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Effect of Drilling Parameters for the Assessment of Roughness of Drilled Holes in Glass Fiber Reinforced Plastic (GFRP)

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Abstract: *Now a day, Glass Fibre-Reinforced Plastics (GFRP) are being widely used in diversity of engineering applications in many different areas such as aerospace, automotive and aircraft industries due to their light weight, high modulus, high specific strength and high fracture toughness. Drilling or Milling of GFRP composite material is a rather complex task owing to its heterogeneity and the number of problems, such as surface accuracy and delamination of drilled holes, which appear during the machining process, associated with the characteristics of the material and the cutting parameters. Current paper focuses the investigational details to find out roughness on drilled hole in GFRP composite laminates by using Taguchi's DOE L9 orthogonal array. The main objective of the present work is to optimize the process parameters in the drilling of GFRP composite using Taguchi DOE and to find the significance of each process parameter using ANOVA. As far as the effect of input factors are considered, the factor spindle speed is having significant and dominating effect on GFRP composite material.*

Keywords - *GFRP composite, Surface roughness, CNC drilling, Taguchi DOE, ANOVA.*

I. INTRODUCTION

Drilling is the common frequently used machining operation in manufacturing parts of fiber-reinforced plastics, because components made of composites are commonly produced by net-shape components that often require the removal of excess material to control tolerances, and milling is used as a curative operation to produce well-defined and high quality surfaces. Now a day, glass fibre-reinforced plastics (GFRP) are being widely used in diversity of engineering applications in many different fields such as aerospace, automotive and aircraft industries due to their light weight, high modulus, high specific strength and high fracture toughness. Much of the literature reported on drilling and milling of GFRP material by conventional tools has shown that the quality of the cut surface especially drilled hole is strongly reliant on the cutting parameters, tool geometry, tool material, work piece material, machining process, etc.

Drilling of GFRP composite materials is a rather complex task owing to its heterogeneity and the number of problems, such as surface roughness and delamination of drilled hole, which appear during the machining process, associated with the characteristics of the material and the cutting parameters. The improper selection of such parameters can lead to unacceptable material degradation, such as fiber pull out, matrix cratering, thermal damage and widespread delamination.

The main objective of the present work is to optimize the process parameters in the drilling of GFRP composite using Taguchi DOE and to find the significance of each process parameter using ANOVA. In the present work, statistical analysis software MINITAB 16 is used to perform the Taguchi and ANOVA analysis. Taguchi design with L9 orthogonal array is used for carrying out the experimentation. The response variable chosen is surface roughness of the drilled GFRP substrates. For measuring machined surface characteristics contact measurement technique is used. The main objective of the work is to find out roughness of drilled GFRP substrate's hole. Following paragraphs thrown the information of some of the recent key publications on machining of GFRP composite.

Hocheng H. et al. (2003) investigated the effects of various drill geometries were rarely discussed in analytical fashion [1]. This study presents a comprehensive analysis of delamination in use of various drill types, such as saw drill, candle stick drill, core drill and step drill. In this analysis, the critical thrust force at the onset of delamination is predicted and compared with the twist drill. C. C. Tsaoa et al. (2008) represents the prediction and evaluation of thrust force and surface roughness in drilling of composite material using candle stick drill [2]. The approach is based on Taguchi method and the artificial neural network. The experimental results indicate that the feed rate and the drill diameter are the most significant factors affecting the thrust force, while the feed rate and spindle speed contribute the most to the surface roughness. P. Praveen Raj et al. (2010) studied the surface roughness, precision and delamination factor in use of Ti-Namite carbide K10 end mill, Solid carbide K10 end mill and Tipped Carbide K10 end mill. A plan of experiment based on Taguchi was established with prefixed cutting parameters and the machining was performed [3]. Author examined that the depth of cut are recognized to make the most significant contribution to the overall performance as compared to cutting velocity and feed rate. The factors which lead to the surface delamination existing in milling carbon fiber reinforced plastic (CFRP) with PCD tool have been studied by Yong Guo Wang et al. (2011) [4]. The surface delamination is summarized by analyzing the experiment results based on studying cutting velocity and cutting feed. Experimental results show that the increasing cutting feed leads to the increment of cutting force which in turn causes the increasing delamination of CFRP materials. B. Ramesh et al. (2012) examined a non-laminated GFRP composite manufactured by pultrusion process was drilled with coated cemented carbide drill [5]. The thrust force and torque during drilling examined by piezoelectric dynamometer. Taguchi's OA and analysis of variance (ANOVA) were employed to study the influence of process parameters such as feed and spindle speed on the force and torque.

M. P. Jenarthanan et al. (2013) used Taguchi's L27 orthogonal array, milling experiments were conducted for GFRP composite plates using solid carbide end mills with different helix angles [6]. The machining parameters such as, spindle speed, feed rate, helix angle and fibre orientation angle are optimized by multi-response considerations namely surface roughness, delamination factor and machining force. N. Naresh et al. (2013) conducted an experiment by using Taguchi's L27 orthogonal array on milling with prefixed cutting parameters for GFRP composite plates using solid carbide end mills [7]. The machining parameters such as, and fibre orientation angle, helix angle, spindle speed and feed rate are optimized with the objective of minimizing the surface roughness, machining force and delamination factor. G Dilli Bab et al. (2013) used Taguchi techniques and on the analysis of variance (ANOVA), was established considering milling with prefixed cutting parameters in Natural Fiber-Reinforced Plastic (NFRP) composite materials using cemented carbide end mill [8]. The results of NFRP composite were compared with Glass Fiber-Reinforced Plastic (GFRP) composites. Xuda Qin et al. (2014) conducted a full factor experimental design, helical milling experiments were performed by using a special cutter. Using the data obtained from the experiments, the correlation between the delamination and the process parameters was established by developing an artificial neural network (ANN) model [9]. Vinod Kumar Vankanti et al. (2014) carried out experiment as per the Taguchi experimental design and an L9 orthogonal array was used to study the influence of various combinations of process parameters on hole quality [10]. Analysis of variance (ANOVA) test was conducted to determine the significance of each process parameter on drilling.

II. EXPERIMENTAL DETAILS

2.1 Experimental Plan

Table 1. Input parameters and their levels of setting

Parameters	**Settings**		
	Level 1	**Level 2**	**Level 3**
Drill Diameter (mm)	8	9.5	11.5
Spindle Speed (rpm)	700	900	1100
Feed rate (mm/min)	100	140	180
Drill material	HSS (M2)	HSS (M42)	Carbide

Table 2. Actual Experimental Design

Expt. Runs	**Drill Diameter (mm)**	**Spindle Speed (rpm)**	**Feed Rate (mm/min)**	**Drill Material**
1	8	700	100	HSS.M2
2	8	900	140	HSS.M42
3	8	1100	180	Carbide
4	9.5	700	140	Carbide
5	9.5	900	180	HSS.M2
6	9.5	1100	100	HSS.M42
7	11.5	700	180	HSS.M42
8	11.5	900	100	Carbide

9	11.5	1100	140	HSS.M2

For conducting the experiments Taguchi L9 (3^4) array is selected. In this array, the numbers of factors are 4 and the numbers of levels are 3. However total numbers of runs are 9. Therefore, numbers of factor selected for the experiments are feed rate (100-140-180 mm/min), spindle speed (700-900-1100 rpm), diameter of drill (8-9.5-11.5 mm) and drill material (HSS.M2-HSS.M42-Carbide). Table 2 shows the actual experimental run with L9 orthogonal array and Table 1 shows the input parameters and their settings for experiment. Roughness (*Ra*) of drilled hole is selected as a response variable for the experiment.

2.2 Tooling and Measurements

The preparation of the experiment started with the cutting of nine work pieces to the required size from a plate of GFRP. These GFRP work pieces are exactly made to size 57 mm X 57 mm X 5 mm. A Vertical Milling Centre (VMC-1260) is used for drilling purpose having 12KgF maximum load table capacity. The GFRP workpiece is hold by a mechanical vice as shown in Fig. 1. Initially a centre drill is carried out so as to ensure accurate drilling of GFRP workpiece. Then according to L9 orthogonal array a drilling is conducted on each workpiece. After drilling the workpiece is unclamped from vice and then it was dried by a pressurised air nozzle. Each drilled workpiece is covered by a plastic sticky paper for protecting hole by dust and swarf.

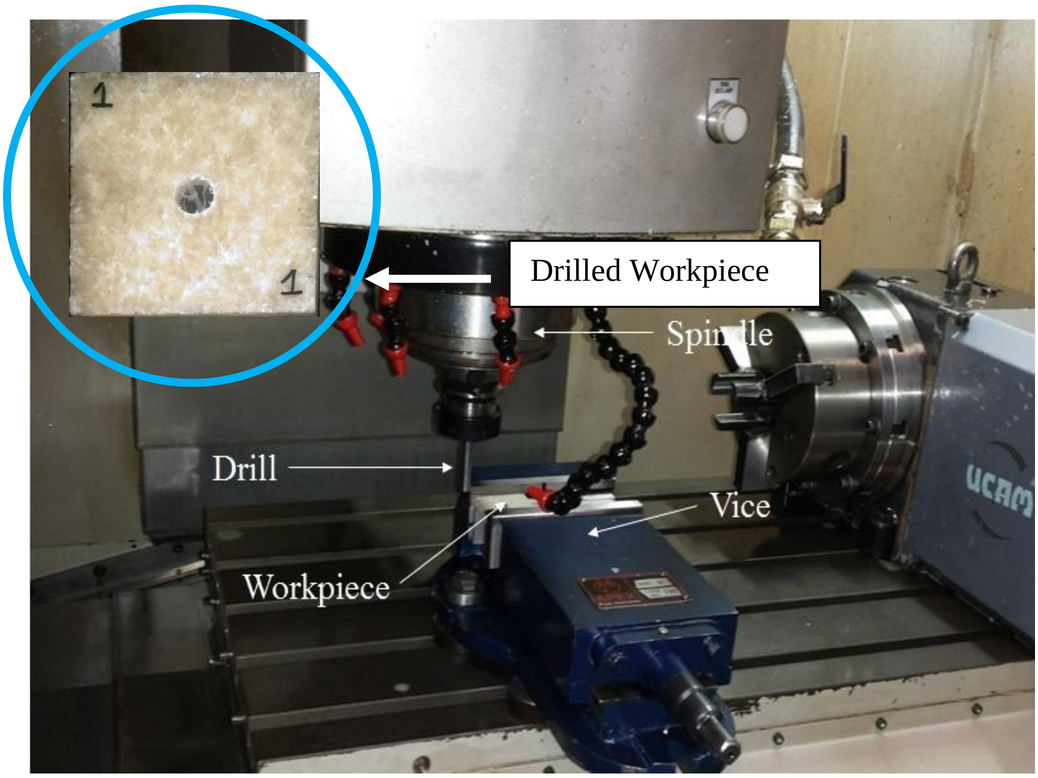

Fig. 1. Closed view photograph of experimental set up

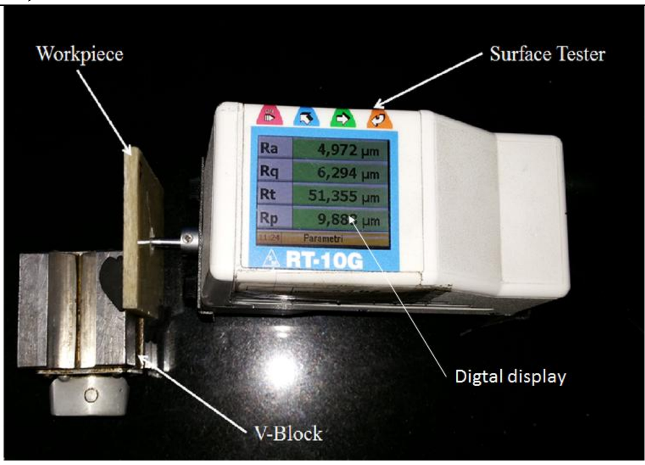

Fig. 2. Setup of measuring surface roughness of drilled hole in GFRP

A roughness tester shown in Fig. 2. made by Strumentazione, Japan Model RT10G having LC 0.001 µm is used to find out Roughness value (*Ra*) of each drilled hole. The probe is turned by 90º to persist the measurements in the grooves between shoulders. On the integrated display, which is shielded by a protective membrane, the roughness parameter can be read easily. In this machine up to 30 readings can be save to ensure mobility. The tester delivered with the skidded pickup SM-SB10, V-block, roughness master.

III. RESULTS AND DISCUSSION

The experiment is performed according to Taguchi L9 orthogonal array. Based on the experimental work, the results were analyzed and are presented in this section. Table 3 shows the results of roughness values (*Ra*). The analysis was conducted to determine the significant factors influencing output variables using statistical software as 'Minitab R-16'. The analysis is carried out to predict the response variable for the unknown value of the input factors. \

Table 3. Results of Roughness values of drilled holes in GFRP (*Ra*)

Substrate No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Roughness values (µm)	1.745	1.247	2.101	0.522	0.873	2.783	0.482	1.936	2.257

The main effects plots for roughness values (ANOM) and the table of analysis of variance (ANOVA) are shown in Fig. 3 and Table 4 respectively. It is observed from the ANOVA that the input factor spindle speed shows a statistical significance on roughness of drilled hole at 95% confidence level as the P-value in the ANOVA for any input variable is less than 0.05. The spindle speed is a more dominating factor on the final surface quality of drilled holes in GFRP material. The percentage contribution of the input variables influencing the roughness are drill diameter: 2.66 %, spindle speed: 64.47 %, feed rate: 32.36 % and drill material: 1 %. The effect of each input factors on the roughness is presented using ANOM plots.

Table 4. ANOVA for Roughness (*Ra*) of drilled GFRP

Source	**DF**	**SS**	**MS**	**F**	**P**	**% Contribution**
Drill diameter	2	0.140	0.070	0.08	0.922	2.66
***Spindle speed**	2	3.391	1.695	5.45	0.045	64.47
Feed rate	2	1.702	0.851	1.44	0.309	32.36
Drill material	2	0.026	0.013	0.01	0.985	1
Error	0	0	-	-	-	-
Total	8	5.259	-	-	-	-

*Statistically Significant Factor

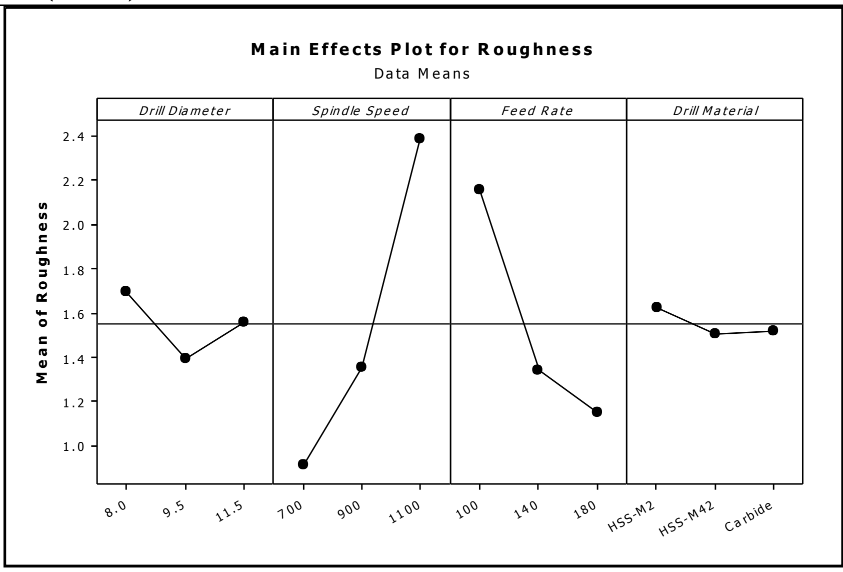

Fig. 3. Main Effect Plots for Roughness of Drilled GFRP

3.1 Effect of drill diameter on roughness of drilled hole

The main effect plot shows that the drill material is having non linear effect on roughness of drilled hole. When the drill diameter is 8 mm the roughness value is 1.7 µm. If the drill diameter is changed to 9.5 mm the roughness value is decreased up to 1.35 µm. Again the roughness of drilled hole is increased up to 1.55 µm when the drill diameter is 11.5 mm. It is seen that as the drill diameter increases it plays a crucial role in maintaining the quality of drilled hole in GFRP substrates.

3.2 Effect of spindle speed on roughness of drilled hole

In CNC drilling operation spindle speed shows a linear effect on roughness of drilled hole and also is having dominating factor for the same. If the spindle speed varies from 700 rpm to 900 rpm to 1100 rpm then the roughness value is also increased from 0.5 µm to 1.3 µm to 2.4 µm. It is observed that when the spindle speed is high a sudden temperature rise in between tool and chip interface on account of higher friction. In this case burned black chips are generated while machining. Lower spindle speed gives a better drilled hole quality on GFRP material.

3.3 Effect of feed rate on roughness of drilled hole

It is observed from the main effect plot that feed rate also shows a linear effect on drilled GFRP substrates. At lower feed rate i.e. at 100 mm/min the roughness of drilled hole is quiet high as 2.2 µm. When the feed rate increases up to 140 mm/min, the roughness value is decreases up to 1.3 µm. However, next step of feed rate increment the roughness value suddenly dropped up to 1.5 µm. Higher feed rates gives the good surface quality of drilled hole.

3.4 Effect of drill material on roughness of drilled hole

It is observed from the main effect plot that drill material is having a non linear effect on roughness of drilled GFRP substrates. If the material is HSS-M2, the roughness value is 1.6 µm. The roughness value is decreased in small amount up to 1.5 µm, when the drill material is HSS-M42. Again the roughness value is increased in small amount up to 1.55 µm, when the drill material is Carbide.

IV. CONCLUSIONS

The present work includes the extensive experimental analysis of CNC drilling processes to understand the ability of the process with effective cutting parameters to generate high degree of drilled holes on GFRP composite material. From the experimental results and subsequent Taguchi's analysis some of the major conclusions can be deduced from the study. As far as the effect of input factors are considered, the factor spindle speed is having dominating effect on final surface quality of drilled hole in GFRP substrate, while the feed rate shows the secondary effect on roughness of drilled holes. It is seen that minimum roughness value is observed as 0.522 µm in this experiment. Also moderate size of drill diameter gives the good drilled hole quality in the GFRP composite material.

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