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Evaluation of Surface roughness and flank wear in drilling of jute flax polymer matrix composites

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Abstract
The important applicational area of jute flax-based polymer composite being the automotive and wall panels. In comparison with the synthetic fibres used in the fabrication of composites, the jute flax fibres can be of great mechanical competent if treated properly with necessary chemicals modifications. In the application of automotive panels even though the jute flax based PMCs are manufactured to a near required shape, the secondary cutting process like drilling is essential for having a joint in an assembly. While performing the drilling process the composite undergo several types of damages including, delamination, cylindricity errors, fibre pull out, matrix cracking, surface roughness and also flank wear concerned with the tool etc. It is thus required to obtain the pure optimal set of parameters while performing drilling operation to control and reduce such damages to the composite as well as the tool. In this work an attempt is made to optimize the parameters involved in machining (drilling) of jute flax based composites in order to minimize the surface roughness and flank wear.

Introduction

Although the demand for composites prepared using carbon fibres, Kevlar fibres and glass fibres is increasing, due to the drawbacks like they are not easily biodegradable and many other environmental factors the usage is restricted [1]. Hence a solution for this is being made ready by developing composites which have high strength and forms alternatives to the synthetic fibres through extracting fibres from plants, vegetables and fruits. For the fulfilment of strict environmental requirements, the European countries have already started using composites made of natural fibres for the interior as well as exteriors of the automobile [2]. Due to some of the better properties like low water retention rate, high strength, good thermal insulation, advantages while processing, easy availability, economy and many other advantageous factors the jute flax fibres are extensively in use today. Application areas of the jute fibre extend from aerospace to the automobile sectors and can be fabricated and joined in required sizes.

As said earlier, even though the parts with the use of composites can be produced to a near net shape there exists a requirement for some machining operations to be performed, drilling in particular when there is a need for a joint in the assembly [3]. In all the cases when drilling is considered it is the set of parameters on the machine along with the tool properties and material which matters the most. With non optimal parameters and tool properties the drilling of composites results in many kinds of damages as discussed in the abstract already. Due to delamination the quality of the hole is compromised and the main reason being the feed rate and the thrust force [4, 5]. It is to the best interest of the researcher to investigate the

parametric influence and the required optimal parameters in drilling of natural composites to solve the major issues in the drilling process.
Glass-coconut fibre-polyester hybrid composite was investigated for the drilling operation by optimizing through regression model and was found that the feed rate plays a major role while drilling such composites [6]. While in the case of the drilling of bamboo fibre reinforced polyester composites it was found that both feed rate and the tool diameter were the major influencing parameters on the delamination [7]. Different types of drill bits with ranging feed rates and speed of the spindle were used to analyse the effect of these parameters on the delamination and surface roughness while drilling lignocellulosic fibre reinforced polymer composites. The optimization was carried out by building a statistical model [8]. Flax/epoxy composites were also been studied for drilling to know the effects of drilling parameters on the quality of the hole by considering different feed rates, spindle speeds and drill bit types. The findings show that the quality of hole is affected by the type of drill bit but not by the feed rate and speed of the spindle [9].
Similar studies have been conducted to know the effects of drilling parameters on the quality of hole drilled in the natural fibres reinforced composites and only two parameters were considered to analyse and optimise the drill quality in terms of delamination and surface roughness. Here, in this study an attempt is made to understand the effects of three different parameters namely feed rate, spindle speed and the diameter of the tool on the surface roughness and flank wear. Delamination of the holes drilled is already discussed by the same author and only the concentration on optimizing parameters to obtain better surface finish in terms of roughness and flank wear is concentrated in this work.

Methodology and the materials
Jute/flax fibres, Araldite LY5138-2 (epoxy resin), and hardener (HY5138)were purchased from the local vendor and hand layup method was used to fabricate the composite panels with 65:35% resin to fibre ratio. Small flakes were initially separated from the dried fibres and fibre sheets were laid upon after applying the releasing agent. $0^{o}/90^{o}$ stacking is done in order to strengthen the laminate and obtain a 7 layered 3.5 mm thick laminateby putting a weight of 30 kgs on the laminate at a temperature of 60^{o} for 10 hrs.

Fig 1: Sample after curing

Sensitive drilling machine was used for the drilling operation with a range of constant speeds (100-2700rpm) and feed rates (0.0041-0.315mm/rev) along with different diameters of the tool (0.4, 0.6, 0.8 and 1.2mm). Surface roughness characteristics were studied using a Mitutoyo surface tester and the important characteristics that is Ra and Rz are considered for the study. 16 trials on the basis of Taguchi L16 array were selected drilling the holes and analysing the surface roughness of each hole.
Tool life and quality of the product while machining majorly depends upon the tool wear. Continuous set of drill tests were performed on the composite laminates to study the wear behaviour and mechanism with varying values of parameters. It is very important to have identified the wear mechanism through various experiments and measurement techniques, hence in this work Scanning Electron Microscope is used as shown in figure 3. Surface roughness interaction parameters are shown in figure 4.

Fig 2 and 3: Surface roughness tester and SEM used to measure flank wear of drill tools

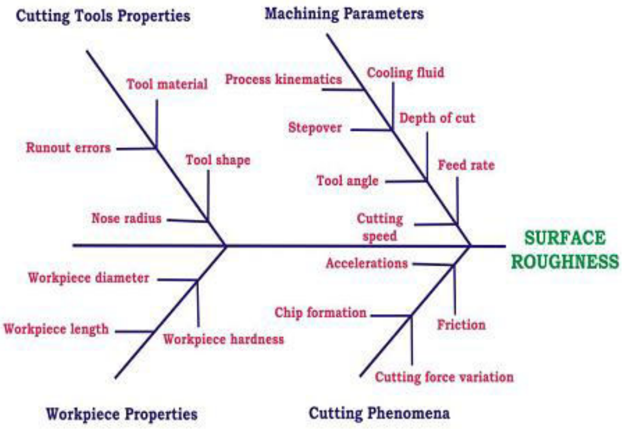

Fig 4: Fishbone diagram for factors affecting surface roughness

The selected parameters for the study are Diameter of the tool – (0.4, 0.6, 0.8 and 1.2mm), feed rates – (0.05, 0.1, 0.15 and 0.2mm/rev) and spindle speeds – (150, 200, 250 and 300rpm). Using RSM the model has been built for analysis and prediction.

Predictive Modeling of the Surface Roughness, flank wear Using Response Surface Methodology

For analysis and prediction of surface roughness characteristics of the drilled holes and tool life prediction by flank wear analysis and prediction the RSM modelling is used. Regression model was developed by using a second order polynomial response and the values for optimal surface roughness and flank wear were predicted.

$$\mathbf{Ra} = -0.248 + 2.240\,d + 5.13\,f - 0.001059\,v - 0.900\,d*d + 27.63\,f*f - 7.55\,d*f$$

$$\mathbf{Rz} = -1.91 + 32.21\,d + 115.7\,f - 0.0671\,v - 14.97\,d*d + 145.4\,f*f + 0.000174\,v*v - 97.7\,d*f - 0.260\,f*v$$

$$\mathbf{Vbc} = -0.0171 + 0.1224\,d - 0.347\,f - 0.000103\,v - 0.0800\,d*d - 1.513\,f*f + 0.314\,d*f + 0.00264\,f*v$$

With the use of the developed regression models the values are predicted and the equation s are given below.

Table 1:L16 array of parameters and the experimental results of surface roughness and flank wear

Trials	d(mm)	f(mm/rev)	v(mm/min)	Ra	Rz	Vbc
1	0.4	0.05	150	0.509	4.992	0.12658
2	0.4	0.1	200	0.8523	6.257	0.14715
3	0.4	0.15	250	1.125	7.481	0.226
4	0.4	0.2	300	1.6636	9.9773	0.381
5	0.6	0.05	200	0.6306	5.703	0.19675
6	0.6	0.1	150	0.984	7.967	0.35127
7	0.6	0.15	300	1.229	7.5037	0.47262
8	0.6	0.2	250	1.77	10.3	0.528
9	0.8	0.05	250	0.6707	8.1717	0.44382
10	0.8	0.1	300	0.829	7.1543	0.7212
11	0.8	0.15	150	1.2843	12.334	0.28797
12	0.8	0.2	200	1.67067	10.214	0.24494
13	1.2	0.05	300	0.7953	6.924	0.39604
14	1.2	0.1	250	0.658	3.643	0.49018
15	1.2	0.15	200	0.9653	4.606	0.38212
16	1.2	0.2	150	1.3223	6.4806	0.55537

Analysis of Variance (ANOVA)

Table 2 shows ANOVA results for the linear [*v, f, d,*] quadratic [v^2, f^2, d^2] and interactive [($v \times f$), ($v \times d$), ($f \times d$)] factors.The F - value 83.41 indicates the model is significant. The percentage contribution of each term is also shown in Table 2. Feed (f) was found to be the most significant factor on the surface roughness (Ra) with 70.510 % contribution of total variation. The next Contributions on surface roughness Ra is coming from the depth of cut and speed having the contribution of 1.21% and 0.93% respectively. Ra does not receive any significant contribution from the [v^2 f^2 d^2]. 2.75% and 3.21 % are the obtained contributions. 4.154%is the contribution of (d ×f). 1.77% contribution is from the residual error. The value of R^2 is98.23%, R^2 (Adj) =97.06% and R^2 (Pred.) =92.12%.

Table 2: Analysis of Variance Ra

Source	DF	Adj SS	Adj MS	F-Value	P-Value	%contribution
Model	6	2.33373	0.38896	83.41	0.000	98.23
Linear	3	1.87951	0.62650	134.35	0.000	79.14
d	1	0.02884	0.02884	6.18	0.035	1.214
f	1	1.67531	1.67531	359.25	0.000	70.510
v	1	0.02217	0.02217	4.75	0.057	0.93
Square	2	0.14156	0.07078	15.18	0.001	5.95
d*d	1	0.06521	0.06521	13.98	0.005	2.75
f*f	1	0.07635	0.07635	16.37	0.003	3.21
2-Way Interaction	1	0.09871	0.09871	21.17	0.001	4.154
d*f	1	0.09871	0.09871	21.17	0.001	4.154
Error	9	0.04197	0.00466			1.77
Total	15	2.37570				
R^2=98.23%		R^2(Adj)=97.06%			R^2(pred.)= 92.12%	

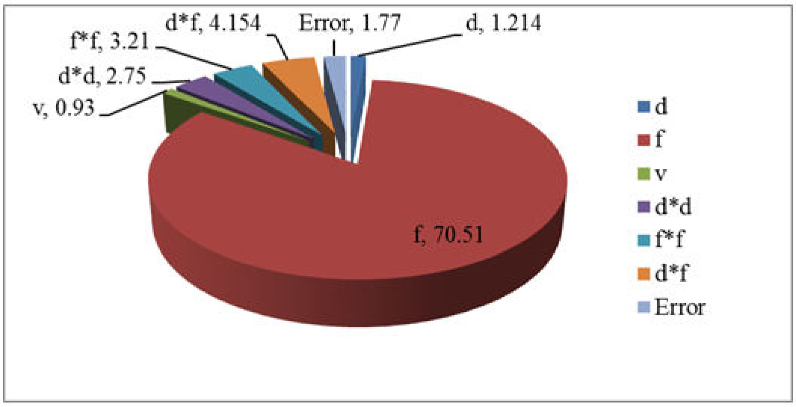

Fig 5: Parametric influence on Ra (in percentage)

Table 3 shows ANOVA results and each term contributing percentage which shows feed rate with a contribution of 13.51% is the major contributing factor.Speed and depth of cut have contributions of 11.14% and 9.71%after the feed rate. No such significance found for [$d^2f^2v^2$] with a contribution of 20.43, 2.61 and 3.73%.(dxf) and (fxv) have a contribution of 20.35 and 4.35% along with a contribution of 6.07% by the residual error. The value of R^2 is 93.95%of the total variations and is explained by the model.

Table 3: Analysis of Variance R_z

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% contribution
Model	8	76.269	9.5336	13.59	0.001	93.95
Linear	3	32.938	10.9792	15.65	0.002	40.57
d	1	7.881	7.8809	11.23	0.012	9.71
f	1	10.969	10.9693	15.63	0.006	13.51
v	1	9.046	9.0456	12.89	0.009	11.14
Square	3	21.726	7.2421	10.32	0.006	26.76
d*d	1	16.587	16.5867	23.64	0.002	20.43
f*f	1	2.115	2.1146	3.01	0.126	2.61
v*v	1	3.025	3.0252	4.31	0.077	3.73
2-Way Interaction	2	20.372	10.1861	14.52	0.003	25.09
d*f	1	16.520	16.5204	23.54	0.002	20.35
f*v	1	3.852	3.8518	5.49	0.052	4.74
Error	7	4.912	0.7017			6.05
Total	15	81.181				
R^2=93.95%		R^2(Adj)=87.03%			R^2(pred.)= 67.32%	

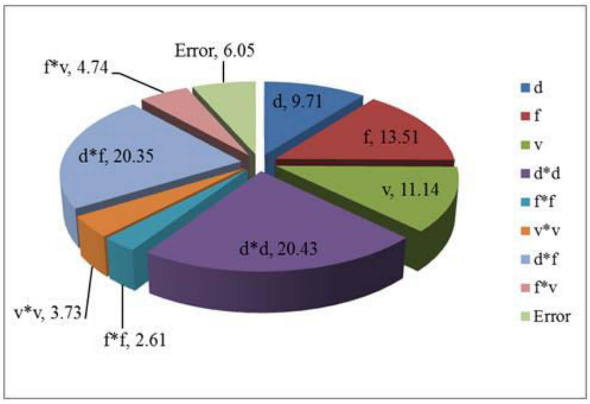

Fig 6: Parametric influence on Rz (in percentage)

Table 4 shows ANOVA results and contribution of every term where speed (v) was found to be most significant factor on the flank wear (Vbc) contributing to 28.52%.Feed rate and depth of cut have the contributions of 19.01% and 16.13%. [d^2f^2] have 13.25% and 2.61%, 6.40% contribution with no such significance. (d ×f), (f × v) have 4.78% and 11.10% contribution along with 17.11% by residual errors.

Table 4: Analysis of Variance Vbc

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% contribution
Model	7	0.002965	0.000424	5.54	0.014	82.91
Linear	3	0.001999	0.000666	8.71	0.007	55.90
d	1	0.000577	0.000577	7.54	0.025	16.13
f	1	0.000680	0.000680	8.89	0.018	19.01
v	1	0.001020	0.001020	13.34	0.006	28.52
Square	2	0.000703	0.000351	4.59	0.047	19.66
d*d	1	0.000474	0.000474	6.20	0.038	13.25
f*f	1	0.000229	0.000229	2.99	0.122	6.40
2-Way Interaction	2	0.000568	0.000284	3.72	0.072	15.88
d*f	1	0.000171	0.000171	2.24	0.173	4.78
f*v	1	0.000397	0.000397	5.19	0.052	11.10
Error	8	0.000612	0.000076			17.11
Total	15	0.003576				
R^2= 82.89%		R^2(Adj) = 67.93%			R^2(pred.)= 40.83%	

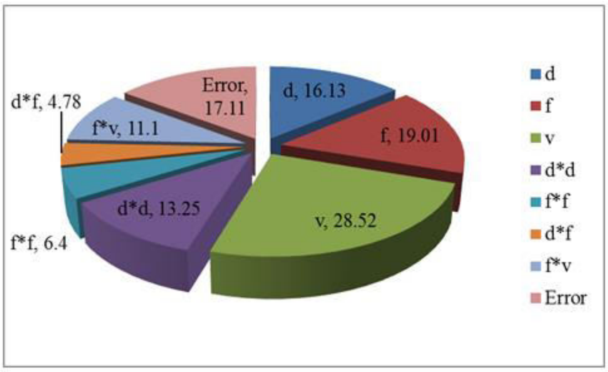

Fig 7: Parametric influence on Vbc (in percentage)

Model Fitness Check

Residuals were used to investigate the adequacy of the models. The difference in the experimental and the predicted values gives the residuals and are investigated using the plots of probability (figure 8-10). No particular trend of the residuals is seen in the plots wherein the distribution of errors is normal. No obvious pattern or an unusual structure is seen from the plots which validates the fitness of the model created and analysed.

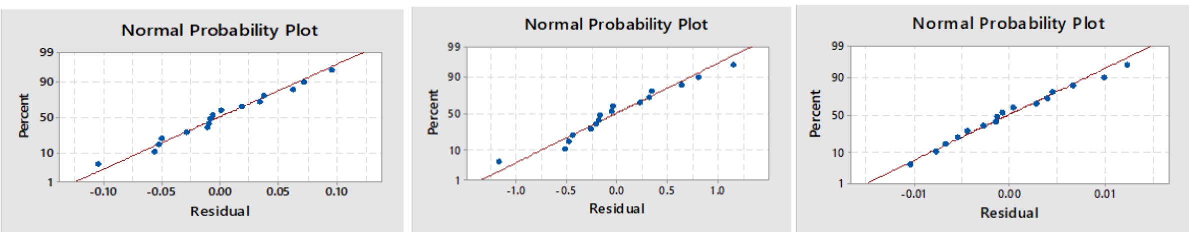

Fig 8, 9 and 10: Residual plots for Ra, Rz and Vbc

Parametric influence on surface roughness and flank wear

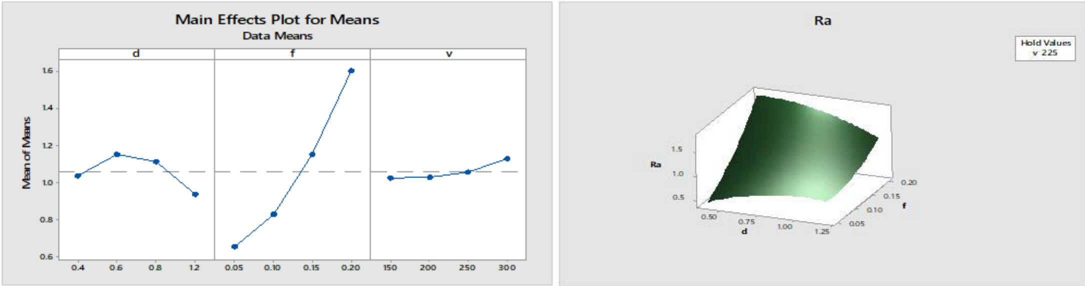

Fig 11 a and b: Main effect of plot for Ra and surface plot for effect of feed and depth of cut on Ra

Fig 11a shows the effect of parameters on the roughness parameter Ra. The major influencing parameter as per the main effect plot is feed rate. Second parameter is depth of cut followed by speed of the spindle which is almost negligible. ANOVA results also show the similar trend. From RSM the effect of feed rate and depth of cut is shown in the figure 11a. Lower cutting depth along with the lower feed rate and speed of mid-range is the best possible parametric combination as per the analysis.

Similar trend can be seen by the main effects plot on Rz which shows (figure 12a) the depth of cut as the major influencing parameter along with the feed rate effecting in the similar manner. The effect of speed of the spindle is here also almost negligible. Results have similarity with the ANOVA results and the surface plots show that the lowest feed rate and the lowest depth of cut along with the mid-range of speed gives an optimum value of Rz (figure 12b).

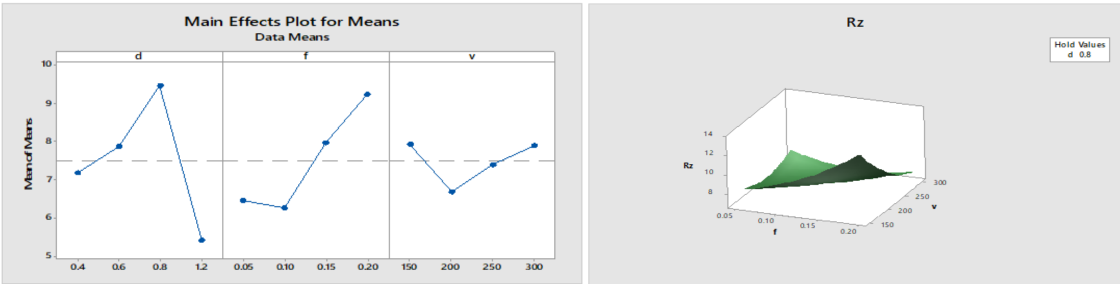

Fig 12 a and b: Main effect of plot for Rz and surface plot for effect of feed and depth of cut on Rz

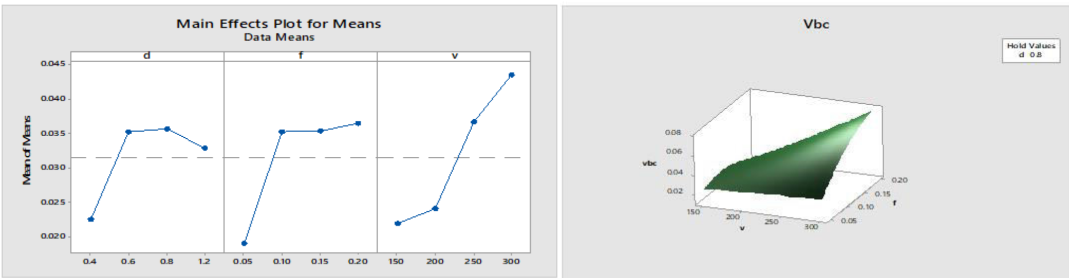

Fig 13 a and b: Main effect of plot for Vbc and surface plot for effect of feed and depth of cut on Vbc

The figure 13a gives better idea of the parametric influence on the Vbc which shows the major influencing parameters are feed rate feed rate flowed by the spindle speed and finally the depth of cut which is almost negligible. The results are similar to ANOVA and the surface plots clearly indicate that the lower feed rate along with the lower spindle speed combined with mid-range of depth of cut gives a better parametric combination.

Table 5: Comparison between experimental and predictive values of surface roughness of drilled composites

Sl.no	Experimental Ra	Predicted Ra	Experimental Rz	Predicted Rz	Experimental Vbc	Predicted Vbc
1	0.509	0.51986	4.992	4.6722	0.0126	0.008575
2	0.8523	0.77952	6.257	6.0285	0.0144	0.014032
3	1.125	1.17734	7.481	7.6804	0.0225	0.025141
4	1.6636	1.71332	9.9773	9.6277	0.0405	0.041901
5	0.6306	0.65934	5.703	6.1814	0.0204	0.021657
6	0.984	0.94936	7.967	9.1375	0.0163	0.020756
7	1.229	1.16575	7.5037	7.6732	0.0501	0.057724
8	1.77	1.73209	10.3	10.3442	0.0541	0.041698
9	0.6707	0.7268	8.1717	7.3629	0.0229	0.02834
10	0.829	0.83539	7.1543	7.2029	0.0632	0.053299
11	1.2843	1.29393	12.334	11.1782	0.0319	0.025263
12	1.67067	1.67884	10.214	10.733	0.0247	0.035097
13	0.7953	0.6986	6.924	7.0977	0.0203	0.021063
14	0.658	0.76201	3.643	4.0817	0.0473	0.042809
15	0.9653	0.96359	4.606	3.9636	0.0371	0.043777
16	1.3223	1.30332	6.4806	6.7435	0.0268	0.023968

Table 5 shows the comparison of the values obtained by experimentation and the values which are predicted using Response Surface Methodology. It can be seen that the values predicted through the statistical model are better as compared to that of the values from experiments. This proves the validity of the model built.

Optimization of Surface roughness, flank wear using RSM

Using the mathematical model predicted minimum Ra is obtained by performing individual response optimization. Table 6 shows the results for surface optimization and the same can be viewed through curves in figure 14. Results indicate that the drilling of the composites be performed using the values: f = 0.050 mm/rev, d = 0.40 mm and s = 300 m/min. The obtained optimized result for Ra is 0.361µm.

Similarly, optimization is performed for Rz also and table 7 shows the results for surface optimization and the same can be viewed through curves in figure 15. Results indicate that the drilling of the composites be performed using the values: f = 0.20 mm/rev, d = 1.20 mm and s = 300 m/min. The obtained optimized result for Rz is 0.6074µm.

Similarly, optimization is performed for Rz also and table 8 shows the results for surface optimization and the same can be viewed through curves in figure 16. Results indicate that the drilling of the composites be performed using the values: f = 0.40 mm/rev, d = 0.20 mm and s = 150 m/min. The obtained optimized result for Ra is 0.0132mm.

Table 6: Ra optimization

Response	Goal	Optimum conditions			Lower	Target	Upper	Predicted	Desirability
		d	f	v					
Ra	minimum	0.40	0.050	300	0.507	0.507	1.77	0.361	1

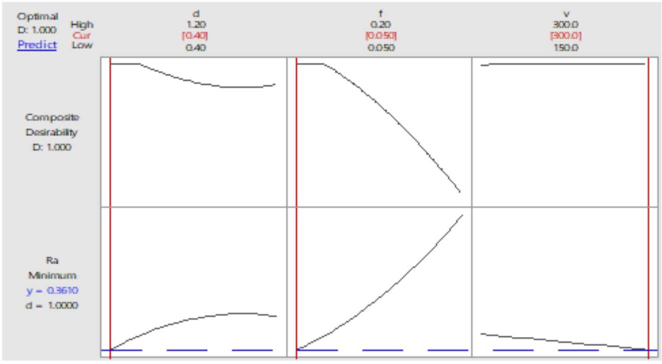

Fig 14: Ra optimization plot

Table 7:Rz optimization

Response	Goal	Optimum conditions			Lower	Target	Upper	Predicted	Desirability
		d	f	v					
Ra	minimum	1.20	0.20	300	3.643	3.643	12.334	0.6074	1

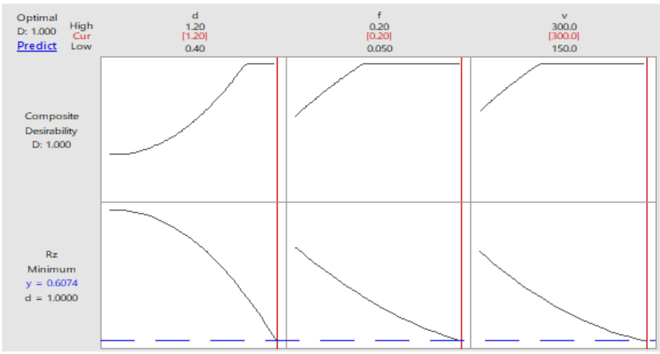

Fig 15: Rz optimization plot

Table 8: Vbc optimization

Response	Goal	Optimum conditions			Lower	Target	Upper	Predicted	Desirability
		d	f	v					
Ra	minimum	0.40	0.20	150	0.0126	0.0126	12.334	0.0132	1

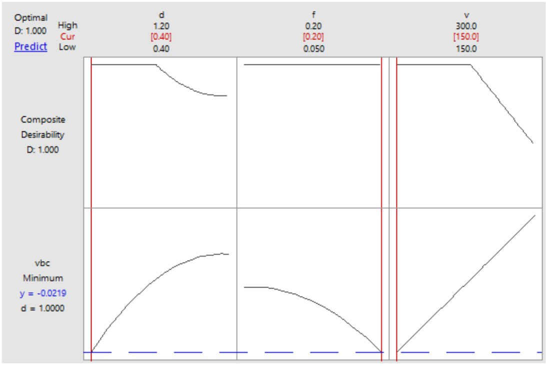

Fig 16: Vbc optimization plotConclusion

Owing to the fact that natural composites have a pivotal role in the field of material, the present work has been undertaken with an aim to scrutinize the process parameters and to examine the quality (surface roughness and flank wear) of drilled hole. The conclusions drawn from the experimental study are as listed below:

- Prediction with 95% confidence is proved using the RSM model to predict Ra, RZ and Vbc values through the results obtained. The detailed evaluation of the parametric influence, even individually is done in all the three case and best possible parametric combination is stated.
- Optimization using RSM gives the values of optimized parameters considered in order to obtain optimized responses in terms of Ra = 0.361 μm, Rz = 0.6074 μm and Vbc = 0.0132 mm.
- The used model and the analysis procedure is proved to be suitable for the analysis and prediction while drilling natural composites.

References

1. Gharde, S., and B. Kandasubramanian. 2019. Mechanothermal and Chemical Recycling Methodologies for the Fibre Reinforced Plastic (FRP). *Environmental Technology & Innovation* 14 (May):100311. Elsevier
2. Khan, T., M. T. B. Hameed Sultan, and A. H. Ariffin. 2018. The Challenges of Natural Fiber in Manufacturing, Material Selection, and Technology Application: A Review. *Journal of Reinforced Plastics and Composites* 37 (11):770–79. *Journals.Sagepub.Com*SAGE Publications Ltd
3. Xu, J., A. Mkaddem, and M. E. Mansori. 2016. Recent Advances in Drilling Hybrid FRP/Ti Composite: A State-of-the-Art Review. *Composite Structures* 135:316–38. *Elsevier*Accessed September 16.
4. Malik, K., F. Ahmad, and E. Gunister. 2021. Drilling Performance of Natural Fiber Reinforced Polymer Composites: A Review. *Journal of Natural Fibers* 19 (12):47 61–79.
5. Nasir, A. A. A., A. I. Azmi, and A. N. M. Khalil. 2022. 'Measurement and Optimisation of Residual Tensile Strength and Delamination Damage of Drilled Flax Fibre Reinforced Composites'. *Elsevier.* Accessed September 16www.sciencedirect.com
6. Jayabal, S., U. Natarajan, and U. Sekar. 2011. Regression Modeling and Optimization of Machinability Behavior of Glass-Coir-Polyester Hybrid Composite Using Factorial Design Methodology. *International Journal of Advanced Manufacturing Technology* 55 (1–4):263–73
7. Abilash, N., and M. Sivapragash. 2016. Optimizing the Delamination Failure in Bamboo Fiber Reinforced Polyester Composite. *Journal of King Saud University - Engineering Sciences* 28 (1):92–20.

8. King Saud University. Choudhury, M. R., M. S. Srinivas, and K. Debnath. 2022. 'Experimental Investigations on Drilling of Lignocellulosic Fiber Reinforced Composite Laminates'. *Journal of Manufacturing* and undefined 2018 *Elsevier* Accessed September16 www.sciencedirect.com
9. RezghiMaleki, H., M. Hamedi, M. Kubouchi,and Y. Arao. 2019. Experimental Investigation on Drilling of Natural Flax Fiber-Reinforced Composites. *Materials and Manufacturing Processes* 34 (3):283–92. Taylor and Francis Inc.