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Research Article

MODELING OF DELAMINATION FACTOR AT ENTRY AND EXIT USING HIGH SPEED DRILLING ON GLASS FIBER REINFORCED POLYMER COMPOSITE

Pallavi H. Agarwal., Vyomesh R. Buch., Deep A. Patel and *Ketulkumar R. Patel

Department of Mechanical Engineering, Babaria Institute of Technology, Varnama, Vadodara, Gujarat, India

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ABSTRACT

This paper reports the experimental investigation of high speed drilling of glass fiber reinforced composite. The relevance of this study is that it establishes empirical relations as a function of machining variables, relevant to analyse the machinability of glass fiber reinforced composite. The response functions considered delamination factor at entry and exit and the machining variables are point angle, cutting speed and feed rate. Experiments are conducted on the basis of response surface methodology technique. Empirical models correlating process variables and their interactions with the said response functions have been established. The models developed reveal that point angle is the most significant parameter. These models can be used for selecting the values of process variables to get the desired values of response parameters.

INTRODUCTION

Composite laminate possess superior properties like higher strength to weight ratio, higher stiffness, lower thermal expansion over other conventional materials. Therefore, composite laminates like GFRP find its place in aerospace industries, aircraft structural components [1]. Machining of GFRP has always been difficult because of multitude of difficulties like fiber pull out, fiber fuzzing, matrix burning, fiber-matrix detachment which result in subsurface damage, reduced strength and short product life. Many researchers have established that GFRP can be machined easily by HSD but detailed mathematical models representing the influence of predominant machining variables on machinability are yet to be established. This paper attempts to develop these empirical models, using response surface methodology. These linear regression models developed may be of interest to process planners dealing with such materials.

Experimental Work

GFRP composite was prepared using hand layup technique. Lapox L-12 with hardener K-6 was used for specimen preparation. Wax was sprayed on the mold surface to avoid the sticking of resin to the surface. Thin polyester films were used at the top and bottom of the mold to get good surface finish. Woven glass fiber (600 GSM) is cut as per mold size (300 mmx250mm) for reinforcement. Lapox L-12 resin and hardener K-6 are mixed in mixing ratio 10:1by weight. Resin in spread with the help of brush and layer of woven glass fiber was placed on the resin and roller was moved to remove trapped air. This process was repeated for 10 layers of glass fiber and then the polyester film is applied on the top surface. Curing is done for 24 hours. After curing specimen of 275 mm x 220 mm was cut, with a thickness of 5.8 mm. High speed drilling was carried out using solid carbide drill. Geometry of the drill were set using grinding machine and point angles so obtained were checked using tool makers microscope.

Experimental Plan

Experiments are planned on the basis of RSM technique used in experimental design. A full factorial design includes effect of all main factors and interaction of factors, 3^3 full factorial design is selected for experimental work. The levels of input parametrs chosen for experiment and their levels is shown in Table 1. Each experiment is performed on CNC micro drilling machine which is controlled with Mech Front V 1.0.0.0. In this investigation the delamination factor was measured as a ratio of total area with hole damage to nominal area of drilled hole. The images of the drilled hole were captured using 3D microscope with 0.97X magnification and 0.1µm resolution.

Corresponding author:* **Ketulkumar R. Patel
Department of Mechanical Engineering, Babaria Institute of Technology, Varnama, Vadodara, Gujarat, India

The digital images of drilled hole were analysed using Image J (Version 1.5 1J8)-public domain software to calculate delamination factor at entry and exit.

Table 1 Input Parameters used for experimentation and their levels

Input Parameter	Coding	Level 1 (-1)	Level 2 (0)	Level 3 (+1)
Cutting Speed(m/min)	X_1	175	205	235
Feed rate (mm/min)	X_2	150	200	250
Point Angle (Degree)	X_3	90	104	118

Mathematical Modeling

According to the experimental plan a total of 27 experiments are conducted, each having the combination of various values of process variables X_1, X_2, X_3. Each of the responses is fitted into a linear equation represented by:

$$\hat{y} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon$$

where, $\hat{y}$ is the response and X_1 , X_2 , X_3 are coded levels of variables. The coefficients β_0, $\beta 1$, β_2 and β_3 can be calculated by solving the following equation:

$$\beta = (X^T X)^{-1} X^T Y$$

where, β is the matrix of parameter estimates, X is the matrix of independent variables, X^T is the transpose of X matrix and Y is the matrix of measured responses. Table 2 gives the design matrix and the responses. Analysis of variance (ANOVA) is performed to test the adequacy of the proposed models.

Table 2 Design matrix and responses

S.No	Input Parameters: Point Angle	Cutting Speed	Feed rate	Output Parameters: Delamination at Entry	Delamination at Exit
1	90	175	150	1.133	1.152
2	90	175	200	1.145	1.150
3	90	175	250	1.159	1.171
4	90	205	150	1.136	1.146
5	90	205	200	1.140	1.160
6	90	205	250	1.186	1.183
7	90	235	150	1.150	1.155
8	90	235	200	1.169	1.164
9	90	235	250	1.166	1.213
10	104	175	150	1.186	1.238
11	104	175	200	1.219	1.228
12	104	175	250	1.169	1.275
13	104	205	150	1.197	1.215
14	104	205	200	1.214	1.228
15	104	205	250	1.176	1.237
16	104	235	150	1.140	1.220
17	104	235	200	1.171	1.213
18	104	235	250	1.180	1.249
19	118	175	150	1.258	1.266
20	118	175	200	1.271	1.260
21	118	175	250	1.229	1.284
22	118	205	150	1.250	1.250
23	118	205	200	1.294	1.231
24	118	205	250	1.241	1.299
25	118	235	150	1.269	1.231
26	118	235	200	1.236	1.259
27	118	235	250	1.255	1.306

First order linear equations are obtained and regression analysis is done for the stated responses delamination at entry and exit. Also, analysis of variance is carried out for a confidence level of 95%.

Delamination at Entry

First order linear equation:

Delamination at Entry = 0.822 + 0.00365 (Point Angle) - 0.000061 (Cutting Speed) + 0.000047 (Feed Rate)

Table 3 Analysis of Variance

Source	DF	Seq SS	MS	F	P
Regression	3	0.047079	0.015693	27.82	0.000
Residual Error	23	0.012973	0.000564		
Total	26	0.060051			
S = 0.0237493		R-Sq = 78.4%		R-Sq(adj) = 75.6%	

Table 3 shows the analysis of variance for Delamination at Entry. The P- value of regression equation indicates that the regression model is significant. The coefficient of determination (R^2) which indicates the goodness of fit for the model and the value of R^2 =78.4% indicates the significance of the model.

Figure 1 shows the normal probability plot for Delamination at Entry. This graph indicates that the residual follows a straight line and there are no unusual patterns or outliers. As a result, the assumptions regarding the residual were not violated and the residuals are normally distributed.

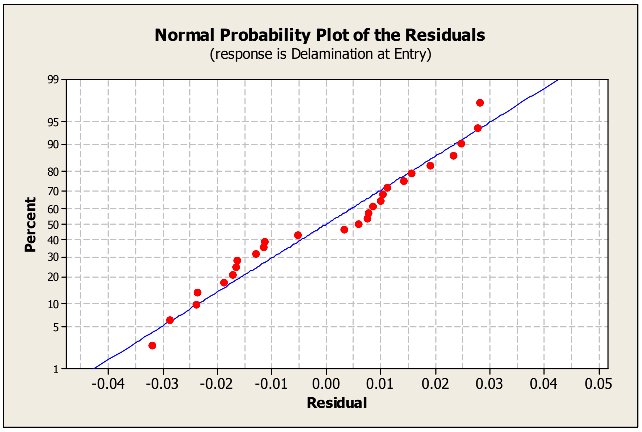

Figure 1 Normal probability plot of Residuals for Delamination at Entry

Delamination at Exit

First order linear equation:

Delamination at Entry = 0.822 + 0.00365 (Point Angle) - 0.000061 (Cutting Speed) + 0.000047 (Feed Rate)

Table 4 Analysis of Variance

Source	DF	Seq SS	MS	F	P
Regression	3	0.050789	0.016930	50.46	0.000
Residual Error	23	0.007716	0.000335		
Total	26	0.058505			
S = 0.0183159		R-Sq = 86.8%		R-Sq(adj) = 85.1%	

Table 4 shows the analysis of variance for Delamination at Exit. The P- value of Regression equation indicates that the regression model is significant. The coefficient of determination (R^2) which indicates the goodness of fit for the model so the value of R^2 =86.8% indicates that the model is highly significant.

From the normal probability plot for residuals of Delamination at Exit shown in figure 2, it is observed that the residual follows a straight line and there are no unusual patterns or outliers. As a result, the assumptions regarding the residual were not violated and the residuals are normally distributed.

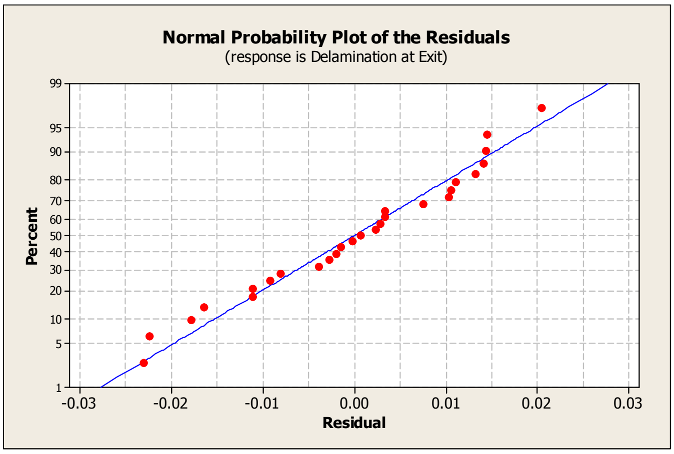

Figure 2 Normal probability plot of Residuals for Delamination at Exit

RESULTS AND DISCUSSION

The effects of input factors on responses are analyzed by observing main effects plots and using analysis of variance (ANOVA) General Linier Model.

Delamination at Entry

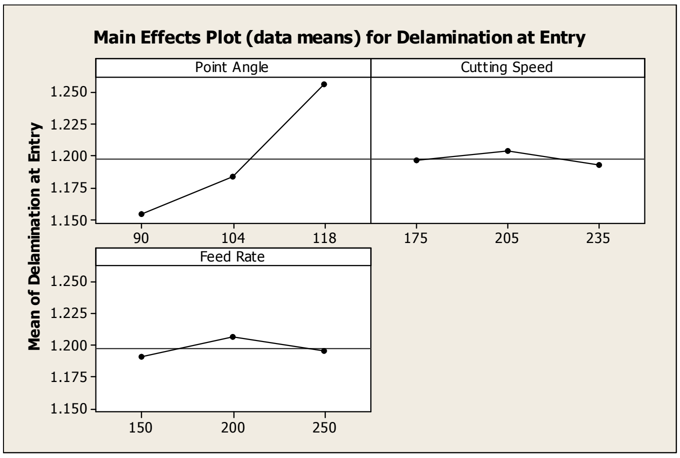

Figure 3 Main Effects Plot (data means) for Delamination at Entry

Table 5 Anova Table for delamination at Entry

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
Point Angle	2	0.049637	0.049637	0.024818	56.95	0.000	82.66
Cutting Speed	2	0.000553	0.000553	0.000276	0.63	0.541	0.92
Feed Rate	2	0.001147	0.001147	0.000574	1.32	0.290	1.91
Error	20	0.008715	0.008715	0.000436			14.51
Total	26	0.060051					100.00
S = 0.020874			R-Sq = 85.49%				R-Sq(adj) = 81.13%

Delamination at Exit

The main effects plots and anova tables for delamination at entry and delamination at exit clearly indicate that the point angle is the most significant factor affecting both delamination at the entry and delamination at exit. The important information that can be obtained from the table is the percentage influence of all factors over responses. P value less than 0.0500 indicate model terms are significant. Values greater than 0.1000 indicate the model terms are not significant.

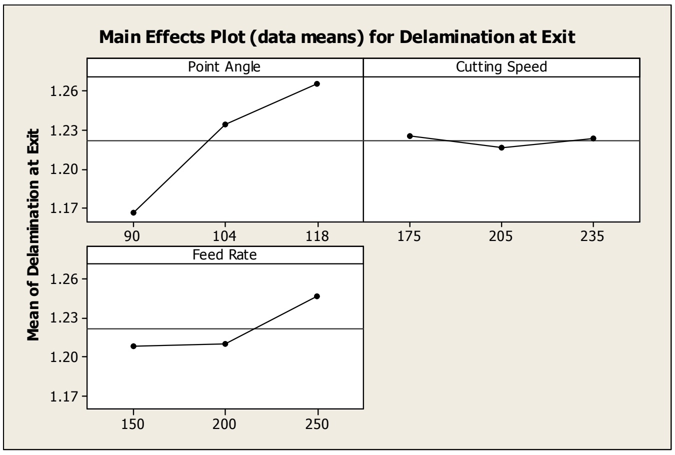

Figure 4 Main Effects Plot (data means) for Delamination at Exit

Table 6 Anova Table for Delamination at Exit

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
Point Angle	2	0.046172	0.046172	0.023086	125.00	0.000	78.92
Cutting Speed	2	0.000353	0.000353	0.000177	0.96	0.401	0.06
Feed Rate	2	0.008286	0.008286	0.004143	22.43	0.000	14.16
Error	20	0.003694	0.003694	0.000185			6.31
Total	26	0.058505					100.00
S = 0.013590			R-Sq = 93.69%				R-Sq(adj) = 91.79%

The percentage contribution by each of the process parameter in the total sum of squared deviation can be used to evaluate the importance of the process parameter change on the quality characteristic. Here, the contribution of point angle is highest for delamination at entry (82.66%) and for delamination at exit (78.92%).

CONCLUSION

From this analysis, it can be concluded that the most significant high speed drilling process variable influencing all the stated machinability parameters of glass fiber reinforced polymer composite is point angle. The order of significance of other parameters are feed rate followed by cutting speed. These models can be effectively utilized by the process planners to select the level of parameters to meet any specific high speed drilling machining requirements on glass fiber reinforced polymer composite within the range of experimentation.

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