability of the experiment is 99.5% obtained from DOE as shown in Figure 4.

3.2. Development of Regression Model. The simplest and efficient mathematical model for the tensile, flexural, and impact strength test was developed by a Response Surface Methodology considering four independent process parameters with desired levels. The regression equations were used to predict the circularity and cylindricity of hybrid composite, and selected parameters are efficiently correlated with experimental results [31].

Table 1: Factors and level of experiments.

Factors	Unit	Notation	Factor level		
			−1	0	+1
Vol.% of sisal fiber	Vol.%	X_1	10	15	20
Vol.% of epoxy resin	Vol.%	X_2	20	25	30

Table 2: Experiment design matrix for the fabrication of specimen.

Description	Exp. 1	Exp. 2	Exp. 3	Exp. 4	Exp. 5	Exp. 6	Exp. 7	Exp. 8	Exp. 9
Std. order	4	9	7	5	6	1	8	2	3
Run order	1	2	3	4	5	6	7	8	9
Vol.% of sisal X_1	−1	0	0	+1	−1	−1	+1	0	+1
Vol.% of epoxy resin X_2	0	0	+1	0	+1	−1	+1	−1	−1

Table 3: Design matrix and average results of mechanical properties.

Run order	Std. order	Vol.% of sisal X_1	Vol.% of epoxy resin X_2	Tensile strength (MPa)	Flexural strength (MPa)	Impact strength (J)
1	4	−1	0	27.62	134.65	4.20
2	9	0	0	31.89	161.34	3.40
3	7	0	+1	27.59	133.84	3.51
4	5	+1	0	27.09	127.91	2.75
5	6	−1	+1	23.92	111.06	4.00
6	1	−1	−1	23.78	103.21	4.30
7	8	+1	+1	21.98	100.83	2.75
8	2	0	−1	28.50	131.19	3.50
9	3	+1	−1	25.06	104.59	2.58

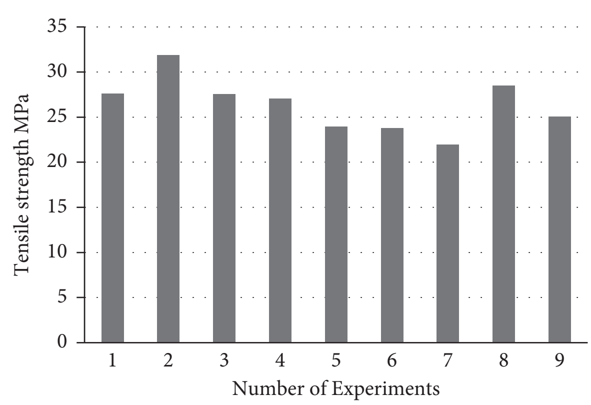


Figure 1: Tensile properties of designed composites.

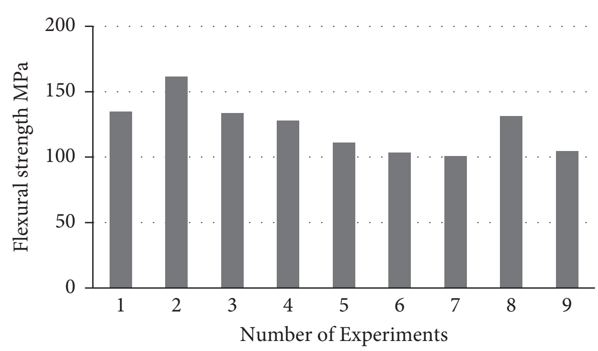


Figure 2: Flexural properties of designed composites.

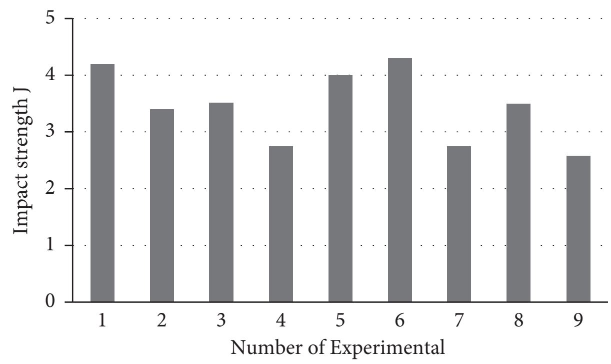


FIGURE 3: Impact properties of designed composites.

TABLE 4: ANOVA for the tensile strength test.

Source	SS	DF	MS	F value	P value Prob > F	Status
Model	72.13	5	14.43	326.66	0.0003	Significant
A-sisal	0.24	1	0.24	5.39	0.1030	
B-epoxy	2.48	1	2.48	56.11	0.0049	
AB	2.59	1	2.59	58.55	0.0046	
A^2	39.07	1	39.07	884.83	<0.0001	
B^2	27.75	1	27.75	628.40	0.0001	
Residual	0.13	3	0.044			
Cor total	72.26	8				

TABLE 5: ANOVA for the flexural strength test.

Source	SS	DF	MS	F value	P value Prob > F	Status
Model	3174.22	5	634.84	414.75	0.0002	Significant
A-sisal	40.49	1	40.49	26.45	0.0142	
B-epoxy	7.60	1	7.60	4.97	0.1122	
AB	33.77	1	33.77	22.06	0.0182	
A^2	1614.98	1	1614.98	1055.09	<0.0001	
B^2	1477.38	1	1477.38	965.19	<0.0001	
Residual	4.59	3	1.53			
Cor total	3178.81	8				

TABLE 6: ANOVA for the impact strength test.

Source	SS	DF	MS	F value	P value Prob > F	Status
Model	3.31	3	1.10	320.26	<0.0001	Significant
A-sisal	3.26	1	3.26	943.94	<0.0001	
B-epoxy	2.817E-003	1	$2.817E-003$	0.82	0.4076	
AB	0.055	1	0.055	16.01	0.0103	
Residual	0.017	5	$3.449E-003$			
Cor total	3.33	8				

$$\begin{aligned}
\text{for tensile strength} &= -109.3015 + 0.53413A + 0.39961B - 1.45009E^{-04} * AB - 1.37077E^{-03} * A^2 - 3.9071E^{-04} * B^2, \\
\text{flexural strength} &= -816.16785 + 3.21139A + 2.88435B - 5.24079E^{-04} * \mathrm{AB} - 8.81253E^{-03} * A^2 - 2.85086E^{-03} * B^2, \\
\text{impact strength} &= 7.52142 - 0.023319A - 3.83062E^{-03} * B + 2.11922E^{-05} * AB.
\end{aligned} \tag{1}$$

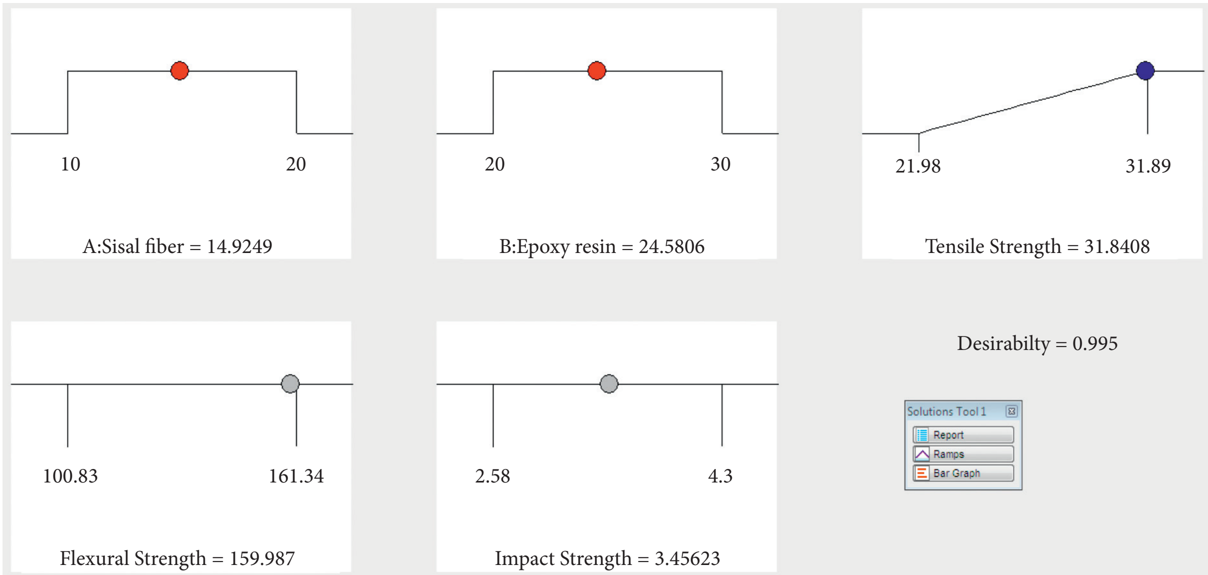


Figure 4: Desirability of tested composite sample result.

Table 7: Comparison of experimental and predicted values of response variables.

Exp.	Tensile strength (MPa)			Flexural strength (MPa)			Impact strength (J)		
	Exp. value	Predict. value	Error (%)	Exp. value	Predict. value	Error (%)	Exp. value	Predict. value	Error value
1	27.62	27.49	+0.47	134.65	134.88	−0.17	4.20	4.17	+0.71
2	31.89	31.59	+0.94	161.34	160.86	+0.29	3.40	3.44	−1.16
3	27.59	27.22	+1.35	133.84	134.96	−0.82	3.51	3.42	+2.63
4	27.09	26.85	+0.89	127.91	130.01	−1.61	2.75	2.70	+1.85
5	23.92	23.95	−0.12	111.06	111.87	−0.72	4.00	4.04	−0.99
6	23.78	23.6	+0.76	103.21	103.56	−0.33	4.30	4.31	−0.23
7	21.98	21.64	+1.57	100.83	101.24	−0.40	2.75	2.80	−1.78
8	28.50	28.53	−0.10	131.19	132.41	−0.92	3.50	3.46	+1.15
9	25.06	24.62	+1.78	104.59	104.45	+0.13	2.58	2.61	−1.14

The evaluated results of tensile, flexural, and impact strength are compared with a predicted value, which is obtained from the design of experiments. The percentage of error is calculated as follows:

$$\% \text{ of error} = \left(\frac{\text{experimental value} - \text{predicted value}}{\text{predicted value}}\right) * 100. \quad (2)$$

The % of error value of mechanical properties is listed in Table 7. The most response variables of all the experiments can be observed when a maximum and minimum percentage of error lies at ±2%. The scatter diagram of the tensile, flexural, and impact strength test shows the experimental value and predicted values of response variables. It can be observed that the predicted value of all response variables is fairly close to the corresponding experimental values shown in Figures 5(a)–5(c). There is a three-dimensional response surface plot of a combined effect of independent variables on tensile, flexural, and impact strength tests. It was clearly understood by viewing Figures 5(d)–5(f) that the tensile and flexural results are obtained in the form of the quadratic curve but linear model formed for impact strength result. It is used to analyze the critical level of factors.

3.3. LINGO Optimization. LINGO is one of the optimization tools to obtain the best result with the minimum number of experiments and reduced cost and time [32]. The optimum values of tensile, flexural, and impact strength of mechanical properties on developed composites specimen are shown in Table 8.

The optimum values of individual response and corresponding factor levels are obtained as shown in Figures 6(a)–6(c). The combo strength of tensile and flexural properties of different applications with different ranges of importance (1 : 1,3 : 1,1 : 3) are evaluated before starting the experiment. During the deformation of the test, the fibers are pulling out. Hence, the tensile strength is less as compared to the flexural strength. Due to the mat form, glass fiber is used to increase the flexural strength and it is used in the outer surface of the specimen.

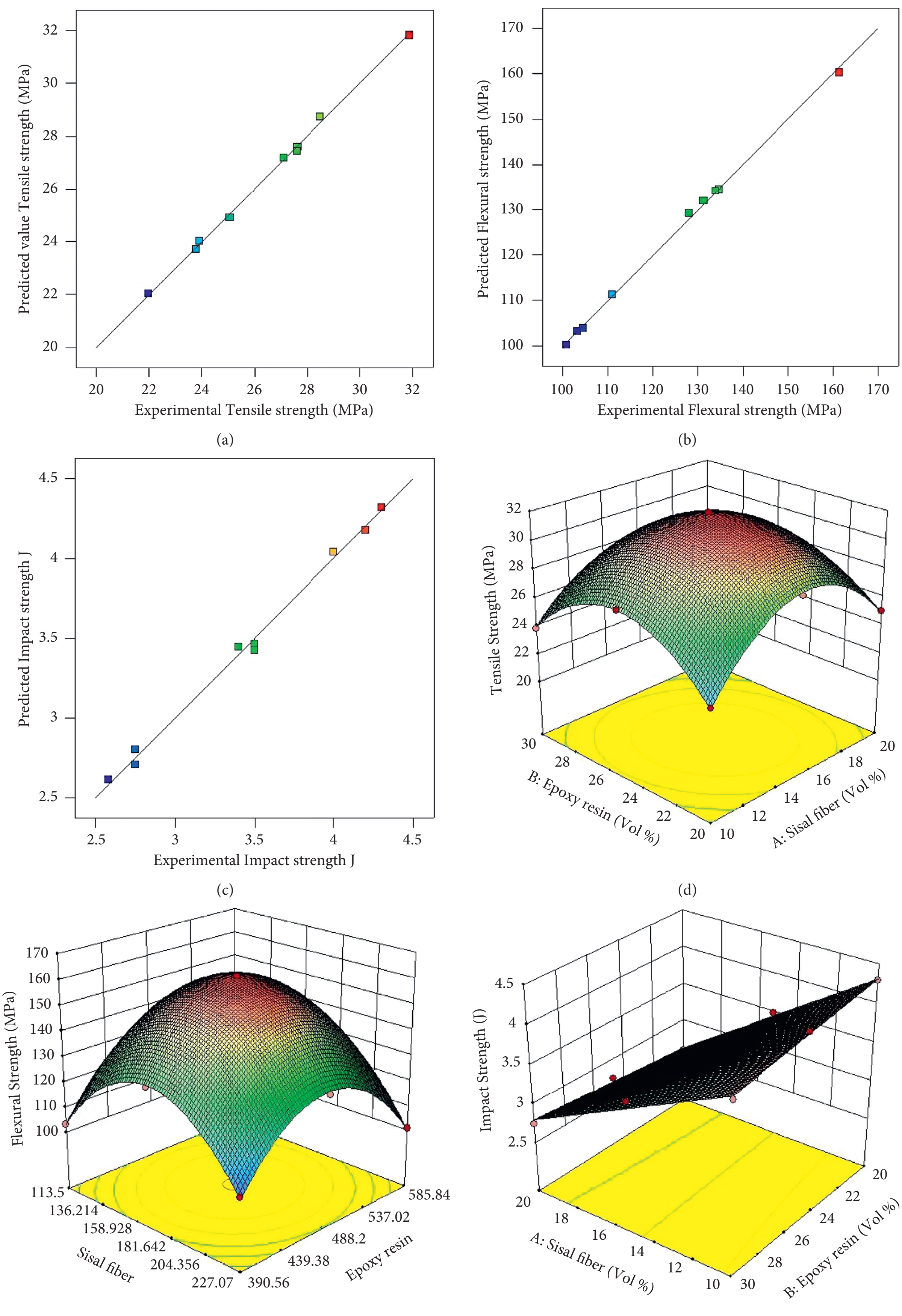
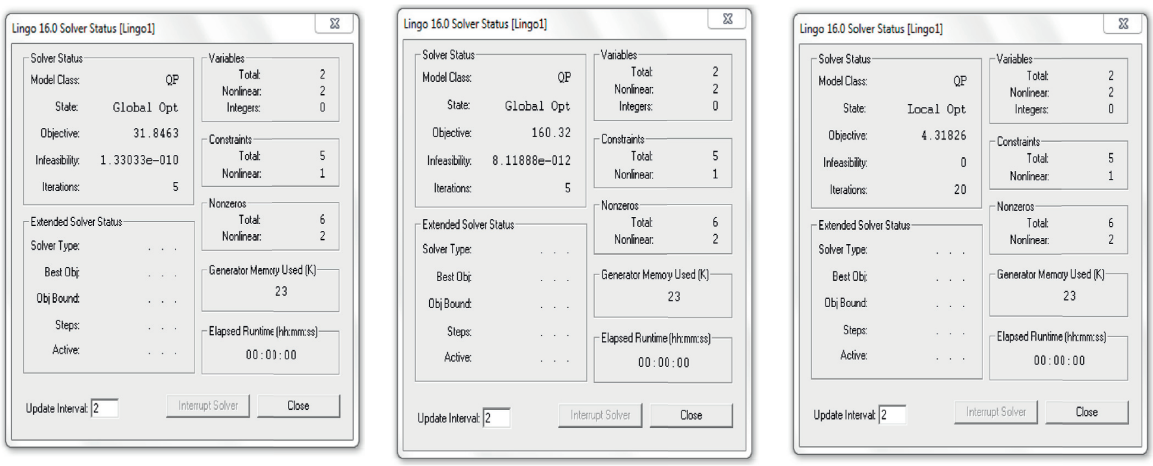


Figure 5: (a–c) Scatter diagrams and (d–f) 3D response surface plots for the tensile, flexural, and impact strength.

Table 8: Various optimum levels of response.

Optimum value		Optimum level of factors	
Response	Strength	Sisal fiber (grms)	Glass fiber (grms)
Tensile strength	31.84626 MPa	169.4426	479.9459
Flexural strength	160.3204 MPa	167.6219	490.4665
Impact strength	4.318260 J	113.5000	390.5800
Tensile and flexural strength (1 : 1)	96.06351 MPa	167.8331	489.2174
Tensile and flexural strength (3 : 1)	63.94075 MPa	168.1365	487.4384
Tensile and flexural strength (1 : 3)	136.1428	167.7684	489.5994



(a) (b) (c)

Figure 6: (a–c) LINGO optimization of tensile, flexural, and impact strength.

Table 9: Confirmation of tested sample results for output response variables.

Factors		Sisal fiber	Epoxy resin
Selected level of factors (Vol.%)		12	23
Mechanical properties	Predicted value	Experimental value	Error (%)
Tensile strength (MPa)	29.67	30	+1.08
Flexural strength (MPa)	146.65	146.75	−0.61
Impact strength (J)	3.92	3.88	−1.04

3.4. Confirmation Test. Confirmation tests were conducted using the same experimental procedure to confirm the results of experiments; by using the regression model equation, the predicted values are compared to the experimental values and the deviation is obtained within the range of error % as shown in Table 9.

4. Conclusion

The optimization of mechanical properties which are tensile, flexural, and impact strength of sisal/glass-fiber-reinforced hybrid composites was analyzed, and the conclusion is as follows:

(i) It is observed that the sisal is the most significant factor for tensile and impact strength properties of designed composites and not much more significant on flexural test

(ii) The experimental results of tensile, flexural, and impact strength are fairly close to the predicted value, which is obtained by RSM, and the error percentage lies at ±2%

(iii) The desirability was obtained as 98.8% of tested composites. From the above investigation, it can be found that the most significant levels of factors are determined and used for specified mechanical applications

(iv) LINGO optimization tool is used to determine the optimum strength of combined response such as tensile and flexural properties and corresponding level of factors

(v) Confirmation tests are done to confirm the results of RSM and ANOVA and error % lies at ±1.5% for predicted and experimental values

Data Availability

The data used to support the findings of this study are included within the article.

Disclosure

This study was performed as a part of the employment of Ambo University, Ethiopia.

Conflicts of Interest

The authors declare that there are no conflicts of interest to publish this article.

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