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EXPERIMENTAL STUDY OF DRILLING GLASS FIBER REINFORCED EPOXY RESIN COMPOSITES (GFREC) USING TAGUCHI METHOD

KEY WORDS: GFREC, Delamination, L_{27} orthogonal array, ANOVA

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ABSTRACT

Glass fiber reinforced epoxy resin composite (GFREC) materials have been widely used for manufacturing structural parts in aerospace and automotive industries because of their excellent mechanical and physical properties. They are also widely used as a substrate in electronics industry for producing printed circuit boards (PCB). Drilling of these composite materials is a complex process, with regard to the quality of drilled components. The principal drawbacks are related to delamination, surface roughness and ovality of the hole produced. In the present work, the objective is to study the effect of the process parameters namely cutting speed, feed rate, drill diameter and thickness of workpiece on quality characteristics in drilling of glass fiber reinforced epoxy resin composites (GFREC). The experiments were designed by using Taguch's L_{27} orthogonal array. Analysis of variance (ANOVA) was used to analyze the effect of all input process parameters on the output responses. The results indicate that feed rate is the most influential factor on the delamination, surface roughness and ovality. Plots of S/N ratio have been used to determine optimum set of input parameters for minimum delamination, surface roughness and ovality.

1. INTRODUCTION

Fiber reinforced composite materials have been widely used for manufacturing aircraft, spacecraft and automobile industries structural parts because of their properties such as high specific strength, high specific stiffness and superior corrosive resistance, high damping and low thermal expansion [1]. Another relevant application for glass fiber reinforced epoxy resin composite (GFREC) materials is in manufacturing the printed wiring board. Glass fiber reinforced epoxy resin composite material is mostly used to manufacture the printed wiring board. In order to improve ion migration and reducing the spacing of conductor pattern, it is important to reduce the drilling damage such as the delamination around the drilled holes of the glass fiber reinforced epoxy resin composite material [2].

Most of the fiber reinforced composite materials are manufactured to a near net shape, but further machining especially drilling pose a great problem due to its anisotropic non homogeneous nature [3]. It was reported that the rejection of parts due to delamination was as high as 60% [4]. Selection of proper machining parameters such as spindle speed, feed rate, drill geometry and material are required to reduce the rate of rejection at the final stage of assembly. Therefore, researchers have to find the optimal solution effectively [5].

2. MATERIALS AND EXPERIMENTAL PROCEDURE

2.1 Materials

In this study, glass fiber reinforced epoxy resin composite (GFREC) material was selected as work piece material. E-glass fibers were used as the reinforcement material and the matrix material was epoxy resin. Twist drills made of HSS were used for the drilling operation. The drilling experiments were conducted in computer numeric control (CNC) vertical machining center (VMC) model super VF-2 (HASS, USA make). The experimental set-up is shown in fig. 1. All the drilled holes were examined with coordinate measuring machine, surftest SJ-201 and profile projector.

Fig. 1: Experimental setup

2.2 Design of experiments

Orthogonal arrays are the experimental designs given by Genichi Taguchi to improve the quality of manufactured goods. Taguchi experimental design method uses orthogonal arrays to study the entire parameter space with a small number of experiments. In this study, four machining parameters were used as control factors and each parameter was designed to have three levels as shown in table 1.

Table 1: Different input parameters and their levels

Parameters	Level-1	Level-2	Level-3
Cutting Speed (rpm)	600	1200	1800
Feed Rate (mm/min)	50	150	250
Drill Diameter (mm)	5	7	9
Thickness of Work Piece (mm)	1.5	2.5	3

The experimental design was according to an L_{27} orthogonal array based on Taguchi method as shown in Table 2.

3. RESULTS AND DISCUSSIONS

The signal to noise (S/N) ratio gives the idea about the variation present in the process. The S/N ratio of each experiment of L_{27} orthogonal array was calculated. The S/N ratios were calculated using the condition smaller is the better. The signal-to-noise ratios were calculated by applying the equation given below:

$$S/N_{LB} = -10\log\left[\frac{1}{n}\sum_{i=0}^{n} x_i^2\right]$$

x_i = Observed value of the response characteristics.
n = Number of repetitions.

Minitab 18.1 statistical software was used for Taguchi Analysis. The effect of input parameters on delamination, surface roughness and ovality was studied using Analysis of Variance (ANOVA).

Table 2: L_{27} experimental design for selected input parameters

Exp. No.	Cutting Speed	Feed Rate	Drill Diameter	Thickness of Workpiece
1	1	1	1	1
2	1	1	2	2
3	1	1	3	3
4	1	2	1	2
5	1	2	2	3
6	1	2	3	1
7	1	3	1	3

8	1	3	2	1
9	1	3	3	2
10	2	1	1	2
11	2	1	2	3
12	2	1	3	1
13	2	2	1	3
14	2	2	2	1
15	2	2	3	2
16	2	3	1	1
17	2	3	2	2
18	2	3	3	3
19	3	1	1	3
20	3	1	2	1
21	3	1	3	2
22	3	2	1	1
23	3	2	2	2
24	3	2	3	3
25	3	3	1	2
26	3	3	2	3
27	3	3	3	1

3.1 Analysis for Delaminaton

The effect of cutting speed, feed rate, drill diameter and thickness of workpiece on mean S/N ratios of delamination is shown in Fig. 2. It shows that in drilling of composites delamination decreases with increase in cutting speed. This is due to the reason that increase of cutting speed increases the temperature produced in drilling of composites, which softens the matrix material and inducing less delamination. It is observed that the delamination increases frequently with increase in feed rate. With the increase in feed rate, thrust force increases resulting in increase in the delamination. The results presented are almost similar to the results presented by [6]. It is observed that the increase of drill diameter increases the delamination.This is due to the reason that increase of drill diameter increases the contact area between the workpiece and drill, which increases the thrust force. It is found that the delamination decreases with the increase of thickness of workpiece in the drilling of composites.

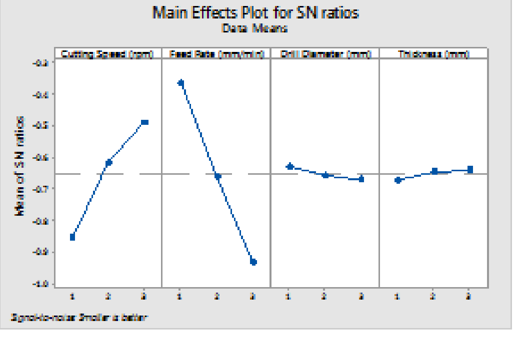

Fig. 2: Main effect plots for delamination (F_d)

Table 3 shows the result of ANOVA for delamination.The purpose of analysis of variance is to identify the parameters that significantly affect the quality characteristics. It can be observed from the table that for delamination the factors feed rate and cutting speed are significant as p value is less than 0.05 whereas drill diameter and thickness of work piece are insignificant as p value is greater than 0.05. The larger F-value affects more on the quality characteristic; therefore feed rate is the most influential factor for delamination.

Table 3: Analysis of variance for S/N ratios of delamination (F_d)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cutting Speed	2	0.616	0.616	0.308	95.12	0
Feed Rate	2	1.44078	1.44078	0.72039	222.48	0
Drill Diameter	2	0.00766	0.00766	0.00383	1.18	0.329
Thickness	2	0.00537	0.00537	0.00269	0.83	0.452
Residual Error	18	0.05828	0.05828	0.00324		
Total	26	2.12809				

Response values for S/N ratios for delamination are given in Table 4. Feed rate is having the highest rank 1 and is the most significant factor followed by cutting speed rank 2 and drill diameter with rank 3 and thickness of workpiece with its lowest rank is the least significant in affecting the delamination. The optimum values of input parameters are cutting speed of 1800 rpm, feed rate 50 mm, drill diameter 5 mm and thickness of workpiece 3 mm.

Table 4: Response table for mean S/N ratios of delamination (F_d)

Level	Cutting Speed	Feed Rate	Drill Diameter	Thickness
1	-0.8543	-0.3661	-0.6308	-0.6732
2	-0.6164	-0.6627	-0.6587	-0.6464
3	-0.4899	-0.9317	-0.6711	-0.6409
Delta	0.3644	0.5656	0.0403	0.0323
Rank	2	1	3	4

3.2 Analysis for Surface Roughness

The plots of S/N ratios of surface roughness for cutting speed, feed rate, drill diameter and thickness of workpiece are shown in Fig. 3. It shows that in drilling of composites surface roughness first decreases and then increases as cutting speed is increased from 600 rpm to 1200 rpm and further to 1800 rpm. The surface roughness was improved by increasing cutting speed due to the reason that increase of cutting speed decreases the thrust force. The results presented are almost similar to the results presented by [7]. It is observed that the surface roughness increases with increase in feed rate, drill diameter and thickness of workpiece. This result was due to the increasing of thrust force and torque. The results presented are almost similar to the results presented by [8].

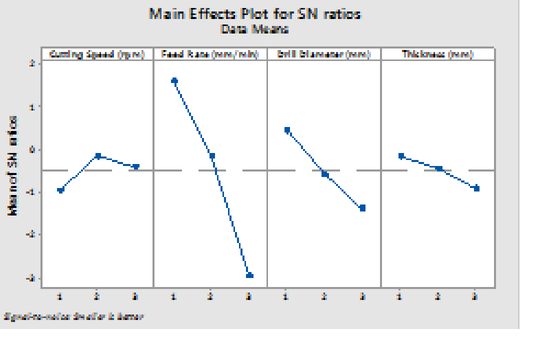

Fig. 3: Main effect plots for surface roughness (R_a)

ANOVA table for S/N ratios of surface roughness is given in Table 5. It is observed from the table that for surface roughness the factors feed rate and drill diameter are significant as p value is less than 0.05 whereas cutting speed and thickness of workpiece are insignificant as p value is greater than 0.05. The F-value is largest for feed rate; therefore feed rate is the most influential factor for surface roughness.

The response table for S/N ratios of surface roughness is represented in Table 6. The delta value is calculated by finding the difference between the maximum and minimum values of mean S/N ratios for each factor. It also shows the rank of various

Table 5: Analysis of variance for S/N ratios of surface roughness (R_a)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cutting Speed	2	3.046	3.046	1.5229	3.19	0.065
Feed Rate	2	94.408	94.408	47.2041	98.93	0
Drill Diameter	2	15.041	15.041	7.5204	15.76	0
Thickness	2	2.616	2.616	1.3082	2.74	0.091
Residual Error	18	8.589	8.589	0.4771		
Total	26	123.7				

Table 6: Response table for mean S/N ratios of surface roughness (R_a)

Level	Cutting Speed	Feed Rate	Drill Diameter	Thickness
1	-0.9596	1.5906	0.4412	-0.1654
2	-0.1526	-0.1689	-0.5892	-0.4449
3	-0.4176	-2.9515	-1.3818	-0.9195
Delta	0.807	4.5421	1.8231	0.7541
Rank	3	1	2	4

parameters in relation with their effect on surface roughness, the higher rank means more affect and lower rank means less affect. Therefore feed rate is having the highest rank 1 and is most significant factor followed by drill diameter rank 2 and cutting speed with rank 3 and thickness of workpiece with its lowest rank is the least significant in affecting the surface roughness.

From the response Table 6 for S/N ratios of surface roughness it is found that the optimum value of levels of input parameters for best surface roughness (minimum) are cutting speed 1200 rpm, feed rate 50 mm/min, drill diameter 5 mm and thickness of workpiece 1.5 mm.

3.3 Analysis for Ovality

The plots of S/N ratios of ovality for cutting speed, feed rate, drill diameter and thickness of workpiece are shown in Fig. 4. It shows that in drilling of composites ovality decreases with increase in cutting speed. It is observed that the ovality first increases and then decreases as feed rate is increased from 50 mm/min to 150 mm/min and further to 250 mm/min. The ovality decreases with increase in feed rate due to increase in the thrust force. The ovality decreases with increase in drill diameter because the vibrations are inversely proportional to the diameter of drill.

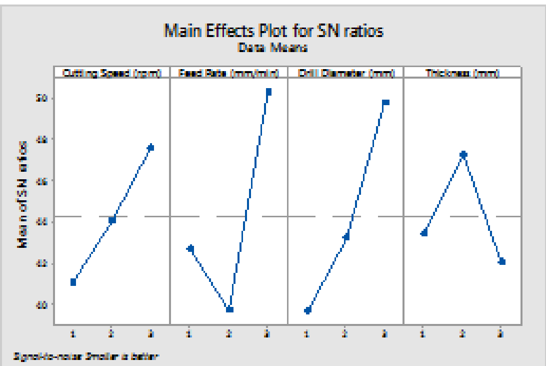

Fig. 4: Main effect plots for ovality

Table 7: Analysis of variance for S/N ratios of ovality

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Cutting Speed	2	188.7	188.7	94.37	3.03	0.073
Feed Rate	2	534.8	534.8	267.39	8.58	0.002
Drill Diameter	2	475.4	475.4	237.71	7.63	0.004
Thickness	2	131.5	131.5	65.76	2.11	0.15
Residual Error	18	560.8	560.8	31.16		
Total	26	1891.3				

It is found that the ovality first decreases and then increases as thickness of workpiece is increased from 1.5 mm to 2.5 mm and further to 3.0 mm in the drilling of composites.

ANOVA table for S/N ratios of ovality is given in Table 7. It indicates the significance of various input process parameters. It is observed from the table that for ovality the factors feed rate and drill diameter are significant as p value is less than 0.05 whereas cutting speed and thickness of workpiece are insignificant as p value is greater than 0.05. The F-value is largest for feed rate; therefore feed rate is the most influential factor for ovality. The response table for S/N ratios of ovality is represented in Table 8.

Table 8: Response table for mean S/N ratios of ovality

Level	Cutting Speed	Feed Rate	Drill Diameter	Thickness
1	41.1	42.71	39.7	43.44
2	44.08	39.73	43.23	47.27
3	47.57	50.31	49.82	42.04
Delta	6.47	10.57	10.13	5.22
Rank	3	1	2	4

The feed rate is having the highest rank 1 and is most significant factor followed by drill diameter with rank 2 and cutting speed with rank 3 and thickness of workpiece with its lowest rank is the least significant in affecting the ovality. From the response Table 8 for S/N ratios of ovality it is found that the optimum value of levels of input parameters for minimum ovality are cutting speed 1800 rpm, feed rate 250 mm/min, drill diameter 9 mm and thickness of workpiece 2.5 mm.

4. CONCLUSIONS

Based on the experimental results presented, the following conclusions can be drawn from drilling of glass fiber reinforced epoxy resin composites (GFREC) using Taguchi method:

- The results of ANOVA reveal that feed rate and cutting speed are significant parameters for delamination.
- It is found that delamination increases as feed rate increases and delamination decreases as cutting speed increases.
- The optimum set of parameters for minimum delamination are cutting speed 1800 rpm, feed rate 50 mm/min, drill diameter 5 mm and thickness of workpiece 3 mm.
- The results of ANOVA reveal that feed rate and drill diameter are significant parameters for surface roughness.
- The surface roughness increases with increase in feed rate and drill diameter.
- The optimum set of parameters for minimum surface roughness are cutting speed 1200 rpm, feed rate 50 mm/min, drill diameter 5 mm and thickness of workpiece 1.5 mm.
- The results of ANOVA reveal that feed rate and drill diameter are significant parameters for ovality.
- The ovality first increases and then decreases as feed rate is increased from 50 mm/min to 150 mm/min and further to 250 mm/min. The ovality decreases with increase in drill diameter.
- The optimum set of parameters for minimum ovality are cutting speed 1800 rpm, feed rate 250 mm/min, drill diameter 9 mm and thickness of workpiece 2.5 mm.

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