Strojniški vestnik - Journal of Mechanical Engineering 62(2016)5, 273-280

DOI:10.5545/sv-jme.2015.2641
Original Scientific Paper
Received for review: 2015-04-29
Received revised form: 2015-09-22
Accepted for publication: 2015-10-19

Modelling and Analysis of the Mechanical Properties of Agave Sisalana Variegata Fibre / Vinyl Ester Composites Using Box-Behnken Design of Response Surface Methodology

Ayyanar Athijayamani[1,*] – Raju Ganesamoorthy[2] – Konda Thulasiraman Loganathan[3] – Susaiyappan Sidhardhan[4]
[1] Alagappa Chettiar College of Engineering and Technology, Department of Mechanical Engineering, India
[2] Jayasuriya Engineering College, Department of Mechanical Engineering, India
[3] Alagappa Chettiar College of Engineering and Technology, Department of Chemistry, India
[4] Government College of Engineering, Department of Civil Engineering, India

In this paper, the Box-Behnken (BB) experimental design of response surface methodology (RSM) was utilized to study the effect of process parameters on the mechanical properties of agave sisalana variegata (ASV) fibre-reinforced vinyl ester (FRVE) composites. The fibre length, fibre content, and fibre diameter were used as process parameters to develop a model using the BB experimental design. Experimental tests were carried out based on the BB design. The experimental tensile and flexural strength values were fitted with the predicted strength values by a second-order polynomial equation via a multiple regression analysis. The results show that the tensile and flexural strength can be predicted by the developed models with more than 98.54 % of the variation in the tensile strength and 99.24 % of the variation in the flexural strength. The level 3 of fibre length (13 mm), level 2 of fibre content (35.19 wt %), and level 1 of fibre diameter (0.24 mm) were selected as the optimal levels of fabrication process parameters using the response surface graph and models. Finally, it was proved that the BB design of response surface methodology could efficiently be applied to the modelling and optimization of the mechanical properties of natural fibre polymer composites.

Keywords: agave sisalana variegata fibre, composite, tensile strength, flexural strength, Box-Behnken design, response surface methodology

Highlights
- *Agave sisalana variegata fibre-reinforced vinyl ester composite is a new series of polymer composites.*
- *Experimental works were carried out based on the Box-Behnken experimental design of response surface methodology.*
- *Mechanical properties, such as the tensile and flexural strength values of composites, were predicted using a second-order polynomial equation by a multiple regression analysis.*
- *The optimal levels of fabrication process parameters were identified using response surface graph and models.*

0 INTRODUCTION

In recent years, there has been growing interest in the use of plant-based natural cellulose fibers, such as sisal, coir, flax, cotton, hemp, jute, kenaf, pineapple, ramie, bamboo, bagasse, roselle, banana and others. as reinforcing agents for polymer resin matrix such as thermoplastics and thermosets [1] and [2]. Their merits make them an attractive ecological alternative to man-made synthetic fibres used for the manufacturing of composites [3] and [4].

Among the various natural fibres, the sisal fibre (*Agavaceae* family) is an important, environmentally friendly and biodegradable one. Moreover, sisal is a strong, stable, and versatile material, and it has been recognized as an important source of fibre for the preparation of composites [5] and [6]. The agave sisalana variegata plant is also one of the most important families of *Agavaceae*, and it has the same features as regular sisalana. People use these plants as a nursery plant in their gardens and lands. The fibres are produced from the leaves of these plants. There is no literature available on the characteristics of agave sisalana variegata (ASV) fibre-reinforced vinyl ester (FRVE) composites.

Generally, the properties of fibre-reinforced polymer composites can be varied continuously over a broad range of values under the control of their process parameters and conditions. Careful selection of process parameters, such as fibre length, fibre volume or weight fraction, the fibre aspect ratio, the nature of the matrix, and fibre-matrix interface, etc., enables finished composite characteristics to be tailored to almost any specific applications. The main objective of this study is to focus on the effects of process parameters such as fibre length, fibre content, and fibre diameter on the tensile strength and flexural strength of ASVFRVE composites. Several authors have been used the BB design of response surface methodology (RSM) to understand better the relationship between the parameters and the response and also to optimize the parameters of the technology in various materials [7] and [8]. In order to have the better understanding and to determine mechanical

*Corr. Author's Address: Alagappa Chettiar College of Engineering and Technology, Department of Mechanical Engineering, India, athimania@rediffmail.com

properties of the composites, the BB experimental design of RSM is used in this study. The experimental tests are performed based on the BB experimental design, and the data sets are recorded. Using these sets of experimental data obtained with experimental tests, mathematical models were then developed to show the effect of each process parameter and their interactions on mechanical properties of ASVFRVE composites. Predicted values were compared with experimental values to examine their agreement.

1 EXPERIMENTAL DETAILS

1.1 Materials

The ASV fibres for this study were procured from Fiber Shop, Tamilnadu, India. The chemical composition and physical properties of ASV fibres were measured at *SITRA*. The chemical composition and physical properties of ASV fibers were obtained by chemical and physical testing at *SITRA*. Table 1 shows the chemical composition and physical properties of ASV fibres.

Table 1. *Chemical composition and physical properties of ASV fibre*

Serial No.	Chemical compositions [%]		Physical properties	
1	Cellulose	69.3	Appearance	Yellowish
2	Hemi-cellulose	19.4	Diameter[mm]	0.67 to 2.4
3	Lignin	7.6	Density [g/cm^o]	1.38
4	Pectin	2.8	Tensile strength [MPa]	63.9 to 170.2
5	Wax	0.9	Modulus [MPa]	8.94 to 17.2

Vinyl ester (VE) resin with a clear yellow appearance, the styrene amount of 40 % to 50 %, a density of 1.145 g/cm^3, viscosity of 400 mPa·s, and specific gravity of 1.09, was used as polymer matrices in this study and purchased from GVR Enterprises, India. Methyl Ethyl Ketone Peroxide (MEKP) ($C_8H_{18}O_6$), cobalt 6 % naphthenate (CoNap) ($C_{20}H_{34}CoO_4$) and N–N dimethyl aniline ($C_8H_{11}N$) were used as an accelerator, catalyst, and promoter, respectively.

1.2 Preparation of Composite Specimens

Composite specimens were fabricated with a hand lay-up method using the mould box (150 mm × 150 mm × 3 mm) developed in our laboratory. A mixture of vinyl ester (VE) resin, accelerator, catalyst, and the promoter was prepared with a ratio of 100:2.5:1.5:2 using a mechanical stirrer. ASV fibres were then added to this mixture at a calculated amount and stirred using a mechanical stirrer to ensure the perfect mixture. After pouring the mixture into the mould, the mould box was closed and allowed to cure at room temperature for 24 h. For each set of combinations, five specimens were fabricated and used for mechanical tests.

1.3 Testing of Composite Specimens

For tests, composites specimens were cut to the size of 150 mm × 20 mm × 3 mm using a wooden board cutter. Tensile tests were performed according to ASTM standard D 638-10 [9] procedure at a crosshead speed of 2 mm/min with a Fuel Instruments & Engineers, India (FIE) testing machine. The flexural strength of the composite was measured with the same machine using the 3-point bending fixture according to standard ASTM D-790-10 [10] with a crosshead speed of 2 mm/min. All tests were performed at room temperature. After the testing, the average mechanical property values were recorded and then used for modelling and analysis.

1.4 BB Experimental Design of RSM

In this study, a BB experimental design of RSM was used to divide the process parameters into three levels. Generally speaking, RSM is a collection of statistical and mathematical techniques that are useful for the modelling and analysing of engineering problems. The optimization of the response surface influenced by various process parameters is the main aim of this technique. They also quantify the relationship between the controllable input process parameters and the obtained response surface [11]. The process parameters are independent variables, which are assumed to be continuous and controllable by experiments with negligible errors. For the true functional relationship between independent variables, a suitable approximation is required.

To determine the optimal level, a second-order polynomial model can be used to correlate the relationship between independent variables and response surface, and is written in the matrix form as follows [8]:

$$\mathbf{Y} = b\mathbf{X} + \varepsilon, \tag{1}$$

where **Y** is a matrix of measured values, **X** is a matrix of independent variables, and b and ε are coefficients and errors, respectively. The value of b is calculated by solving Eq. (1) as follows [8]:

$$b = \left(\mathbf{X}'\mathbf{X}\right)^{-1}\mathbf{X}'\mathbf{Y}, \tag{2}$$

where $\mathbf{X'}$ is the transpose of the matrix $\mathbf{X}$ and $(\mathbf{X'X})^{-1}$ is the inverse of the matrix $\mathbf{X'X}$. Usually, a second-order model is utilized in RSM in the following form **[8]**:

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i=1}^{k-1} \sum_{j=2}^{k} \beta_{ij} x_i x_j + \varepsilon, \quad (3)$$

where Y *is* the response variable (dependent variable), x_i is the predictor variable (independent variable), β_0 is constant, β_{ii} (i = 1, 2, ..., k) and β_{ij} (i = 1, 2, ..., k; j = 1, 2, ..., k) are regression coefficients which are determined by the least square method, and ε is an error.

In this study, the BB experimental design of RSM was chosen for determining the relationship between the response variables (tensile strength, flexural strength and impact strength) and process parameters (fibre length, fibre content, and fibre diameters). A BB experimental design is a spherical, revolving design and has the advantage of requiring fewer experiments (15 trials) than a full factorial design would (27 trials). A BB design is a rotatable second-order design based on three-level incomplete factorial designs. It requires an experiment number according to **[12]**:

$$N = k_2 + k + c_p, \quad (4)$$

where k is the factor number and (c_p) is the replicate number of the central point **[13]**.

According to the BB experimental design, the process parameters of the ASVFRVE composite were tested in a 15-run experiment to determine their optimal levels. The process parameters chosen for this study were designated as A_1, A_2, A_3 and prescribed into three levels, coded +1, 0, −1 for high, medium and low values, respectively. Table 2 shows the levels of the variable chosen for the BB experimental design. Three test parameters were coded according to the following equation **[14]**:

$$x_i = \frac{A_i - A_o}{\Delta A} \quad i = 1, 2, 3, \quad (5)$$

where x_i is the coded value of a process parameter (independent variable); A_i is the actual value of a process parameter (independent variable); A_o is the actual value of a process parameter (independent variable) at the center point; and ΔA is the step change value of a process parameter (independent variable). BB experimental design for the three parameters and three levels is shown in Table 3 with a total of 15 trials. The model for three parameters is of the following form **[12]**:

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \\ + \beta_{23} x_2 x_3 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{33} x_3^2, \quad (6)$$

where Y is the predicted response, β_0 is constant; x_1, x_2, and x_3 are process parameters (independent variables); β_1, β_2 and β_3 are linear coefficients; β_{12}, β_{13} and β_{23} are cross product coefficients and β_{11}, β_{22} and β_{33} are the quadratic coefficients **[15]**. The quality of the model was checked by an F-test and the determination coefficient R^2.

Table 2. *Levels of variable chosen for the BB experimental design*

Variables	Symbol		Coded variable level		
			Low	Medium	High
	Uncoded	Coded	-1	0	+1
Fiber length fly, [mm]	A_1	x_1	3	8	13
Fiber content f_c [wt%]	A_2	x_2	18.88	35.19	51.49
Fiber diameter f_d [mm]	A_3	x_3	0.24	0.85	1.45

Table 3. *BB experimental design with actual and coded values for mechanical properties of ASVFRVE composites and results*

Trials	Actual and coded level of variables			Experimental properties	
	x_1 f_l [mm]	x_2 f_c [wt%]	x_3 f_d [mm]	Tensile strength; σ_t [MPa]	Flexural strength; σ_f [MPa]
1	3 (–1)	18.88 (–1)	0.85 (0)	30.7	34.7
2	13 (+1)	18.88 (–1)	0.85 (0)	36.6	48.7
3	3(–1)	51.49 (+1)	0.85 (0)	33.5	34.2
4	13 (+1)	51.49 (+1)	0.85 (0)	36.3	43.7
5	3 (-1)	35.19 (0)	0.24 (–1)	35.8	40.8
6	13 (+1)	35.19 (0)	0.24 (–1)	41.3	52.3
7	3 (–1)	35.19 (0)	1.45 (+1)	33.9	36.2
8	13 (+1)	35.19 (0)	1.45 (+1)	38.8	51.3
9	8 (0)	18.88 (–1)	0.24 (–1)	34.2	40.5
10	8 (0)	51.49 (+1)	0.24 (–1)	36.9	39.3
11	8 (0)	18.88 (–1)	1.45 (+1)	31.1	39.6
12	8 (0)	51.49 (+1)	1.45 (+1)	33.1	38.1
13	8 (0)	35.19 (0)	0.85 (0)	37.8	46.9
14	8 (0)	35.19 (0)	0.85 (0)	37.8	46.9
15	8 (0)	35.19 (0)	0.85 (0)	37.8	46.9

2 RESULTS

A BB experimental design with three-parameters and three-coded levels, including three replicates at the centre point, was used to determine the response (mechanical properties of ASVFRVE composite). In 15 trials of the BB experimental designs, three centre point trials were added to provide a measure of process stability and inherent variability. Fiber length f_l, fibre content f_c and fibre diameter f_d were the independent variables studied to predict the mechanical properties of ASVFRVE composite. Using the relationship between the process parameter mentioned in Table 2, the actual levels of the variables for each of the experiments in the design matrix were calculated, and the experimental results obtained as given in Table 3. From the experimental results listed in Table 3, the second-order response functions representing mechanical properties of the ASVFRVE composites can be expressed as a function of the process parameter. The relationship between the mechanical properties of the ASVFRVE composite and process parameters were obtained from the multiple regression analysis for coded unit as follows:

For the tensile strength model equation:

$$\sigma_t = 13.17 + 0.82x_1 + 1.09x_2 + 0.53x_3 - \\ -9.51\times10^3 x_1x_2 - 0.05x_1x_3 - 0.02x_2x_3 + \\ +2\times10^3 x_1^2 - 0.01x_2^2 - 1.09x_3^2. \quad (7)$$

For flexural strength model equation:

$$\sigma_f = 5.92 + 1.74x_1 + 1.69x_2 + 2.53x_3 - \\ -0.01x_1x_2 + 0.29x_1x_3 - 7.60\times10^3 x_2x_3 - \\ -0.02x_1^2 - 0.02x_2^2 - 3.69x_3^2. \quad (8)$$

The mechanical properties of the ASVFRVE composites at any regime in the interval of our experimental design could be calculated from Eqs. (7) and (8).

The analysis of variance (Table 4) for the tensile strength showed that this model was significant ($P<0.01$) with an F-value of 37.62. There is only a 0.05 % chance that a "Model F-value" this large could occur due to noise. The P-values were used as a tool to check the significance of each coefficient, which also indicates the interaction effects between each independent variable. The regression of all the linear term (x_1, x_2, and x_3) and quadratic coefficients of x_3^2 was significant; two cross-products (x_1, x_2) were also significant. Values greater than 0.1000 indicate the model terms are not significant. The fitness of the model was further confirmed by a satisfactory value of the determination coefficient, which was calculated to be 0.9854, indicating that 98.54 % of the variability in the response could be predicted by the model. The second order quadratic model for tensile strength was regressed by considering only the significant terms and shown as below:

$$\sigma_t = 13.17 + 0.82x_1 + 1.09x_2 + 0.53x_3 - \\ -9.51\times10^3 x_1x_2 - 1.09x_3^2. \quad (9)$$

The analysis of variance for the flexural strength was given in Table 5. The table reveals that the model for the flexural strength is significant ($P < 0.01$) with an F-value of 72.07.

There is only a 0.01 % chance that a "Model F-value" this large could occur due to noise. The P value (Prob > F) less than 0.05 indicates that the model terms are significant. In this case x_1, x_2, x_3, x_1x_2, x_2^2, and x_3^2 are significant model terms. An R^2 of 0.9924 indicates that the model developed explains 99.24 % of the variance in the dependent variable (flexural strength). The second-order quadratic model for flexural strength was regressed by considering only the significant terms and shown as:

Table 4. *ANOVA for response surface quadratic model for optimization of tensile strength of ASVFRVE composites*

Source	Sum of squares	Degree of freedom	Mean square	F-value	p-value Prob>F
Model	118.32	9	13.15	37.62	0.0005
A-Length	45.6	1	45.6	130.48	<0.0001
B-Content	6.48	1	6.48	18.54	0.0077
C-Diameter	15.96	1	15.96	45.67	0.0011
AB	2.4	1	2.4	6.87	0.047
AC	0.09	1	0.09	0.26	0.6334
BC	0.12	1	0.12	0.35	0.5796
A^2	9.231E-003	1	9.231E-003	0.026	0.8773
B^2	47.19	1	47.19	135.02	< 0.0001
C^2	0.59	1	0.59	1.69	0.2503
Residual	1.75	5	0.35	-	-
Lack of fit	1.75	3	0.58	-	-
Pure Error	0	2	0	-	-
Cor Total	120.07	14	-	-	-

$$\sigma_f = 5.92 + 1.74x_1 + 1.69x_2 + 2.53x_3 - -0.01x_1x_2 - 0.02x_2^2 - 3.69x_3^2. \quad (10)$$

3 DISCUSSION

The experimental and predicted values of the mechanical properties of the ASVFRVE composites are given in Table 6.

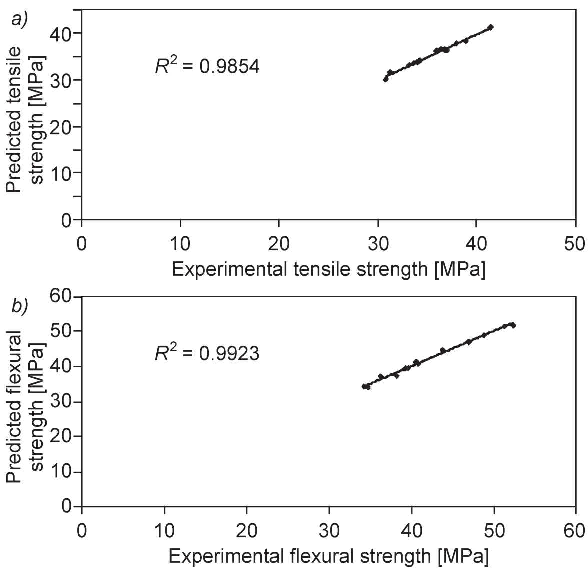

Fig. 1. *Relation between experimental and predicted values of a) tensile strength, and b) flexural strength*

Table 5. *ANOVA for response surface quadratic model for optimization of flexural strength of ASVFRVE composites*

Source	Sum of squares	Degree of freedom	Mean square	*F*-value	*p*-value Prob > *F*
Model	481.6	9	53.51	72.07	<0.0001
A-length	313.75	1	313.75	422.56	<0.0001
B- content	8.41	1	8.41	11.32	0.02
C-diameter	7.41	1	7.41	9.98	0.0251
AB	5.06	1	5.06	6.82	0.0476
AC	3.24	1	3.24	4.36	0.091
BC	0.022	1	0.022	0.03	0.8686
A^2	0.59	1	0.59	0.8	0.4133
B^2	140.79	1	140.9	189.62	<0.0001
C^2	6.73	1	6.73	9.06	0.0297
Residual	3.71	5	0.74	-	-
Lack of Fit	3.71	3	1.24	-	-
Pure Error	0	2	0	-	-
Cor Total	485.31	14	-	-	-

The actual and predicted values of the tensile and flexural strength obtained using model equations (Eqs. (7) and (8)) are presented in Fig. 1. The predicted values are in good agreement with the experimental data values, indicating a good fitness (R^2 value of 0.985 for tensile strength, R^2 value of 0.992 for flexural strength).

Table 6. *Experimental and predicted values of tensile strength and flexural strength of ASVFRVE composites*

Trial	Tensile strength [MPa]		Flexural strength [MPa]	
	Experimental	Predicted	Experimental	Predicted
1	30.7	30.21	34.7	33.96
2	36.6	36.54	48.7	48.74
3	33.5	33.56	34.2	34.16
4	36.3	36.79	43.7	44.44
5	35.8	36.33	40.8	40.75
6	41.3	41.60	52.3	51.48
7	33.9	33.80	36.2	37.03
8	38.8	38.28	51.3	51.35
9	34.2	34.16	40.5	41.29
10	36.9	36.31	39.3	39.39
11	31.1	31.69	39.6	39.51
12	33.1	33.14	38.1	37.31
13	37.8	37.80	46.9	46.90
14	37.8	37.80	46.9	46.90
15	37.8	37.80	46.9	46.90

3.1 Validation of Models

To validate the developed model, ten additional experiments were carried out using random conditions as given in Table 7; the statistical results calculated by the developed model were compared with the experimental results. The relative deviation (RD) was calculated with the following equation:

$$\mathrm{RD} = \frac{\text{Predicted value - Actual value}}{\text{Actual value}} \times 100,$$

The results show the low relative deviation; therefore, this developed model could be used to describe the important process parameters that affect the mechanical properties of ASVFRVE composites.

3.2 Effect of Process Parameters on Mechanical Properties

In order to gain a better understanding of the results, the 3D response surface plots of predicted models are presented in Fig. 2. It is evident from the results that all the input process parameters have a significant effect on the tensile strength of the ASVFRVE composite. Fig. 2a shows the effect of fibre content and fibre length on the tensile strength of the ASVFRVE composite. When the fibre length, fibre loading and fibre diameter was 3 mm, 18.88 wt%, and 0.85

Table 7. *Process parameters and their corresponding experimental and predicted strength values with relative error percentage for validation*

Trials	Process parameters			Tensile strength [MPa]			Flexural strength [MPa]		
	f_l	f_c	f_d	Experimental	Predicted	*R* [%]	Experimental	Predicted	*R* [%]
1	4	19.34	1.4	30.13	30.87	2.46	34.11	34.72	1.78
2	7	39.56	0.65	41.94	42.99	2.50	50.89	51.12	0.45
3	11	48.24	1.2	43.71	43.94	0.54	52.96	53.43	0.88
4	5	28.11	0.93	37.46	37.52	0.15	45.44	44.73	1.57
5	9	41.82	0.33	43.84	44.86	2.32	52.51	53.08	1.09
6	12	25.74	0.78	39.98	40.67	1.73	52.65	53.37	1.37
7	6	33.47	1.3	40.19	39.12	2.67	47.33	46.78	1.17
8	8	44.65	0.33	43.97	44.59	1.42	50.88	51.88	1.96
9	10	30.88	0.84	40.79	41.49	1.73	52.87	53.11	0.45
10	5	22.67	1.1	34.62	34.30	0.91	39.92	40.74	2.06

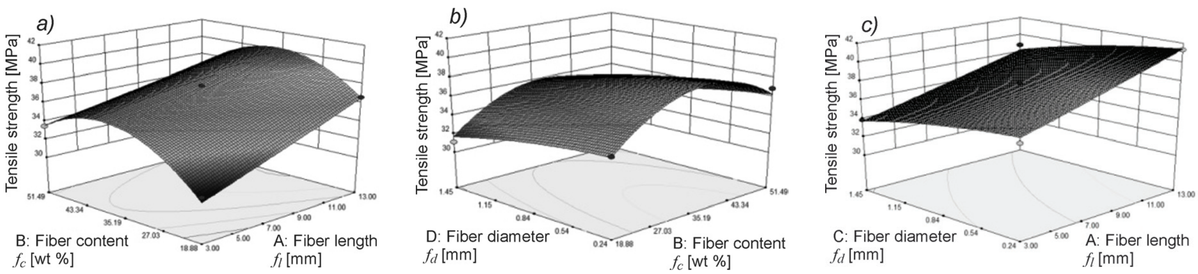

Fig. 2. *3D response surface plots showing a) the effect of fiber length (x_1) and fiber content (x_2), b) the effect of fiber content (x_2) and fiber diameter (x_3), and c) the effect of fiber length (x_1) and fiber diameter (x_3) on the tensile strength of ASVFRVE composites*

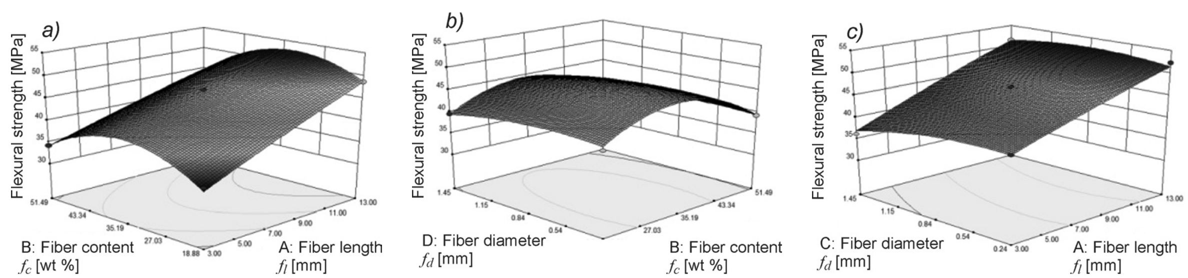

Fig. 3. *3D response surface plots showing (a) the effect of fiber length (x_1) and fiber content (x_2), (b) the effect of fiber content (x_2) and fiber diameter (x_3), and (c) the effect of fiber length (x_1) and fiber diameter (x_3) on the flexural strength of ASVFRVE composites*

mm, the tensile strength of the composites became minimal. Fig. 2b shows the effect of fibre diameter and fibre content on the tensile strength, and Fig. 2c shows the effect of fibre diameter and fibre length on the tensile strength. The maximum tensile strength value was observed in the composite having a fiber content of 35.19 wt%, fiber diameter of 0.24 mm, and a fiber length of 13 mm respectively. Thus, the interaction between the fibre length and fibre loading strongly affected the tensile strength in the composite specimen.

Fig. 3 show the 3D response surface plot for flexural strength. Fig. 3a shows the effect of fibre length and fibre content on the flexural strength. This 3D response graph suggests that as the fibre length increases the flexural strength of composite increases. The flexural strength was also influenced by the fiber content. The flexural strength is found to be greater when the fibre length and fibre content was 13 mm and 35.19 wt% in the ASVFRVE composites. It is observed that the fibre length and fibre content are essential to increase the flexural strength. Fig. 3b shows the effect of fibre diameter and fibre content on the flexural strength and Fig. 3c shows the effect of fibre diameter and fibre length on the flexural strength. The maximum flexural strength values were observed when the fibre diameter is at 0.24 mm when compared to 0.85 mm and 1.45 mm. It was also observed that the maximum flexural strength value was identified at low fibre content and high fibre length.

3.3 Optimization of Process Parameters and the Response

After studying the effect of the process parameters on the mechanical properties of ASVFRVE composite, the levels of these parameters that give the optimal mechanical properties were determined. It is evident from the second-order quadratic equations (Eqs. (7) and (8)) and 3D response plots (Figs. 2 and 3) that the fiber length (x_1) in level 3, fiber content (x_2) in level 2, and fiber diameter (x_3) in level 1 increases both the tensile strength and the flexural strength of the ASVFRVE composite. This level of fibre length may be higher than the critical fibre length. The most effective fibre reinforcement is achieved if the length of the fibre exceeds the critical fibre length, which is also depending on the diameter of the fibre [16].

The fibre content (35.19 wt%) was identified as the optimal fibre content to obtain the better mechanical properties of ASVFRVE composites and above which the properties of the composite may drop. This level of fibre content is higher than critical fibre content. To be suitable for reinforcement material the fiber materials must increase the tensile strength and modulus of elasticity of the matrix and meet the following conditions: the fibers must exceed critical fiber content; the strength and rigidity of fibers itself must exceed the strength and rigidity of the matrix alone; there must be optimal bonding between the fibers and matrix. In the fibre reinforced polymer composites, composite strength also depends on fibre diameter. The smallest fibre diameter could achieve higher mechanical properties due to its larger specific contact surface with the matrix. In this study, the maximum tensile and flexural strength values were observed in the composite having a fiber diameter of 0.24 mm (x_3) at level 1. The strength values were decreased with increasing fibre diameter to level 2 (0.85 mm) and level 3 (1.45 mm).

Thus, level 3 of fibre length (x_1), level 2 of fibre content (x_2), and level 1 of fibre diameter (x_3) were selected as the optimal levels of process parameters. For confirmation, five fresh experimental tests were carried out at the optimal levels of the process parameters and the results obtained are given in Table 8, which summarizes the process parameters, the average of the experimental strength value, the predicted strength value and the percentages of error. The confirmation result shows that the prediction models developed through the BB design of the RSM are quite accurate as the percentage of error in the prediction was in good agreement.

The effectiveness of the BB design of RSM is also proved by several authors in natural fibres and their polymer composites [17] and [18].

Table 8. *Confirmation test results*

Fiber length [mm]	Fiber content [wt%]	Fiber diameter [mm]	Variable	Tensile strength [MPa]	Flexural strength [MPa]
13	35.19	0.24	Average	41.7	52.1
			Predicted	41.4	51.5
			Error [%]	-0.7194	-1.1516

4 CONCLUSION

A three-level BB design of response surface methodology was employed in this paper to optimize the fabrication process parameters for mechanical properties of ASVFRVE composites. The process parameters selected for this work were fibre length, fibre content, and fibre diameter. The experimental strength values were fitted with the predicted strength values by a second-order polynomial equation by a multiple regression analysis and more than 98.54% of the variation in the tensile strength and 99.24% of the variation in the flexural strength could be predicted with the developed models. The validation results revealed that there was good agreement between the predicted and experimental values. The optimal fabrication process parameters for the tensile and flexural strength of ASVFRVE composites were determined using the response surface graph and models. Level 3 of fibre length (13 mm), level 2 of fibre content (35.19 wt %), and level 1 of fibre diameter (0.24 mm) were selected as the optimal level of fabrication process parameters. Additionally, five fresh, experimental tests were carried out at the optimal levels of the process parameters for the confirmatory study. Under the optimal conditions, the corresponding response value predicted for the tensile and the flexural strength were 41.7 MPa and 52.1 MPa, respectively. The present paper has proved that the BB design of response surface methodology could efficiently be applied for the modelling and optimization of the mechanical properties of natural fibre polymer composites. It is also an economical way of obtaining the maximum amount of information in a short time duration and with a reduced number of experiments.

5 NOMENCLATURE

SITRA South India Textile Research Association, India
ANOVA Analysis of variance
f_l Fiber length [mm]
f_c Fiber content [wt%]
f_d Fiber diameter [mm]
R Relative error percentage [%]

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