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Some Studies on Delamination of Glass Fiber Reinforced Plastics (GFRP) in CNC Milling

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Abstract— Currently glass fiber-reinforced plastics (GFRP) are being widely used in variety of Engineering applications in many different fields such as aerospace, automotive and aircraft industries due to their properties such as light weight, high modulus, high specific strength and high fracture toughness. Milling of GFRP composite materials is a rather complex assignment owing to its heterogeneity and the number of problems, such as surface delamination, which appear during the machining process, related with the characteristics of the material and the machining parameters. Present paper focuses the experimental details to find out delamination factor on GFRP composite laminate by using Taguchi's DOE L9 OA. 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 nearly predominant influence on the delamination factor of drilled holes on GFRP composite by using CNC milling process.
Keywords- GFRP composite; Delamination factor; Drilling; DOE; ANOVA

I. INTRODUCTION

Milling is the universal frequently used machining operation in manufacturing parts of fiber-reinforced plastics, because components made of composites are commonly shaped by net-shape components that often need the removal of excess material to organize tolerances, and milling is used as a corrective operation to produce well-defined and high quality drilled surfaces. In recent years, glass Fiber-reinforced plastics (GFRP) are being widely used in variety 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 milling of GFRP material by conventional tools has shown that the quality of the cut surface especially drilled hole is strongly dependent on the cutting parameters, tool geometry, tool material, work piece material, machining process, etc.

Milling of GFRP composite materials is a rather difficult task owing to its heterogeneity and the number of problems, such as surface delamination, which appear during the machining process, associated with the characteristics of the material and the cutting parameters. An improper selection of these parameters can lead to unacceptable material degradation, such as fiber pull out, matrix cratering, thermal damage and widespread delamination. Delamination factor (*Fd*) is defined as the quotient between the maximum width of damage (W_{max}) and width of cut (W) as shown in Figure 1.

$$Fd = \left(\frac{W \max}{W} \right)$$

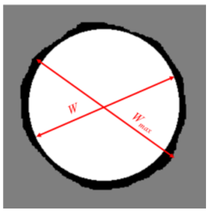

Figure 1. Measurement of maximum width of damage of a drilled hole in GFRP

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 was used to perform the Taguchi and ANOVA analysis. Taguchi design with L9 orthogonal array was employed. The response variable chosen is delamination factor of the drilled GFRP components. For measuring machined surface characteristics contact measurement technique is considered. Delamination is measured by cutting workpiece into two halves. The main objective of the work is to find our delamination factor of drilled GFRP substrates. Following paragraphs shows some of the recent key publications on machining of GFRP.

Hocheng H. *et al.* (2003) investigated the effects of various drill geometries were rarely discussed in analytical fashion [4]. This study presents an inclusive 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 assessment 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 point out 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 [7]. A map of experiment based on Taguchi was established with prefixed cutting parameters and the machining was performed. Author examined that the depth of cut are recognized to make the most considerable contribution to the overall performance as compared to cutting velocity and feed rate. The factors which lead to the surface delamination accessible in milling carbon fiber reinforced plastic (CFRP) with PCD tool have been studied by Yong Guo Wang *et al.* (2011) [10]. The surface delamination is summarized by analyzing the testing 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 [1]. 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 carried out for GFRP composite plates using solid carbide end mills with different helix angles [5]. The machining parameters such as, spindle speed, feed rate, helix angle and Fiber 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 [6]. The machining parameters such as, and Fiber 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 recognized considering milling with prefixed cutting parameters in Natural Fiber-Reinforced Plastic (NFRP) composite materials using cemented carbide end mill [3]. 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 with 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 [8]. Analysis of variance (ANOVA) test was conducted to determine the significance of each process parameter on drilling.

II. EXPERIMENTAL DETAILS

2.1. Experimental Plan

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 (1000-1500-2000 rpm), diameter of drill (8-10-12 mm) and drill material (HSS-Ceramic-Carbide). Table 1 shows the input parameters and their settings and Table 2 shows the actual experimental run with L9 orthogonal array for the experiments. Delamination factor (*Fd*) is selected as a response variable for the experiment.

Table 1. Input parameters and their level of settings

Parameters	Level of Settings of Parameters		
	Level 1	Level 2	Level 3
Drill Diameter (mm)	8	10	12
Spindle Speed (rpm)	1000	1500	2000
Feed Rate (mm/min)	100	140	180
Drill Material	HSS	Ceramic	Carbide

Table 2. Actual experimental design with L9 OA

Expt. Runs	Drill Dia. (mm)	Spindle Speed (rpm)	Feed Rate (mm/min)	Drill Material
1	8	1000	100	HSS
2	8	1500	140	Ceramic
3	8	2000	180	Carbide
4	10	1000	140	Carbide
5	10	1500	180	HSS
6	10	2000	100	Ceramic
7	12	1000	180	Ceramic
8	12	1500	100	Carbide
9	12	2000	140	HSS

2.2. Tooling and measurements

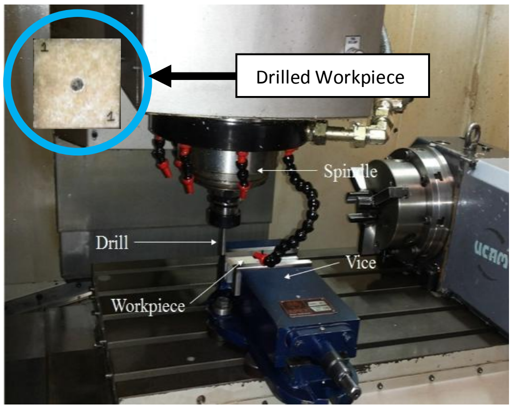

Figure 2. Closed view setup of operation

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 50 mm X 50 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 vice as shown in Figure 2. Initially a centre drill was made so as to ensure accurate drilling of GFRP workpiece. Then according to L9 orthogonal array a drilling operation is conducted in each workpiece. After drilling, the workpiece is unclamped from vice and then it was dried by a pressurized air nozzle. Each drilled workpiece is covered by a plastic wrapped paper for protecting hole by dust and swarf.
A profile projector made by DYNASCAN Model PT-300 is used to find out delamination factor (*Fd*) of each drilled hole. It consists of a projector having a light sensor, collimating lens, work holding table, projection system having mirrors and lenses, screen on which image of workpiece is projected and a measuring device. The light source is a tungsten lamp, filament lamp or high pressure mercury lamp. The object to be tested is placed on the work table. The light beam after passing the object to the projector passes into the projection system comprising lenses and mirrors. The lenses are used to obtain desired magnification and mirrors to direct the beam of light on screen.

RESULTS AND ANALYSIS

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. Measurement of Delamination Factor (Fd)

Substrate Nos.	1	2	3	4	5	6	7	8	9
Delamination Factor (µm)	1.0026	1.0194	1.0013	1.0243	1.0155	1.0002	1.0228	1.0786	1.0010

Table 4. ANOVA Table for Delamination Factor (Fd)

Source	DF	SS	MS	F	P	% Contribution
Drill diameter	2	0.001159	0.000579	0.94	0.442	23.82
Spindle speed	2	0.002069	0.001034	2.22	0.190	42.53
Feed rate	2	0.000347	0.000173	0.23	0.801	7.13
Drill material	2	0.001289	0.000645	1.08	0.397	26.52
Error	0	0	-	-	-	-
Total	8	0.004864	-	-	-	100

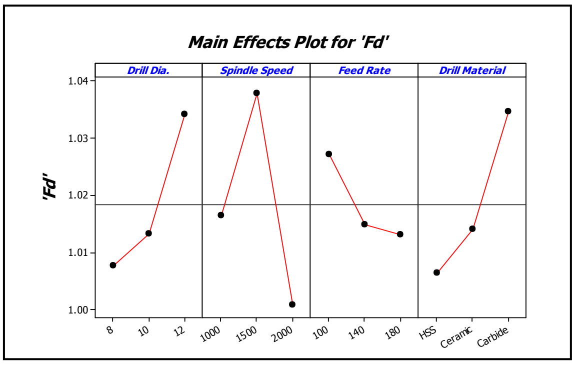

Figure 3. Main effects plots for Delamination factor (Fd)

Table 3 shows the results of delamination factor (*Fd*). The analysis is conducted to determine the significant factors influencing output variables using statistical software named as 'Minitab R-16'. An analysis is done to predict the response variable for the unknown value of the input factors.
The main effects plots for Delamination factor (ANOM) and the table of analysis of variance (ANOVA) are shown in Figure 3 and Table 4 respectively. It is observed from the ANOVA table, there is no statistically significant factor in this experiment. Since the P-value in the ANOVA table for any input parameter is not less than 0.05, there is a not statistically significant relationship between any input parameter and the response variables at the 95.0% confidence level. Noticed that the highest P-value is 0.801 in the ANOVA table. Since the P-value is not less than 0.05, that term is not statistically significant at the 95.0% confidence level. The percentage contribution of the input variables influencing drill diameter: 23.82%, spindle speed: 42.53%, feed rate: 7.13% and drill material: 26.52%.

CONCLUSION

The present work includes the general experimental investigation of CNC milling process to understand the ability of the process with effective cutting parameters to generate high degree of drilled holes on GFRP composite. 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 nearly predominant influence on the delamination factor of drilled holes on GFRP composite. It is seen that minimum delamination factor observed as 1.0002 µm in the experiment. Also the drill material of HSS given the good drilled hole quality in the GFRP composite.

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