INVESTIGATIONS ON SURFACE ROUGHNESS OF NATURAL (BANANA / COIR / SISAL) FIBER REINFORCED HYBRID POLYMER MATRIX COMPOSITES

Venkatachalam GOPALAN[1], Sivakiran GOMPA[2], Vishnu Pratheek CHALLA[3], Yash GANGWAL[4], Vignesh PRAGASAM[5], Annamalai KRISHNAMOORTHY[6]

The use of composites is increasing with increasing demand for advanced materials with specific properties required for specific applications. Composite materials are being used in a lot of applications, based on, type of resin and other reinforcements. Generally, resins are reinforced with a wide range of natural and synthetic fibers in different ways such as short/long/woven. In this investigation, samples are fabricated using three fibers, three resins and three fiber lengths. Samples are prepared with fibers of 5% wt. ratio reinforced with resin/CSNL of 80:15% wt. ratio using response surface methodology (RSM) as the design of experiments. The optimum conditions were obtained from the previous phase of the authors' work and surface roughness is found out for all samples. Surface roughness plots were drawn for different combinations of fibers, resins, and range of lengths.

Keywords: Banana fiber, Coir fiber, Sisal fiber, Surface Roughness, Response Surface Methodology.

1. Introduction

The use of composite materials has grown rapidly nowadays and hence the demand for composite materials is increasing day by day. In this regard, it is very important to study the machining characteristics of composite materials. It is essential to know optimized values of speed, feed, and depth of cut to get an optimized output.

Sivakiran et al. [1] carried out an experiment on natural fiber reinforced polymer matrix composites, to study the effect of different combinations of speed,

[1] Prof., SMBS, Vellore Institute of Technology, Chennai Campus, India, e-mail: g.venkatachalam@vit.ac.in
[2] Stud., SMEC, Vellore Institute of Technology, Vellore Campus, India, e-mail: sivakirangompa225@gmail.com
[3] Stud., SMEC, Vellore Institute of Technology, Vellore Campus, India, e-mail: pratheek.vishnu@gmail.com
[4] Stud., SMEC, Vellore Institute of Technology, Vellore Campus, India, e-mail: vkg.jain@gmail.com
[5] RA., SMEC, Vellore Institute of Technology, Vellore Campus, India, e-mail: vigneshps310@gmail.com[5]
[6] Prof., SMBS, Vellore Institute of Technology, Chennai Campus, India, e-mail: ka651210@gmail.com

feed, and depth of cut on the material removal rate and surface roughness of polymer composites. They found an optimum condition to achieve a good surface finish on polymer composites after machining. Hussain et al. [2] studied a detailed analysis of Response Surface Methodology (RSM) and concluded that RSM is very much helpful for modeling and analyzing cutting power in the machining of glass fiber reinforced polymer (GFRP) composites with respect to various combinations of machining parameters.

Palanikumar [3] used computing techniques like fuzzy inference systems, ANFIS to get an analysis of the experiments performed for machining. Durao et al. [4] investigated the effects of tool geometry and feed rate on surface roughness of drilled holes and found that the results of surface roughness are varying a lot. Machining of composites has several issues such as delamination, fiber pull out, tool wear, etc.

Ferreira et al. [5] studied the effects of reinforcement on the delamination of composites. To choose an optimum input parameter to get a minimum surface roughness, when machining of composites, is very much required. Palanikumar et al. [6] investigated glass fiber reinforced plastics (GFRPs) to know the effect of machining parameters on surface roughness and they concluded that speed, feed, depth of cut and fiber orientation angle are influencing parameters.

Mohan et al. [7] conducted experiments using speed, feed, and depth of cut and size of the drill bit as input parameters and found that speed and size of drill bit have influences on thrust force and feed rate has an effect on delamination of composites. Wang and Zhang [8] carried out experiments on machining of epoxy composites with carbon fiber as the reinforcement and found that the fiber orientation plays an important role in the machining of composites. Sahin and Riza [9] concluded that response surface methodology is very useful in predicting the output which is affected by varying inputs.

The objective of this work is to study the machining characteristics of natural fiber reinforced hybrid polymer matrix composites. The influences of types of resins, types of natural fibers and length of fiber on surface roughness during machining are investigated. The natural fibers used for the experimentation are jute, banana, and sisal. The type of resins used here is an isophthalic polyester resin, general-purpose resin, and vinyl ester resin as synthetic resins and cashew nut shell liquid (CNSL) as a natural resin. The hybrid polymer is prepared with 80:15% wt. ratio of synthetic resin and CNSL respectively. The lengths of fibers used for the experimentation are in the range of mm, mm-micron and micron. The fiber percentage is taken as 5% wt. Response Surface Methodology (RSM) is chosen from the Design of Experiments (DoE) to prepare the composite material samples.

2. Experimental Procedure

2.1. Materials

The raw natural fibers, banana, coir, and sisal are chopped into small lengths as per requirement and used for reinforcement purposes. Resins such as General Purpose (GP) resin, Isophthalic resin, Vinyl ester resin, Cashew Nut Shell Liquid (CSNL) are used as matrix. These fibers and resins are purchased from local suppliers, Chennai, Tamil Nadu.

2.2. Methodology

The natural fibers are initially cut into small size and fed into the pulverizing machine to reduce the length of the fiber as mm, mm-micron, micron. The resin and CSNL are mixed in 80:15% wt. ratio for 15 minutes to blend well and then 5% wt. of chopped fibers in different lengths (as per table 2) are added to the resin mixture and stirred well for 30 minutes to obtain a uniform dispersion of fibers within the matrix. A PVC pipe of 1-inch diameter is cut into 15 cm of length and fixed vertically over a flat plate to serve as a mold for specimens. Finally, the hardener is added to the mixture and transferred to the mold as shown in Figure 1 to prepare the samples.

Fig. 1. Sample preparation process

Table 1 shows the 3-Parameter 3-Level for the design of an experiment based on Response Surface Methodology method. In tables 1, 2, and 3, General Purpose resin, Isophthalic resin, and vinyl ester resin are abbreviated as GP, IP, and VE respectively. Length of fibers more than 1 mm is coded as ‘mm’, less than 1 mm and more than 100 microns are coded as ‘mm-micron’, less than 100 microns are coded as ‘micron’. The size separation is done using a sieve shaker machine.

Table 1

Experimental Design Parameters and Levels

Symbol	Process Parameters	Levels		
		-1	0	+1
X1	Types of Resin	GP	IP	VE
X2	Types of Fiber	Sisal	Coir	Banana
X3	Length of Fiber	mm	mm-micron	micron

Table 2 shows the 20 combinations of parameters and levels based on Response Surface Methodology. Samples, as shown in Figure 1, are prepared based on Table 2 combinations.

Table 2

RSM table for a different combination of parameter and levels for sample preparation

Exp. No.	Type of Resin		Length of fiber		Type of fiber	
	Coded Value	Actual Value	Coded Value	Actual Value	Coded Value	Actual Value
1	-1	GP	0	mm-micro	0	coir
2	-1	GP	0	mm-micro	0	coir
3	0	I.P	1	micro	-1	sisal
4	-1	GP	0	mm-micro	-1	sisal
5	1	VE	-1	mm	1	banana
6	0	I.P	-1	mm	1	banana
7	1	VE	0	mm-micro	0	coir
8	0	I.P	1	micro	1	banana
9	1	VE	0	mm-micro	0	coir
10	0	I.P	-1	mm	-1	sisal
11	-1	GP	-1	mm	0	coir
12	1	VE	1	micro	1	banana
13	-1	GP	0	mm-micro	0	coir
14	-1	GP	1	micro	0	coir
15	1	VE	-1	mm	-1	sisal
16	1	VE	1	micro	-1	sisal
17	-1	GP	0	mm-micro	0	coir
18	-1	GP	0	mm-micro	0	coir
19	0	I.P	0	mm-micro	0	coir
20	-1	GP	0	mm-micro	1	banana

Sivakiran et al. [1] investigated the surface roughness and material removal rate for banana fiber reinforced polymer composites. They prepared the sample using chopped banana fibers mixed with Isophthalic resin/CSNL mixture and prepared 20 samples for analysis. They considered speed, depth of cut and feed rate as process parameters and took 5 levels each for analysis. After the machining was carried out, they observed the material removal rate and surface roughness for all 20 samples and tabulated. Then they conducted ANOVA analysis using Minitab software to find the regression equation for surface roughness as shown in eq. (1),

$$Surface\ roughness = 10.16 + 0.00216A - 1.54B - 13.4C \quad (1)$$

where A – Speed; B – Depth; C – Feed

Equation (1) is fed into RSM optimizer in Minitab software to obtain the optimized results. After analysis, the optimized values are speed 440 rpm, feed 0.25 mm/rev, and depth of cut 2 mm. The individual sample is machined through turning operation in a lathe machine by fixing the above-optimized values. A carbide tool is used to machine the samples. After machining, the surface roughness of the samples is analyzed using the Profilometer. Surface roughness is taken in three different locations for consistency. The surface roughness values of all samples are tabulated in Table 3.

Table 3

Experimental observation of Surface roughness values

Exp. No.	Type of Resin		Length of fiber		Type of fiber		Surface roughness microns
	Coded Value	Actual Value	Coded Value	Actual Value	Coded Value	Actual Value	
1	-1	GP	0	mm-micro	0	coir	7.255
2	-1	GP	0	mm-micro	0	coir	8.744
3	0	I.P	1	micro	-1	sisal	6.102
4	-1	GP	0	mm-micro	-1	sisal	6.678
5	1	VE	-1	mm	1	banana	8.461
6	0	I.P	-1	mm	1	banana	4.859
7	1	VE	0	mm-micro	0	coir	12.730
8	0	I.P	1	micro	1	banana	5.118
9	1	VE	0	mm-micro	0	coir	6.471
10	0	I.P	-1	mm	-1	sisal	10.536
11	-1	GP	-1	mm	0	coir	6.041
12	1	VE	1	micro	1	banana	10.404
13	-1	GP	0	mm-micro	0	coir	6.499
14	-1	GP	1	micro	0	coir	5.329
15	1	VE	-1	mm	-1	sisal	8.371
16	1	VE	1	micro	-1	sisal	3.309
17	-1	GP	0	mm-micro	0	coir	10.355
18	-1	GP	0	mm-micro	0	coir	5.221
19	0	I.P	0	mm-micro	0	coir	8.058
20	-1	GP	0	mm-micro	1	banana	7.325

3. Results and Discussion

3.1. Mean Effect Plot and Surface Plot

The mean effect plot in Figure 2 shows how the different levels of a factor affect the response.

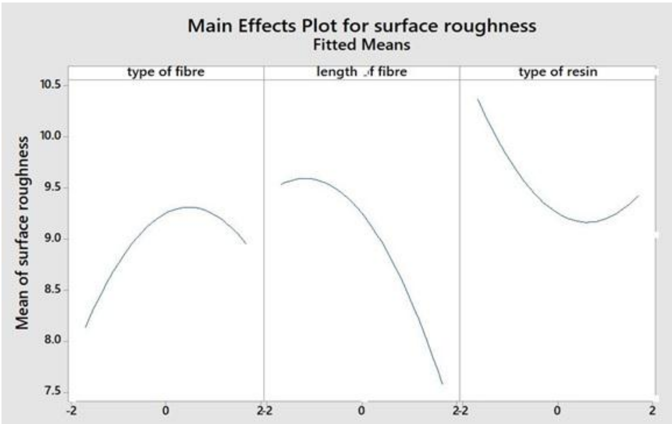
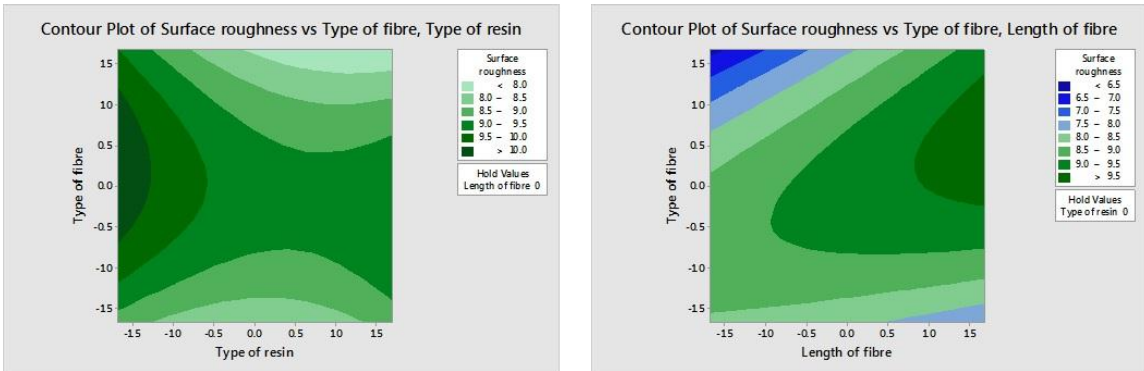
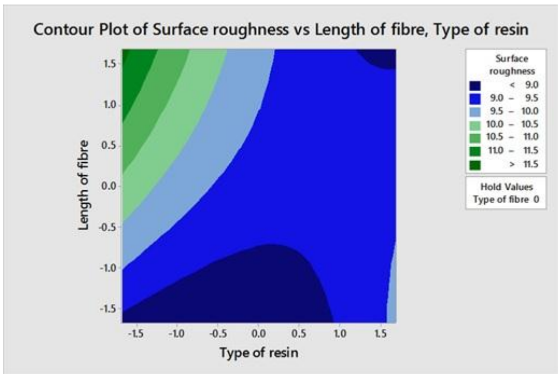


Fig. 2. Mean effect plot for surface roughness

From Figure 2, X-axis indicates the levels of different parameters and the Y-axis indicates the mean surface roughness. It is observed that low surface roughness values are obtained from the combination having GP resin, mm-micron length, and sisal fiber. Similarly, high surface roughness values are observed for the combination of vinyl ester resin, mm-micron length, banana fiber.



a) b)



c)
Fig. 3. Contour plot for Surface roughness
a) Type of fiber vs. Type of resin; b) Type of fiber vs. Length of fiber;
c) Length of fiber vs. Type of resin.

It is also observed that as the level of the type of fiber increases, there is a decrease in surface roughness which means that banana fiber-reinforced composite exhibits more surface roughness when compared to sisal fiber. When the level for the length of fiber increases, the surface roughness decreases which implies that the mm size of the fiber-reinforced composite has more surface roughness and the micron size of the fiber-reinforced composite has the least. Similarly, as the level for the type of resin increases, it is observed that the surface roughness decreases. It is concluded that surface roughness is more for GP compared to vinyl ester.

From Figure 3, the numbers, in X and Y axes, indicate the coded value. For the length of the fiber, -1 indicates mm, 0 indicates mm-micron, and 1 indicates micron size. For Resin, -1, 0, 1 indicates GP, IP, and VE respectively. For types of fiber -1, 0, 1 indicates sisal, coir, and banana fibers. The coded values with their types are mentioned in table 1. Figure 3 a) shows the variation of surface roughness with different types of resin, types of fiber. Figure 3 b) shows the counterplot of surface roughness against the type of fiber and length of the fiber. Figure 3 c) explains the influences of the length of fiber and type of resin on surface roughness.

3.2. Regression Equation

Using Minitab software the regression equation for surface roughness is derived and it is shown in equation (2),

$$\boldsymbol{Surface\ roughness = 9.252 + 0.240F - 0.574L - 0.278R - 0.244F^2 - 0.241L^2 + 0.224R^2 - 0.058FL - 0.022FR + 0.233LR} \quad (2)$$

where F – Type of fiber, L – Length of fiber, R – Type of resin.

Now as per equation (2), substituting type of fiber, length of the fiber, type of resin from table 3, one can predict the surface roughness of the composite. For example, to get the surface roughness for the combination of GP, Coir fiber, micron-size length of the fiber, one should substitute -1, 0 and 1 in place of the type of resin, type of fiber and length of the fiber, respectively.

In equation (2), it is observed that the type of fiber has a positive effect on surface roughness, and the length of the fiber, type of resin have a negative impact on surface roughness.

4. Conclusion

An attempt is made, keeping the machining parameters constant and varying types of resin, types of fibers, length of fibers, and to investigate the surface roughness of fiber-reinforced composite. Response surface methodology is used to design the experiment. Surface roughness is measured and the trend is observed. It is observed that surface roughness decreases, by changing the length of fiber from mm to micron size. Samples prepared using general-purpose resin have minimum surface roughness while samples prepared using isophthalic resin give maximum surface roughness. It is observed that banana fiber reinforced samples exhibit maximum surface roughness, and sisal fiber-reinforced composites exhibit minimum surface roughness.

REFERENCES

[1] *Sivakiran, Yash Gangwal, Venkatachalam, Pandivelan, Ayyappan*. Investigations on machining of banana fiber reinforced hybrid polymer matrix composite materials. Material Today: Proceedings, v 5, p 7908-7914, 2018.

[2] *Hussain S A, Pandurangadu V, Palanikumar K.* Surface Roughness Analysis in Machining of GFRP Composites by Carbide Tool (K20). European Journal of Scientific Research, v 41, n 1, p 84-98, 2010.

[3] *Palanikumar K.* Surface roughness model for machining glass fiber reinforced plastics by PCD tool using fuzzy logic. Journal of Reinforced Plastics and Composites, v 28, n 18, p 2273–2286, 2009.

[4] *Duraõ L M P, Gonçalves D J S, Tavares J M P S, De Albuquerque V H C, Vieira A A, Marques A T.* Drilling tool geometry evaluation for reinforced composite laminates. Composites Structure, v 92, p 1545–1550, 2010.

[5] *Ferreira J R, Coppini N L, Miranda G W A.* Machining optimization in Carbon Fiber Reinforced Composite Materials. Journal of Materials Processing Technology, v 92, p 135–140, 1999.

[6] *Palanikumar K, Karunamoorthy L, Karthikeyan R.* Assessment of factors influencing surface roughness on the machining of glass fiber-reinforced polymer composites. Materials and Design, v 27, p 862–871, 2006.

[7] *Mohan N S, Ramachandra A, Kulkarni S M.* Influence of process parameters on cutting force and torque during drilling of glass–fiber polyester-reinforced composites. Composites and Structure, v 71, p 407-413, 2005.

[8] *Wang X M, Zhang L C.* An experimental investigation into the orthogonal cutting of unidirectional fiber-reinforced plastics. International Journal of Machine Tools Manufacturing, v 43, p 1015–1022, 2003.

[9] *Sahin Y, Riza A M.* Surface roughness prediction model in the machining of carbon steel by PVD coated cutting tools. American Journal of Applied Science, v 1, n 1, p 12–17, 2004.