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Influence of Delamination Factor in Drilling of Carbon Fibre Reinforced Composite

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Abstract: This paper deals with the effects of process parameters on delamination factor during drilling of carbon fiber reinforced composites. The damage caused at the exit of the drilled hole is characterized by delamination factor and thrust force, which is evaluated by considering point angle, cutting velocity and feed rate as affecting process parameters. The drilling experiments are conducted as per Taguchi's parameter design using HSS twist drills. The response of the delamination factor and thrust force are analyzed for the corresponding independent variables such as point angle, cutting velocity and feed rate. The ANOVA table is used to investigate the percentage contribution of each independent variable with the corresponding response variable. Regression analysis is used for observing the line of best fit through the data in order to make estimates and predictions about the behavior of the variables. Finally the optimal combinations of the variables are analyzed to obtain high quality drilled holes.

KEYWORDS: Carbon fiber reinforced composites, Drilling, Delamination factor.

I. INTRODUCTION

The predominant reinforcement used to achieve high stiffness and high strength in composites is the carbon fibers. It is produced by the pyrolysis of the precursor fibers such as, polyacrylonitrile or pitch. The filaments of the precursors are oxidized at the temperature 300oC and heated further to 1500-3500oC in a nitrogen atmosphere.

Then the carbon chain remains, black and bright filaments are obtained. The fibers are drawn at high temperature to increase the modulus of elasticity. Their high production cost has so for

excluded them from widespread commercial applications. Since the carbon fiber reinforced composites are manufactured at very high cost, more attention should be taken on the operations to be performed on it.

Drilling is a most often practiced machining process in aerospace and automotive

industries to fit the composite skins to the other structures of the system. So, there is a need to produce damage free holes on the composites before

it is taken to the assembly section. Delamination at the exit surface and the fiber pull out are the major defects on drilling CFRP materials, due to the forces acting during the machining process.

The machining of carbon fiber composite materials is not the same as the machining of conventional metals. Also, surface damage such as cracking and delamination of the machined surface is severe and obtaining low surface-roughness is not easy. Hence, the cutting speed and feed rate of the machining operation should be selected carefully in the machining of carbon fiber composite materials.

Davim et al (2003) studied the cutting parameters for damage free drilling in carbon fiber reinforced epoxy composite material. The experiment was carried out toperform drilling in an autoclave carbon fiber reinforced plastic laminates using HSS and cemented carbide (k10) drills and delamination factor was studied. It is concluded that k10 drill, presents a better performance than HSS drill and delamination factor increases with increase in cutting speed and feed rate.

Gaitonde.V.N et al (2007) investigated the effects of process parameters on delamination during high-speed drilling of carbon fiber reinforced plastic (CFRP) composite by considering cutting speed, feed rate and point angle as affecting process parameters. The effects of cutting speed, feed rate and point angle on delamination factor were analyzed using the models by generating response surface plots. The

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investigations reveal that the delamination tendency decrease with increase in cutting speed. The study also suggests low values of feed rate and point angle combination for reducing the damage.

Hocheng et al (2007) studied the effect of tool wear on delamination in drilling composites. This paper presents a comprehensive analysis of delamination caused by the drill wear for twist drill in drilling CFRP material and concluded that though the critical thrust force is higher with increasing wear , the delamination becomes more liable to occur because the actual thrust force increases with wear.

Tsao (2007) investigated the effects of drilling parameters with using three step- core drills in drilling composite material, Taguchi method was selected to realize the effects of drilling parameters (diameter ratio, feed rate and spindle speed) and concluded that drilling induced delamination of various step-core drills, increased with decrease in diameter of the drill and spindle speed and increase in feed rate.

Luis Miguel Durao et al (2007) investigated the delamination factor with various drill bits like HSS twist drill, Carbide twist drill, carbide brad drill, carbide dagger drill and made use in drilling carbon/epoxy and glass/epoxy material, and conclude that delamination damage can be reduced by proper combination of tool, cutting speed, and feed rate. From all those drills, carbide twist drill had the best results for thrust force and delamination factor.

Basavarajappa.S et al (2008) has studied the influence of cutting parameters on drilling characteristics of hybrid metal matrix composites. The Taguchi design of experiments and analysis of variance (ANOVA) are employed to analyze the drilling characteristics of these composites. The experiments were conducted to study the effect of spindle speed and feed rate on feed force, surface finish and burr height using solid carbide multifaceted drills of 5mm diameter. The results reveal that the dependent variables are greatly influenced by the feed rate rather than the speed for the composites. The ceramic–graphite reinforced composite has better machinability than those reinforced with SiCp composites.

Although much research has been carried out on effects of cutting parameters on delamination during drilling of CFRP composites, not much work is reported on the effect of point angle. This work focuses on the effect of process parameters namely cutting speed, feed rate, and point angle on delamination factor.

II. EXPERIMENTAL PLAN

The experiments had been carried out in a carbon fiber composite material; in this experimental study a HSS drill of 4mm dia was used. A vertical machining center with a maximum spindle speed of 5000 rpm was used to perform the experiments. The plan of experiments is made of eighteen tests and the considered parameters are point angle (θ) cutting velocity (V) and the feed rate (f). The thrust force during drilling is measured by using the Kistler, Quartz 3-Componentdynamometer, type 9257B. The assignment of the levels to the factors for the eighteen experiments is plotted on the table below.

Table 1: Assignment of the levels to the factors

Exp No	Point Angle (deg) (Ө)	Cutting Velocity (m/min) (V)	Feed Rate (mm/min) (f)
1	85	6.28	50
2	85	6.28	100
3	85	6.28	150
4	85	12.56	50
5	85	12.56	100
6	85	12.56	150
7	85	18.84	50
8	85	18.84	100
9	85	18.84	150
10	118	6.28	50
11	118	6.28	100
12	118	6.28	150
13	118	12.56	50
14	118	12.56	100
15	118	12.56	150
16	118	18.84	50
17	118	18.84	100
18	118	18.84	150

The treatment of the experimental results is based on the analysis of variance (ANOVA) and the regression and correlation techniques to estimate the contribution of the parameters and their relations towards the response variables.

ANOVA is a technique to estimate quantitatively the relative contribution in which each controlled parameter makes on the overall measured response and is expressed as a percentage. Regression analysis is the mathematical

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process of using observations to find the line of best fit through the data in order to make estimates and predictions about the behavior of the variables. Point angle (X1), Cutting velocity (X2) and Feed rate (X3) are the three independent variables and the thrust force and delamination factor are the dependent variable (Ŷ).The equation describing the relationship among four variables is

$$\hat{Y} = a + b1X1 + b2X2 + b3X3 \quad (1)$$

a and b's are the true coefficients to be used to weight the observed X's and they areobtained by solving these four normal equations.

$$\Sigma Y = na + b1\Sigma X1 + b2\Sigma X2 + b3\Sigma X3 \quad (2)$$

$$\Sigma X1Y = a\Sigma X1 + b1\Sigma(X1)2 + b2\Sigma X1X2 + b3\Sigma X1X3 \quad (3)$$

$$\Sigma X2Y = a\Sigma X2 + b1\Sigma X1X2 + b2\Sigma(X2)2 + b3\Sigma X2X3 \quad (4)$$

$$\Sigma X3Y = a\Sigma X3 + b1\Sigma X1X3 + b2\Sigma X2X3 + b3\Sigma(X3)2 \quad (5)$$

Table 2: Thrust force and the Delamination factor for each experiment.

Exp. No	ThrustForce(N)	DelaminationFactor
1	40.79	1.083
2	46.07	1.102
3	67.03	1.188
4	17.13	1.077
5	29.58	1.089
6	45.97	1.133
7	14.04	1.058
8	25.34	1.083
9	36.15	1.103
10	55.28	1.146
11	75.14	1.185
12	94.36	1.225
13	33.67	1.128
14	50.75	1.146
15	77.6	1.164
16	28.31	1.107
17	45.79	1.133
18	52.61	1.149

The experimental results are based on the analysis of variance (ANOVA) which is used to measure the percentage contribution and statistical significance of the independent variables over the dependent variable. ANOVA table for thrust force is shown in the table 3.

Table 3: ANOVA Table for Thrust Force

Source ofvariance	Degrees offreedom	Sum ofsquares	Variance	Percentage ofContribution	F-test
Point Angle	1	2845.3	2845.3	37.34	80.98
Velocity	2	2035.4	1017.7	26.70	54.43
Feed	2	2736.0	1368	35.91	56.60
Error	12	301.6	25.1	3.95	
Total	17	7618.4			

The analysis shown in table 3 was undertaken for level of significance of 5% that is, for level of confidence 95%. The table value of frequency for degree of freedom (1, 12) for point angle and degree of freedom (2, 12) for both feed rate and cutting velocity. Here table value is less than calculated value, and then the calculated value presents a statistical significance for point angle.

Table Value = 4.747
Table Value = 3.885

In table 3 the percentage of each variable on the thrust force is shown. Point angle is the greater influence factor on thrust force over feed rate and cutting velocity.The ANOVA table for delamination factor (Df) for the holes drilled by HSS tool is shown in the table 4

Table 4 ANOVA Table for Delamination Factor

Source of variance	Degrees of freedom	Sum of squares	Variance	Percentage of Contribution	F-test
Delamination	1	0.0121161	0.0121161	36.16	54.02
Factor	2	0.0075164	0.0037582	22.43	16.75
Velocity	2	0.0111814	0.0055907	33.37	24.92
Feed	12	0.0026917	0.0002243	8.03	
Error	17	0.0335056			
Total					

The analysis shown in table 4 was undertaken for level of significance of 5% that is, for level of confidence 95%. The table value of frequency for degree of freedom (1, 12) for point angle and degree of freedom (2, 12) for both feed rate and cutting velocity. Here table value is less than calculated value, and then the calculated value presents a statistical significance for delamination factor.

Table Value = 4.747
Table Value = 3.885

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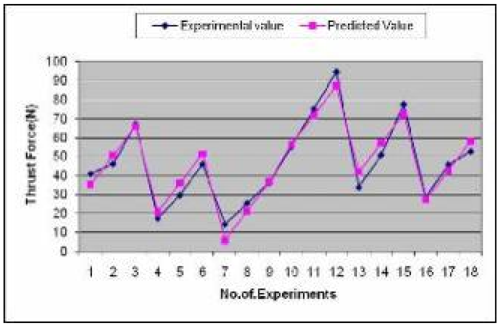

Figure 1: Experimental Vs Predicted values

Point angle is the greater influence factor on delamination factor over feed rate and cutting velocity. The percentage of contribution of error is less than the percentage of contribution of cutting velocity and feed rate.

From the experimental values the regression equation is derived for both thrust force and delamination factor. The percentage prediction accuracy of the model is checked by the formula given below.

$$PPA=100/n\Sigma[(Ev - Pv) / Pv] \quad (6)$$

n- Number of Experiments Ev = Experimental value Pv = Predicted value

The experimental values for the thrust force were analyzed using the regression table. The obtained equation for the thrust force is shown below.

Thrust force (N) $\hat{Y}1 = - 20.3 + 0.644\ X1 - 2.34\ X2 + 0.308\ X3$ (7) the percentage prediction accuracy of the model is checked. So the calculations for accurate values of the thrust force can be predicted (R-Sq. = 94.3%). The graph which represents the accuracy of the model is plotted below.

The experimental values for the delamination factor are analyzed using the regression table. The obtained equation for the delamination factor is shown below.

Delamination factor $\hat{Y}2 = 0.957 + 0.00157\ X1 - 0.00393\ X2 + 0.000603\ X3$ (8)

The percentage prediction accuracy of the model is checked .So the calculations for accurate values of the delamination factor can be predicted (R-Sq. = 90.7%).The graph which represents the accuracy of the model is plotted below.

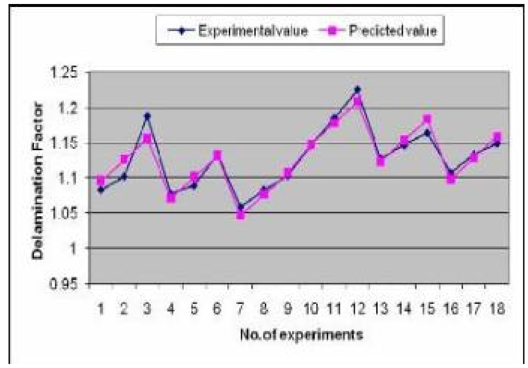

Figure 2: Experimental Vs Predicted values

CONFIRMATION TEST:

The point angle of 85° cutting velocity of 18.84 m/min and feed rate of 50 mm/min are having lower thrust force as well as lower Delamination factor Values. So, the optimal parameter is taken as point angle 85°, cutting velocity 18.84 m/min and feed rate 50 mm/min and used for conformation test. And the finally the conformation test values resembles as the experimental value i.e., thrust force of 14.02 and Delamination factor of 1.052.

CONCLUSION:

Thrust force and delamination factor depends on the drill point angle and the feed rate which increases with the increase in both the point angle and the feed rate. But point angle has high percentage of contribution than feed rate and also seen that thrust force and delamination factor decreases with increase in cutting velocity in both point angles 118º and 85º. Irrespective of feed rate and cutting velocity by decreasing point angle both thrust force and delamination factor decreases considerably. It is proved statistically using ANOVA that the drill point angle, feed rate and cutting velocity significantly influence the thrust force and delamination factor in drilling. The model predicted for thrust force and delamination factor correlates with the experimental values.

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