Optimization of drilling parameters on CFRP composites

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Abstract
Purpose – Purpose of this paper is to inspect different parameters which influence the machining process of CFRP composites, for example cutting speed, feed and drill bit type and their significance in choosing the surface roughness and delamination factor.

Design/Methodology/Approach - . This work utilizes Analysis of variance (ANOVA) to figure out the exact response variable values. Likewise the examination of difference is utilized to explore the drilling parameters.

Findings – The primary cutting parameter that influences the drilling operations was figured out and it is clear from the study that the exploratory results of delamination factor are in great rough guess with the anticipated results according to RSM.

Research Limitations/Implications - As a result of the picked examination approach, the exploration results may need generalisability. Consequently, scientists are urged to test the proposed suggestions further.

Originality/Value - This paper clearly says about the exact feed, speed and drill bit type ranges for reducing delamination and increasing surface finish of a CFRP material.

Keywords : Delamination, Taguchi, ANOVA, RSM

Article Classification : RESEARCH PAPER

Introduction

The utilization of fiber fortified polymer composite materials are on the ascent because of their uncommon properties like high particular quality and firmness, excellent corrosion resistant, high damping, low warm development and high crack strength. They find exceptionally valuable applications in discriminating fields in aviation and cars particularly in protection utilization.

Tsao [1] Observed the thrust force on drilling CFRP composite by using core drill and core saw and he noticed that thrust force raises for both core saw drill and core drill with increase in feed. The thrust brings down the ascent in spindle speed. Higher speed of spindle decreases the heat generation on drilling activity and brings down tool wear.

Durao et al [2] Observed that lower feed rate brings down axial thrust force and hazard of delamination. The ideas that put forward through this research is that reduction in feed rate increases drill temperature and the drilled region of the plate softens and raises the danger on thermal damages.

Karimi, Navid Zarif et al [3] Studied the impacts of drilling parameters on the thrust force, adjusted delamination factor and compressive residual strength of unidirectional glass/epoxy resin by the application of Taguchi method.

Ozden Isbilir [4] Conducted a numerical investigation of the effects of drill geometry on reducing delamination of carbon fiber reinforced composites by developing a 3D finite element model and he proposed that by appropriate drill geometry work piece defects can be kept under control

D lliescu et al [5] Evaluated the effect of thrust force in drilling of carbon composite material and describes the development of a phenomenological model between the thrust force, the drilling parameters and the tool wear.

Lee, Seung-Chul et al [6] Studied about the drilling characteristics and mechanical properties of CFRP composites. In order to find out mechanical characteristics according to orientation angles by stacking in 6 different types along with the change of stacking composition method of a CFRP composite, 3 point bending test and transverse bending test had been carried out by them.

T.J Grilo et al [7] Examined the influence of three distinct drill geometries and cutting parameters in the delamination through two delamination factors. Best result was obtained with a feed rate of 2025 mm/min and spindle speed of 6750 rpm with spur drill.

Amrindel Pal Singh et al [8] Described the state of art in controlled drilling process by the use of neural network, fuzzy logic, supervising, PI, PID, pole placement and adaptive controllers. Their experimental results indicates that thrust force and torque have not been controlled simultaneously for delamination free drilling in PMC's.

Juan Carlos Campos Rubio et al [9] Investigated the drilling process of reinforced and unreinforced polyamides using Taguchi method. Paper reveals that the quality of the holes can be improved by proper selection of cutting parameters like tool point geometry, spindle speed (rpm) and feed rate (mm/rev).

M senthilkumar et al [10] Conducted an experiment on changing drilling parameters and found out the optimum cutting conditions for drilling of GFRP/Ti stacks using GA optimization method. Also they studied about tool wear by drilling 100 holes each with 118° and 130° point angle drills and satisfiable evacuation was at 130° point angle drills when compared with 118° point angle drills.

C.L Kuo et al [11] Conducted an experiment to analyze the influence of cutting speed (Ti/CFRP/Al:30/120/120 and 36/144/144 m/min) and feed rate (0.05,0.08,0.12 and 0.15 mm/rev) on work piece surface integrity following single shot drilling of multilayer metallic composite stacks (Ti-6Al-4V/CFRP/Al-7050) using CVD diamond coating tool.

Robert et al [12] Studied on CFRP chip roots for five different unidirectional fiber orientations using an orthogonal cutting test that produces weakened work pieces and it allows truly representative cutting circumstances due to continuous cut and constant cutting speed. Inspection of the chip roots are based on light microscopy, SEM and micrographs. In association with earlier experiments in house it labels to take in wear mechanisms when machining CFRP. As a conclusion fracture orientations, chip formations and chip movement allow for the perceive of CFRP chip formation.

A Krishnamoorthy et al [13] Performed drilling on CFRP composite plates by Taguchi's L27 othogonal array. By grey relational analysis optimal combination of drilling parameters were selected based on five different output performance characteristics thrust force, torque, entry delamination, exit delamination and eccentricity of holes. By using ANOVA they discovered that feed rate is the powerful factor in drilling of CFRP composites.

T.V Rajamurugan et al [14] develops a relationship between drilling parameters such as fiber orientation angle, tool feed rate, rotational speed and tool diameter in association with delamination of GFRP composites. Proposed model can be potentially applied to find out the delamination in drilling of GFRP composites within the factors and their limits are observed. The results pointed that the rise in feed rate and drill diameter increases the delamination size. since there is no clear effect on the fiber oriented angle.

K Palanikumar [15] Based on Taguchi's method, developed an effective method for the optimization of drilling parameters with multiple performance characteristics. By considering the thrust force, work piece surface roughness and delamination factors spindle speed and feed rate are optimized. Finally he concluded that feed rate is the highly influential parameter than that of the spindle speed.

R.A Kishore et al [16] studied the effect of cutting speed, feed rate and drill point geometry on the residual tensile strength of the drilled unidirectional glass fiber reinforced epoxy composite using Taguchi's method and proposes an optimal condition for higher residual strength.

Thiagarajan Rajmohan et al [17] conducted an experiment on drilling hybrid metal matrix composites and the process variables used are spindle speed, feed rate and weight of SiC. Experimental measured responses are thrust force, surface roughness and burr height. As a conclusion he got optimum spindle speed as 1855 rpm, feed rate of 50 mm/min and 15% SiC which results in minimum thrust force of 584 N, surface roughness of 1.67 µm and burr height of 0.16 mm.

V. N Gaitonde et al [18] Conducted an experiment for minimizing burr size in drilling using artificial neural network using particle swarm optimization approach. The models needed for optimization is established through ANN with the drilling methodologies proposed as per full factorial design. Paper concludes in a way that larger point angle for bigger drill diameter values have great deal in controlling burr size.

Naresh Neeli [19] Develops a numerical model for delamination through Response Surface Methodology (RSM) and break down the impacts of the whole individual information machining parameters (cutting rate, profundity of cut and feed rate) on the reactions in processing of glass fiber reinforced plastics (GFRP) composites with strong carbide end factory cutter covered with polycrystalline diamond (PCD).

R. Jeyapaul [20] This paper is to reported the readiness, characterisation and machinability of resin hybrid GFRP composites, which are made of glass fiber and the blend of epoxy & polyester resin.

Method Of experimentation

The objective of this experimental study was to determine the influence of cutting parameters on CFRP when carrying out drilling operation. Unsaturated polyester resin was used by adding suitable hardener and accelerator. Schematic representation of CFRP is shown in the figure 1.

Fig 1 : Sandwiched Carbon Fiber Reinforced Polymer

This paper utilizes ANOVA technique, which is extremely alluring and successful system to manage reactions influenced by number of variables. In this system, fundamental parameters which are expected to have influence on procedure results are situated at diverse columns in an outlined orthogonal cluster. With such a game plan totally randomized investigations can be directed. This system is additionally helpful for concentrating on the collaborations between the parameters. This strategy is a capable outline of tests apparatus, which gives a straightforward, efficient and methodical way to deal with focus ideal cutting parameters. Contrasted with the ordinary way to deal with experimentation, this system lessens definitely the quantity of examinations that are obliged to display the reaction capacities. In ANOVA exploratory outline, 3 levels of control elements are adequate to handle the issues just the spindle speed, feed and drill bit type.

The sandwich composite is produced by method for two 5 mm thickness glass fiber strengthened composite plates . The aggregate thickness of the plate is 10 mm. The measure of the plate produced for leading the machining investigations is 100 X 100cm X 10mm. The mechanical properties of the composite material utilized is mentioned in the table 1.

Table (1): Fiber Properties

Fiber Properties	
Tensile Strength	**1200 MPa**
Tensile Modulus	**15 MPa**
Strain	**1.5 %**
Density	**1.76 gm/cmˆ3**
Filament Diameter	**7 μm**

The drilling tests are done on Computer Numeric Control (CNC) vertical machining focus. The work piece is cinched on the machine table with a reinforcement plate underneath the sandwich board keeping in mind the end goal to decrease the way out harm or way out delamination and surface roughness. Typically low feed and high speed is suggested for drilling composite and low speed is prescribed for machining high quality steel. The parameters and their extents utilized for the experimentation are given in Table 2. Here drill Bit 1, 2, 3 represents various drill bits namely HSS 10mm (fig 2(a), TiAlN Solid carbide 10mm (fig 2(b)) and TiN coated carbide 10mm (fig 2(C)).

Fig 2(a)

Fig 2(b)

Fig 2(c)

Cutting Parameters and their range considered for experimentation

Cutting Parameters	**Range**
Cutting Feed (f), mm/rev	**50, 75, 100**
Cutting Speed (N), RPM	**6000, 7000, 8000**
Drill Bit Type	**1, 2, 3**

Table (2): Cutting parameters and their range of experimentation

The run of the mill bored openings are displayed in Fig (3). The figures showed that there is a delamination happens on the outskirts of the gaps bored. This delamination is to be lessened so that the dismissal rate of composite materials can be diminished.

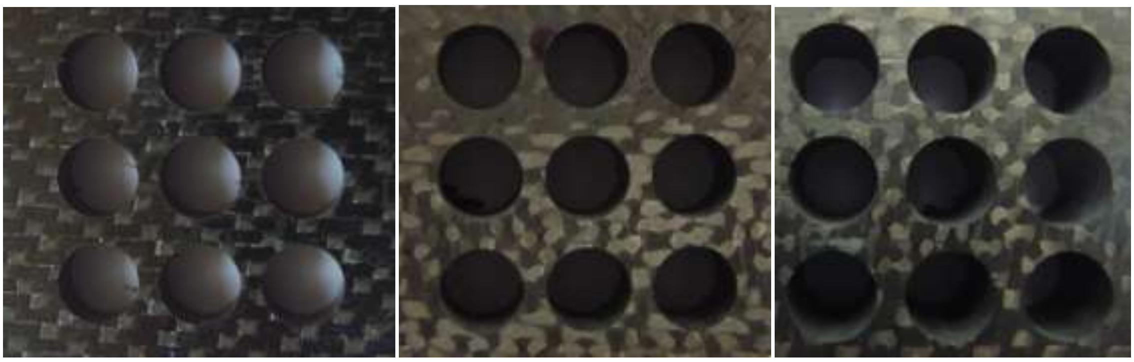


Fig (3):Drilled composite material

In drilling of composite materials, the opening quality is to be looked after appropriately, which is the primary need in assembling. The nature of the opening can be measured by distinctive files, for example, surface finish, roundness slip, gap width with resilience, and so forth. Delamination element is an essential term utilized as a part of composite commercial enterprises to gauge the nature of the bored gap. Delamination is a harm phenomena, which happen because of the anistrophy and fragility of the composite materials. The harm around the gaps (delamination) is measured and broke down in this study by utilizing apparatus creator magnifying lens produced by RADICAL Instruments, India. The delamination variable (Fd) is dictated by the accompanying connection:

$$Fd = \frac{\text{Maximum diameter of the delamination zone}}{\text{Hole Diameter}}$$

$$Fd = \frac{D_{max}}{D}$$

The scheme of measurement of the delamination is presented in Fig. 4. Fig. 4 (a) shows the drilled hole with delamination. Fig. 4 (b) shows the delamination measurement in the drilled portion of the hole.

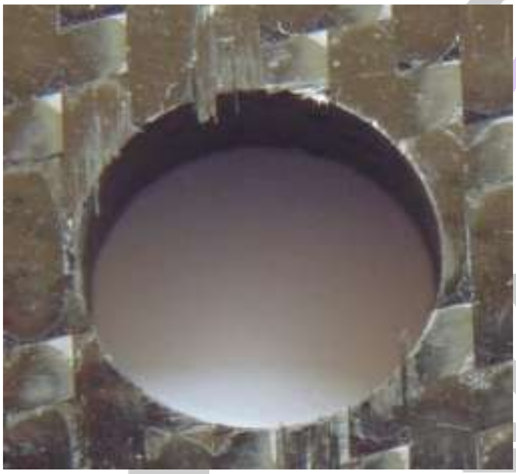
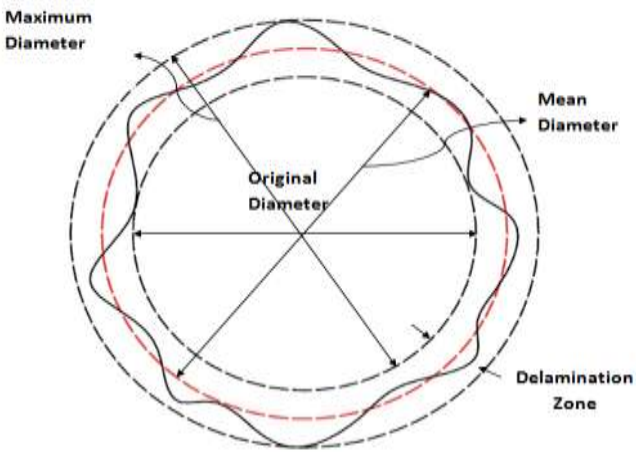


Fig (4a) : Drilled holed image



Fig(4b) : Scheme for measuring Delamination

Results and Discussion

In the mechanical related fields, drilling is the primary operation which involves give or takes 40% of the assembling operations. Drilling of composite materials is not quite the same as the customary materials. Particularly, when sandwich structures are utilized, they have distinctive properties at diverse areas. Amid the boring of composite materials, there are distinctive issues emerges, for example, fiber breakage, network splitting, fiber/framework debonding, fiber draw out, fluffing, warm degration, spalling and delamination. Delamination which happens on the passage what's more, leave side of the composite structure is critical and is to be diminished which lessen the bearing quality and material steadiness. The harm or delamination in penetrating is for the most part because of the push of the apparatus on the composite material. Table which shows the various drilling parameters which affects the delamination in drilling composite materials is shown in the table (3).

I) Considering Delamination as the output Parameter

SL NO	SPEED	FEED	DRILL BIT	DELAMINATION
1	6000	50	1	1.03
2	6000	50	2	1.025
3	6000	50	3	1.03185
4	6000	75	1	1.043
5	6000	75	2	1.031
6	6000	75	3	1.05
7	6000	100	1	1.065
8	6000	100	2	1.06285
9	6000	100	3	1.065

10	7000	50	1	1.03
11	7000	50	2	1.0117
12	7000	50	3	1.035
13	7000	75	1	1.035
14	7000	75	2	1.03
15	7000	75	3	1.035
16	7000	100	1	1.057
17	7000	100	2	1.055
18	7000	100	3	1.074
19	8000	50	1	1.03684
20	8000	50	2	1.03823
21	8000	50	3	1.04475
22	8000	75	1	1.055
23	8000	75	2	1.05
24	8000	75	3	1.06347
25	8000	100	1	1.083
26	8000	100	2	1.072
27	8000	100	3	1.083

Table (3) : delamination in drilling composite materials

From the available data, general linear model and main effect plot diagram Fig (5) are created using Minitab and found that feed rate is the vital component that affects the delamination factor in a CFRP material.

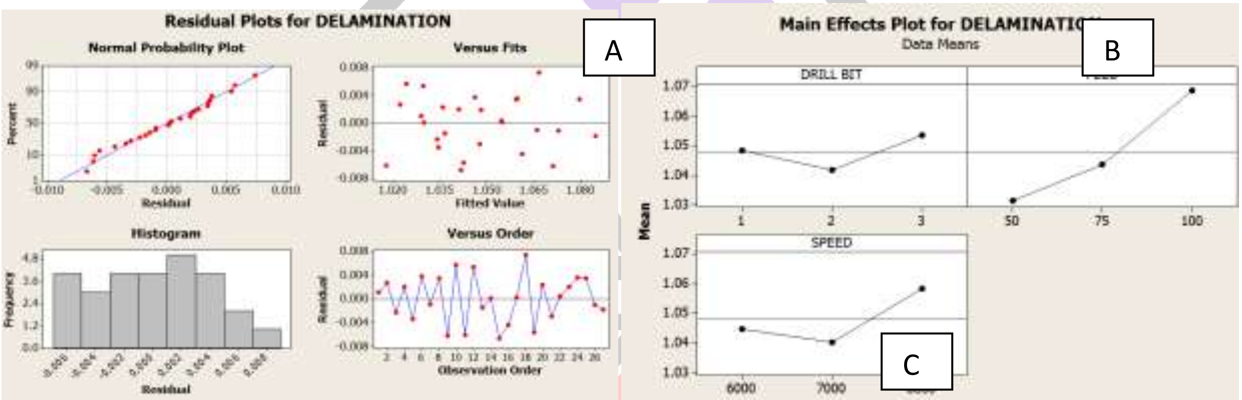


Fig (5) : Residual and main effect plot for delamination factor

Evaluation of Delamination Using ANOVA

The analysis of variance (ANOVA) is a procedure used to draw the conclusion, concerning which parameters influence the reaction of the asked process through the arrangement of exploratory results. This examination is done for significance level of $\alpha = 0.05$, i.e., for a confidence level of 95%. The P values in the ANOVA Table ( ) are the acknowledged significance levels, connected with Fischer's F test for every wellspring of variations. The sources with P values under 0.05 are considered to have measurably critical commitment to the execution measures. From the ANOVA presented in table (4), it is clear that the feed rate is the prior factor which affects the delamination (70.93) trailed by the spindle speed (17.8) in strong carbide drills and drill bit type (6.96).

Analysis of Variance for DELAMINATION, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
DRILL BIT	2	0.0006302	0.0006302	0.0003151	16.04	0.000
FEED	2	0.0064244	0.0064244	0.0032122	163.53	0.000
SPEED	2	0.0016100	0.0016100	0.0008050	40.98	0.000
Error	20	0.0003929	0.0003929	0.0000196		
Total	26	0.0090575				

S = 0.00443208   R-Sq = 95.66%   R-Sq (adj) = 94.36%

Table(4): Analysis of variance for delamination

II) **Considering Surface Roughness as the output parameter**

SL NO	SPEED	FEED	DRILL BIT	SURFACE ROUGHNESS
1	6000	50	1	3.09
2	6000	50	2	2.99
3	6000	50	3	3.02
4	6000	75	1	3.36649
5	6000	75	2	3.25
6	6000	75	3	3.41
7	6000	100	1	3.53556
8	6000	100	2	3.31111
9	6000	100	3	3.54
10	7000	50	1	3.09
11	7000	50	2	2.97785
12	7000	50	3	3.09
13	7000	75	1	3.32
14	7000	75	2	3.21
15	7000	75	3	3.22
16	7000	100	1	3.40623
17	7000	100	2	3.27
18	7000	100	3	3.42257
19	8000	50	1	3.11
20	8000	50	2	3.05
21	8000	50	3	3.15
22	8000	75	1	3.39943
23	8000	75	2	3.28
24	8000	75	3	3.41
25	8000	100	1	3.64948
26	8000	100	2	3.51
27	8000	100	3	3.66305

Table (5): Surface Roughness in drilling composite materials

Like that of the above tabular column, here we are using the tabulation for finding out the priority of input parameters such as speed, feed and drill type which affects the surface roughness of the CFRP material shown in table (5). From the available data, general linear model and main effect plot diagram Fig (6) are created using Minitab and found that feed rate is the vital component that affects the surface roughness in a CFRP material.

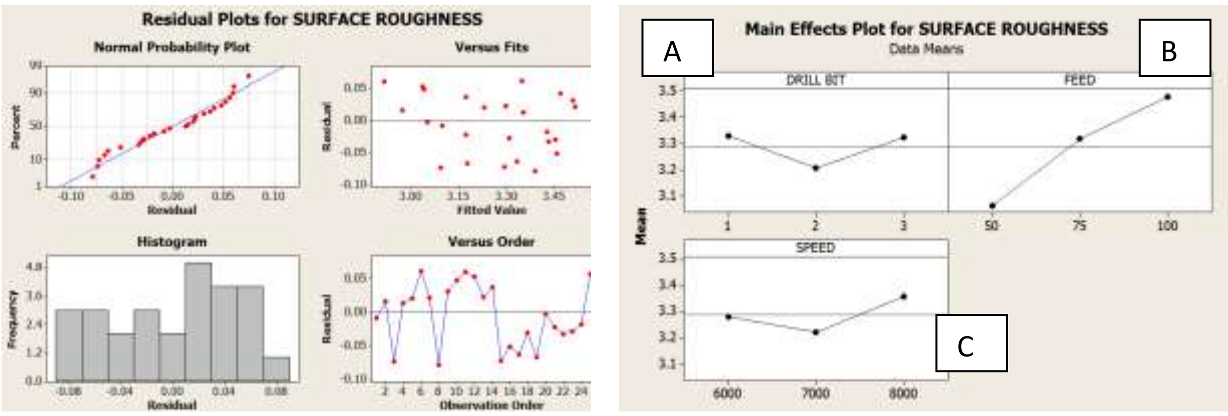


Fig (6) : Residual and main effect plot for Surface Roughness

Evaluation Of Surface Roughness Using ANOVA

This examination is done for significance level of α = 0.05, i.e., for a confidence level of 95%. The P values in the ANOVA (Table 6) are the acknowledged significance levels, connected with Fischer's F test for every wellspring of variations. The sources with P values under 0.05 are considered to have measurably critical commitment to the execution measures. From the ANOVA it is watched that the feed rate is the prior factor which affects the surface roughness (77.39) trailed by drill bit type (8.74) in strong carbide drills and speed (8.105).

Analysis of Variance for SURFACE ROUGHNESS, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
DRILL BIT	2	0.08931	0.08931	0.04465	15.17	0.000
FEED	2	0.79072	0.79072	0.39536	134.35	0.000
SPEED	2	0.08281	0.08281	0.04141	14.07	0.000
Error	2	0 0.05885	0.05885	0.00294		
Total	26	1.02170				

S = 0.0542470 R-Sq = 94.24% R-Sq (adj) = 92.51%

Table (6): Analysis of variance for surface roughness

Response Surface Methodology

The response surface methodology(RSM) is a measurable device utilized for demonstrating and investigating issues in which a reaction of premium is impacted by a few variables. In the present work, the central composite design (CCD) of RSM is utilized for setting up observational connections among the procedure parameters. The RSM model decided for anticipating the delamination component (Fd) can be communicated as: Delamination equals

2.52707 – ((4.2166E – 04)* (Speed)) + ((3.111E – 05)* (Feed)) – (0.0808* (Drill Bit Type)) + ((3.09444E – 08)* (Speed*Speed)) + ((1.77778E – 06) * (Feed *Feed)) + (0.0222778* (Drill Bit*Drill Bit)) – ((6.66667E -09)* (Speed*Feed)) – ((6.66667E – 07)* (Speed*Drill Bit))- ((433333E – 05)* (Feed*Drill Bit))

Similarly the surface roughness component (SR) can be represented as:

7.55391 -0.00137065* (Speed) + 0.0140256* (Feed) -0.556428* Drill Bit Type + 9.56567E-08* (Speed*Speed) -7.60880E-05* (Feed *Feed) + 0.121938* (Drill Bit*Drill Bit) +7.52867E-07* (Speed*Feed) + 7.18250E-06* (Speed*Drill Bit) + 0.000214500* (Feed*Drill Bit)

Analysis Of Delamination and Surface Roughness Using 3D Response Surface Plots Of RSM

The delamination propensity can likewise be investigated through RSM model by creating 3D response surface plots.

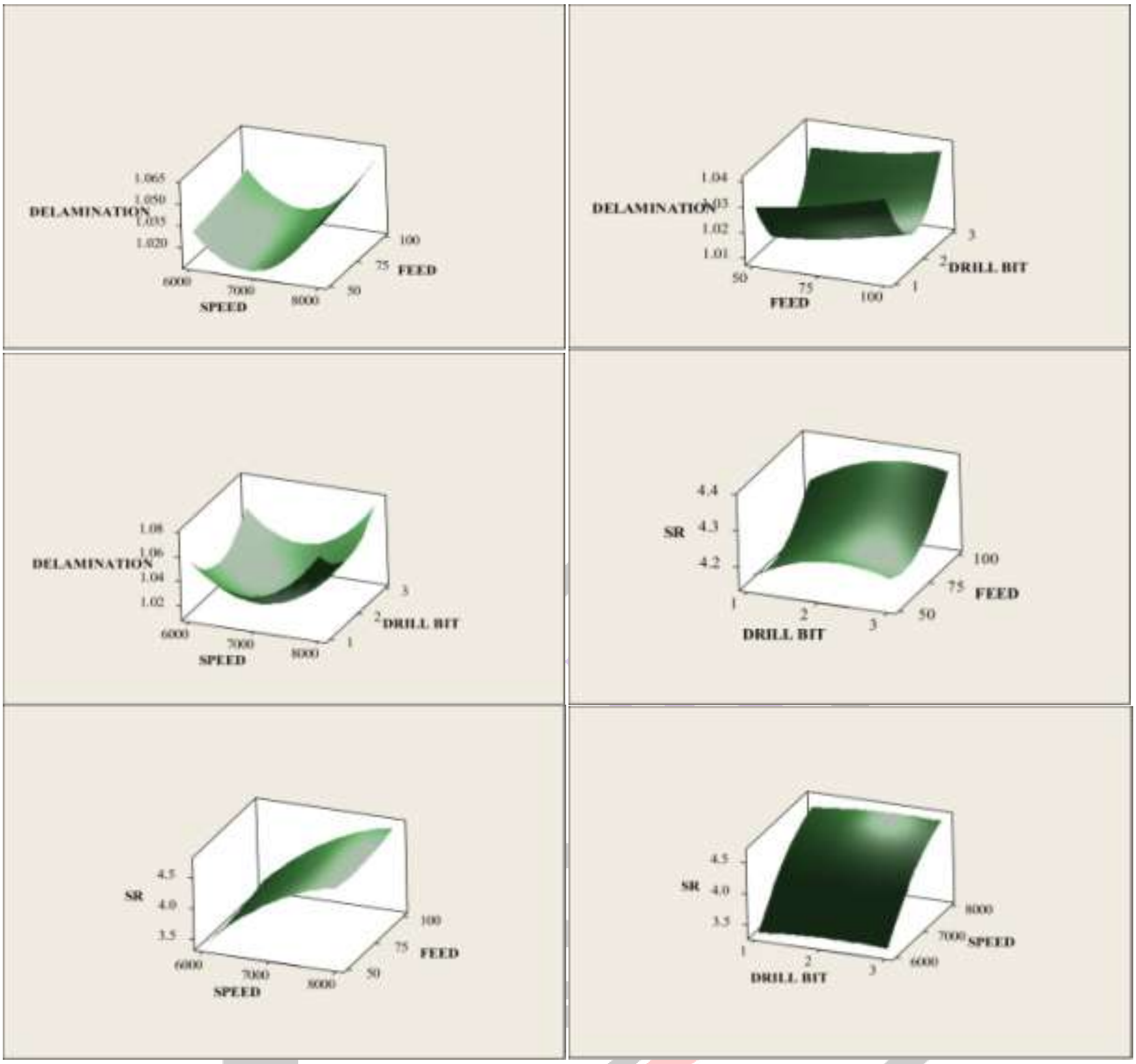


Fig (7): 3D response surface plots

The created model can be utilized just for the parameters considered inside of the points of confinement and is a constraint for this study. From the figure (7), it is clear that the delamination factor of CFRP composite increases with increase in feed, speed and type of drill bit and decreases at a particular point where the feed rate is at a satisfiable level. For minimizing delamination in penetrating of CFRP composites, high spindle speed and low feed rate are favored. By utilizing legitimate apparatus geometry and drill measure, the delamination in boring of composites can be decreased. X axis and Y axis of the figure plots the input variables and the Z axis denotes the response variables such as Delamination and Surface roughness (SR) Increase in thrust force leads to increase in drilling induced delamination (Palanikumar 2012), whereas, increase in spindle speed raises the temperature while drilling of composites, thus softening the matrix material, thereby reducing the delamination (Palanikumar2011). In the case of surface roughness also the highlighting factor, that is the prior percentage which influence is that feed rate.

Confirmation Test For Optimum Process Parameters

The confirmation test outcomes got for optimum process parameters amid drilling of CFRP composite with the given inputs like feed, speed and sort of drill material are demonstrated in Table(7).It is seen from the outcomes that the test and the anticipated estimations of delamination variable are in great concurrence with more than 99 % confidence level and surface roughness close to 99% of confidence level.

Results For confirmation test for optimal cutting condition				
Response	Optimum Cutting Parameters	Experimental	Prediction	Percentage Of Agreement
Delamination	A2B1C2	1.0117	1.00923	99.75
Surface Roughness	A2B1C2	2.97	2.92	98.31

Table (7): Results For confirmation test for optimal cutting condition

CONCLUSION

The following conclusions can be drawn from the result of drilling of a GFRP composite.

1. The model created by method of design software (MINITAB) bundle demonstrates the impact of process parameters on delamination.

2. The examination uncovers that there is an immaculate connection between the test and the anticipated results of delamination factor. This shows that RSM model can be successfully used to anticipate the delamination factor.

3. The ANOVA demonstrates that the spindle speed and drill bit type have only a negligible impact on drilling affected delamination.

4. The study uncovers that delamination component increment with expansion in feed rate.

5. The study exhibits that the minimum delamination is obtained for the optimum process parameters (spindle pace of 7000 rpm, feed rate of 50 mm/min)

References

[1] Tsao, C. C. "Thrust force and delamination of core-saw drill during drilling of carbon fiber reinforced plastics (CFRP)." *The International Journal of Advanced Manufacturing Technology* 37.1-2 (2008): 23-28.

[2] Durão, Luís Miguel P., et al. "Drilling tool geometry evaluation for reinforced composite laminates." *Composite Structures* 92.7 (2010): 1545-1550.

[3] Karimi, Navid Zarif, et al. "Effect of the drilling process on the compression behavior of glass/epoxy laminates." *Composite Structures* 98 (2013): 59-68.

[4] Isbilir, Ozden, and Elaheh Ghassemieh. "Numerical investigation of the effects of drill geometry on drilling induced delamination of carbon fiber reinforced composites." *Composite Structures* 105 (2013): 126-133.

[5] Iliescu, D., et al. "Modeling and tool wear in drilling of CFRP." *International Journal of Machine Tools and Manufacture* 50.2 (2010): 204-213.

[6] Lee, Seung-Chul, et al. "A study on mechanical properties of carbon fiber reinforced plastics by three-point bending testing and transverse static response." *Journal of materials processing technology* 201.1 (2008): 761-764.

[7] T.J. Grilo, R.M.F. Paulo, C.R.M. Silva, J.P. Davim "Experimental delamination analyses of CFRPs using different drill geometries" in Composites: Part B 45 (2013) 1344–1350.

[8] Singh, Amrinder Pal, Manu Sharma, and Inderdeep Singh. "A review of modeling and control during drilling of fiber reinforced plastic composites."*Composites Part B: Engineering* 47 (2013): 118-125.

[9] Rubio, Juan Carlos Campos, et al. "Investigations on the drilling process of unreinforced and reinforced polyamides using Taguchi method." *Composites Part B: Engineering* 55 (2013): 338-344.

[10] SenthilKumar, M., A. Prabukarthi, and V. Krishnaraj. "Study on tool wear and chip formation during drilling carbon fiber reinforced polymer (CFRP)/titanium alloy (Ti6Al4V) stacks." *Procedia Engineering* 64 (2013): 582-592.

[11] Kuo, Chun-Liang, et al. "The effect of cutting speed and feed rate on hole surface integrity in single-shot drilling of metallic-composite stacks." *Procedia CIRP* 13 (2014): 405-410.

[12] Voß, Robert, et al. "Chip root analysis after machining carbon fiber reinforced plastics (CFRP) at different fiber orientations." *Procedia CIRP* 14 (2014): 217-222.

[13] Krishnamoorthy, A., Boopathy, S.R., Palanikumar, K. and Davim, J.P. (2012), Application of grey fuzzy logic for the optimization of drilling parameters for CFRP composites with multiple performance characteristics, Journal of Measurement, 45, 1286– 1296.

[14] T.V. Rajamurugan, K. Shanmugam, K. Palanikumar,"Analysis of delamination in drilling glass fiber reinforced polyester composites," Materials and Design 45 (2013) 80–87.

[15] K. Palanikumar, "Experimental investigation and optimisation in drilling of GFRP composites," Measurement 44 (2011) 2138–2148.

[16] Kishore, R. A., et al. "Taguchi analysis of the residual tensile strength after drilling in glass fiber reinforced epoxy composites." *Materials & design* 30.6 (2009): 2186-2190.

[17] Rajmohan, Thiagarajan, and Kayaroganam Palanikumar. "Application of the central composite design in optimization of machining parameters in drilling hybrid metal matrix composites." *Measurement* 46.4 (2013): 1470-1481.

[18] Gaitonde, V. N., and S. R. Karnik. "Minimizing burr size in drilling using artificial neural network (ANN)-particle swarm optimization (PSO) approach."*Journal of Intelligent Manufacturing* 23.5 (2012): 1783-1793.

[19] Mugundhu, Jenarthanan, R. Jeyapaul, and Naresh Neeli. "Analysis of factors influencing delamination in milling process of glass fibre reinforced plastic (GFRP) composite materials." *Multidiscipline Modeling in Materials and Structures* 9.3 (2013): 293-306.

[20] Jenarthanan, M. P., and R. Jeyapaul. "Evaluation of milling characteristics of resin hybrid GFRP laminates using Taguchi approach." *Pigment & Resin Technology* 42.5 (2013): 288-297.