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Université de Lorraine • Poznan University of Technology

Research Paper

Investigations on Tensile and Flexural Characteristics of Fly Ash and Banana Fiber-Reinforced Epoxy Matrix Composites

Venkatachalam GOPALAN1), Shashank Kumar SHARMA2)
Anil Kumar JANGID2), Vignesh PRAGASAM2)*
Nilesh SATONKAR1), Pandivelan CHINNAIYAN2)

1) *School of Mechanical and Building Sciences*
Vellore Institute of Technology
Chennai Campus – 600 127, Tamil Nadu, India
e-mail: g.venkatachalam@vit.ac.in, satonkarnilesh123@gmail.com

2) *School of Mechanical Engineering*
Vellore Institute of Technology
Vellore – 632 014, Tamil Nadu, India
e-mail: ps_pradeep9@yahoo.com, anil786py@gmail.com, cpandivelan@vit.ac.in
*Corresponding Author e-mail: vigneshps310@gmail.com

Polymer matrix composites (PMCs) generally use the inorganic and non-biodegradable materials as reinforcements. This paper presents a PMC with reinforcement of fly ash and banana fiber. The epoxy resin is used as a matrix. This paper investigates the influences of the percentage of fly ash, the percentage of banana fiber and the size of banana fiber on tensile and flexural behaviors of fly ash and banana fiber reinforced epoxy matrix composite. Taguchi's orthogonal array is used in the design of the experiments in the sample preparations. Analysis of variance (ANOVA) is employed to find the significance of input parameters on tensile and flexural behaviors.

Key words: polymer matrix composites; reinforcement; natural fiber; mechanical behavior.

1. Introduction

In today's modern world, the need for more efficient material is very significant for the development of new products. For this, composites play a major role as they have a strong load-carrying material reinforced into weaker material. Reinforcement provides strength and rigidity to help and support the structural load.

Cheung *et al.* [1] stated that polymer matrix composites (PMCs) are widely used, but the mechanical properties of polymers are inadequate for any structural purposes. In particular, their strength and stiffness are low compared to ceramics and metals. These difficulties are overcome by reinforcing polymers with other materials. Chandramohan and Marimuthu [2] employed natural fibers as reinforcing material in polymer composites to enhance the mechanical property of composites. In India, banana is abundantly cultivated. Maleque *et al.* [3] made banana stem fibers in the configuration of woven fabric and used it as reinforcement for epoxy polymer composites and conducted different tests such as tensile, flexural and impact analysis. Other researchers investigated several types of natural fibers such as bamboo, kenaf, hemp, flax, and jute to study the effect of these fibers on the mechanical properties of composite materials [4]. Venkateshwaran and Elayaperumal [5] studied the mechanical properties like tensile, flexural, impact and water absorption of banana/epoxy composite material.

Recently, the use of micro-fibrillated cellulose (MFC) has attracted researchers' attention as a mechanical performance enhancer in PMCs due to environmental concern [6]. The use of natural fibers for the reinforcement of composites has lately received attention from both academia and industries [7]. This is being driven by environmental and economic reasons in addition to health concerns. Unlike the traditional glass, carbon, boron and Kevlar fibers, natural fibers are renewable, biodegradable, low-density and cost-effective. In addition, the natural fibers are less abrasive to tooling, less harmful to humankind and have good thermal and acoustic properties [8].

Furthermore, Sapuan *et al.* [9] fabricated Musaceae/epoxy composites, and conducted tensile and flexural tests. Their results showed a good improvement in mechanical properties when the banana fiber was reinforced with pure epoxy and thus the authors recommended using it for household utilities. Liu *et al.* [10] studied the mechanical properties of randomly oriented woven banana fiber/epoxy composite, and the results showed a significant difference in the composite property in both directions.

Sepe *et al.* [11] investigated the mechanical properties of chemically treated hemp fiber-reinforced composites. (3-Glycidyloxypropyl) trimethoxysilane acted as a coupling agent along with alkaline treatment and improved the mechanical properties of hemp fiber-reinforced composites. Sathishkumar *et al.* [12] investigated the tensile and flexural effects of snake grass fiber-reinforced composites. Untreated, chopped, snake grass fibers were reinforced with isophthalic polyester resin, and it was found that an increase in volumetric fraction, increases the tensile and flexural properties of composites. Ramesh *et al.* [13] evaluated the mechanical properties of sisal-jute-glass fiber-reinforced composites. The composites were tested for tensile, flexural and impact strengths and their interfacial properties. They also analyzed the internal crack and internal structure of composites using the scanning electron microscope (SEM).

Sanjay *et al.* [14] studied the mechanical properties of banana/glass fiber-reinforced composites. They conducted tensile, flexural, impact and hardness tests on the composites, and their results summarized that banana/glass/epoxy composites' experimental values are closer to pure glass/epoxy composites' experimental values. They also investigated the water absorption tendency for pure glass fiber composites and pure banana fiber composites. Alaaeddin *et al.* [15] investigated the physical and mechanical properties of sugarcane fiber-reinforced composites. They reinforced a polyvinylidene fluoride with short sugar palm fiber using the injection molding process and analyzed the mechanical and physical properties of composites.

From the above literature survey, it can be concluded that significant contributions were made by different researchers on the investigations of natural fiber-reinforced PMCs.

In this work, the authors conduct a study on reinforcing banana fiber and fly ash in powder form with epoxy resin and investigate the tensile and flexural strengths of PMCs. Since banana fiber and fly ash are biodegradable and eco-friendly, these composite materials can be used for manufacturing daily utility products at low cost.

2. Material, fabrication and testing

Banana fiber, a natural fiber, is used as reinforcement. Fly ash is a byproduct, which is available abundantly and can be used for reinforcement purpose along with banana fiber. Epoxy polymer LY551 is used as matrix and hardener HY951 is used for curing purposes. Taguchi L9 orthogonal array is used in the design of experiments, which is shown in Table 1. The various parameters to be considered are as follows:

1) fly ash content (% in w/w) – 5% (A1), 10% (A2), 15% (A3),
2) banana fiber content (% in w/w) – 2% (B1), 4% (B2), 6% (B3),
3) banana fiber size in mm – 10 (C1), 1 (C2), 0.001 (C3).

A total of nine samples are made using different combinations by varying the three parameters as shown in Table 1. The samples are made according to the American standard of Testing Methods – ASTM D3039/D3039M standard dimension for the tensile test and ASTM D790 standard dimensions for the flexural test. The specimen dimensions are $250 \times 25 \times 2.5$ mm for the tensile test and $155 \times 13 \times 4$ mm for the flexural test.

The untreated banana fiber is first washed thoroughly with distilled water to remove dust and impurities. The fibers are then soaked in 8% (w/w) NaOH solu-

Table 1. Orthogonal matrix.

Samples	Parameter 1	Parameter 2	Parameter3
1	A1	B1	C1
2	A1	B2	C2
3	A1	B3	C3
4	A2	B1	C2
5	A2	B2	C3
6	A2	B3	C1
7	A3	B1	C3
8	A3	B2	C1
9	A3	B3	C2

tion and rinsed thoroughly. Chemical treatment with NaOH increases the surface area of exposed fiber for better bonding with resin; in turn, it increases the mechanical strength of composites. Also, the chemical treatment enhances the flexural rigidity of the fibers. Lastly, this treatment clears all the impurities that are adjoining the fiber material and stabilizes the molecular orientation [9]. After the fibers are chemically treated, they are left to dry for at least two days in the shade to remove all the moisture. Then these dried fibers are ground in the mixer/grinder to break down into the required sizes. After the grinding, the mechanical sieve machine is used to segregate the fibers in the required sizes. The samples are made using a paper mold as the composite does not require any baking or heating for curing. The paper molds are made in accordance with the ASTM standard dimensions for PMC's tensile and flexural testing. The epoxy resin and the fiber are mixed thoroughly with a mechanical stirrer, and the hardener is added (ratio of 10:1 with epoxy) with the resin and mixed thoroughly. Then the mixture is poured into a respective mold for fabricating tensile and flexural samples. The mold is kept at a level surface, and the setup is left to cure for 24 hours at atmospheric temperature and pressure. The cured samples are then removed.

3. Results and discussions

3.1. Tensile test results

Tensile samples are prepared according to ASTM D3039/D3039M standard. A total of nine samples are prepared as per the orthogonal matrix and tested in the INSTRON machine, and the values are tabulated. Table 2 presents Young's modulus values obtained from the tensile testing. Young's modulus of pure epoxy varies from 3.25–3.43 GPa, and the ultimate tensile strength (UTS) ranges from

Table 2. Results from the tensile test done in the INSTRON machine.

Samples	Fly ash % (w/w)	Fiber vol. % (w/w)	Fibre size [mm]	Young's modulus [GPa]	Ultimate tensile strength [MPa]
1	5	2	10	2.86	70
2	5	4	1	3.26	68
3	5	6	0.001	3.52	71
4	10	2	1	3.31	54
5	10	4	0.001	3.44	63
6	10	6	10	3.75	72
7	15	2	0.001	2.50	55
8	15	4	10	3.44	71
9	15	6	1	4.08	69
Pure Epoxy [16, 17]				3.25–3.43	64–70

64–70 MPa [16, 17]. It is inferred from Table 2 that the sample number 9 with the combination of 15% fly ash (w/w %), 6% fiber (w/w %) and 1 mm length of fibers provides maximum Young's modulus value. Figure 1 shows the load vs. extension graph from the INSTRON machine for samples 6 and 9 under tensile loading.

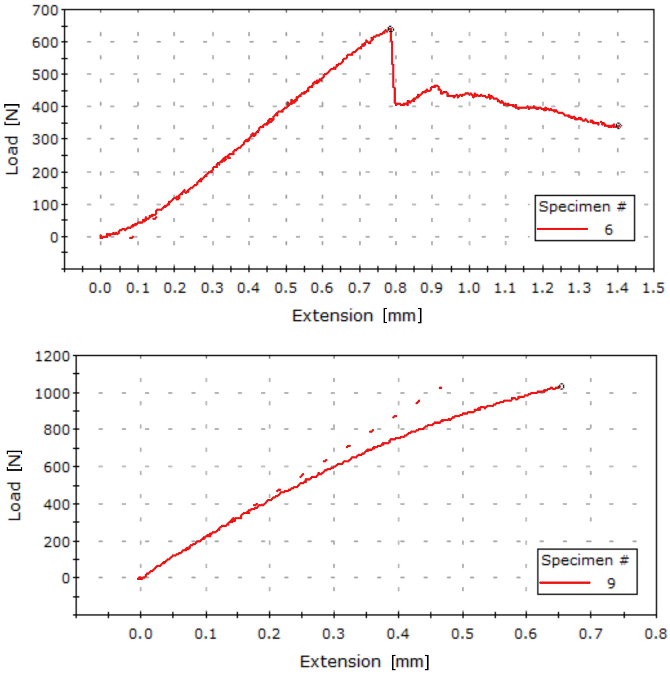

Fig. 1. Load vs. extension graph for tensile test.

3.1.1. ANOVA for Young's modulus. The analysis of variance (ANOVA) is a statistical tool used to determine the variation between the groups and within the group. ANOVA provides a statistical test between two or more population means [18]. The ANOVA technique is based on the standard deviation between or within the group. ANOVA can handle the number of test samples as long as the standard deviation is not greatly different. ANOVA is used to generate a regression equation, which gives the inter-dependency of the variables to the results and the degree to which they affect the results [19]. To assess the impact of these variables on Young's modulus, the MINITAB 16 software is used and the obtained results are presented in the form of the main effects plot and contour plots. Figure 2 represents the main effects plot which illustrates the effect of fly ash percentage, fiber percentage and fiber size on Young's modulus. It can be inferred from the first plot that the maximum value of Young's modulus is obtained when the fly ash percentage is 10%. Similarly, the second plot gives us the value of fiber percentage for which the maximum value of Young's modulus is obtained. This value is found to be 6% from the plot. From the next plot, it is drawn that the maximum value of Young's modulus is obtained when the fiber size is 1 mm. It can also be inferred that the variation of Young's modulus with respect to the fly ash percentage is very small, whereas, the variation of Young's modulus with the fiber percentage is very large.

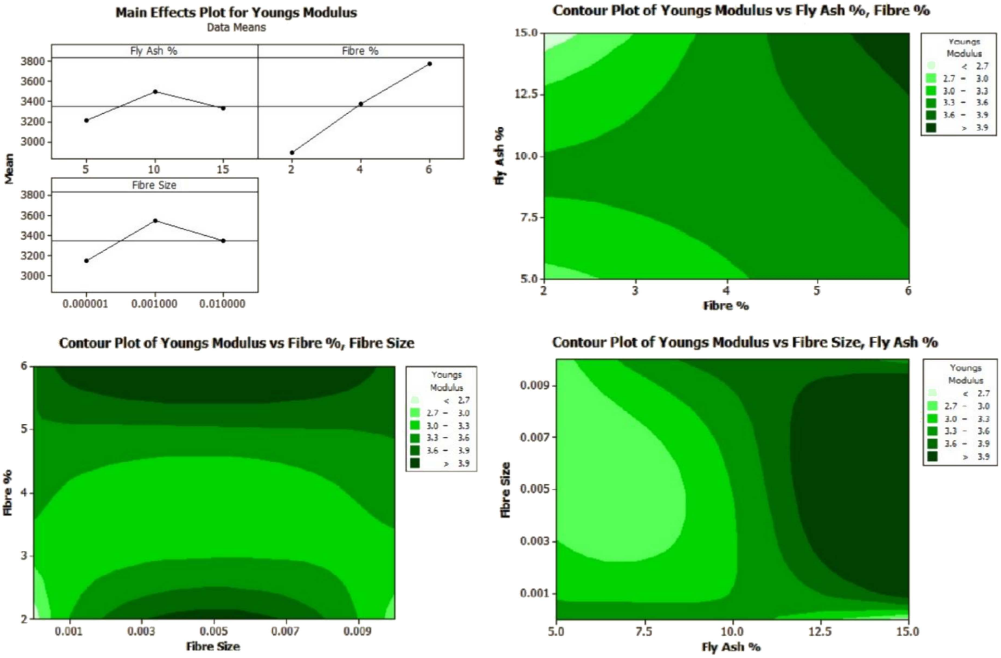

FIG. 2. Main effects and contour plot for Young's modulus.

Contour plots help in relating the varying parameters with the response output. Figure 2 depicts the contour plots which illustrate the variation of Young's modulus against the variation of the fly ash % (w/w), fiber vol. % (w/w) and fiber size in mm. From Fig. 2, it can be drawn out that Young's modulus is maximum for the fly ash content of 15% and the fiber content of 6%. Similarly, the maximum value of Young's modulus is obtained for the combinations of fiber content 6% and any size. Also, the value of Young's modulus can be seen maximum at 2% of fiber vol. content and 5 mm of fiber size.

3.1.2. Regression equation for Young's modulus The ANOVA analysis of the experimental data results in an equation called the regression equation. This mathematical equation considers all the parameters presented and weighs their effects on Young's modulus value. Thus, the equation helps to predict the variation of the value of Young's modulus when the weighing parameters are varied:

$$\text{Young's modulus } = 2.32 + 0.0124 \text{ Fly Ash } \% + 0.222 \text{ Fiber } \% + 3.5 \text{ Fiber Size.} \tag{3.1}$$

The level of influence of each parameter can be found from the coefficient values. The coefficient of fiber size is greater than the other two parameters. Hence from Eq. (3.1), it can be concluded that the fiber size has the strongest effect on Young's modulus value. The fiber content also has a strong influence on Young's modulus value, but it is weaker than the effect of fiber size. The fly ash content has the weakest effect on Young's modulus value. Comparison of Table 2 and Eq. (3.1) reveals that the first term in Eq. (3.1) denotes Young's modulus value of the pure epoxy sample.

3.1.3. ANOVA for the ultimate tensile strength. The tensile testing also gives the value for the UTS. These results are tabulated in Table 2.

The experimental data obtained from Table 2 is used to find out the regression equation and to plot the main effects plot and the contour plots for the UTS. From the main effects plot (Fig. 3) it is observed that fly ash content does not affect the UTS to some extent. The variation observed between the varying amounts of fly ash and the UTS value is very small, although the UTS is found to be maximum for 15% fly ash content. From the next plot, it is evident that the fiber content greatly affects the UTS value. The UTS value is found to be maximum for 6% fiber content. From the third plot, it is seen that as the fiber size increases, the UTS also increases. The maximum value of the UTS is observed at 15% (w/w) fly ash, 6% (w/w) fiber and 0.01 mm fiber size. From the main effects plot, it is evident that the fiber content greatly affects the UTS value.

Figure 3 shows the contour plots of the UTS vs. fly ash content, fiber vol. content and fiber size. The maximum UTS values are obtained at the fiber content

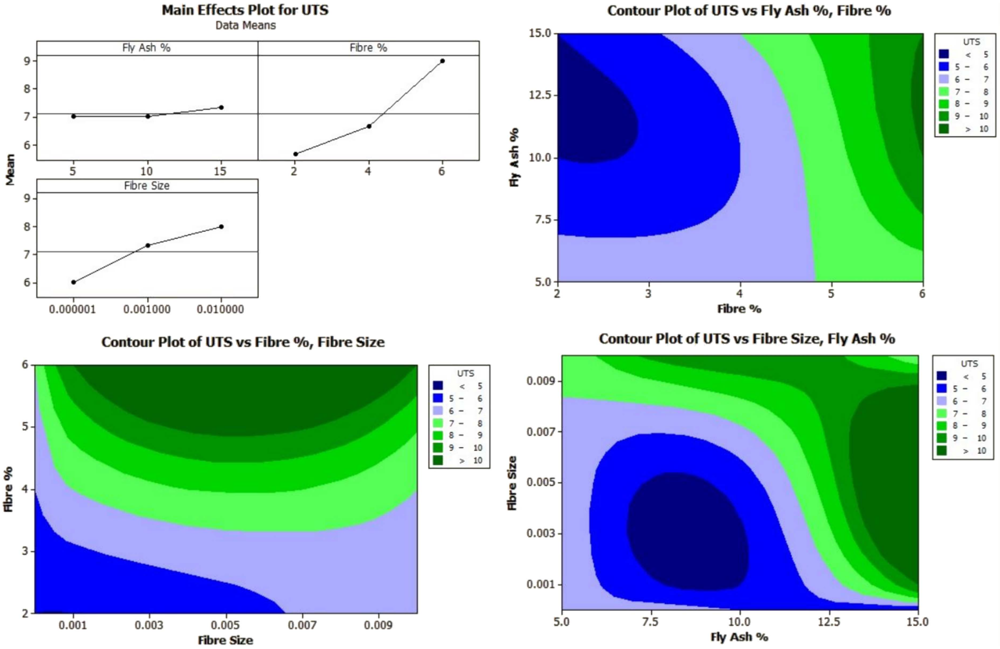

FIG. 3. Main effects and contour plot for the ultimate tensile strength (UTS).

of 6% and corresponding fly ash content values ranging from 10% to 15%. In fact, the fiber size values do not affect the maximum UTS at these fiber content values.

3.1.4. Regression equation for the UTS. The regression equation relating all the varying parameters to the response parameter is calculated using the experimental data and with the help of MINITAB 16 software. This equation gives the relation between the varying parameters, i.e., fly ash content, fiber content and fiber size, for the UTS:

$$\text{UTS} = 2.89 + 0.0333 \text{ Fly Ash } \% + 0.833 \text{ Fiber } \% + 150 \text{ Fiber Size.} \tag{3.2}$$

The coefficient values associated with the parameters convey the level of influence of different parameters on the UTS. The coefficient value associated with fiber size is too large compared with the other two parameters. This shows that the load transfer is effective when the fiber size is large. From Eq. (3.2), it is observed that the fiber size has the maximum effect on the UTS. The fiber content also affects the UTS value greatly, but not as much as the size. The fly ash content has the least weight in the UTS value calculation. Comparing Table 2 and Eq. (3.1), one can understand that the first term in Eq. (3.2) denotes the UTS value of the epoxy sample with no reinforcement.

3.2. *Flexural test result*

The samples are subjected to flexural test using 3 points bending test in the INSTRON 8801 machine, and the test results for the maximum flexural stress are presented in Table 3. Flexural strength of pure epoxy varies from 15–22 MPa [20, 21]. Figure 4 shows the flexural stress vs. flexural strain graph for samples 1 and 7 under the bending load.

Table 3. Results from the tlexural test done in the INSTRON machine.

Samples	Fly ash % (w/w)	Fiber vol. % (w/w)	Fibre size [mm]	Flexural stress [MPa]
1	5	2	10	52.58677
2	5	4	1	43.88249
3	5	6	0.001	35.001700
4	10	2	1	39.648550
5	10	4	0.001	33.2912
6	10	6	10	50.0039
7	15	2	0.001	45.03446
8	15	4	10	56.33928
9	15	6	1	41.1315
Pure Epoxy [20 21]				15–22

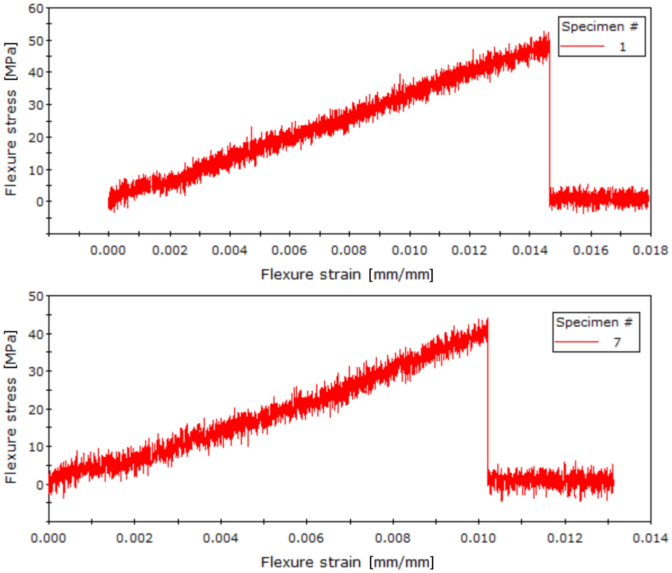

FIG. 4. Flexural stress vs. flexural strain graph for the bending test.

3.2.1. ANOVA analysis for flexural stress. The experimental data from the flexural test is fed into the MINITAB 16 software, and the main effects plot, contour plots, and regression equation are obtained. From the main effects plot (Fig. 3), it is inferred that the maximum flexural stress is obtained at 15% (w/w) fly ash content. Also, the plot follows a downward trend as the fly ash content is increased from 5% to 10%, then again follows an upward trend to attain maximum value at 15%. When the fiber content increases, the flexural strength decreases. As the fiber size increases, the flexural strength increases. From the main effects plot, it is observed that the maximum flexural strength is obtained at 15% (w/w) fly ash, 2% (w/w) fiber, and 0.01 mm of fiber size.

Figure 5 shows the contour plots for the maximum flexural stress vs. the fly ash content, fiber content and the fiber size. From the first contour plot, as shown, it is evident that the maximum value of flexural stress is obtained at 15% fly ash content, and the corresponding value of the fiber content is around 4% with fiber size ranging from 1 to 10 mm.

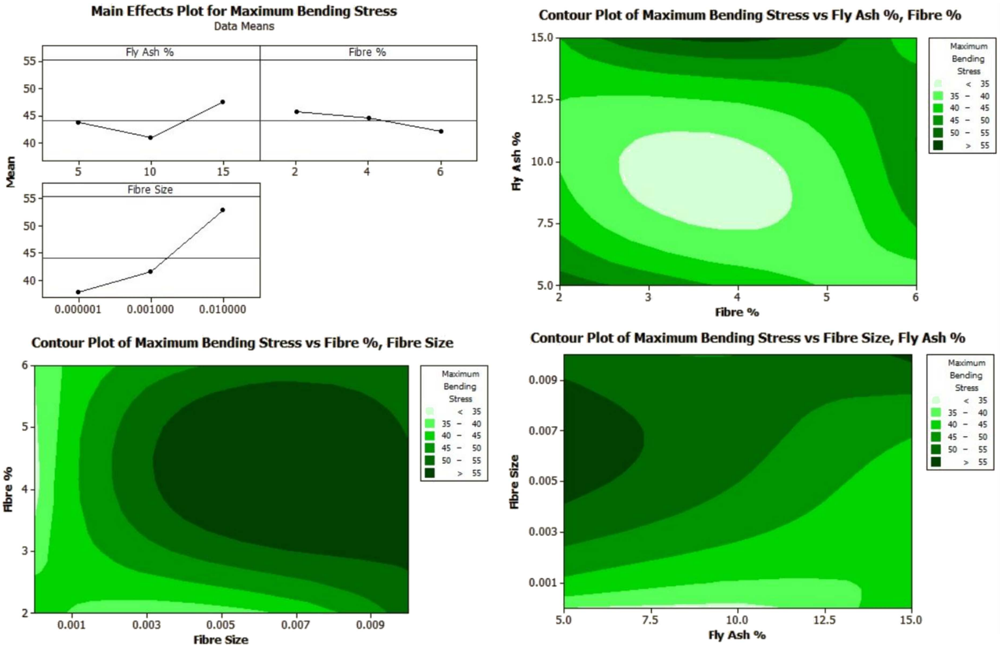

FIG. 5. Main effects and contour plot for the flexural stress.

3.2.2. Regression equation for flexural stress. The regression equation obtained from the experimental data for the maximum flexural stress is shown in Eq. (3.3):

$$\text{Flexural stress} = 38.9 + 0.368\ \text{Fly Ash}\ \% - 0.93\ \text{Fiber}\ \% + 1421\ \text{Fiber size}. \tag{3.3}$$

From the regression equation, it can be clearly seen that the fiber size plays an important role in determining the value of maximum flexural stress as it has the highest coefficient value. This shows that load transfer from matrix to fiber is effective when large fibers are used. Fiber content also plays a major role in determining the maximum flexural stress value, but not as much as the size. Fly ash content plays the least important role, or it affects the maximum flexural stress the least. The first term in Eq. (3.3) denotes the flexural strength value of the pure epoxy sample, which is evident when one compares Table 3 and Eq. (3.3).

4. Conclusions

This study, on the banana fiber-reinforced epoxy PMC with fly ash as filler using the tensile and flexural tests, helps in understanding of the material's structural properties. Young's modulus, the UTS, and the maximum flexural stress values give a better understanding of the mechanical properties of the material, and the effect of the varying factors in the composition. ANOVA (analysis of variance) is implemented to obtain the relation between the predicted parameters and responses. The various plots for the same are also obtained using this technique. The following are some notable conclusions from this study:

1) The effect of fly ash on the UTS is feeble. Also, there is no trend observed within the test values tested for the other two responses.
2) The fiber content plays a major role in Young's modulus and the UTS values, whereas, for the maximum flexural stress, it is quite the contrary. Higher fiber content enhances the composite's tensile properties but affects the flexural properties negatively.
3) There is a clear upward trend observed in the values of the UTS and the maximum flexural stress with the increase in fiber size, although Young's modulus does not show any trend for the same.

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