INVESTIGATION OF PROCESS PARAMETERS IN MILLING GFRP COMPOSITES

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Abstract: High quality surface milling of Fibre reinforced Plastic (FRP) materials present variety of issues, such milling is one of the foremost oftentimes used material removal processes in machining of FRPs to produce a well-defined surface and has surface delamination related to the characteristics of the material and therefore the cutting parameters used. The surface quality and dimensional precision greatly have an effect on the elements throughout their useful life, especially in cases wherever the elements come in contact with different elements or materials. Optimization of machining parameters is an necessary step in machining. This project presents a new approach for optimizing the machining parameters on end milling of glass-fibre reinforced plastic (GFRP) composites. Optimization of machining parameters was done by Taguchi's L27 orthogonal array and milling experiments were conducted for GFRP composite plates using solid carbide end mills with various helix angles. The parameters of machining such as, spindle speed, feed rate and helix angle are optimized by multi-response concerns particularly surface roughness and delamination factor. Based on mean effective plots, the optimum levels of parameters have been investigated and significant contribution of parameters is determined by analysis of variance.

Keywords: ANOVA; Design of experiments; GFRP composites; Machining; Taguchi.

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1. Introduction

Composites are one of the foremost wide used materials as a result of their ability to totally different things and also the relative case of combination with alternative materials to serve specific functions and exhibit desirable properties. ls. Glass-fibre-reinforced plastic (GFRP), an advanced compound matrix composite material, the use of GFRP composites in engineering applications like automotive, aircraft and manufacture of space ships and ocean vehicles industries have been inflated significantly in recent years because of their light weight, high modulus, specific strength, superior corrosion resistance, high fracture toughness and resistance to chemical and microbiological attacks (Praveen Raj and ElayaPerumal, 2010[1]). GFRP composite materials are extremely abrasive when machined. Thus the selection of the cutting tool and the cutting parameters are very necessary within the machining process. Fibre-glass is simply a composite consisting of glass fibres, either continuous or discontinuous, contained within a compound matrix. The machining of composite is different from the conventional machining of metal because of the composites are anisotropic and non-homogeneous nature (Ramkumar et al., 2004[2]). Taguchi method has been widely used in engineering analysis. It provides a simple efficient and systematic approach to optimize design for performance quality and cost. These techniques consist of a plan of experiments with the target of acquiring information in a controlled method, executing these experiments, in order to get information regarding the behavior of a given process. The main trust over Taguchi technique is the use of parameter design that is an engineering technique for product or process design that focuses on determining the parameters settings manufacturing the best levels of quality Analysis of variance is a mathematical technique which is predicated on the least square approach. The purpose of ANOVA is to analyze the process parameters that significantly affect the performance characteristics. As per this technique, if the calculated value of the F ratio of the developed model does not exceed the standard tabulated value of F ratio for a desired level of confidence, then the model is considered to be adequate among the confidence limit. The variance ratio is denoted by F in ANOVA tables, it is the ratio of the mean square due to a factor and the error mean square. In robust design, F ratio will be used for qualitative understanding of the relative factor effects. A high value of F means the effect of that factor is large campared to the error variance. So, the larger the value of F, the more necessary is that factor in influencing the process response.

Adeel et al. (2010) [3] presented experimental study to optimize the cutting parameters using two performance measures, surface temperature and surface roughness of the workpiece. Optimal cutting parameters for each performance measure were obtained using Taguchi techniques. The results showed that the work piece surface temperature will be sensed and used effectively as an indicator to regulate the cutting performance and improves the optimization process, they concluded that it is possible to increase machine utilization and reduce production cost in an automatic manufacturing environment. Suleymanet al. (2011) [4] reported that the tool nose radius is the dominant factor on the surface roughness in turning of AISI steel.

Godfrey et al. (2006) [5] performed CNC drilling operations on 3004-O aluminum alloy, they developed the model of correlating the interactions of some drilling control parameters such as speed, feed rate and drill diameter and their effects on axial force and torque functioning on the cutting tool throughout drilling by means that of response surface methodology.

Machining force also plays a key role in analyzing the machining process of FRPs. The value of machining force within the work piece is determined using the equation: Fm=√(Fx^2+Fy^2+Fz^2). Generally, machining force increases with feed rate and decreases with cutting velocity. Evaluation of machining parameters of hand lay-up GFRP related to machining force was also applied by Paulo Davim et al. (2004) on milling using cemented carbide (K10) end mill.

Singh and Bhatnagar, (2006) [6] made an attempt to correlate the drilling-induced damage with the drilling parameters of unidirectional GFRP composite laminates. AsifIqbal et al. (2010)[7] investigated the relationships and parametric interactions between the three controllable variables (voltage, rotational speed of electrode and feed rate) on the material removal rate, electrode wear ratio and surface roughness in EDM (Electrical Discharge Machining) milling of unsullied steel by RSM.

Sivasankaran et al. (2009)[8] presented an artificial neural network (ANN) model for predicting and analyzing the workability behavior during cold upsetting of sintered Al-SiC powder metallurgy metal matrix composites under triaxial stress state condition.

Hoda et al. (2012) [9] predicted the values of some of metal removal rate, and surface roughness using artificial neural networks based on variation of certain predominant parameters of an electrochemical broaching process such as applied voltage, feed rate and electrolyte flow rate.

2. Experimentation and Methodology

2.1 Material and Tool

Glass fiber reinforced plastics (GFRP) plates made by Hand lay-up method is used for these experiments. GFRP plates are of 200 mm x 100 mm x 3 mm thick with 12 lay-up with desired milling operations. The GFRP composite plates used in this study is shown in fig.1 (before machining) and fig.2 (after machining). The cutting tool is made up of solid carbide of 5 mm diameter. The solid carbide end mill of different helix angles (25°, 35°, and 45°) are shown in fig..3.

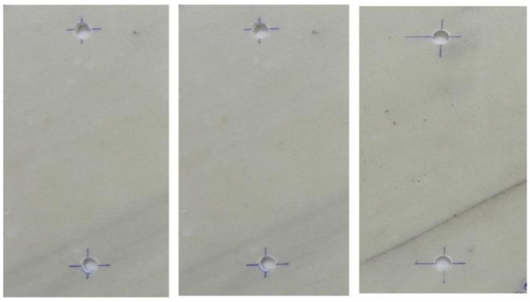

Fig.1 GFRP Composite Plates Before Machining

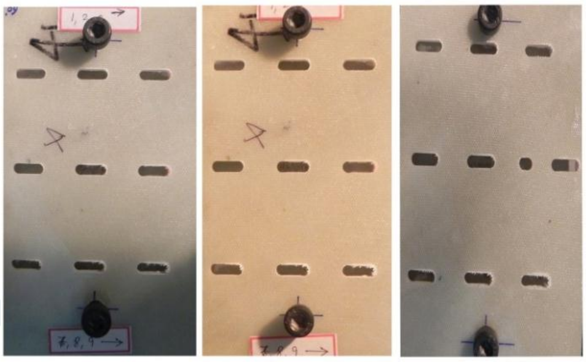

Fig2.GFRP Composites plates after machining

Fig. 3 solid carbide end mill with different helix angles

Table.1 Specification of milling machine

Type of machine	Vertical machine centre
Make	Hartford, Taiwan
Table size	810 x 400 mm
Spindle motor power	7.5 KW
Spindle speed	60-8000 rpm
Feed	1-7000 mm/min
X axis	510 mm
Y axis	400 mm
Z axis	400 mm
Accuracy (Positioning)	± 0.005/300 mm

Table.2 Process control parameters and their levels

			Levels		
Process parameter	**Units**	**Notation**	**1**	**2**	**3**
Helix angle	^{o}(degrees)	Ɵ	25	35	45
Spindle speed	rpm	N	2000	4000	6000
Feed rate	mm/rev	f	0.04	0.08	0.12

2.2 MEASUREMENTS

2.2.1 Measurement of Surface Roughness

The Output responses considered in this study are surface roughness (Ra) and delamination factor (Fd). The measurement and calculation of responses based on the input parameters are described below.

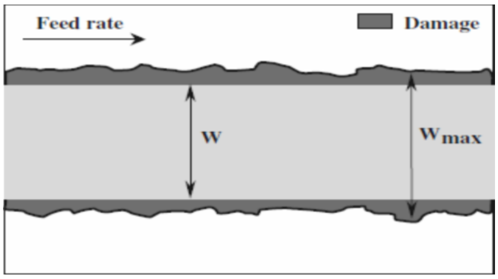

Fig. 4 Diagram Of Measurement That Were Made Over Each Milling Surface

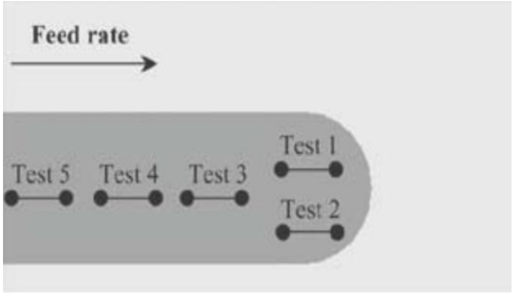

Fig. 5 Diagram Of Measurement That Were Made Over Each Milling Surface

2.2.2 Measurement of Delamination Factor

The damage caused on the GFRP composite material was measured perpendicular to the feed rate with a tool maker's microscope, as observed in Fig.6. The composite material was positioned and fixed on the XY stage glass of the microscope, and then the alignment of an initial measurement purpose with one of the cross-hairs was made on the machined feature. Moving the XY stage glass by turning the micrometer head with a Digital Counter to the final point with constant cross-hair has been measured the damage (maximum width). After the measuring of the maximum width of damage (W_{max}) suffered by the fabric, the damage normally appointed by Delamination factor (F_d) was determined. This factor is outlined as the quotient between the maximum dimension of damage (W_{max}), and the width of cut (W). The value of delamination factor (F_d) will be obtained by the subsequent equation:

$$Fd = W_{max} / W \quad (1)$$

W_{max} being the maximum width of damage in mm and W be the width of cut in mm

2.3. Plan of Experiments

Robust design is an engineering methodology for getting product and process conditions that are minimally sensitive to the varied causes of variation to produce high-quality product with low manufacturing costs. Taguchi's parameter design is an vital tool for robust design. It offers a simple and systematic approach to optimize design for performance, quality and cost. Taguchi methods that combine the experiment design theory and the quality loss function are applied to the robust design of product and process. Taguchi method uses a special design of orthogonal arrays to study the whole parameter space with a little number of experiments. The methodology of Taguchi for three factors at three levels is used for the experiments. The factors and levels assumed are tabulated in Table .2. The orthogonal array L27 is selected as shown in Table .3, which has 27 rows corresponding to the number of tests with the required columns. The plan of experiments contains 27 tests wherever the second column is assigned to the helix angle (Ɵ), the third column is assigned to the spindle speed (N) and the fourth column is to the feed rate (f). The quality characteristics are surface roughness and Delamination factor.

3. Results and Discussion

Analysis of the influence of each control factor (θ, N, and f) on the surface roughness was performed with a signal-to-noise (S/N) response table. The experimental design, results for surface roughness and delamination factor and S/N ratios are shown in Table .3. The control factors and their un-coded tool lives were included in this table.

Table 3. Response table

TCN	**Helix angle (^{o})**	**Spindle speed (rpm)**	**Feed rate (mm/rev)**	**Responses (Signal to Noise Ratio)**	
				Surface roughness	**Delamination factor**
1	25	2000	0.04	0.82	-0.08
2	25	4000	0.08	1.41	-0.13
3	25	6000	0.12	0.45	-0.16
4	35	2000	0.08	-0.83	-0.21
5	35	4000	0.12	-1.44	-0.10
6	35	6000	0.04	0.72	-0.18
7	45	2000	0.12	-4.03	-0.27
8	45	4000	0.04	-2.41	-0.21
9	45	6000	0.08	-2.28	-0.15
10	25	2000	0.04	-0.67	-0.10
11	25	4000	0.08	-1.94	-0.18
12	25	6000	0.12	-2.21	-0.29
13	35	2000	0.08	-4.19	-0.34
14	35	4000	0.12	-4.56	-0.48
15	35	6000	0.04	-3.41	-0.27
16	45	2000	0.12	-5.20	-0.56
17	45	4000	0.04	-3.97	-0.49
18	45	6000	0.08	-4.19	-0.51
19	25	2000	0.04	-2.86	-0.32

20	25	4000	0.08	-4.30	-0.40
21	25	6000	0.12	-4.71	-0.63
22	35	2000	0.08	-5.93	-0.50
23	35	4000	0.12	-6.36	-0.66
24	35	6000	0.04	-4.51	-0.27
25	45	2000	0.12	-7.89	-0.76
26	45	4000	0.04	-6.28	-0.40
27	45	6000	0.08	-6.53	-0.48

Table 4. S/N response table of surface roughness

Symbol	*Control factors*	*Average Signal to Noise ratio (db)*				*Rank*
		Level 1	Level 2	Level 3	Max-min	
θ	Helix angle (o)	-1.23	-2.46	-3.35	2.12	1
N	Spindle speed (rpm)	-2.47	-2.40	-2.16	0.32	3
f	Feed rate (mm/rev)	-1.80	-2.34	-2.91	1.11	2

It could be seen in Table 4. That the strongest influence was exerted by Helix angle, followed by Feed rate, and lastly Spindle speed respectively. Since the first level of the surface roughness was about -1.23db while the third level of the surface roughness was about -3.35db the difference being the most highest of2.12db. It is followed by the feed rate and spindle speed.

Table 5. S/N response table of Delamination factor

Symbol	*Control factors*	*Average Signal to Noise ratio (db)*				*Rank*
		Level 1	Level 2	Level 3	Max-min	
θ	Helix angle (o)	1.13	1.28	1.41	0.28	1
N	Spindle speed (rpm)	1.30	1.28	1.25	0.05	3
f	Feed rate (mm/rev)	1.21	1.27	1.35	0.14	2

It could be seen in Table 5. That the strongest influence was exerted by Helix angle, followed by Feed rate, and lastly Spindle speed respectively. Since the first level of the Delamination factor was about 1.13 db while the third level of the surface roughness was about 1.28 db the difference being the most highest of 0.28db. It is followed by the feed rate and spindle speed.

3.1. Main effects Plots on the surface roughness

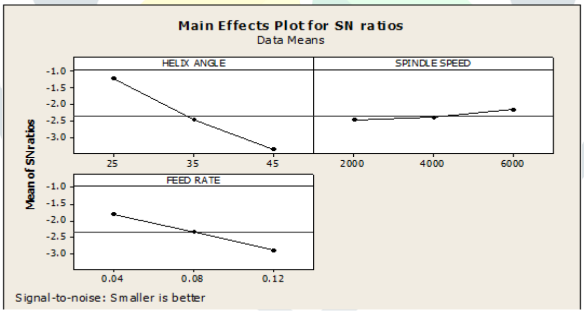

Figure 7 Main effect plots for surface roughness S/N ratio (dB)

Fig.7. shows the main effect plots for surface roughness of the work piece for S/N ratios, respectively. The greater is the S/N ratio, the smaller is the variance of the surface roughness around the desired value. Optimal testing conditions of these control factors might be very easily determined from the Fig.7, The best surface roughness value was at the higher S/N value in the response graph (Fig.7). For main control factors, Fig.7 indicates the optimum condition for the tested samples (Ɵ1, N3 and f1).

3.2. Analysis Of Control Factors For Delamination Factor.

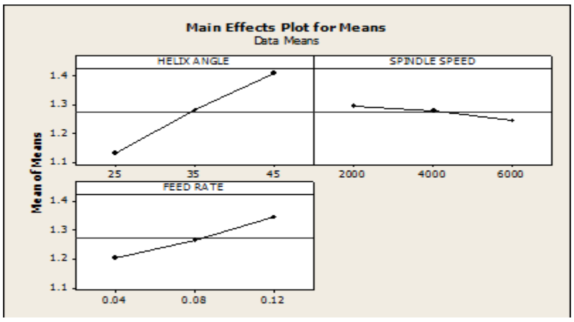

Figure 8 Main effect plots for Delamination factor of S/N ratio

for Delamination issue of the GFRP for S/N ratios and mean values, respectively. The greater is the S/N ratio, the smaller is the variance of the Delamination factor around the desired value. Optimal testing conditions of these control factors can be very easily determined from the response graph(Fig.8). The less Delamination factor value was at the higher S/N value in the response graph(Fig.8). For main control factors, table 5 indicates the optimum condition for the tested samples (θ3, N1, and f3).

4. Conclusions

The following conclusions can be drawn from results of surface roughness of GFRP work piece.

- The L27 Orthogonal array was adopted to investigate the effects of helix angle, Spindle speed and Feed rate on the surface roughness. The results showed that the Helix angle exerted the greatest effect surface roughness, feed rate and lastly the Spindle speed.
- The estimated S/N ratio using the optimal testing parameter for the surface roughness was calculated. Furthermore, the ANOVA indicated that the helix angle was high significant but alternative parameters were also significant on the surface roughness at 90th confidence level.
- The percentage contributions of Helix angle, feed rate and Spindle speed were about 88.99, and 10.25 and 0.643 on the surface roughness, respectively.

The following conclusions can be drawn from results of Delamination factor on machining GFRP work piece.

- The L27 Orthogonal array was adopted to investigate the effects of helix angle, Spindle speed and Feed rate on the Delamination factor. The results showed that the Helix angle exerted the greatest effect on Delamination Factor, feed rate and lastly the Spindle speed.
- The estimated S/N ratio using the best testing parameter for the Delamination factor was calculated. Moreover, the ANOVA indicated that Helix angle was high significant but alternative parameters were also significant on the Delamination factor at 90 percent confidence level.
- The percentage contributions Helix angle, feed rate and Spindle speed were about 61.33, 28.76 , and 9.244 on the Delamination factor, respectively.

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Nomenclature

θ : Helix angle
N : Spindle Speed
f : Feed rate
W_{max} : Maximum Width of Cut
W : Width of Cut
R_a : Surface Roughness
F_d : Delamination Factor

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