International Journal of Advance Research in Science and Engineering
Volume No.07, Special Issue No.04, March 2018
www.ijarse.com
IJARSE
ISSN: 2319-8354

Optimization of the Process Parameters to Minimize the Thrust Force in Drilling of CFRP Composites by Taguchi Method and RSM

Murthy. BRN*

***** *Department of Mechanical and Manufacturing Engineering,*
Manipal Institute of Technology, Manipal 576104, Karnataka, (India)

ABSTRACT

Carbon Fiber Reinforced Polymer (CFRP) composites are finding wide application in all fields as they offer an excellent combination of strength, low weight and high modulus. The tensile strength of carbon fiber is equal to glass fiber while its modulus is about three to four times higher than glass fiber. Drilling is the most common machining operation performed on composites for the fabrication and the quality of hole has an important influence on its applications. In the present work, experiments were conducted to check the effect of drill point angle, spindle speed, feed rate and drill diameter on the thrust force generated during drilling of hole. The Carbon Fiber Reinforced Polymer (CFRP) test specimen is prepared by hand-layup method. Design of Experiments (DOE) technique is used to design the drilling experiment procedure. The results have indicated that among the variables considered for study, drill point angle has maximum influence on the thrust force followed by the spindle speed. Feed rate has minimum influence on the quality of drilled hole. The research has also resulted in the listing of the optimum combination of process parameters using Response Surface Methodology (RSM) and Taguchi Method.

Keywords: CFRP composite drilling, Thrust force, DOE, RSM, Taguchi method.

I.INTRODUCTION

Carbon fiber reinforced plastics (CFRP) exhibit properties such as high strength, high specific stiffness, high damping and low thermal expansion wear resistant (Guu et al., 2001). Hence, they find wide applications in aerospace industries, defense, ships, automobiles, machine tools, sports equipment's, transportation structures, power generations, oil and gas industries (Guu et al., 2001; Arul et al., 2006). Composite materials are synergistic combination of two or more micro-constituents that differ in physical form and chemical composition. The objective of having two or more constituents is to take benefit of superior properties of all the constituents without compromising on weakness of either (Mohan et al., 2005). However, CFRP composites pose different kinds of machining problems due to the presence of two or more dissimilar phases. Thus, the mechanism of machining composites has been recognized as a process different from that of homogeneous metal removal of conventional materials (Koenig et al., 1985). The composite materials are characterized by marked anisotropic, structural non-homogeneity and lack of plastic deformation (Devim et al., 2003). It was observed that the damage during machining on carbon/epoxy laminates reduces the strength and fatigue life of the part (Persson et al., 1997).

Although CFRP composites are produced to near-net shape, additional operation such as drilling is required in final stage during assembly of structures. The drilling operation on FRP composites has several undesirable effects such as fiber breakage, de-bonding, pull out, stress concentration, thermal damage, spalling, micro cracking, delamination, etc. Among the problems caused by drilling, delamination is the defect in composite structure, occurs mainly due to localized bending in the zone situated at the point of attack of the drill. The delamination drastically reduces assembly tolerance and strength against fatigue, thus degrading the long-term performance of composites (Chen *et al*., 1997, Won *et al*., 2002). Delamination is one of the most critical defects because it is responsible for the rejection of approximately 60% of the components produced in the aircraft industry (Wong *et al*., 1992). So many case studies have been made to minimize the delamination free hole by adopting different types of drill bit (Piquet *et al*., 2000; Hocheng *et al*., 2003) and selection of process parameters (Miller, 1987, UgoEnemuoh *et al*., 2001). Surface finish of the drilled hole has formulated as an important design feature in many situations such as parts subject to fatigue loads, precision fits, fastener holes and aesthetic requirements. Therefore measuring and characterizing surface properties represent one of the most important aspects in manufacturing process. Tsao and Hocheng (2008) have evaluated the surface roughness in drilling of composite materials. They indicated that the feed rate and spindle speed contribute the most to the surface roughness. The surface finish in drilling composite materials have been found to be influenced by a number of factors such as feed rate, cutting speed, drill geometry, tool wear and tool material (Hocheng *et al*., 1992; Chen. *et al*., 1997, Koplev *et al*., 1983). Many research works shows a significant influence of thrust force on the quality of the drilled holes and this thrust force generated is dependent on the process parameters. Hence, an attempt has been made in this work for optimization of process parameters such as spindle speed, feed rate, drill diameter and drill point angle to minimise the thrust force developed during drilling of CFRP composite material using Taguchi Method and RSM.

II. EXPERIMENTATION

2.1 The Test Specimen

The composites were made by hand layup moulding method. The reinforcement consists of carbon fiber mat which are manufactured by transforming the polyacrylonitrile fiber under the high heat and pressure resulting into strong carbon fiber fabrics. General purpose polyester resin (GP) with a room temperature curing accelerator catalyst methyl ethyl ketone peroxide (MEKP) hardener was used as the matrix system. The weight fraction of the composite is 50% and the post curing of the composite laminate is carried out for about 10 hours. The properties of the reinforced carbon fiber are presented in table 1 and the prepared test specimen is shown in figure 1.

Table 1: Properties of carbon fibers

Fibre type	Woven mat 0˚/90˚
Density g/cc	1.80
Tensile Strength, Gpa [ksi]	500
Strain to Failure [%]	2.4
Tensile Modulus, Gpa	138
Coefficient of Thermal Expansion : 10-6/0c	0.54
Mat Thickness (mm)	0.2

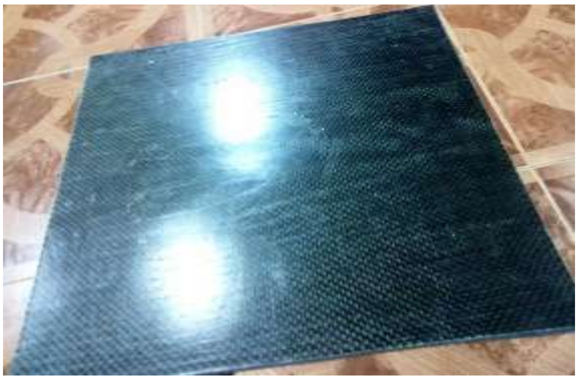


Figure 1: Prepared test specimen

2.2 Experimental methods

The experiment has been conducted on the TRIAC CNC vertical machining centre which enables high precision machining. The laminate composite specimen was rigidly held by the fixture which is attached to the dynamometer mounted on the machine table. The thrust force and the torque were measured with the help of Kisteler dynamometer and the charge amplifier. The data collected was transferred to a computer for further analysis. Solid carbide drills have been used in the present study because of their better heat and wear resistance characteristics. The experimental set-up is shown in figure 2. Technical specifications of TRIAC CNC are as follows: Tool Type (ATC)-BT30, Tool holding capacity, (ATC)-8 tools, spindle speed (programmable) 100 – 4000 rpm. Maximum feed rate on X and Y axis -2500 mm/min. Maximum feed rate on Z axis -1000 mm/min.

Figure 2: Experimental set-up

2.3 Taguchi Method

Taguchi defines the quality of a product in terms of the loss imparted by the product to the society from the time products are shipped to the customer. Some of these losses occur due to the deviation of the product's functional characteristics from its desired value and these are called losses due to functional variation. Uncontrollable factors, which cause the functional characteristics of a product to deviate from their target values, are known as noise factors. Taguchi recommends analyzing the means and S/N ratio using conceptual approach which involves graphing the effects and identifying the factors visually that appear to be significant without using ANOVA, which makes the analysis simple. The characteristics of the S/N ratio are given by the following equations.

Larger the better characteristics

$$\frac{S}{N}=10 \log \ln \left(\sum \frac{1}{y^2}\right) \quad .....(1)$$

Nominal is the better characteristic:

$$\frac{S}{N}=10 \log \frac{\bar{y}}{s^2\ y} \quad ....(2)$$

Smaller is the better characteristic:

$$\frac{S}{N} = 10 \log \ln (\Sigma y^2).....(3)$$

Where, $\bar{y}$ the average of observed data, S^2y is the variation of y, n is the number of observations and y is the observed data. For each type of the characteristics, with the above S/N ratio transformation, the smaller the S/N ratio the better is the result when we consider delamination factor, surface roughness, thrust force, torque and stress. In this work, in order to identify the best cutting parameters and to obtain minimum surface roughness, S/N ratio characteristic and L18 orthogonal array are used. Table 2 indicates drilling test parameters and levels.

Table 2: Factors and levels.

Levels	(DA) drill point angle (deg)	(DD) drill diameter (mm)	(S) spindle speed (rpm)	(F) feed rate (mm/min)
1	90	8	750	50
2	103	10	1000	75
3	118		1250	100

2.4 Response surface methodology (RSM)

RSM is a collection of statistical and mathematical techniques that are useful for the modeling and analyzing problems in which a response of interest is influenced by several variables. RSM also quantifies the relationship between the controllable input parameters and obtained response surfaces. The main goal of RSM is to optimize the response that is influenced by various process parameters.

2.5 Measurement of thrust force

The generated thrust force was measured by using the Kistler dynamometer and the charge amplifier. For each combination of the process parameters, experiments were conducted twice and the average of two readings were taken. Figure 3 shows the dynamometer and the charge amplifier used and figure 4 shows a sample of a readings obtained for the thrust force.

Figure 3: Kistler dynamometer with charge amplifier.

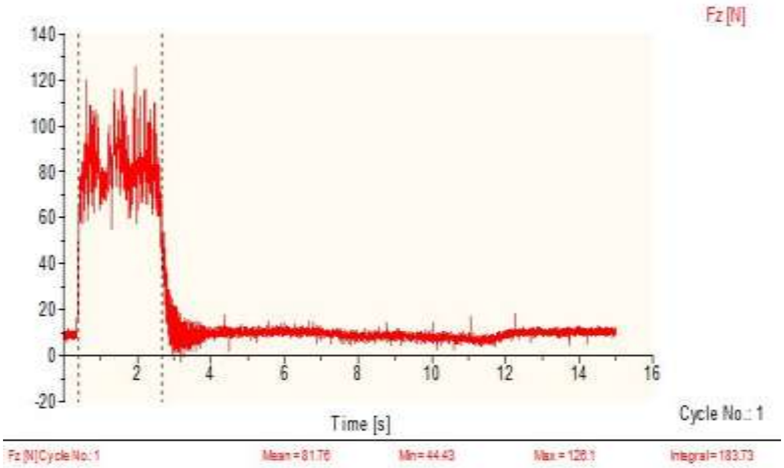


Figure 4: Sample data of thrust force.

III.RESULTS AND DISCUSSION

The quality of hole plays a vital role in drilling. From the various literatures it is clear that, the quality of a drilled hole is mainly dependent on the thrust force generated during the drilling process. Obtaining desired hole dimensions, roundness and surface finish along the length of the hole are of vital importance to the industry. To have a better quality holes, it is necessary to control the influence of process parameters such as spindle speed, tool feed rate, drill diameter and the drill point angle on the thrust force generated during drilling. In this study, the drilling experiments are conducted on the CFRP composite laminate at different cutting conditions and the results are shown in Table 3.

Table 3: Experimental and predicted values for the thrust force

Drill angle(deg)	Drill dia (mm)	Speed (rpm)	Feed (mm/min)	Thrust-N Experimental
90	8	750	50	50.164
90	8	1000	75	56.645
90	8	1250	100	57.935
103	8	750	50	90.123
103	8	1000	75	87.745
103	8	1250	100	76.36
118	8	750	75	94.44
118	8	1000	100	91.91
118	8	1250	50	81.215
90	10	750	100	76.995
90	10	1000	50	57.1
90	10	1250	75	55.46
103	10	750	75	88.36
103	10	1000	100	82.96
103	10	1250	50	78.234
118	10	750	100	119.175
118	10	1000	50	104.225
118	10	1250	75	100.7

The main effect plots for Signal to Noise ratio (S/N) of thrust force (smaller is the better) is shown in the figure 5. It is evident from the plot that the drill point angle and spindle speed are the most significant design parameters those influence the thrust force. As the slope gradient of these parameters are large, variation of S/N ratio is also large. The drill diameter and tool feed rate are the least contributing process parameters for thrust force as their slope gradient is smaller.

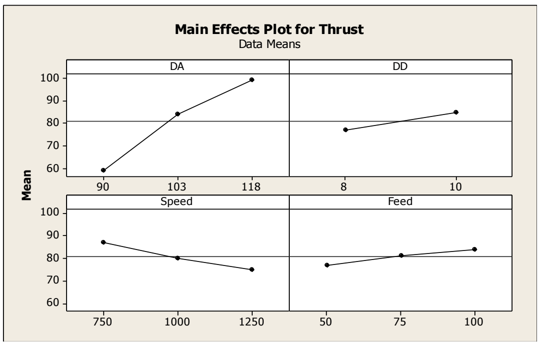


Figure 5: Main effect plot for thrust force

Taguchi analysis of the Thrust force

The Taguchi analysis for the thrust force is given in the table 5. From the table we find that Drill point angle is the most influential factor on Thrust force followed by Spindle speed, Drill diameter & Feed rate in the sequential order. The optimum combination to achieve minimum thrust force generated is presented in table 6.

Table: 4 S-N response table for Thrust (smaller is better)

Level	DA	DD	Speed	Feed
1	59.05	76.84	87.38	76.84
2	83.96	84.80	80.10	81.39
3	99.44		74.98	84.22
Delta	40.39	7.96	12.39	7.38
Rank	1	3	2	4

Table: 6 Optimum combination of parameters to obtain minimum thrust

Drill angle	Drill Dia	Speed	Feed
90°	8 mm	1250 rpm	75 mm/min

The analysis of variance (ANOVA) for S/N ratio of thrust force is carried out for a significance level of alpha = 0.05, i.e. for a confidence level of 95%. The P values in the ANOVA table are the realized significance levels, associated with Fischer’s F test for each source of variation. The sources with P values less than 0.05 are considered to have statistically significant contribution to the performance measures. It can be seen from table that spindle drill point angle has the highest contribution (P=78.18%), followed by spindle speed (P=7.3%). The investigation reveals that ANOVA results of thrust force are in good agreement with the conceptual S/N ratio approach used for data analysis. The ANOVA results are presented in table 7.

Table 7: Analysis of Variance for Thrust force, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	P%
DA	2	4984.09	4984.09	2492.05	52.61	0.000	78.182
DD	1	285.38	285.38	285.38	2.03	0.034	4.47
Speed	2	465.39	465.39	232.69	4.91	0.033	7.30
Feed	2	166.30	166.30	83.15	1.76	0.222	2.64
Error	10	473.66	473.66	47.37			
Total	17	6374.82					

S = 6.88228   R-Sq = 92.57%   R-Sq(adj) = 87.37%

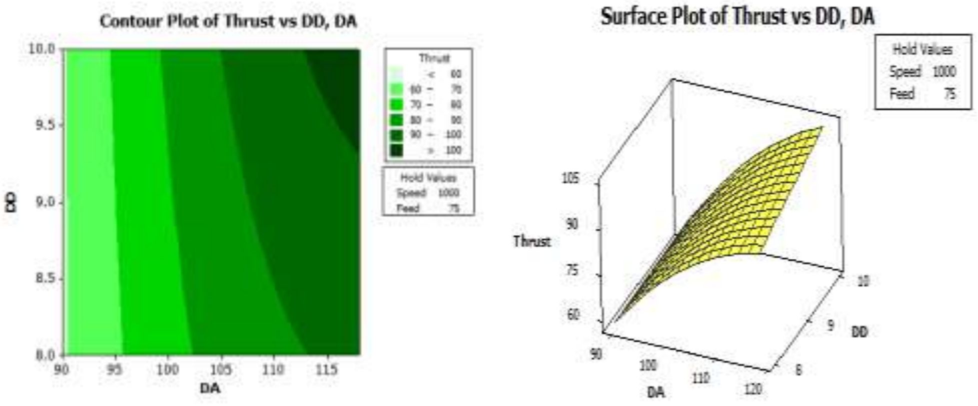
The regression equation:

The regression equation shows the correlation between the input variables and the response parameter. The regression equation obtained for the thrust force at the present experimentation conditions is presented in the equation below.

Thrust = - 89.8 + 1.43 DA + 3.98 DD - 0.0248 Speed + 0.148 Feed.

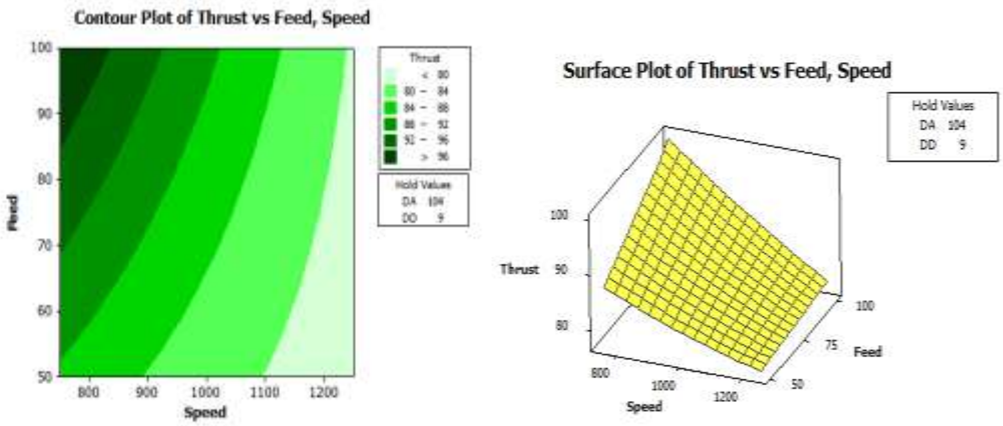
In the regression equation, since all the process parameters except spindle speed are assigned with the positive sign, the thrust force increases for any increment in the level of these input variables, but decreases with increment in the level of spindle speed.

The thrust force of the process is analyzed by generating contour plots and the corresponding 3D response surface plots. Figure 6 shows the interaction effects of drill diameter and drill point angle on the thrust force. According the plot, the thrust force increases with increase in the values of drill diameter and drill point angle. Similarly figure 7 shows the interaction effect of spindle speed and feed rate and from the figure it is clear that, the thrust force increases with increase in feed rate value, but decreases with increase in the spindle speed.



(a) (b)

Figure 6: Contour and Surface plot of thrust vs DD, DA



(a) (b)

Figure 7: Surface plot of thrust vs Feed, Speed.

Figure 8 is the RSM optimization plot for the thrust force. In the plot the influence level of a particular variable over the thrust force is represented by its slope gradient. If the slope gradient of a particular parameter is more, the influence level of that parameter over the thrust force is also more. The plot shows the maximum slope gradient for the parameter drill point angle. Hence the influence level of this parameter is more on thrust force. The plot is showing the optimum combination of process parameters in order to achieve the minimum thrust force in the drilling of CFRP composite material. According to the plot, the optimum combination of parameters is: drill point is 90^0, drill diameter is 8mm, spindle speed is 1250 rpm and feed rate is 50 mm/min (DA1 DD1 S3 F1). The advantage of the RSM optimization plot is that, in addition to the optimum combination of process parameters it will show the value of the response parameter obtained for that particular combination. For the present experimentation the minimum possible thrust force is 48.125 (y value in the plot). From the observations of the present work, it can be concluded that the optimum combination of process parameters obtained by DOE and RSM methods are similar.

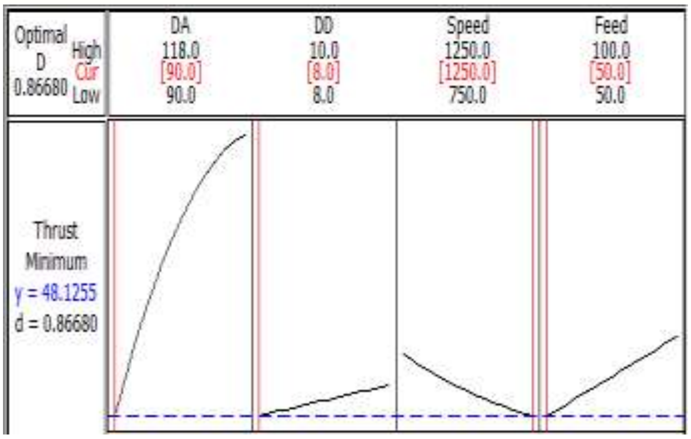


Figure 8: RSM optimization plot to obtain minimum thrust force.

IV.CONCLUSIONS

Based on the experimental results, the following inferences can be drawn in the drilling of CFRP composite materials using solid carbide drill bits.

1. The model generated by means of the commercial software (MINITAB 16) package shows the influence of the process parameters on the thrust force.

2. The results reveal that, the drill point angle is the most influencing design parameter on the thrust force followed by drill point angle.

3. The interaction plot reveals that the minimum thrust force is obtained at smaller drill point angle, smaller drill diameter, higher spindle speed and lesser feed rate.

4. For the present experimentation condition, the feed rate is the design parameter which shows the minimum influence.

5. The Experimentation reveals that ANOVA results are in good agreement with the conceptual S/N ratio approach used for data analysis.

6. The optimum combination of parameters obtained by Taguchi Method and RSM are same.

REFERENCES

[1.] Guu, Y.H., Hocheng, H., Tai, N.H., Liu, S.Y. (20010, Effect of electrical discharge machining on the characteristics of carbon fibrereinforced carbon composites, *Journal of Material. Science* 36, 2037–2043.

[2.] Arul, S., Vijayaraghavan, L., Malhotra, S.K., Krishnamurthy, R., (2006), The effect of vibratory drilling on hole quality in polymeric composites. *Int. Journal of Mach. Tools Manuf.* 46, 252–259.

[3.] Mohan, N.S., Ramachandra, A., Kulkarni, S.M., (2005), Influence of process parameters on cutting force and torque during drilling of glass-fiber polyester reinforced composites. *Composite Structures*, 71, 407–413.

[4.] Koenig, W., Wulf, C., Grass, P., Willersheid, H., (1985) Machining of fiber reinforced plastics. *Ann. CIRP* 34, 536–548.

[5.] Davim, J.P., Reis, P., (2003), Drilling carbon fiber reinforced plastics (CFRP) manufactured by autoclave—experimental and statistical study, *Material Design*, 24, 315–324.

[6.] Persson, E., Eriksson, I., Zackrisson, L., (1997), Effect of holemachining defects on strength and fatigue life of composite laminates, *Journal of Composite structures*, 28, 141–151.

[7.] Chen, W., (1997) Some experimental investigations in the drilling of carbon fiber-reinforced plastic (CFRP) composite laminates. *Int. J. Mach. Tools Manuf.* 37, 1097–1108.

[8.] Won, M.S., Dharan, C.K.H., (2002) Drilling of aramid and carbon fiber polymer composites. *Journal of Manufacturing Science and Engineering,* 124, 778–783.

[9.] Wong TL, Wu SM, GroyGM. (1982) An analysis of delamination in drilling of composite materials. In: *Proceedings of the 14th SAMPE technology conference. Atlanta, GA, USA;* . 471–483.

[10.] Piquet R, Ferret B, Lachaud F, Swider P. (2000) Experimental analysis of drilling damage in thin carbon/epoxy plate using special drills, *Journal of Composites* 31, 1107–15.

[11.] 11. Friedrich M. O.,Burant R. O, and Mc.Ginty M. J, (1979) Cutting tools/drills: part 5-point styles and applications, Journal of Manufacturing, Enineering 83, 1979, pp29-31.

[12.] H. Hocheng, C.C. Tsao, (2003) Comprehensive analysis of delamination in drilling of composite materials with various drill bits, *Journal of Material Processing Technology,* 140, 335–339.