



Optimization of process parameters and mechanical properties of hybrid fibre reinforced by epoxy resin by response surface methodology (RSM)

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Abstract

Natural fibers and synthetic fibers have several advantages that have made them particularly attractive to the automobile industry. These include relatively good mechanical strength, low density better thermal and acoustic insulation and low cost. According to the need the different type of fibers composites (Natural, synthetic and composite of natural and synthetic) can be reinforced.

In this work, there are 20 experiments are conducted to fabricate the hybrid (glass fiber and coir fiber) composite fiber with the help of design expert software and these fabricated composite fiber were tested according to ASTM standards and found the optimum and maximum tensile strength and strain of the composite fiber. Two quadratic model were given to correlate the process variables to the responses. The glass fiber is most significant factor for both the responses. The optimized input process parameters were found of glass fiber, coir fiber and filler are 100 gram of glass fiber, 40 gram of coir fiber and 80 gram of filler (Epoxy + Hardener) respectively. The optimized output responses value of tensile strength and strain were found 49.27 MPa and 14.43% respectively.

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Keywords: Natural Fiber, Synthetic fiber, tensile strength, Strain, Optimization

1. Introduction

A composite is combination of two materials in which one of the materials, called the reinforcing phase, is in the form of fibers, sheets, or particles, and is embedded in the other materials called the matrix phase. The reinforcing material and the matrix material can be metal, ceramic, or polymer. Composites typically have a fiber or particle phase that is stiffer and stronger than the continuous matrix phase and serve as the principal load carrying members. The matrix acts as a load transfer medium between fibers, and in less ideal cases where the loads are complex, the matrix may even have to bear loads transverse to the fiber axis. The matrix is more ductile than the fibers and thus acts as a source of composite toughness. The matrix also serves to protect the fibers from environmental damage before, during and after composite processing. When designed properly, the new combined material exhibits better strength than would each individual material. Composites are used not only for their structural properties, but also for electrical, thermal, tribological, and environmental applications. Life cycle environmental performance of natural fiber composites with glass fiber

reinforced composites and found that natural fiber composites are environmentally superior in the specific applications studied. Natural fiber composites are likely to be environmentally superior to glass fiber composites in most cases [1]. The physical and mechanical behavior of banana fiber reinforced polymer composite and noticed that kraft mashed banana fiber material has better flexural strength. The tensile strength is detected maximum at 30 mm fiber length whereas the impact strength is noticed maximum at 40 mm length of fiber. Consolidation of 40% untreated banana fibers gives 20% rise in the tensile strength and 34% rise in impact strength [2]. Another effective method of surface chemical modification of natural fibers is graft copolymerization. Optimized vinyl grafted natural fibers, consisting of the orderly arrangement of grafted moieties, act as compatible reinforcing fibers with several resin systems to obtaining better fiber-matrix adhesion of the resulting bio-composites [3]. Cellulose fibers have been used for long time in the manufacture of various products such as rope, string, clothing, carpets and other decorative products. One of the major uses of kenaf fiber is to make a range of paper and cardboard products as a substitute for wood fibers which are the most abundantly used

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<https://doi.org/10.36037/IJREI.2019.3608>

cellulose fibers. The most efficient cellulose fibers are those with high cellulose content coupled with a low micro-fibril angle in the range of $7-12^\circ$ to the fiber axis [4]. The plant fiber properties directly influence the physical parameters of the fiber-reinforced composites. Flax fiber properties are controlled by the molecular fine structure of the fibers which is affected by growing conditions and the fiber processing technique used [5]. Natural fibers are hygroscopic in nature and they absorb or release moisture depending on environmental conditions [6]. Fillers are used for a variety of reasons such as cost reduction, density control, improved processing, control of thermal expansion, optical effects, magnetic properties, thermal conductivity, electrical properties, and improved hardness and wear resistance, flame retardancy etc [7]. Depending upon the application and the type of property to be imparted to the composite, size of fibers are accordingly determined [8]. The mechanical properties of natural fiber based polymer composites are influenced by many factors such as fibers volume fraction, fiber length, fiber aspect ratio, fiber-matrix adhesion, fiber orientation [9]. The composite materials are successfully replacing the traditional materials due to lightweight, easy handle, renewable resources, nontoxic, high tensile strength [10]. 3-point flexural test to qualitatively assess such effects for 55, 60 and 65 weight percentages of E-glass fibers reinforced epoxy composites during cryogenic and after thawing conditions. The specimens were tested at a range of 0.5 mm/min to 500 mm/min crosshead speed to evaluate the sensitivity of mechanical response during loading at ambient and sub-ambient (-80°C temperature) [11]. The mechanical properties of banana fiber based epoxy composite have been studied and it was observed that the tensile strength is increased by 90% of the pseudo-stem banana fiber reinforced epoxy composite associated to virgin epoxy [12]. A systematic experimental design to find the parameters that can affect conductivity and strength can be employed by utilizing the response surface methodology (RSM) procedure coupled with central composite design (CCD) and further subjected to regression analysis. RSM reduces the number of required experimental runs to achieve a statistically validated result [13]. The mechanical properties, especially interfacial performances of the composites based on natural fibers due to the poor interfacial bonding between the hydrophilic natural fibers and the hydrophobic polymer matrices [14]. Jute fibers were treated with alkali (NaOH) solution and physico-chemical properties of jute fibers was investigated. The treatments were applied under ambient and elevated temperatures and high pressure steaming conditions. The results indicated that the uniaxial tensile strength increased by up to 65% for alkali-steam treatment. The treatments without steaming were not as effective [15]. The Tensile properties and scanning electron Microscope analysis of Bamboo/glass fibers Reinforced epoxy Hybrid composites were studied. The effect of alkali treatment of the bamboo fibers on these properties was also studied. It was observed that tensile properties of the hybrid composite increase with glass fiber content [16]. The influence of fiber length on the mechanical and physical properties of nonwoven short banana, random oriented fiber and epoxy composite have been investigated and they described that the tensile properties and percentage elongation of the composite attained a maximum in composite fabricated from 15 mm fiber length [17]. The

composites material having 20% treated fiber loading possess maximum values for above-mentioned properties than untreated composites, 10% and also 30% treated fibers composites. The interfacial area having main role in influential the strength of polymer material since fiber procedures a separate interface with the matrix. The effects of this study uncovered that short zig-zag fiber composites with great rigidity and element mechanical properties might be effectively ready utilizing banana fiber as reinforcement in a polyurethane matrix inferred from castor oil. Composite materials reinforced by aluminum and synthetic fibers [18]. (Nylon and GFRP) were examined from the analysis of computational modal analysis [19-20]. In this work, Mathematical modelling was carried out by response surface method (RSM) and optimum value was opt with RSM results and optimize the input parameters (i.e. glass fiber, coir fiber and epoxy resin) and output responses (i.e. tensile strength and strain) for fabrication of hybrid composite fiber with the help of epoxy resin.

2. Materials and Method

In this work, glass fiber (synthetic) and coir fiber (natural) were used as shown in fig.1. The epoxy resins are being widely used for many advanced composites due to their many advantages such as excellent adhesion to wide variety of fibers, good performance at elevated temperatures and superior mechanical and electrical properties. In addition to that they have low shrinkage upon curing and good chemical resistance. Due to several advantages over other thermoset polymers as mentioned above, epoxy (LY 556) and hardener (HY951) was used as shown in fig.2.



(a)



(b)

Figure 1: (a) Coir fiber, (b) Glass fiber



Figure 2: Epoxy (LY 556) and hardener (HY951)

Before making fiber plate, we need of design experiments, there are 20 experiments are taken for different fiber composition using design expert software. These composition are mentioned in table 1. According to this table maximum weight of glass fiber, Coir and filler (Epoxy LY556 + Hardener HY951) have been taken 100 gm, 50 gm and 100 gm whereas minimum weight of glass fiber, Coir and filler (Epoxy LY556 + Hardener HY951) have been taken 60 gm, 30 gm and 60 gm.

In this work, glass fiber, epoxy and hardener were taken as reinforcement is collected from the local fiber shop and coir fiber was taken from local source. A mild steel mould having dimension 170 x 110 x 10mm is used for composite fiber fabrication. One layer of glass fiber with epoxy and hardener are mixed and this mixture is poured in to the moulded base plate after that second layer of coir fiber was fed on to the glass fiber

layer and then third layer of glass fiber again fed on the coir fiber and making sandwich of synthetic and natural fiber. After this process this die will be pressed by the hydraulic press with constant pressure 10 kg/cm² for 1 hour. A releasing agent is used to facilitate easy removal of the composite form the die after that composite fiber will be placed at room temperature for 72 hours. The composition and designation of the composites prepared for the design of experiments listed in table 1.

3. Results and Discussion

3.1 Tensile strength

The mechanical properties such as tensile strength of hybrid composite fiber (natural and synthetic fiber) with epoxy resin have been studied. There are 20 experiments were conducted by variation of fiber and epoxy mixing with the help of design expert software.

Fig. 3-5 shows the tensile strength and strain of composite fiber with increase fraction of coir and glass fibers. Weight of glass fiber with different parameters of epoxy resin have a significant effect on tensile strength of the composite fiber. Increase the glass fiber content shows a gradually increase in tensile strength. This behavior can be explained by straight nature of long glass fiber. This straight behavior of glass fiber is help to properly align in longitudinal direction and thus results in increases in tensile strength. 80 gram glass fiber, 40 gm coir fiber and 100 gram (epoxy+hardener) shows the maximum tensile strength of 57 MPa. Whereas 60 gram glass fiber, 50 gm coir fiber and 100 gram (epoxy+hardener) shows minimum tensile strength of 31 MPa.

Table 1: Input processing parameters and their responses

Run	A:Glass fiber (gm)	B:Coir (gm)	C:Filler (LY556 +HY951) (gm)	Tensile Strength (MPa)	Strain (%)
1	100	50	60	46	14
2	100	30	100	53	17
3	60	50	60	34	10
4	80	40	80	32	9
5	80	40	80	37	11
6	100	40	80	57	15
7	80	40	80	38	11
8	80	30	80	41	10
9	80	40	80	34	12
10	60	30	100	32	11
11	100	50	100	54	16
12	60	40	80	32	10
13	60	50	100	31	8
14	80	40	60	35	11
15	80	40	100	42	12
16	80	40	80	34	10
17	80	50	80	39	11
18	100	30	60	38	12
19	60	30	60	44	14
20	80	40	80	32	10

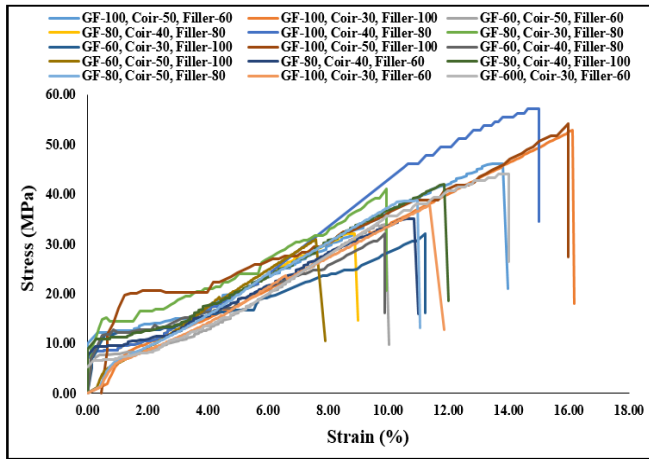


Figure 3: Stress strain diagram for composite fiber reinforced by epoxy resin

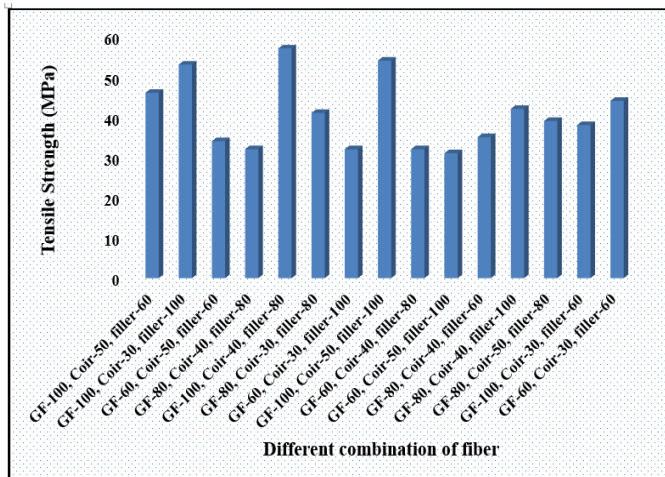


Figure 4: Comparison of tensile strength and different combination of fiber

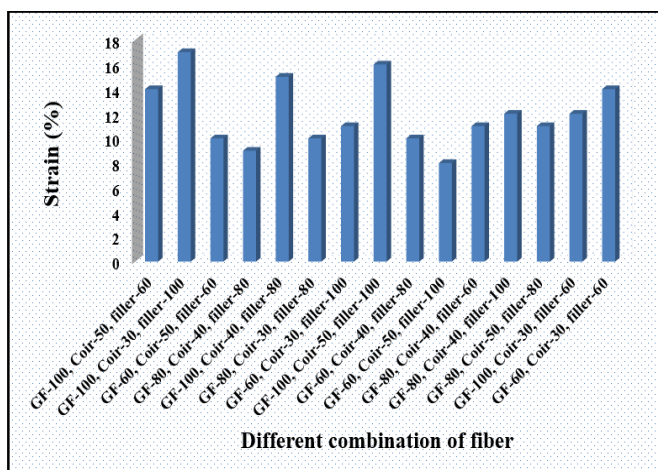


Figure 5: Comparison of strain and different combination of fiber

Similarly, when the weight of coir fiber is increases than the tensile strength of composite fiber is decreases, because the curly behavior of coir fiber is constrains to long fibers to properly align

in longitudinal direction and thus results in decreases in tensile strength. When the percentage of glass fiber increases in composite then high energy is required to break the specimen, so when the fiber loading increases, more energy can be dissipated.

3.2 Response surface Methodology

Response surface methodology is as set of statistical and mathematical techniques which will be useful to develop the model, optimize and analyzed the engineering problems. Is also have many application in the field of development and design. It's a valuable tool for constructing and optimizing the models [21].The glass fiber, coir fiber and filler weight (Epoxy and hardener) are the variables selected for our experimental investigation. The different factor and their levels for this investigation as shown in table 1. Now, there is correlation between an input parameters and output responses were given by

$$Y = F(x_1, x_2, x_3, \dots, x_n) + \varepsilon$$

Where ε represent the noise or error observed in the output response (Y). If we denote expected response to be $E(Y) = F(x_1, x_2, x_3, \dots, x_n)$ then the surface represented by

$$\eta = F(x_1, x_2, x_3, \dots, x_n)$$

The variable $(x_1, x_2, x_3, \dots, x_n)$ are called normal variable.

3.3 Analysis of variance (ANOVA)

Analysis of variance (ANOVA) is used to investigate the influence of process parameters on the responses characteristics. The purpose of ANOVA test is to determine the significance of process parameters which affect the mechanical properties of composite fiber. Table 2-3, represents the results of analysis of variance and suggested that the glass fiber is the most significant factor. The F-test (Fisher's test) may also be used to determine which process parameter has a significant effect on the mechanical properties.

3.4 Developing a mathematical model

The experimental results were obtained and analyzed to produce regression model. The statistical software design expert suggested second order quadratic regression surface model for predicting the optimum conditions for the fabricated hybrid composite. The empirical relationship was developed for the response variable i.e. ultimate tensile strength, and strain of composite fiber under the input processing parameters i.e. glass fiber, coir fiber and filler (Epoxy and hardener) and found best fit model in terms of equations. The mathematical empirical relationship for tensile strength, and strain are as follow.

$$\text{Tensile Strength} = 215.73 - 3.25A - 1.9B - 0.70C + 0.0125 AB - 0.0118 AC + 0.0012 BC + 0.0136A^2 + 0.009 B^2 - 0.0012 C^2$$

$$\text{Strain} = 73.91 - 1.085A - 0.132B - 0.526C + 0.005 AB + 0.00375 AC - 0.00125 BC + 0.0043A^2 - 0.0027B^2 + 0.0018 C^2$$

Where A, B and C are the glass fiber, Coir and filler (Epoxy +

Hardener) weight respectively, and A^2 , B^2 , and C^2 are the square and interaction terms in the above equations, positive coefficient have positive effect on tensile stress and strain, whereas negative coefficient will decrease the strength of the hybrid composite material.

Table 2: Analysis of variance (ANOVA) for tensile strength for composite fiber

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	982.67	9	109.19	5.32	0.0076	significant
A-Glass fiber	562.5	1	562.5	27.43	0.0004	
B-Coir	1.6	1	1.6	0.078	0.7857	
C-Filler	22.5	1	22.5	1.1	0.3196	
AB	50	1	50	2.44	0.1495	
AC	180.5	1	180.5	8.8	0.0141	
BC	0.5	1	0.5	0.0244	0.879	
A^2	81.82	1	81.82	3.99	0.0737	
B^2	2.51	1	2.51	0.1222	0.7339	
C^2	0.8182	1	0.8182	0.0399	0.8457	
Residual	205.08	10	20.51			
Lack of Fit	173.58	5	34.72	5.51	0.0422	Not significant
Pure Error	31.5	5	6.3			
Cor Total	1187.75	19				

Table 3: Analysis of variance (ANOVA) for strain for composite fiber

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	95.45	9	10.61	9.87	0.0007	significant
A-Glass fiber	44.1	1	44.1	41.04	< 0.0001	
B-Coir	2.5	1	2.5	2.33	0.1582	
C-Filler	0.9	1	0.9	0.8376	0.3816	
AB	8	1	8	7.45	0.0212	
AC	18	1	18	16.75	0.0022	
BC	0.5	1	0.5	0.4653	0.5106	
A^2	8.2	1	8.2	7.64	0.02	
B^2	0.2045	1	0.2045	0.1904	0.6719	
C^2	1.45	1	1.45	1.35	0.2717	
Residual	10.75	10	1.07			
Lack of Fit	5.25	5	1.05	0.9537	0.5201	not significant
Pure Error	5.5	5	1.1			
Cor Total	106.2	19				

The developed models was tested using ANOVA method with the help of design expert software. The ANOVA results for tensile strength and strain for hybrid composite fiber are shown in table 2-3. All models gives the highly significant fisher's F value which shows that the model adequately representing the relationship between input process parameters and response. The fisher's F value of the tensile strength for hybrid composite fiber was found 5.32, whereas the fisher's F value for the strain was 9.87. The P value is very small for tensile strength P (0.0076) which represented that the generated models have only 0.76% chance that a model Fisher's value could occur due to noise, whereas developed model for strain have only 0.07% chance that a model Fisher's F value could occur due to noise. For tensile strength model, the residual error value (205.08) should be the sum of lack of fit (173.58) and pure error (31.5). By this column of fit summary recommended quadratic model is statically significant for analyzing the tensile strength of hybrid composite fiber.

3.5 Optimization of input process parameters

The contour plot and 3D response surface graph are made based on the model developed by considering the optimum process parameters. The optimum tensile strength and strain value of hybrid composite fiber is exhibited by the peak of response surface as shown in fig. 6-7. The effect of straight behavior of glass fiber on hybrid composite fiber is to increase the tensile strength whereas curly behavior of coir fiber is decrease the tensile strength as shown in fig. 8-9. When the glass fiber is increases than the tensile strength also increases whereas tensile strength is decreases when coir fiber increases. The maximum tensile strength (57 MPa) was found at 80 gram glass fiber, 40 gm coir fiber and 100 gram (epoxy+hardener) as shown in fig. 4.

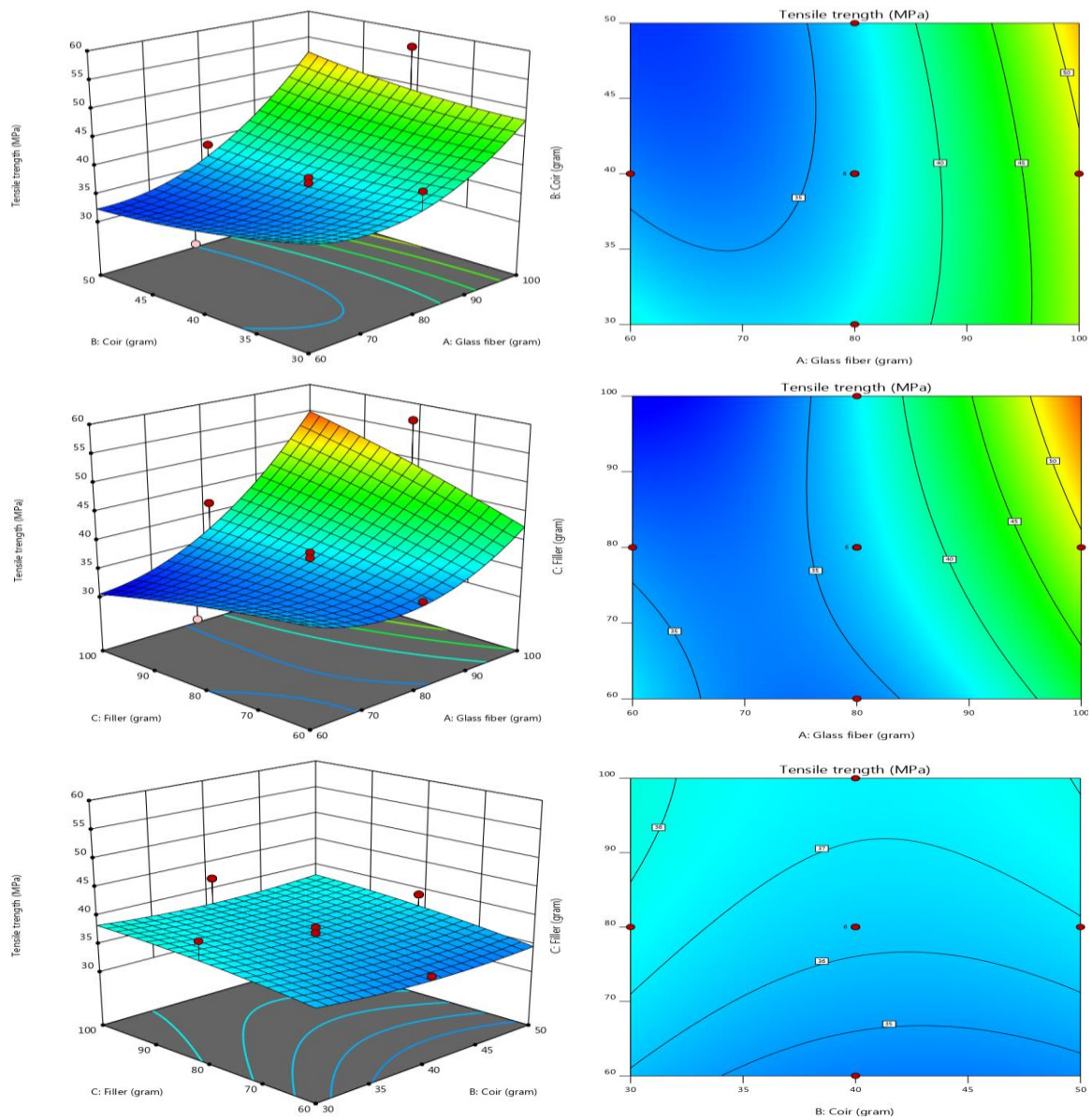
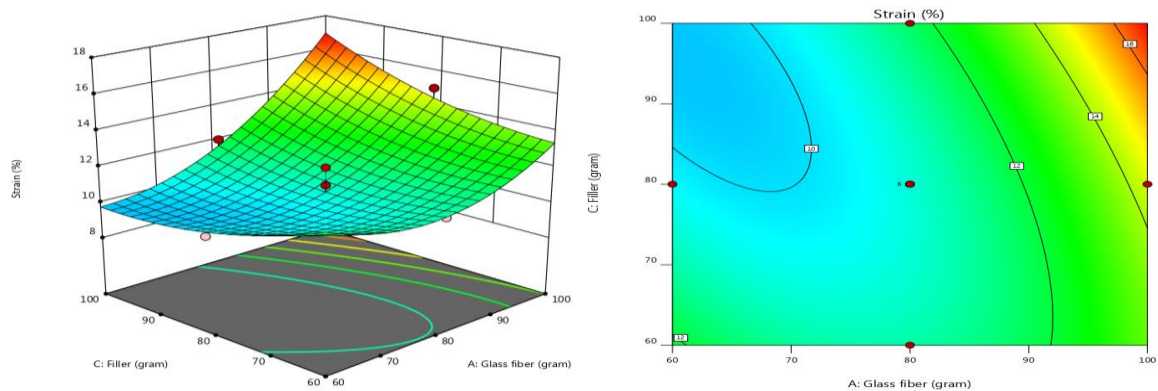


Figure 6: 3D response surface plot and contour plot for tensile strength for hybrid composite fiber



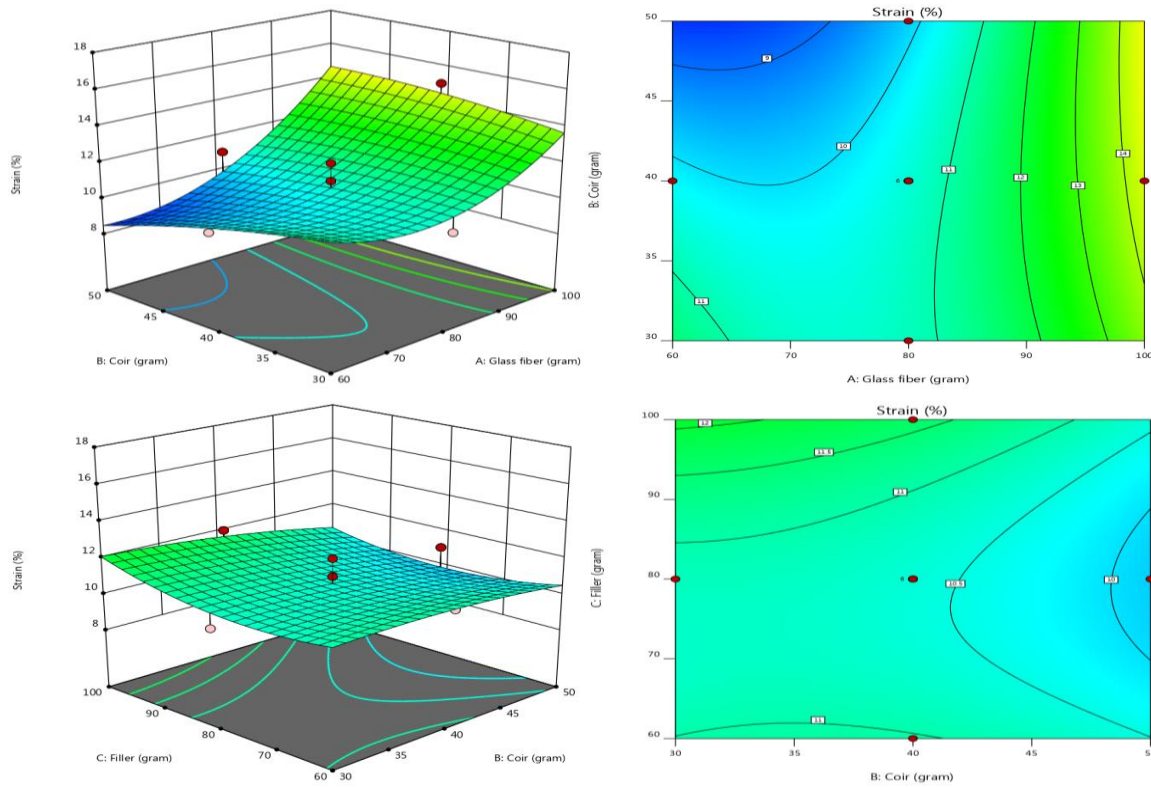


Figure 7: 3D response surface plot and contour plot for percentage strain for hybrid composite fiber

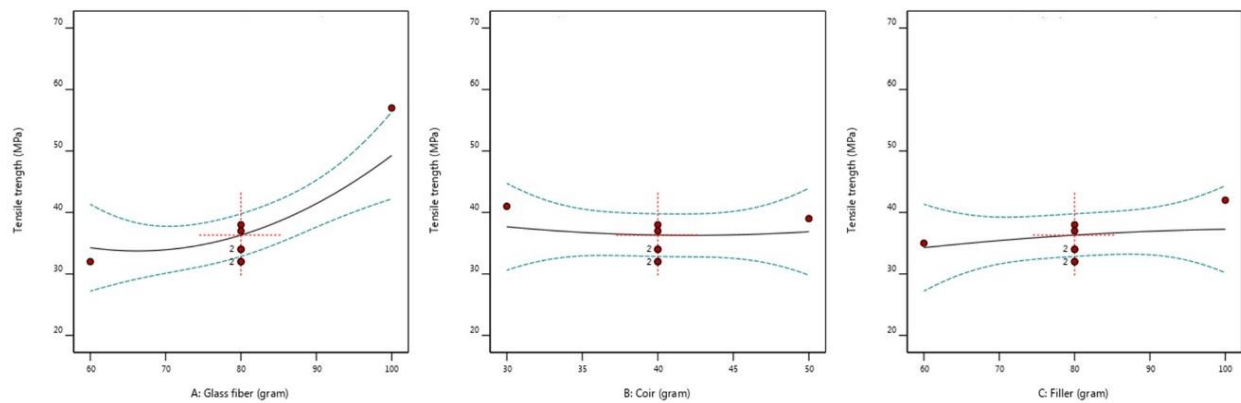


Figure 8: Variation of Tensile strength and input processing parameters of hybrid composite fiber

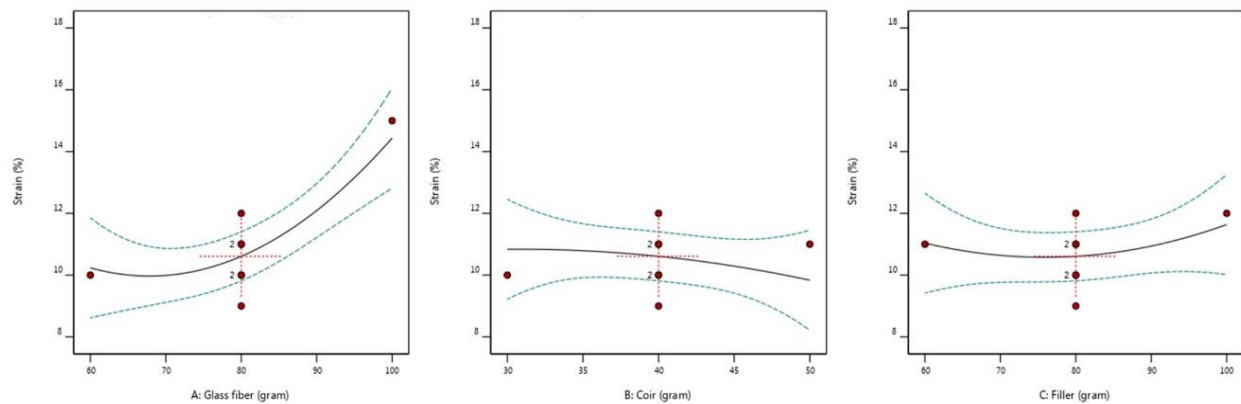


Figure 9: Variation of strain and input processing parameters of hybrid composite fiber

The ramp report and optimized contour plot as shown in fig. 10 are displayed in which the individual response graph is given for better understanding. The red dot and grey dot is mentioned on the ramp report which indicate that the optimized input and output responses of the composite fiber. The optimized input process

parameters value of glass fiber, coir fiber and filler are 100 gram, 40 gram and 80 gram respectively whereas optimized output responses value of tensile strength and strain are 49.27 MPa and 14.43% respectively.

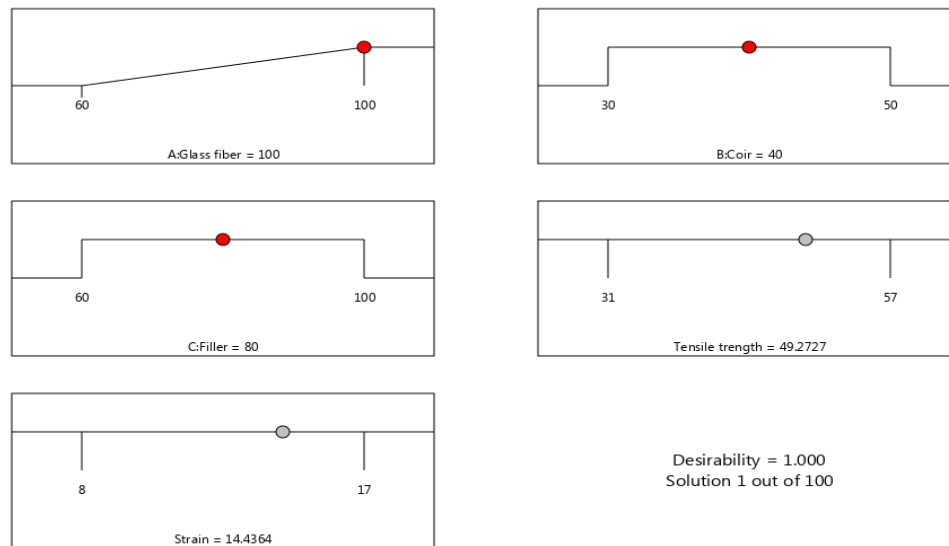


Figure 10: Optimize value of input and their output responses of composite fiber

4. Conclusions

In this work, there are 20 experiments are conducted to fabricate the hybrid (glass fiber and coir fiber) composite fiber with the help of design expert software and these fabricated composite fiber were tested according to ASTM standards and found the optimum and maximum tensile strength and strain of the composite fiber. The following conclusion are made during this work.

- The effect of glass fiber, coir fiber and filler weight were successfully studied using response surface methodology.
- Two quadratic model were given to correlate the process variables to the responses. The glass fiber is most significant factor for both the responses.
- The maximum tensile strength and strain were found 54 MPa and 16% respectively at input parameters of 100 gram of glass fiber, 50 gram of coir fiber and 100 gram of filler (Epoxy + Hardener).
- The optimized input process parameters were found of glass fiber, coir fiber and filler are 100 gram of glass fiber, 40 gram of coir fiber and 80 gram of filler (Epoxy + Hardener) respectively.
- The optimized output responses value of tensile strength and strain were found 49.27 MPa and 14.43% respectively.

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Cite this article as: Ashok Kumar, Jitender Kumar, Deepak Juneja, Optimization of process parameters and mechanical properties of hybrid fibre reinforced by Epoxy Resin by response surface methodology (RSM), International Journal of Research in Engineering and Innovation Vol-3, Issue-6 (2019), 399-407. <https://doi.org/10.36037/IJREI.2019.3608>