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Delamination analysis of carbon-glass hybrid polymer composites in drilling process

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Abstract— Hybrid composites of carbon-glass fibre have gained wide application in various facets of engineering due to material property enhancements. In common practices, hybrid composite are manufactured to near-net shapes; however, finishing operation that involves machining operation such as drilling is essential for assembly with other components. In this paper, the parametric effects of controlled parameters on delamination during drilling carbon/glass hybrid polymer composite are presented. Taguchi design of experiment is employed to statistically analyze the drilling performance of carbon/glass hybrid composite. The experiments were conducted to elucidate the effects of spindle speed, feed rate and tool geometry on delamination using tungsten carbide (K20) tool of 8 mm diameter. The results showed that the delamination values are greatly influenced by the feed rate and tool geometry rather than spindle speed. This is likely due to the higher thrust force exerts on the workpiece during drilling operation.

Index Terms— Carbon and glass hybrid composite, Delamination, Drilling, Taguchi method, Analysis of Variance (ANOVA)

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1 Introduction

With raising the price of oil in recent years, the automotive designers and engineers have deeply concerned about light-weight material in structure design to save the consumption of oil [1]. These targets can be achieved by hybridization two different type of fibre reinforced plastic (FRP) either by distinct physical or mechanical properties such as carbon-glass hybrid FRP composite. It can provide significant weight savings components and exhibit high specific strength and modulus, excellent corrosion resistance and most importantly is the low material cost which is not easily obtain from same fibre reinforcements composite and metal alloys [2].

Although composite components are produced to near- net shape, secondary machining such as drilling is needed to achieve the tolerances requirements for final stages needs such as make holes for screws, rivets and bolts to assembly different composite components. Machining hybrid FRP composite materials is a critical task due to its inhomogeneous, anisotropic and extremely abrasive properties. Hence, the defects present in drilling FRP composite such as delamination, fibre pullout, matrix-cracking and tool wear are different from those encountered in drilling metals [3]. Damage-free and precise holes must be produced from drilling process to ensure the assembly parts have high strength and fatigue life.

Based on literature, delamination has been recognized as a major defect in drilling process due to tendency in poor assembly tolerance and degrading the long term performance [4]. In aircraft industry, delamination leads approximately 60% part rejections during final assembly process [5]. Two type of delamination in drilling composite are known as peel up at entrance and push out at exit planes of the composite laminates. Most of previous studies have been found delamination is dependent of tool geometry and parameter setting during drilling process [6–8]. Davim et al. [7] and kilickap [9] noticed that delamination increased with cutting speed and feed rate during conventional drilling carbon or glass FRP composite using design experiments. However, Gaitonde et.al [10] reported that drilling associated delamination decreased with cutting speed during high speed drilling in carbon FRP composite laminates. In Tsao and Hocheng [11] studies has been shown thrust force during drilling is one of factors affected the size of delamination zone and it is believed that below the critical thrust force no delamination appears. They have noticed that the critical thrust force depend on input variables such as feed rate, spindle speed, tool material and geometry in drilling process. Abrao et.al [12] focused on effect of cutting tool geometry on thrust force and delamination when drilling glass fibre reinforced plastic composite. Lower thrust force were obtained when drilling composite laminates using special drill bits such as step drill bits and candle drill bits or small point angle drill bit. Thus, decreasing the thrust force in drilling may be one of the key to produce a quality hole in composite laminates.

Up to now, there have focused in analyzing factors of delamination in drilling single type of FRP composite such glass FRP composite or carbon FRP composite. Simultaneously, the study on effects in drilling hybrid composite laminates has so far not been experimentally investigated by other researcher. Based on above reasons, the purpose of this paper is to present a robust method (Taguchi and ANOVA) to select the optimum parameter and significant factors from feed rate, spindle speed and tool geometry based on delamination factor during drilling carbon-glass FRP hybrid composite laminates.

2 Methodology

2.1 Sample fabrication

The delamination in drilling process have been measured for machining of carbon-glass FRP hybrid composites under different cutting conditions with uncoated cement carbides tool

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using the application Taguchi's orthogonal array and ANOVA analysis. Based on the analysis results, the optimum drilling parameters for the minimum delamination have been determined. The feed rate is dominant factor for delamination followed by spindle speed for peel up and tool geometry push out delamination. For achieving high quality hole on carbon-glass FRP hybrid work piece, middle range spindle speed (7500 rpm) , lower feed rate (0.08 mm/rev) and lower point angle such as step drill are preferred. The optimum setting can be a reference or guideline for composite industry to minimum the delamination in drilling hybrid composite.

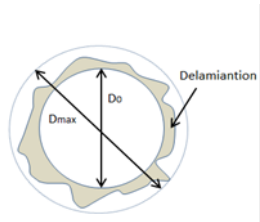

Fig.1: Delamination factor scheme

2.2 Machine tool setup and data acquisition

The delamination in drilling process have been measured for machining of carbon-glass FRP hybrid composites under different cutting conditions with uncoated cement carbides tool using the application Taguchi's orthogonal array and ANOVA analysis. Based on the analysis results, the optimum drilling parameters for the minimum delamination have been determined. The feed rate is dominant factor for delamination followed by spindle speed for peel up and tool geometry push out delamination. For achieving high quality hole on carbon-glass FRP hybrid work piece, middle range spindle speed (7500 rpm) , lower feed rate (0.08 mm/rev) and lower point angle such as step drill are preferred. The optimum setting can be a reference or guideline for composite industry to minimum the delamination in drilling hybrid composite.After conducting experiments, the peel up and push out delamination zone was measured using optical microscope (Olympus Tokyo, SZ2-STU1) and Image J software. The delamination factor (F_d) [14] was then determined as follows:

$$F_d = D_{max} / D_0 \quad (1)$$

Where the unit of Dmax is the maximum diameter of damage hole, D0 is the actual diameter of hole.The average reading of five trials of delamination factor was taken base on schema shows in Fig. 1.

2.3 Taguchi experimental design

Taguchi is a combining the experiment design theory and quality loss function concept to study the effect of parameter space with small number of experiment and minimum cost but with reliable results [6]. The experiments were conducted according to orthogonal array of L_{27} which each combination factors appears equal number of times. Three important machining process parameter, namely feed rate,*f*, spindle speed,*s*, and special tool geometry in three different level were considered in drilling carbon-glass FRP hybrid composite, as shown in Table 1. Three different machining levels were selected based on the knowledge for composite industry, machining tool limitation and little work in the reported literature. The experiments results (delamination) are analysis in lower the better signal-to-noise (S/N) ratio. The formula used to calculating lower the better S/N ratio is given below:

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

Where *y* is observed response value and *n* is number of replications. The response table and graph from S/N ratio data was used to determine the optimal parameter for a quality drilling process. Furthermore, analysis of variance (ANOVA) was performed to estimate significant parameters contribution to the quality response [15]. Software Minitab 16 was used this study to analysis and evaluate the delamination based on S/N ratio and ANOVA data.

Table 1: Experimental parameters and their level

Factors	*Level* 1 (low)	2 (medium)	3 (high)
A: Spindle speed (rpm)	5000	7500	10000
B: Feed rate (mm/rev)	0.08	0.16	0.24
C: Tool geometry (point angle :85^0)	Twist	Step	Brad and spur

3 RESULTS AND DISCUSSION

The delamination in drilling process have been measured for machining of carbon-glass FRP hybrid composites under different cutting conditions with uncoated cement carbides tool using the application Taguchi's orthogonal array and ANOVA analysis. Based on the analysis results, the optimum drilling parameters for the minimum delamination have been determined. The feed rate is dominant factor for delamination followed by spindle speed for peel up and tool geometry push out delamination. For achieving high quality hole on carbon-glass FRP hybrid work piece, middle range spindle speed (7500 rpm) , lower feed rate (0.08 mm/rev) and lower point angle such as step drill are preferred. The optimum setting can be a reference or guideline for composite industry to minimum the delamination in drilling hybrid composite.

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Table 2: Response table for peel up based on S/N ratio

Level	Speed	Feed	Geometry
1	-1.4678	-0.7446	-1.1486
2	-1.1540	-1.0881	-1.1993
3	-0.9740	-1.7632	-1.2480
Delta	0.4938	1.0186	0.0995
Rank	2	1	3

Table 3: Response table for push out based on S/N ration

Level	Speed	Feed	Geometry
1	-1.820	-1.630	-1.619
2	-1.785	-1.840	-1.586
3	-1.813	-1.947	-2.213
Delta	0.035	0.318	0.627
Rank	3	2	1

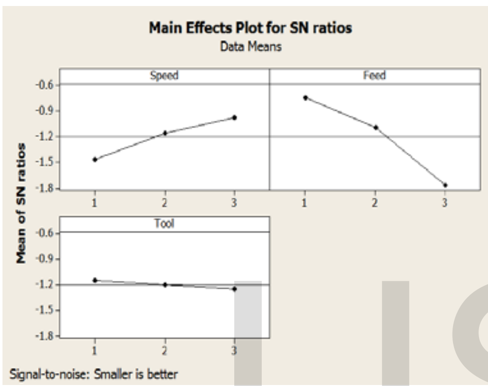

Fig.2: Response table for peel up delamination

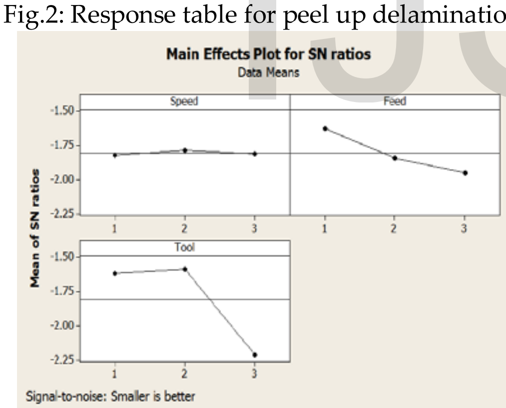

Fig.3: Response table for push out delamination

In response graph and table, realizing that some of the responses are larger than the other, but it is not providing a clear criterion values for estimated each design parameters to the contribution of the minimum delamination. The purpose can be achieved by ANOVA through calculating the variability of the computed S/N ratio for each parameter and associated degree of freedom in the experiment [17]. Table 4 shows the ANOVA analysis for peel up delamination and the effects are obtained from response table. The F-value of the factors which is more than table value; $F_{0.05,\ 2,8}= 4.46$ are considered as significant at 95%confidence level. From it is found that feed is the major factor affecting the peel up delamination followed by spindle speed. In the Table 5, feed rate and tool geometry are found to be the most significant factors influencing the push out delamination.

Table 4: ANOVA results of peel up delamination

Source	Degree of freedom	Sum of squares	Mean square	F-value	P
Speed	2	1.12396	0.56198	13.62	0.003
Feed	2	4.83439	2.41719	58.58	0.000
Geometry	2	0.04453	0.02227	0.54	0.603
Speed x Feed	4	0.39570	0.09892	2.40	0.136
Speed x Geometry	4	0.28367	0.07092	1.72	0.238
Feed x Geometry	4	0.05183	0.01296	0.31	0.861
Residual Error	8	0.33011	0.04126		
Total	26	7.06418			

The delamination in drilling process have been measured for machining of carbon-glass FRP hybrid composites under different cutting conditions with uncoated cement carbides tool using the application Taguchi's orthogonal array and ANOVA analysis. Based on the analysis results, the optimum drilling parameters for the minimum delamination have been determined. The feed rate is dominant factor for delamination followed by spindle speed for peel up and tool geometry push out delamination. For achieving high quality hole on carbon-glass FRP hybrid work piece, middle range spindle speed (7500 rpm) , lower feed rate (0.08 mm/rev) and lower point angle such as step drill are preferred. The optimum setting can be a reference or guideline for composite industry to minimum the delamination in drilling hybrid composite.

Table 5: ANOVA results for push out delamination

Source	**Degree of freedom**	**Sum of squares**	**Mean square**	**F-value**	**P**
Speed	2	0.00601	0.00301	0.11	0.899
Feed	2	0.47098	0.23549	8.42	0.011
Geometry	2	2.24317	1.12158	40.10	0.000
Speed x Feed	4	0.16030	0.04007	1.43	0.308
Speed x Geometry	4	0.08123	0.02031	0.73	0.598
Feed x Geometry	4	0.11941	0.02985	1.07	0.432
Residual Error	8	0.22376	0.02797		
Total	26	3.30486			

4 Conclusion

The delamination in drilling process have been measured for machining of carbon-glass FRP hybrid composites under dif-

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ferent cutting conditions with uncoated cement carbides tool using the application Taguchi's orthogonal array and ANOVA analysis. Based on the analysis results, the optimum drilling parameters for the minimum delamination have been determined. The feed rate is dominant factor for delamination followed by spindle speed for peel up and tool geometry push out delamination. For achieving high quality hole on carbon-glass FRP hybrid work piece, middle range spindle speed (7500 rpm) , lower feed rate (0.08 mm/rev) and lower point angle such as step drill are preferred. The optimum setting can be a reference or guideline for composite industry to minimum the delamination in drilling hybrid composite.

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REFERENCES

[1] P. Feraboli and A. Masini, "Development of carbon/epoxy structural components for a high performance vehicle," Composites Part B: Engineering, vol. 35, no. 4, pp. 323–330, Jan. 2004.

[2] K. S. Pandya, C. Veerraju, and N. K. Naik, "Hybrid composites made of carbon and glass woven fabrics under quasi-static loading," Materials & Design, vol. 32, no. 7, pp. 4094–4099, Aug. 2011.

[3] W. Chen, "Some experimental investigations in the drilling of carbon fibre-reinforced plastic (CFRP) composite laminates," pp. 1097–1108, 1996.

[4] S. R. Karnik, V. N. Gaitonde, J. C. Rubio, a. E. Correia, a. M. Abrão, and J. P. Davim, "Delamination analysis in high speed drilling of carbon fiber reinforced plastics (CFRP) using artificial neural network model," Materials & Design, vol. 29, no. 9, pp. 1768–1776, Oct. 2008.

[5] U. a. Khashaba, "Delamination in drilling GFR-thermoset composites," Composite Structures, vol. 63, no. 3–4, pp. 313–327, Feb. 2004.

[6] C. C. Tsao, "Investigation into the effects of drilling parameters on delamination by various step-core drills," Journal of Materials Processing Technology, vol. 206, no. 1–3, pp. 405–411, Sep. 2008.

[7] J. . Davim and P. Reis, "Study of delamination in drilling carbon fiber reinforced plastics (CFRP) using design experiments," Composite Structures, vol. 59, no. 4, pp. 481–487, Mar. 2003.

[8] H. Hocheng and C. . Tsao, "Comprehensive analysis of delamination in drilling of composite materials with various drill bits," Journal of Materials Processing Technology, vol. 140, no. 1–3, pp. 335–339, Sep. 2003.

[9] E. Kilickap, "Optimization of cutting parameters on delamination based on Taguchi method during drilling of GFRP composite," Expert Systems with Applications, vol. 37, no. 8, pp. 6116–6122, Aug. 2010.

[10] V. N. Gaitonde, S. R. Karnik, J. C. Rubio, a. E. Correia, a. M. Abrão, and J. P. Davim, "Analysis of parametric influence on delamination in high-speed drilling of carbon fiber reinforced plastic composites," Journal of Materials Processing Technology, vol. 203, no. 1–3, pp. 431–438, Jul. 2008.

[11] C. C. Tsao and H. Hocheng, "Evaluation of thrust force and surface roughness in drilling composite material using Taguchi analysis and neural network," Journal of Materials Processing Technology, vol. 203, no. 1–3, pp. 342–348, Jul. 2008.

[12] a. M. Abrão, J. C. C. Rubio, P. E. Faria, and J. P. Davim, "The effect of cutting tool geometry on thrust force and delamination when drilling glass fibre reinforced plastic composite," Materials & Design, vol. 29, no. 2, pp. 508–513, Jan. 2008.

[13] D. Liu, Y. Tang, and W. L. Cong, "A review of mechanical drilling for composite laminates," Composite Structures, vol. 94, no. 4, pp. 1265–1279, Mar. 2012.

[14] J. . Davim and P. Reis, "Study of delamination in drilling carbon fiber reinforced plastics (CFRP) using design experiments," Mar. 2003.

[15] N. S. Mohan, S. M. Kulkarni, and a. Ramachandra, "Delamination analysis in drilling process of glass fiber reinforced plastic (GFRP) composite materials," Journal of Materials Processing Technology, vol. 186, no. 1–3, pp. 265–271, May 2007.

[16] K. Palanikumar, L. Karunamoorthy, and R. Karthikeyan, "Assessment of factors influencing surface roughness on the machining of glass fiber-reinforced polymer composites," Materials & Design, vol. 27, no. 10, pp. 862–871, Jan. 2006.

[17] A. I. Azmi, "Machinability Study of Fibre- Reinforced Polymer Matrix Composites," University of Auckland, 2013.

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