Optimization of Basalt Hybrid Particulate Glass Fibre-Reinforced Polymer Composite for Minimizing Delamination Effect during Milling

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ABSTRACT

Glass FibreReinforcedPolymer composite materials are extremely abrasive when machined. The machining process depends on the selection of the cutting tool and the cutting parameters.Milling process is significantly affected by the nature of these materials to undergo delamination under the action of machining forces, cutting force, feed force and depth force .Thus it is necessary to optimize the process parameters such as feed rate , spindle speed , helix angle and depth of cut for minimizing delamination effect in milling of Hybrid pariculate glass fibre-reinforced polymer composite (Basalt fibre, glassfibre, fly ash with epoxy resin). The preparation, characterisation and machinability of the composite is also reported. The basalt hybrid particulate Glass Fibre-Reinforced Polymer(GFRP) is prepared by conventional Hand layup technique. A major problem faced during milling, known as delamination, is the mode of failure resulting in poor dimensional stability, surface roughness and performance deterioration. This study is focused to minimize the delamination by finding the optimal set of milling parameters such as helix angle of the cutter, spindle speed, depth of cut and feed rate during milling of Hybrid particulate glass FRP composites. A Vision inspection system (Fig.2)is used to measure the delamination. Using Central composite design matrix, the experiments is conducted and the data obtained are analyzed using signal-to-noise ratio to identify the optimal milling conditions. The Analysis of variance(ANOVA) is conducted to determine the significance of each process parameter associated with the milling of Hybrid particulate GFRP composites. The correlation is obtained by multiple-variable linear regression using Minitab 17 software. The predicted value was compared with the results of confirmation test and the results shows a good agreement between predicted and actual value of delamination.

KEY WORDS: HybridParticulate Glass FibreReinforcedPolymerComposites,Milling,Delamination,Central Composite Design Matrix,Analysis Of Variance.

1. INTRODUCTION

Hybrid particulate glass FRP composites is considered to be an alternative to heavy materials. Its applications ranges from aircraft to machine tools due to their light weight, high specific stiffness and high specific strength (Venu Gopala Rao, 2007) Generally Hybrid particulate glass FRP composites are manufactured to shape components. Due to its Isotropic and Heterogeneous nature it is difficult to obtain high level surface finish by means of conventional machining . Hybrid particulate glass FRP composite materials are extremely abrasive when machined. Thus the tool and cutting parameters are selected in such a way to reduce delamination as it limits the application of the composite.

2. MATERIALS AND METHODS

Construction: To achieve the objective of this experimental work, Hybrid particulate glass FRP composites made of pure epoxy matrix (Araldite LY556) reinforced with basalt fibre , woven fibre glass using hardener (HT 972) was fabricated by Hand-layup procedure with 3 mm thickness (5 lay-ups) and a fibre orientation of 0/90°.The Hybrid particulate glass FRP composite made of pure epoxy (LY 556) resin matrix reinforced with basalt fibre , glass fibre and fly ash along with the hardener (HY 951) and the hand layup technique is employed for fabricating the specimen. 450g of epoxy resin, 100g of fly ash and 50g of chopped glass fibre were used to prepare the specimen of dimension 300x300x10 mm thick with 5 lay-up, having fibre orientation of 0/90˚. A release agent is applied during the fabrication at the bottom and top of the material to prevent sticking of specimen to surface. To squeeze out the air pockets and excess resin, a roller was used. A50kg weight was placed over the specimen and it was cured in a room temperature for 24 hours. The specimen prepared was tested and it was utilized for milling process.

Figure.1. Hybrid Basalt GFRP Composite

The properties of hybrid particulate composite are represented in Table.1.

Table.1. Properties of hybrid particulate composite

1.	Density	1681 Kg/m^3
2.	Compressive Strength	12.69 KN
3.	Tensile strength	84.94Mpa
4.	Impact Load	4J (Maximum)
5.	Young's Modulus	150 MPa

The HSS milling tool coated with tungsten carbide of helix angles 25°, 35° and 45° were used to perform the milling operation in the particulate composite material. The experiment was conducted using a CNC machine. The central composite design was used to design the experiments for each set of parameters in order to predict the influence of each factor on the response.

Table.2. Process control parameters and their limits

`			**Levels**			
Process parameters	**Units**	**Notation**	**Variable**	**-1**	**0**	**1**
Helix Angle	Degrees	H	A	25	35	45
Spindle speed	RPM	V	B	500	1000	1500
Feed rate	mm/min	F	C	200	400	600
Tool Dia	mm	D	D	1	1.5	2

Measurement of Delamination factor: The milling process performance on Hybrid particulate glass FRP composites was determined by delamination. The delamination caused on the composite material was measured perpendicular to the feed rate with a Vision Inspection System.

Figure.2. Vision Inspection system

The composite material was positioned and fixed on the XZ stage glass of the Vision inspection system, and then the alignment of an initial measuring point with one of the cross-hairs was made on the machined feature. The damage (maximum width) is measured by moving the XZ stage glass.This is done by turning the Digital counter fixed micrometer head to the same cross hair final point. Using this value(W_{max}), the damage normally assigned by delamination factor (F_d) was determined.This factor is defined as the ratio between the maximum width of damage (W_{max}) and the width of cut (W). The value of delamination factor (F_d) can be obtained by the following equation:

$F_d = W_{max}/ W$ (1)

Where, W_{max} is the maximum width of damage in mm and W is the width of cut in mm

Response Surface Methodology and experimental design: By the Response Surface Methodology (RSM) and by careful design of experiments, optimization of a response(output variable) which is influenced by several independent variables(input variables) can be done effectively. The objective is to study the relation between response and input parameters. The process steps involved in RSM were (i) Designing a fit of experiments for extent of the true mean response of interest, (ii) Determining the mathematical exemplar for an adequate fits, (iii) Determining the optimum permeate of input factors that produces restraint or minimum rate of response and (iv) Verifying the approach and interactive effects of practice variables on the input parameters over two dimensional and three dimensional graphs. The response surface assuming all variables are measurable can be expressed as follows

$y = f (x_1, x_2,....,x_k)$ (2)

The response variable 'y' needs to be optimized. The input variables are assumed to be continuous so as to find a suitable approximation for the true functional relationship between independent variables and the response surface. Usually a second-order model is utilized in response to surface methodology.

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

here 'ε' is a random error, 'β' is the coefficients, should be determined in the second-order model, is obtained by the least square method.

Owing to slightly wider ranges of the factors, it is decided to use a three level face-centered central composite design to optimise the experimental conditions. Face-centered central composite designs of second order was used to establish the mathematical relation of the response surface without losing its accuracy using the smallest number of experiments. In the present case, the size of the experiment is 30 for four machining parameters shown in table.3.

Table.3. Values of delamination factor (F_d) as a function of the cutting parameters

	Coded Variables				**Uncoded Variables**				**Response**
	Factor A	**Factor B**	**Factor C**	**Factor D**	**H**	**S**	**F**	**D**	**DF**
Run	**Degrees**	**RPM**	**mm/min**	**Mm**	**Degrees**	**RPM**	**mm/min**	**mm**	**Delamination Factor**
1	0	1	0	-1	35	1500	400	1	1.043525
2	1	0	0	1	45	1000	400	2	1.038925
3	0	0	1	1	35	1000	600	2	1.056995
4	0	1	-1	0	35	1500	200	1.5	1.02991
5	-1	0	0	1	25	1000	400	2	1.048265
6	-1	0	-1	0	25	1000	200	1.5	1.03508
7	-1	-1	0	0	25	500	400	1.5	1.04898
8	0	0	-1	1	35	1000	200	2	1.030195
9	0	-1	0	1	35	500	400	2	1.0443
10	-1	0	1	0	25	1000	600	1.5	1.06188
11	1	1	0	0	45	1500	400	1.5	1.03964
12	1	0	1	0	45	1000	600	1.5	1.05254
13	1	0	0	-1	45	1000	400	1	1.039355
14	0	0	0	0	35	1000	400	1.5	1.04381
15	-1	1	0	0	25	1500	400	1.5	1.04896
16	0	0	0	0	35	1000	400	1.5	1.04381
17	0	0	0	0	35	1000	400	1.5	1.04381
18	0	1	0	1	35	1500	400	2	1.043095
19	-1	0	0	-1	25	1000	400	1	1.048695
20	0	0	-1	-1	35	1000	200	1	1.030625
21	1	0	-1	0	45	1000	200	1.5	1.03041
22	0	0	0	0	35	1000	400	1.5	1.04381
23	1	-1	0	0	45	500	400	1.5	1.03964
24	0	0	0	0	35	1000	400	1.5	1.04385
25	0	0	1	-1	35	1000	600	1	1.057425
26	0	-1	0	-1	35	500	400	1	1.044525
27	0	1	1	0	35	1500	600	1.5	1.05671
28	0	0	0	0	35	1000	400	1.5	1.04381
29	0	-1	-1	0	35	500	200	1.5	1.03087
30	0	-1	1	0	35	500	600	1.5	1.05771

To simplify the calculation the natural values of input parameters are converted into coded values. The coded numbers for the variables used in tables are obtained from the following transformation equation:

$$X_i = \frac{[2X-(X_{max}+X_{min})]}{[X_{max}-\frac{X_{min}}{2}]} \quad (4)$$

where, X_{max} is the upper level of the parameter, The lower level of the parameter is denoted by X_{min} and X_i is the required coded values of the parameter of any value of X ranging from X_{min} to X_{max}.

3. RESULTS

Determination of Delamination Factor has been the subject of experimental and theoretical investigations as it enlightens upon fundamental problems such as friction, contact deformation, heat and electric current conduction, tightness of contact joints and positional accuracy. Obtaining the desired surface roughness proves challenging in process planning. The study of surface roughness characteristics of Hybrid Particulate glass FRP composites depends on many factors, and is more influenced by the cutting parameters like Helix Angle , Spindle speed, feed rate etc., for a given machine tool and work piece set-up.The correlation is obtained by multiple-variable linear regression using Minitab 17 software. A conformation test is conducted to check the predicted value and the results shows good agreement between predicted and actual values of delamination.

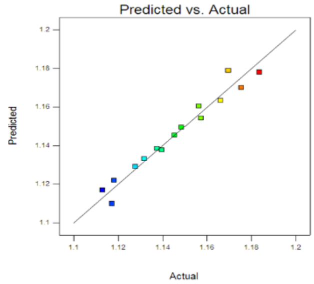

Figure.3. Predicted Vs Actual graph

As per the recommendation from the fit summary, for analysis of delamination, the quadratic model is statistically significant. The results for the surface roughness and delamination quadratic model in the form of ANOVA are given in table.4.

Table.4. ANOVA table for entry delamination

Source	Sum of squares	Df	Mean square	F- value	p-value (Prob>F)	Effect	Percentage contribution
Model	2.26E-03	14	1.62E-04	254.25	< 0.0001	Significant	99.58
A	2.20E-04	1	2.20E-04	345.64	< 0.0001	Significant	9.67
B	1.46E-06	1	1.46E-06	2.3	0.1505		
C	2.03E-03	1	2.03E-03	3196.93	< 0.0001	Significant	89.45
D	4.70E-07	1	4.70E-07	0.74	0.4034		
AB	1.00E-10	1	1.00E-10	1.57E-04	0.9902		
AC	5.45E-06	1	5.45E-06	8.58	0.0104		
AD	0	1	0	0	1		
BC	4.00E-10	1	4.00E-10	6.29E-04	0.9803		
BD	1.05E-08	1	1.05E-08	0.017	0.8994		
CD	0	1	0	0	1		
A^2	2.03E-06	1	2.03E-06	3.19	0.0942		
B^2	2.52E-09	1	2.52E-09	3.96E-03	0.9506		
C^2	5.83E-07	1	5.83E-07	0.92	0.3536		
D^2	4.70E-07	1	4.70E-07	0.74	0.4037		
Residual	9.54E-06	15	6.36E-07				
Lack of Fit	9.54E-06	10	9.54E-07				
Pure Error	1.33E-09	5	2.67E-10				
Cor Total	2.27E-03	29					

R^2=99.58, Adjusted R^2 =99.19

The R^2 value and adjusted R^2 for delamination are 99.58% and 99.19% respectively. This means that regression model provides an excellent explanation of the relationship between the independent factors and the responses. The associated '*p* 'value for the model is lower than 0.05 (i.e., α=0.05 or 95% confidence) which shows that the model is considered to be statistically significant. Significant effects on delamination are only due to Factor 'A'. As seen from the result the more significant parameter is the feed rate for surface roughness and delamination as compared to the Spindle speed,depth of cut and Helix angle due to higher 'F' value. Helix angle is less significant compared to feed rate and the other model terms are said to be insignificant due to less 'F' value.

The model adequacy is checked by using the ANOVA technique. According to this technique, if the calculated value of the '*F'* ratio of the developed model does not exceed the standard tabulated value of '*F'* ratio for a desired level of confidence (say 99.6%), then the model is considered to be adequate within the confidence limit. The variance ratio is the ratio of mean square due to a factor and error mean square and is denoted by '*F*'. In robust design,the relative factor effects can be understanded qualitatively using the 'F' ratio. A high value of '*F'* means that the effect of that factor is large compared to the error variance. So, the larger the value of '*F* 'for a factor, the process response is influenced more by that factor. The lack of fit was found to be less than $F_{0.01}$ (10, 6) in the present research study and, hence the developed model may be accepted.

By backward elimination process the insignificant terms are eliminated to appropriately fit the surface roughness and delamination quadratic model.The reduced model results for surface roughness show that the model is significant (R^2 and adjusted R^2 are 99.58% and 99.19%, respectively). It is seen that the regression model is fairly well fitted with the observed values. After eliminating the insignificant terms, the experimental values are analyzed using response surface analysis and the following relation has been established for delamination of GFRP composites.

Final Equation in Terms of Actual Factors:

Delamination Factor (F_d)= +1.04382 – (4.27917E-003 * Helix Angle) –(3.48750E-004 * Spindle Speed) +(0.013014 * Feed) –(1.97917E-004 * Depth of Cut) +(5.00000E-006 * Helix Angle * Spindle Speed) –(1.16750E-003 * Helix Angle * Feed) –(1.40666E-020 * Helix Angle * Depth of Cut) –(1.00000E-005 * Spindle Speed * Feed) –(5.12500E-005 * Spindle Speed * Depth of Cut) (-5.53192E-017 * Feed* Depth of Cut) +(5.43958E-004 * Helix Angle^2) –(1.91667E-005 * Spindle Speed^2) +(2.91458E-004 * Feed^2) –(2.61667E-004 * Depth of Cut ^{2})

Figure 4 shows the Main Effects Plot of the factors considered for Delamination. The influence of different cutting parameters on machining of Hybrid Particulate Glass FRP composites are studied by using response graph and response table. From the figure it is observed that delamination factor value increases with increasing the feed rate whereas in case of Depth of cut , Helix angle and Spindle speed , the delamination factor value first increases and then decreases.

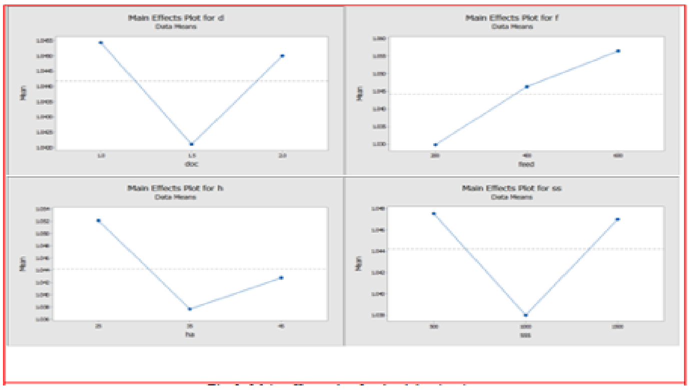

Figure.4. Main Effects Plot For The Delamination

From the Response Table [Table.5], it is declared that feed rate is the main parameter which affects the delamination factor .

Table.5. Response Table for Delamination

Helix Angle	Average Helix Angle	Spindle Speed	Average Spindle Speed	Feed	Average Feed	Depth of Cut	Average Depth of Cut
25	1.0521	500	1.047533	200	1.029767	1	1.045433
35	1.037667	1000	1.038	400	1.046333	1.5	1.0421
45	1.042767	1500	1.047	600	1.056433	2	1.045
Avg	0.014433		0.009533		0.026667		0.003333

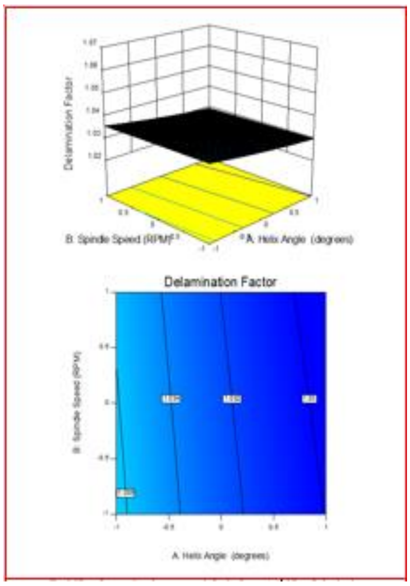

Figure. 53D surface graph and contour graph for the factors A and B on Delamination

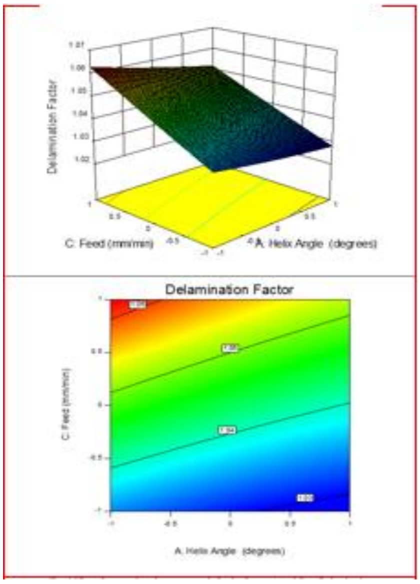

Figure. 63D surface graph and contour graph the factors A and C on Delamination

Fig.5, shows the effect on delamination factor due to helix angle and spindle speed. As it seen from the figure, the delamination tends to decrease considerably with helix angle increment and increases slightly with an increase in spindle speed. As it seen from the contour graph, the delamination factor value lies within 1.035, when the spindle speed varies from 500 rpm to 1500 rpm and helix angle values ranges from 25 to 45 degrees.

The estimated response surface for the delamination factor in relation to the individual parameters of the helix angle and feed rate is shown in Fig.6. As it seen, the delamination increase steadily by increase in feed rate and decreases slightly with an increase of helix angle. This is due to the increase in the feed rate causes a sharp rise in the feed force which in turn causes higher friction and produces more damage on the surface. As read from the contour graph, the delamination value lies within 1.063, when the helix angle varies from 25 to 45 degrees and feed rate ranges from 200 to 400 mm/min.

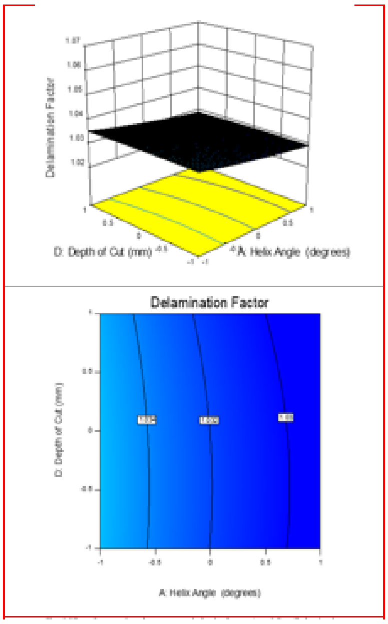

Figure.7. 3D surface graph and contour graph for the factors A and D on Delamination

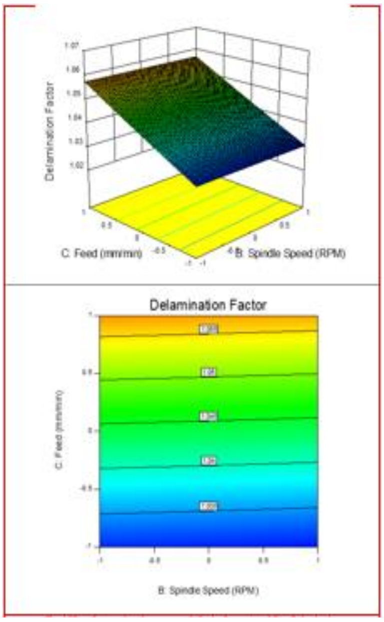

Figure.8. 3D surface graph and contour graph thefactors B and C on Delamination

The variation in delamination factor in relation to the individual parameters of the helix angle and Depth of cut is clearly seenfrom Fig.7. The delamination increase slightly by increase in feed rate and decreases considerably with an increase of helix angle. This is due to the increase in the feed rate causes a sharp rise in the feed force which in turn causes higher friction and produces more damage on the surface. As read from the contour graph, the delamination value lies within 1.035, when the helix angle varies from 25 to 45 degrees and Depth of cut varies from 1 to 2 mm.

Upon varying the spindle speed and feed rate, the delamination increases steadily in feed rate and increases slightly with an increase of spindle speed as shown in Fig.8. As read from the contour graph, the delamination value lies within 1.057, when the spindle speed varies from 500 to 1500 rpm and feed rate ranges from 200 to 400 mm/min.

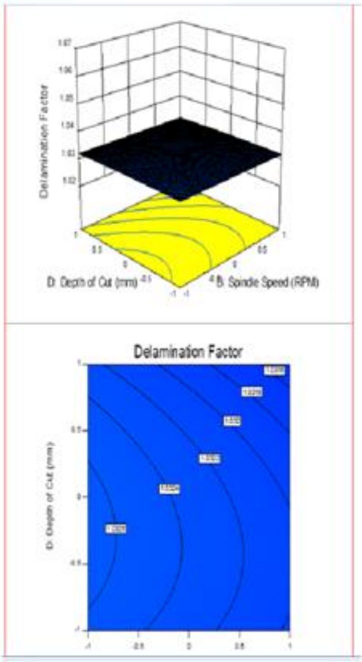

Figure. 9.3D surface graph and contour graph for factors B and D on Delamination

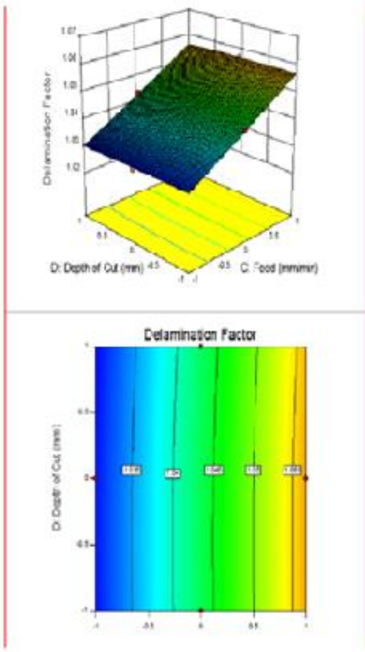

Figure.10.3D surface graph and contour graph for the factors C and D on Delamination

It is found that on any changes in to the individual parameters of the spindle speed and depth of cut the delamination factor also varies accordingly from Fig.9. As it seen, the delamination increase slightly by increase in spindle speed and moderately increases with an increase of depth of cut. As read from the contour graph, the delamination value lies within 1.033, when the spindle speed varies from 500 to 1500 rpm and depth of cut ranges from 1 to 2 mm.

The effects on delamination factor on variation of the individual parameters of the Depth of cut and feed rate is obtained in Fig.10. As it seen, the delamination increase steadily by increase in feed rate and moderately increases with an increase of depth of cut. This is due to the increase in the feed rate causes a sharp rise in the feed force which in turn causes higher friction and produces more damage on the surface. As read from the contour graph, the delamination value lies within 1.057, when the depth of cut varies from 1 to 2 mm and feed rate ranges from 200 to 400 mm/min.

4.CONCLUSIONS

Based on the experimental results presented, the following conclusions were drawn from drilling resin hybrid glass fibre-reinforced plastic composites using solid carbide tool:

- Hybrid particulate glass FRP composites produces less damage than the pure epoxy HFRP laminates, considering the same cutting parameters (spindle speed, feed rate helix angle and depth of cut).
- Feed rate is the cutting parameter that present the highest statistical and physical influence on delamination factor, for pure epoxy and Hybrid particulate glass FRP composites, respectively.
- The developed mathematical model successfully predicted the delamination during Milling of Hybrid particulate glass FRP composites.
- RSM is a very appropriate technique to forecast the main and interaction effects of machining parameters that contribute to delamination.
- The delamination factor increases progressively with increase in Feed rate and slightly decrease in helix angle. In other words, at higher feed, the delamination of the particulate composite material is large.
- From ANOVA, the Feed rate has a greater influence to the delamination (89.45%) followed by the helix angle.

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