Application of Response Surface Methodology in Drilling of Carbon Fiber Reinforced Polymer Composite (CFRP)

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Abstract*:* In the present work, response surface methodology (RSM) is applied to determine the optimum machining conditions leading to minimum delamination in drilling of CFRP (carbon fiber reinforced plastic) composite. The experimental plan and analysis is based on full factorial design taking spindle speed, feed rate as important parameters. The optimum combination for the parameters is found spindle speed 1486 rpm and feed rate 0.1490 mm/rev. and the optimal delamination was found 1.2051. The second order response surface methodology model in terms of drilling parameters are developed for delamination. Prediction using response surface methodology (RSM) on the basis of experimental results. The experimentation is carried out with HSS tool for drilling of CFRP.

Key words: Drilling, CFRP, RSM, Delamination, Optimization.

I. INTRODUCTION

Carbon Fibre reinforced plastic(CFRP) composites are wide utilized in real world engineering application like automotive, craft and manufacture of spaceships and ocean vehicles' industries thanks to their important advantages over alternative materials. They supply high specific strength/stiffness, superior corrosion resistance, light-weight weight construction, low thermal conduction, and high fatigue strength, ability to char and resistance to chemical and microbiological attacks. As a consequence of the widening vary of applications of FRP; the machining of those materials has become a really vital subject for analysis. (Suthar, 2016) Machining composite materials may be a rather advanced task because of their non-uniformity, anisotropy, and high abrasiveness of fibers, and it exhibits considerable issues in drilling method like de-lamination, fibres pull-out, hole shrinkage and thermal degradation (Teli et.al.,2017 and Faraz et al., 2009). Many non-traditional machining processes like optical device cutting, water jet cutting, ultrasonic cutting, electro discharge machining, etc., are developed for application on composite for machining holes. As a result of the anisotropic and non-uniform structure of composite, drilling of composite causes some issues, that don't occur in alternative materials. Among the defects caused by drilling, de-lamination round the drill hole site seems to be the foremost critical, which might result in a lowering of bearing strength and might be harmful to durability by reducing the in-service life below fatigue loads (Tagliaferri et. al.,1990). Therefore, addressing a way to improve the standard of holes in drilling of composites is imperative.

Davim et al. (2004) investigated on evaluating the cutting parameters like cutting speed, feed rate, depth of cut etc involving machining force within the work piece, de-lamination issue, surface roughness and drilling by K10 carbide tool and realize most surface end of hole on fiber material by using of taguchi and analysis of variance. Mohan et al. (2005) implementation the Taguchi optimization methodology applied to optimize cutting parameters in drilling of fibre reinforced composite material. The result of method parameters on machining method is set by analysis of variance. Speed, feed rate, and drill size and specimen thickness this parameter evaluated as input. Experiments did using TRIAC VMC CNC machining center to relate the cutting parameter and thrust force and torque. An orthogonal array, signal-to-noise (S/N) ratio were used to investigate the influence of those parameters on cutting force, torque, tool material etc throughout drilling. Analysis did by of the Taguchi methodology represent all parameters, speed and drill size were found imposing additional vital influence on cutting thrust than the specimen thickness, material removal rate and the feed rate.

Hochengaand and Tsao (2006) have mentioned de-lamination is well correlated with the drilling thrust force. In drilling operations, the centre of the twist drill induces a large thrust force, which can cause separation of plies at the exit as the inter-laminar bonding yields. De-lamination at the exit side can be reduced if a drill with a small chisel edge is used. The candle stick drill has a smaller centre than a twist drill. It punches through the last plies over a smaller area compared with the twist drill. Thus, a smaller width of the last laminate is subjected to a bending force from the centre. Saw drills and core drills eliminate the chisel, while the step drill cuts a hole mainly at the second stage after its chisel is through. Latha et al. (2011) allotted drilling tests on CNC drilling machine. The parameters thought-about for the drilling are spindle speed, feed rate and diameter of the drill bits. Multiple correlation analysis was used for the modelling of process parameters in drilling of FRP composites. Taguchi's S/N magnitude relation analysis and desirability based approach were used for the optimization of method parameters for reducing the de-lamination in drilling of GFRP composites. The results discovered that the issue feed rate and drill diameter were the foremost influential parameters that affected the de-lamination in drilling of FRP composites. The interaction between the parameters additionally affected the delimitation in drilling of FRP composites.

Meenu Gupta and Surinder Kumar Gill (2012) deals with the study and development of a cutting force prediction model. Sheikh-Ahmad and Mohammad (2014) conducted edge trimming of carbon fibre reinforced composites using diamond abrasive cutters and also the result of feed rate, spindle speed and depth of cut on machining quality was investigated. Cutting forces, specific cutting energy, surface roughness and work piece temperature were measured and analyzed. It had been found that depth of cut was the foremost necessary parameter to influence machine-ability. Trimming with low equivalent chip thickness values was found to be the foremost appropriate in terms of the amount of machining responses and machining injury. The cutting temperatures were found to exceed the glass transition temperature of the epoxy matrix once machining with massive depth of cut. Parida (2015) examined the surface roughness of carbon fibre reinforced plastic composite on the basis of cutting parameters like depth of cut, speed, and feed rate. The surface quality was found to relate closely to the cutting speed, feed rate, and depth of cut. The Taguchi method was adopted during this study to analyze the influence of surface roughness by cutting parameters. Further, analysis of variance was accustomed analyze the influence of method parameters and their interaction effects throughout machining.

There are several challenges with machining CFRP material, as are the fibers are characterized by high strength, which makes the material difficult to cut, leading to: wear on the cutting tool and splintering/fraying. It has a high elastic modulus, making it abrasive. The plastic matrix is sensitive to heat and can melt. The structure is built up by layers of material, which can lead to delamination.

The major drawbacks associated in machining of these composites are fiber pull out, breakage of fibers, delamination, matrix burning, matrix cracking and subsurface damage which lead to poor surface quality and dimensional inaccuracy. Hence, it becomes indeed essential for the manufacturer to understand machining behavior of CFRP composites. Out of several conventional machining operations, turning and drilling operations are commonly performed for machining of CFRP composites to make/assemble desired shape and size of product and to achieve required level of dimensional accuracy. Earlier trend was to select the machining variables randomly based on the operator's skills in which product quality might not be as per the desired level. With advancement of time, manufacturers are giving more attention to enhance both quality and productivity, simultaneously. As machining parameters significantly influence on machining performance features, appropriate setting and proper control of machining parameters is of utmost importance to achieve desired product quality and satisfactory process performance (productivity). Hence, it is of vital necessity to go for optimization of machining parameters towards enhancing overall machining performance.

II. Calculation of Delamination

Delamination originated when drilling of CFRP composites. The damage generated associated with drilling carbo fibre reinforced plastic composites were found, both at the entrance and the exit of drilling holes. To determine the delamination factor around the holes, the maximum diameter (Dmax) in the delamination zone was measured (Figure 1). The value of delamination factor (Fd) can be determined by the following equation (Arul et. al., 2006).

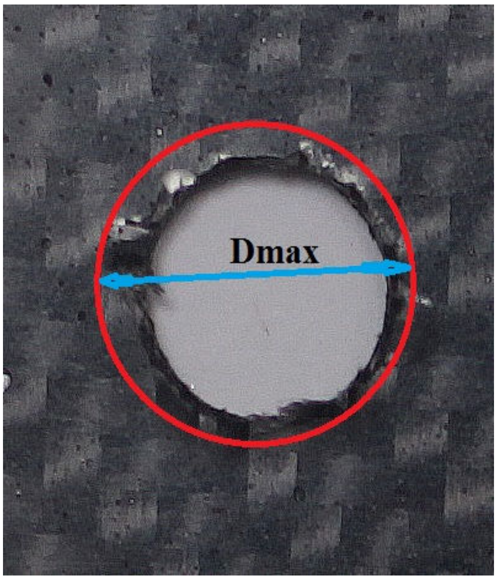

Figure 1: Delamination around Drilling Hole

$$Fd = Dmax/Ddrill \quad (1)$$

In which, Dmax is the maximum diameter of the delamination zone in mm and Ddrill is diameter of the drill in mm.

III. Experimental Procedure

The CFRP specimen used for this investigation is prepared by hand lay-up technique. CFRP tensile strength and tensile modulus are respectively 3450 MPa and 230 GPa. In the present investigation HSS tool is used as the tool material for the drilling operation and diameter used 8mm. All the experiments are carried out on VMC machine. Solid laminate of carbon fiber reinforced plastic composite. Drilling in CFRP specimen is conducted according to full factorial design. This requires 9 runs and conduct three levels of parameters. The parameters choose for experimentation is spindle speed and feed rate. The drilling parameters and their levels are shown in Table I.

Table I. Influencing parameters & their levels

Level / Factor	Spindle Speed (rpm)	Feed rate (mm/rev.)
1	800	0.05
2	1600	0.1
3	2400	0.15

IV. Response Surface Methodology (RSM)

Response surface methodology would be defined as a methodology for constructing simple approximations of structural responses based on analysis of results. RSM adopts for both mathematical modeling and statistical techniques that are useful for the predicting results and analysis of problems. It also builds a relationship between measured responses and the important input parameters. The purpose of developing mathematical models are relating the responses and their factors for optimization of machining process. Table II illustrate the design of experiment and delamination values.

Table II. DOE and Delamination Value.

Experiment	Spindle Speed	Feed Rate	Delamination
1	1	1	1.5472
2	1	2	1.4881
3	1	3	1.2797
4	2	1	1.4695
5	2	2	1.2264
6	2	3	1.1979
7	3	1	1.5538
8	3	2	1.3504
9	3	3	1.4361

V. Development of Delamination Model

The relationship between the delamination and the machining parameters such as spindle Speed, and feed rate for a second order response surface model is developed using Response surface methodology in coded units from the observed data which is given as follows.

Delamination=2.434- 0.000811 Speed- 8.41 Feed+23.6 Feed ×F Feed + 0.00094 Speed×Feed

VI. Model Adequacy Checking

The plot of normal probability of the residuals and the plots of the residuals versus order of the data for delamination are shown in Figure 2. From the normal probability plot of residuals i.e. error = predicted value from model-actual value. This gives support that terms mentioned in the model are significant. Figure 2 also reveals that there is noticeable pattern or unusual structure present in the data. Hence, the RSM model developed is significant and adequate.

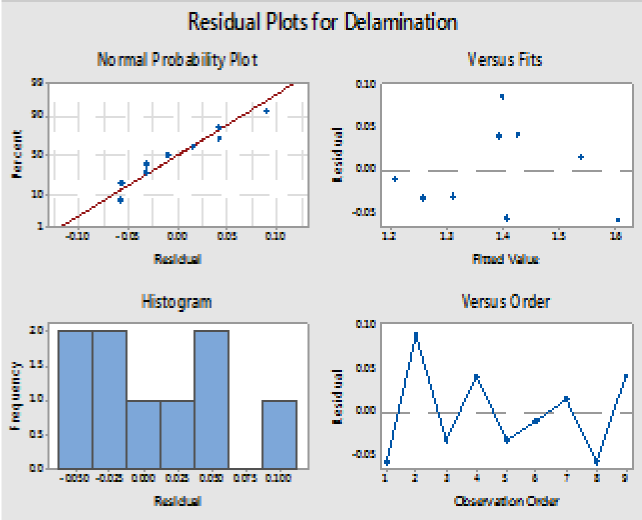

Figure 2 Residual Plots

VII. Results and Analysis

Counter plot and surface plots are reveals that at the lower values of cutting speed and feed rate, the delamination is minimum. Figure 3 and 4 shown counter plot and Surface Plot for our experiment.

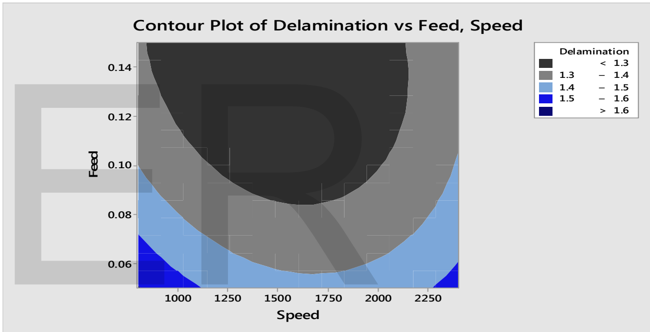

Figure 3 Counter Plot

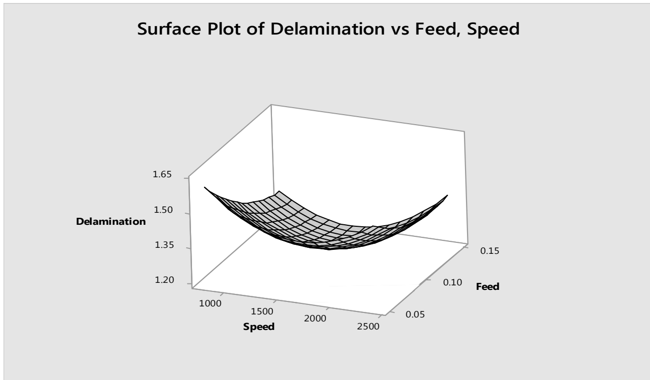

Figure 4 surface Plot

The individual response optimization analysis using the desirability function analysis associated in RSM has been performed for achieving the minimum delamination based on the developed mathematical model. Desirability function analysis optimization results for power consumption is shown in figure 5.

Optimal machining parameters obtained are – spindle speed of 1486 rpm at feed rate of 0.1490 mm/rev. The optimized delamination obtained is 1.2051. The desirability value is

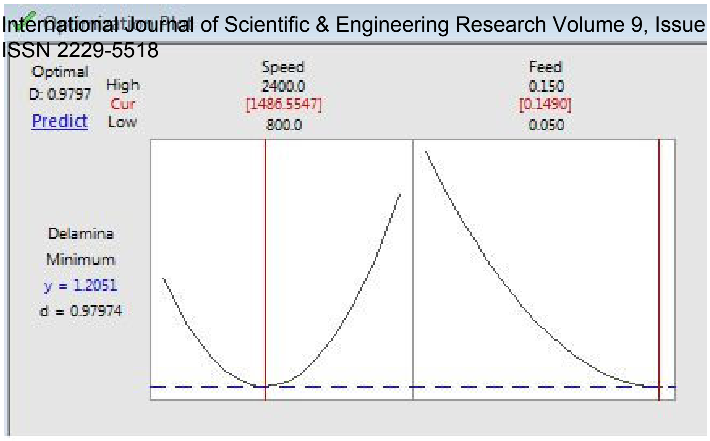

Figure 5 Optimization Plot

0.97974, which is very close to 1.0.

VIII. CONCLUSIONS

This paper presented the following conclusions of an experimental investigation of the effect of process parameters on delamination in drilling of CFRP composite with HSS, 8 mm diameter tool.

1. The effect of drilling parameters on the delamination has been evaluated with the help of response surface methodology. The optimum drilling conditions to minimize the delamination is determined.
2. The second-order response surface model for surface roughness is developed from the observed data.
3. From the normal probability plot, it is found that residuals generally fall on a straight line implying that errors are distributed normally. Hence, the RSM model developed is significant and adequate.
4. The optimal parametric combination - spindle speed 1486 rpm and feed rate 0.1490 mm/rev.
5. The minimum delamination found by RSM is 1.2051.

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