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An optimization of the machining parameters on delamination in drilling ramie woven reinforced composites using Taguchi method

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Abstract. In this study, the drilling parameters will be evaluated to obtain optimal parameters in minimizing the impact of drilling damage on composite materials reinforced by ramie woven. The impact of damage observed in the study is delamination that occurs in the drill hole, where the smaller value is desired. The drilling parameters are optimized using the Taguchi method with two control factors, namely the feed rate and spindle speed, each parameter is designed in three levels. This experiment then carried out on four different diameter drill bits, i.e., 4, 6, 8 and 10 mm. While experimental planning uses L_9 orthogonal arrays and the "smaller is better" approach is given as a standard analysis. By performing an analysis of variance (ANOVA) statistics can be determined for the significance of each drilling parameter. A series of experiments were carried out to get the appropriate optimization. It was found that the critical factor causing delamination in drilling is the feed rate followed by spindle speed, where this phenomenon occurs in each diameter of the drill bit.
Keywords: delamination, ramie woven, Taguchi method and ANOVA.

1. Introduction

The growing demand for composite materials and in 2017 is expected to reach $ 29.9B with a 7% annual growth projection [1]. The primary industries of composite users are in the fields of aerospace, construction, transportation, and wind energy. To obtain the final geometry of a composite product, manufacturing and machining processes will be needed, such as edge cutting machines and drill machines. However, it is challenging to obtained maximize finishing compared to the machining process in metals. The leading cause is the homogeneity of the material, anisotropic properties and complex damage phenomena that occur during the cutting process. This results in a poor surface finish, dimensional inaccuracy, and component rejection, [2].

According to Bosco et al. [3], during the machining process of the composite, various problems will arise, such as damage to reinforcing fibers, cracks in the matrix, detachment of bonds between fibers/matrices, fiber pull-out, fuzzing, thermal degradation, spalling and delamination. Delamination that appears on the entry and exit side of the composite is significant and must reduce because it can degrade bearing strength and material stability. Damage and delamination due to processing processes generally occur due to the thrust force of the cutting tool against the composite material. Delamination on the drilling process can be analyzed by looking directly at the delamination factor or by searching for thrust force or torque in drilling composite materials. Delamination is an occurrence of damage, which comes up because of the anisotropy and the brittleness of composite materials. In practice, it is needed to determine optimal machining parameters to reduce defects in the machining process to produce high-quality products.

Several approaches have been made before to get the machining process parameters to optimize production results, including using the Taguchi and ANOVA method applications. With this approach, researchers have been able to maximize the parameters used in machining on composite materials. Pang et al. [4], reported that the application of the Taguchi method in hybrid composites with epoxy matrix reinforced by halloysite nanotubes and aluminum was able to determine the best combination of machining parameters that provided an optimal response with lower surface roughness and cutting forces. Mohan et al. [5] used the Taguchi method to analyze delamination damage and use multiple factors in the process of GFRP composite material and suggested optimization of machining parameters. With the same method Sunny et al. [6], concluded that using ANOVA was able to reveal that the feed rate as the primary parameter in machining had much influence on the high delamination factor. Likewise in a study conducted by Tsao [7] using the Response Surface Methodology based on Taguchi method in evaluating the effect of drilling parameters on delamination damage found that there are several factors that are crucial factors in influencing damage factors, i.e.; cutting velocity ratio, feed rate, inner drill type and inner drill diameter. Balaji et al. [8], have applied Taguchi and ANOVA methods to observe the effect of machining parameters on drill bit vibrations and surface roughness. Delamination factors on the entry and exit side of the drilling process have also been analyzed using ANOVA by comparing between experimental results and ANFIS predictions, and it was found that on average the delamination damage at the entry side was smaller than on the exit side, [9]. With the same method Gashemi et al. [10], show that delamination factors increase from low and high parameter values in the experimental range of predetermined settings. Ultimately, delamination factors can be minimized by optimizing machining parameters. Hamdan et al. [11] claim that the Taguchi optimization method is the most effective method for optimizing machining parameters, where response variables can be identified. The optimal combination of drilling parameters is obtained using the signal-to-noise ratio (S/N) analysis, concluded that the feed rate and cutting speeds are the most influential factors on delamination. Meanwhile, the best delamination results are obtained at lower cutting speeds and feed rates, [12].

The primary goal of this paper is to optimization and analyze the effect of machining parameters, such as feed rate, spindle speed by different diameter drill bit on delamination damage produced by drilling polymer composites reinforced by ramie's woven (NFRP) using the Taguchi and ANOVA method designs.

2. Material and Experimental Set-up

2.1. Workpiece Material

The workpiece used in the experiment was made using the hand lay-up technique. Ramie's woven from ramie yarn type S12/3 (Fig. 1) is used as a polyesters YUKALAC @ 157 BQTN-EX reinforcement. The workpiece material is made in the form of plat measuring 200 × 200 × 5 ± 0.2 mm.

The drilling process uses a Pillar drill type TCA-35 ERLO (Fig.2.a). The drill bits used are type brad & drill bits spurs with diameters of 4, 6, 8 and 10 mm respectively (Fig.2.b). The drilling process is carried out without using coolant. The machining parameters used are feed rates 0.1, 0.18 and 0.24 mm/rev, while the spindle speed is 93, 443 and 1420 rpm. Delamination damage around the drill hole was taken by EPSON L220 scanner with 2400 DPI resolution, and delamination was measured using the image-pro plus 4.5 software application.

Fig. 1. Ramie woven with S12/3 type yarn

a) b)

Fig. 2. a) Pillar drill TCA-35 ERLO; b) "Brad & spur" drill's bit

2.2. Delamination Factor (F_d)

Most studies on the damage caused by drilling on composite materials say that the most common cause is delamination observed appearing on the entry and exit side of the hole. Delamination factor is using to illustrate the level of delamination damage. The delamination factor can be solved using the following equation:

$$F_d = \frac{D_{max}}{D} \quad (1)$$

Where, D_{max} is the maximum diameter created due to delamination around the hole and D is the hole or drill diameter.

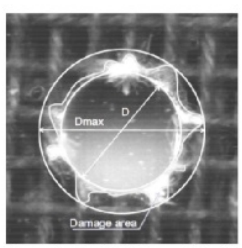


Fig.3. Illustrating the definition of delamination size

2.3. Taguchi method, analysis of variance (ANOVA) and experimental set-up

The Taguchi method was first coined by Dr. Genichi Taguchi in 194[illegible] this method was developed to improve the quality of products and processes and to be able to reduce costs and resources to a minimum. The Taguchi method is off-line quality control which means preventive quality control. Off-line quality control is carried out at the beginning of the life cycle product, namely repairs at the beginning to produce the product (to get right first time). Taguchi's contribution to quality is loss function, orthogonal array, and robustness. In the Taguchi method, there are three stages to optimize product design or production processes, namely system design, parameter design, and tolerance design [13]. Orthogonal arrays are used to determine the number of minimal experiments that can provide as much information as possible of all the factors that affect the parameters. The most critical part of orthogonal arrays lies in selecting the combination of levels from the input variables for each experiment. The experimental results are then converted into a signal-to-noise (S/N) ratio to measure quality characteristics that deviate from the desired value [5]. Furthermore, Mohan et al. [5] stated that in practice, there were three categories of quality characteristics in the S/N ratio analysis. The three categories and equations are as follows:

Nominal is the best characteristic:

$$\frac{S}{N} = 10\,\log\frac{\bar{y}^2}{S_{\bar{y}}^2} \tag{2}$$

Smaller the better characteristic:

$$\frac{S}{N} = -10\,\log\frac{1}{n}\left(\sum y^2\right) \tag{3}$$

And larger the better characteristic:

$$\frac{S}{N} = -\log\frac{1}{n}\left(\sum\frac{1}{y^2}\right) \tag{4}$$

Where, $\bar{y}$ is the average of observed data, s^2 the variation of y, n the number of observations, and y is the observed data.

In this study, the feed rate and spindle speed are two machining parameters that are used as control factors and each parameter is designed in three levels. This analysis is done at four different tool diameters and does not compare each other. Drilling parameters and levels used in this experiment are as shown in table 1. For the delamination factor, S/N ratio was calculated using *smaller is the best* characteristic.

Table 1. Parameters and levels of experiment set-up

Drilling parameter	Level 1 (Low)	Level 2 (Medium)	Level 3 (High)
Feed rate, *f* (mm/rev)	0.1	0.18	0.24
Spindle speed, *N* (rpm)	93	443	1420

Three control factors were accommodated into experimental studies using orthogonal arrays based on the Taguchi method L_9 as shown in Table 2. Taguchi method analysis in this study was done using Minitab v.17 software. Contributions of factors, interactions and the effect of each process on observed values were investigated using analysis of variance (ANOVA). ANOVA is a statistical technique to determine the degree of difference or similarity between two or more groups of data [14].

The desired level of significance in this analysis is α = 0.05, to identify drilling parameters that affect delamination damage.

Table 2. Orthogonal array based on Taguchi method L_9

Experiments	Feed rate	Spindle speed
1	1	1
2	1	2
3	1	3
4	2	1
5	2	2
6	2	3
7	3	1
8	3	2
9	3	3

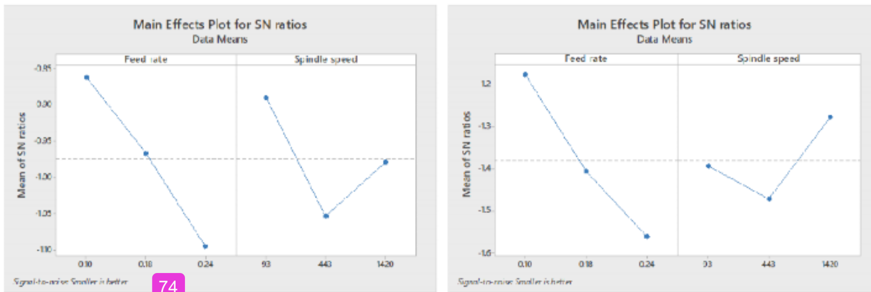
3. Result and Discussion

Diameter 10 mm

Table 3. S/N response table for delamination factor on diameter drill bits 10 mm.

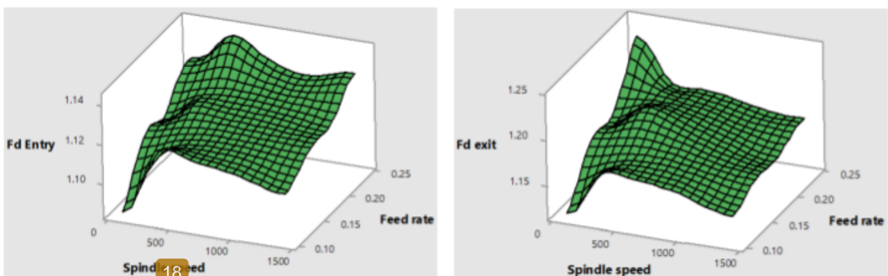
Exp. No.	Design of Experiment		Delamination Factor		S/N ratio	
	Feed rate	Spindle speed	Entry side	Exit side	Entry side	Exit side
1	0.10	93	1.085	1.119	-0.712	-0.976
2	0.10	443	1.121	1.172	-0.990	-1.379
3	0.10	1420	1.107	1.144	-0.884	-1.169
4	0.18	93	1.111	1.172	-0.918	-1.380
5	0.18	443	1.124	1.197	-1.014	-1.562
6	0.18	1420	1.118	1.158	-0.970	-1.277
7	0.24	93	1.128	1.234	-1.042	-1.823
8	0.24	443	1.143	1.185	-1.158	-1.476
9	0.24	1420	1.133	1.173	-1.084	-1.384

Tables 3, 5, 7 and 9 are experimental results which are transformed into the signal to noise (S/N) ratio, each table is made in different diameters of drill bits. Fig.4 shows the effect of parameters on delamination damage on the entry side and exit side of the borehole. On the input side the optimal parameters are obtained at the feed rate of 0.1 mm/rev and the spindle speed of 93 rpm, likewise on the output side of the optimum occurs at the feed rate 0.1 mm/rev but differs from the spindle speed, the optimal parameters are obtained at the spindle speed of 1420 rpm. From the two parameters, it can be seen that the addition of the feed rate significantly causes the increase in delamination damage, whereas the increase in the spindle speed does not affect to the delamination damage substantially. These results are in line with several previous studies e.g., Gashemi et al. [10], Sunny et al. [6] and Kilickap [12]. This phenomenon occurs because according to Gashemi, the increase in delamination due to the rise in the feed rate is caused by heat generation that occurs when the contact between the drill tool and the workpiece. Fig.5 is a 3D surface plot that shows the interaction between the feed rate and spindle speed to the delamination factor on the entry side and exit side. The graph shows that the minimum delamination factor occurs at a feed rate of 0.1 mm/rev and a spindle speed of 93 rpm.



a) entry side b) exit side

Fig. 4 Main effect plot for S/N ratio on delamination damage in diameter drill bits 10 mm



a) entry side b) exit side

Fig.5 3D interaction (f × N) plot on the diameter drill bit 10 mm

The results of the analysis of variance (ANOVA) in delamination damage due to drilling on the 10 mm drill bit are shown in table 4. From both sides of the drill hole, only the factor on the entry side has a P-value <0.05, which means that the data is significant. Whereas in other factors the P-value >0.05 shows that statistically, the information is not substantial to the growth of delamination damage. When viewed from a percentage of contribution both factors have a statistical and physically significant contribution to delamination damage both in the entry side and exit side, it can be seen that the participation of the feed rate factor is higher than the spindle speed of 61.4% on the entry side and 50.0% on the exit side. But if we review the percentage of errors on the exit side by 37.5% higher than the acceptable level (15%). According to Kahwash et al. [2], this occurs because the emergence of interactions is unconsidered among several control factors.

Table 4. Analysis of variance for means on diameter drill bits 10 mm

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	% contribution
Entry side						
Feed rate	0.08121	2	0.040603	14.94136	0.01394	61.4%
Spindle speed	0.04012	2	0.020059	7.381850	0.045444	30.3%
Error	0.01087	4	0.002717			8.2%
Total	0.132195	8				
Exit side						
Feed rate	0.22706	2	0.11353	2.666301	0.183702	50.0%
Spindle speed	0.05789	2	0.02895	0.668985	0.561523	12.5%

Error	0.17200	4	0.04300		37.5%
Total	0.45696	8			

Fig.6 illustrates the relation between the control factor (feed rate and spindle speed) and the delamination factor on the entry side and exit side in the form of a multiple linear regression graph. The following equation obtains the chart:

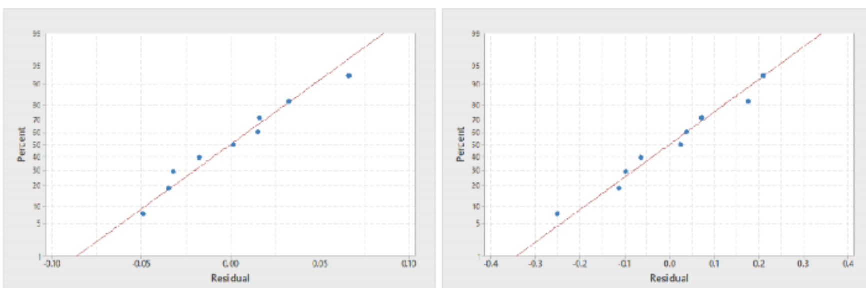
$$F_d\,\text{entry} = -0.9746 + 0.1124\cdot f_{0.10} + 0.0075\cdot f_{0.18} - 0.1199\cdot f_{0.24} + 0.0840\cdot N_{93} - 0.0793\cdot N_{443} - 0.0047\cdot N_{1420} \quad (5)$$

R^2 = 0.9178

$$F_d\,\text{exit} = -1.3807 + 0.2061\cdot f_{0.10} + 0.256\cdot f_{0.18} - 0.1805\cdot f_{0.24} - 0.0126\cdot N_{93} - 0.0913\cdot N_{443} + 0.1039\cdot N_{1420} \quad (6)$$

R^2 = 0.6236

Where F_d is a delamination factor that occurs in the entry side or exit side, f is the feed rate in mm/rev and N is the spindle speed in rpm.



a) entry side b) exit side

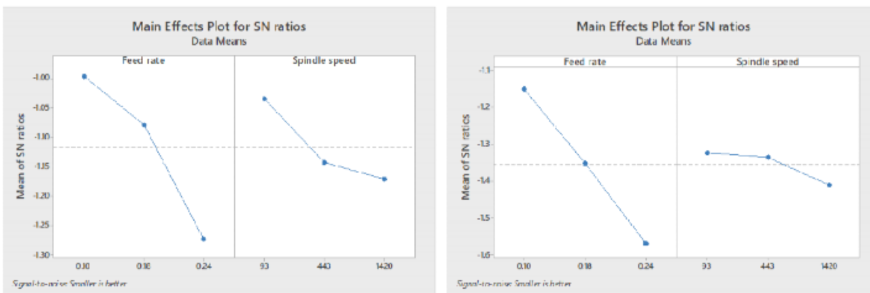
Fig.6 Normal probability plot (response is delamination factor)

3.2 Diameter 8 mm

Table 5. S/N response table for delamination factor on diameter drill bits 8 mm

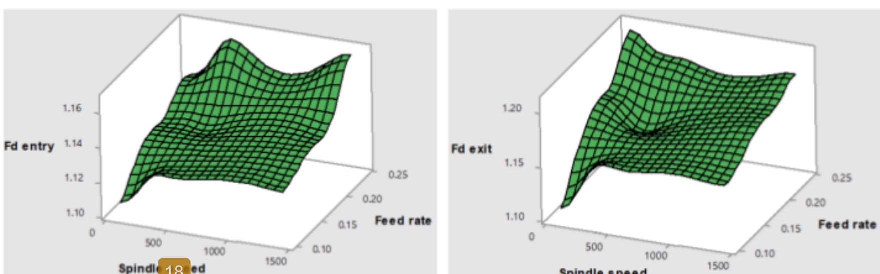
Exp. No.	Design of Experiment		Delamination Factor		S/N ratio	
	Feed rate	Spindle speed	Entry side	Exit side	Entry side	Exit side
1	0.10	93	1.108	1.112	-0.892	-0.920
2	0.10	443	1.127	1.157	-1.041	-1.267
3	0.10	1420	1.129	1.156	-1.054	-1.260
4	0.18	93	1.130	1.175	-1.064	-1.398
5	0.18	443	1.130	1.150	-1.059	-1.217
6	0.18	1420	1.137	1.180	-1.116	-1.437
7	0.24	93	1.141	1.210	-1.147	-1.653
8	0.24	443	1.165	1.191	-1.329	-1.522
9	0.24	1420	1.167	1.193	-1.344	-1.534

In Tables 5 and Fig.7 show the effect of the parameter process on delamination factors that have been transformed in the S/N ratio. At the 8 mm drill bit diameter, it can be seen that the optimal parameters are obtained in the feed rate and spindle speed which are smaller at 0.1 mm/rev and 93 rpm. The same thing is earned both on the entry side and exit side. In general, the influence of the feed rate on delamination factors looks very significant compared to the effect of spindle speed. Likewise, from the interaction between the feed rate and spindle speed to the delamination factor, that to obtain smaller delamination damage is collected on the feed rate parameter 0.1 mm/rev and the 93 rpm spindle speed as shown in Fig. 8.



a) entry side b) exit side

Fig. 7 Main effect plot for S/N ratio on delamination damage in diameter drill bits 8 mm



a) entry side b) exit side

Fig.8 3D interaction (f × N) plot on the diameter drill bit 8 mm.

As in table 6, the results of an analysis of variance (ANOVA) delamination factor on the 8 mm drill diameter indicates that the feed rate has the most significant contribution as the cause of delamination damage in the drill holes of 74.3% (entry side) and 69.5% (exit side). Conversely, the spindle speed parameter does not show a significant contribution to drilling this diameter, i.e., 19.1% (entry side) and 3.4% (exit side). This result is in line with the results of previous researcher Tsao et al. [15] and Palanikumar et al. [16], which revealed that the feed rate contributed significantly to delamination compared to spindle speed.

Table 6. Analysis of variance for means on diameter drill bits 8 mm

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	% contribution
Entry side						
Feed rate	0.121895	2	0.060947408	22.48598	0.006672	74.3%
Spindle speed	0.03134	2	0.015669894	5.781262	0.066063	19.1%
Error	0.010842	4	0.002710463			6.6%
Total	0.164076	8				

Exit side						
Feed rate	0.265264	2	0.1326321	5.132236	0.078634	69.5%
Spindle speed	0.013163	2	0.006581372	0.254668	0.786855	3.4%
Error	0.103372	4	0.025842945			27.1%
Total	0.381799	8				

The correlation between control factors and delamination factors on both sides of the drill hole is depicted in the multiple linear regression graph as in Fig. 9, with the regression equation as follows:

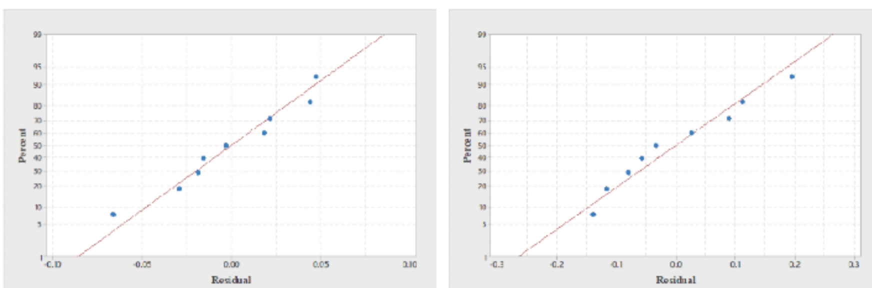
$$F_d\,\text{entry} = -1.1161 + 0.1207 \cdot f_{0.10} + 0.0366 \cdot f_{0.18} - 0.1573 \cdot f_{0.24} + 0.0818 \cdot N_{93} - 0.0268 \cdot N_{443} - 0.055 \cdot N_{1420} \quad (7)$$

$$R^2 = 0.9339$$

$$F_d\,\text{exit} = -1.3564 + 0.2073 \cdot f_{0.10} + 0.0057 \cdot f_{0.18} - 0.2131 \cdot f_{0.24} + 0.0327 \cdot N_{93} + 0.0210 \cdot N_{443} - 0.0537 \cdot N_{1420} \quad (8)$$

$$R^2 = 0.7293$$

Where F_d is a delamination factor that occurs in the entry side or exit side, f is the feed rate in mm/rev and N is the spindle speed in rpm.



a) entry side b) exit side

Fig.9 Normal probability plot (response is delamination factor).

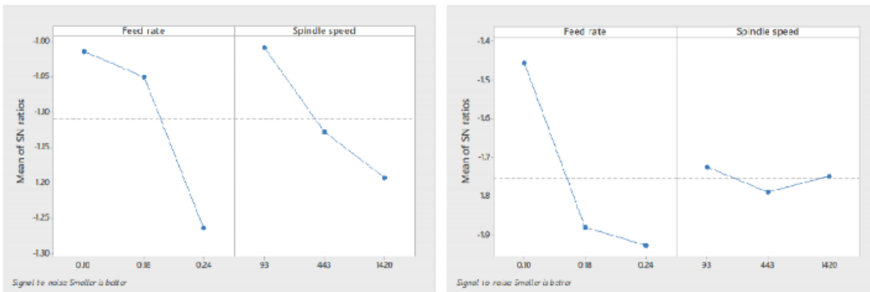
3.3. Diameter 6 mm

The phenomenon that occurs in drilling results with 6 mm drill bit diameter has the same inclination as drilling 8 mm drill bit diameter. Optimal parameters are obtained at the feed rate of 0.10 mm/rev and the 93 rpm spindle speed. The effect of the significance of the machining settings on delamination is due more to the feed rate than to the spindle speed, and this applies equally to the entry side and exit side (see table 7 and Fig. 10).

Table 7. S/N response table for delamination factor on diameter tools 6 mm

Exp. No.	Design of Experiment		Delamination Factor		S/N ratio	
	Feed rate	Spindle speed	Entry side	Exit side	Entry side	Exit side
1	0.10	93	1.113	1.150	-0.929	-1.214
2	0.10	443	1.117	1.247	-1.113	-1.617
3	0.10	1420	1.122	1.193	-1.001	-1.534

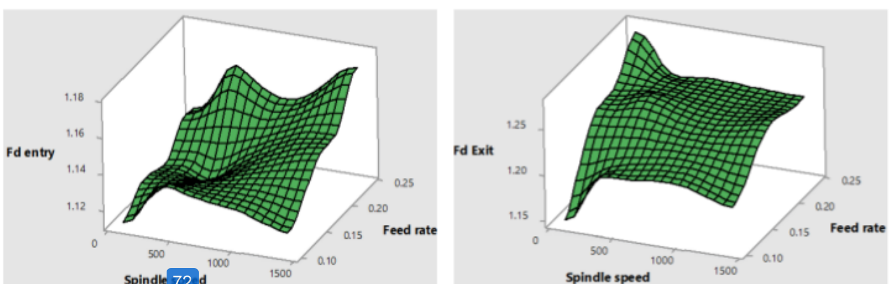
4	0.18	93	1.121	1.236	-0.994	-1.840
5	0.18	443	1.137	1.205	-0.963	-1.920
6	0.18	1420	1.147	1.242	-1.194	-1.880
7	0.24	93	1.135	1.277	-1.103	-2.123
8	0.24	443	1.163	1.235	-1.309	-1.830
9	0.24	1420	1.173	1.235	-1.383	-1.830



a) entry side b) exit side

Fig. 10 Main effect plot for S/N ratio on delamination damage in diameter drill bits 6 mm

Interaction between feed rate and spindle speed on delamination factors as described in Fig.11 shows that the smallest delamination factor is obtained from machining parameters, of each feed rate 0.1 mm/rev and spindle speed 93 rpm, both on the exit side and entry side.



a) entry side b) exit side

Fig.11 3D interaction (f × N) plot on the diameter drill bit 6 mm.

From the results of the analysis of variance (ANOVA) on drilling drill diameter of 6 mm (table 8), it is explained that the significance of the influence of drilling parameters (feed rate and spindle speed) on delamination damage is not visible on both sides of the borehole. This can be seen in the P-value both the feed rate and the spindle speed above the significance level specified (P-value >0.05). In contrast, when viewed from the contribution of drilling parameters to the delamination damage, the feed rate has the highest participation of 54.8% followed by the spindle speed of 26.1%. On the exit side, in terms of contribution to damage only the feed rate contributes to delamination which is 72.9%.

From the above results, it can be said that it is essential to use a minimum feed rate to reduce delamination damage to drilling as mentioned by Gaitonde et al. [17], that a low feed rate will reduce the scattering effect and produce less heat, which will reduce the defects that occur in the drilling process.

Table 8. Analysis of variance for means on diameter 6 mm

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	% contribution
Entry side						
Feed rate	0.11020	2	0.0550976	5.7338	0.0669	54.8%
Spindle speed	0.05240	2	0.0262013	2.7266	0.1790	26.1%
Error	0.03844	4	0.0096093			19.1%
Total	0.20104	8				
Exit side						
Feed rate	0.40671	2	0.203354	5.6242	0.0688	72.9%
Spindle speed	0.00620	2	0.003101	0.0858	0.9195	1.1%
Error	0.14463	4	0.036157			25.9%
Total	0.55754	8				

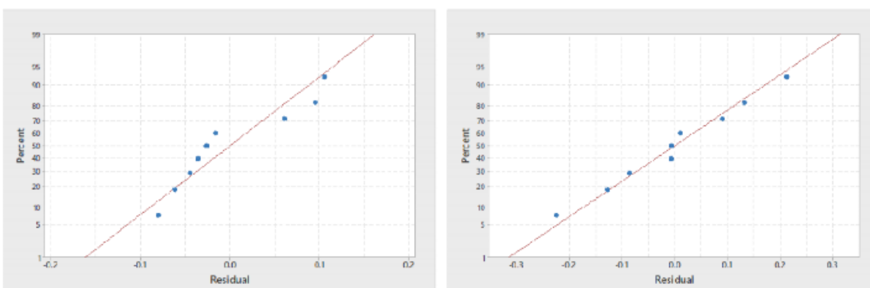
The graph of the correlation between control factors and delamination factor (Fig. 12) is described in the form of multiple linear regression, with the following equation:

$$F_d\text{ entry} = -1.1099 + 0.0957\cdot f_{0.10} + 0.0594\cdot f_{0.18} - 0.1551\cdot f_{0.24} + 0.1013\cdot N_{93} - 0.0186\cdot N_{443} - 0.0828\cdot N_{1420} \quad (9)$$

$$R^2 = 0.8088$$

$$F_d\text{ exit} = -1.7541 + 0.198\cdot f_{0.10} - 0.126\cdot f_{0.18} - 0.174\cdot f_{0.24} + 0.029\cdot N_{93} - 0.035\cdot N_{443} + 0.006\cdot N_{1420} \quad (10)$$

$$R^2 = 0.7406$$



a) entry side b) exit side

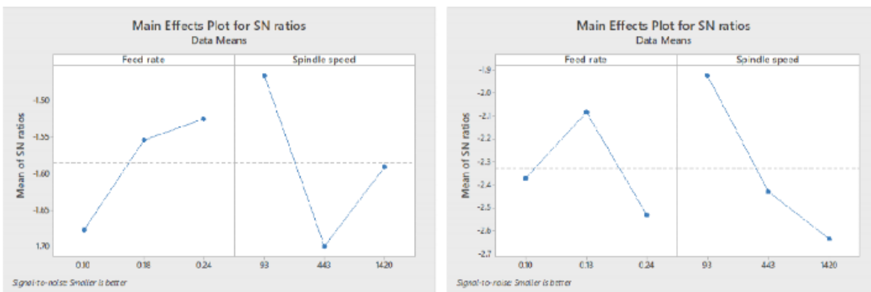
Fig.12 Normal probability plot (response is delamination factor)

3.4. Diameter 4 mm

In drilling a drill diameter of 4 mm, the results are in contrast to drilling on drill diameters 10, 8 and 6 mm. At this drill diameter, the optimal parameters occur at the feed rate 0.24 mm/rev and the 93 rpm spindle speed for the entry side boreholes. While for optimal exit side parameters occur at the feed rate 0.18 mm/rev and the spindle speed of 1420 rpm (see table 9 and Fig. 13). Likewise, the interaction of two variables (feed rate and spindle speed) on delamination induced by drilling described in response surface plots (Fig. 14) does not show the significance of delamination damage changes due to increased drilling parameters.

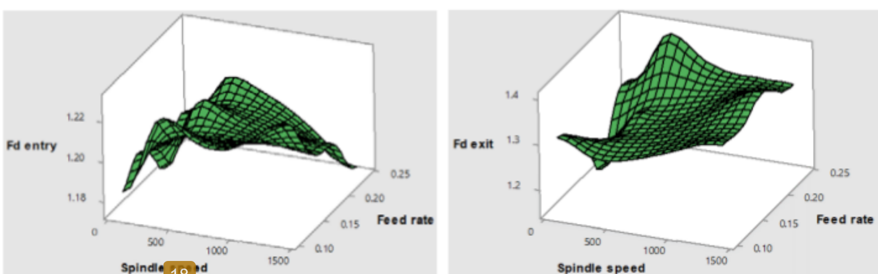
Table 9. S/N response table for delamination factor on diameter tools 4 mm

Exp. No.	Design of Experiment		Delamination Factor		S/N ratio	
	Feed rate	Spindle speed	Entry side	Exit side	Entry side	Exit side
1	0.10	93	1.185	1.312	-1.471	-2.360
2	0.10	443	1.225	1.278	-1.760	-2.131
3	0.10	1420	1.230	1.353	-1.801	-2.624
4	0.18	93	1.176	1.152	-1.408	-1.230
5	0.18	443	1.214	1.292	-1.682	-2.223
6	0.18	1420	1.198	1.380	-1.572	-2.799
7	0.24	93	1.191	1.284	-1.519	-2.174
8	0.24	443	1.210	1.401	-1.658	-2.932
9	0.24	1420	1.175	1.331	-1.398	-2.486



a) entry side b) exit side

Fig. 13 Main effect plot for S/N ratio on delamination damage in diameter drill bits 4 mm



a) entry side b) exit side

Fig.14 3D interaction (f × N) plot on the diameter drill bit 4 mm

From the observation of the results of the analysis of variance (ANOVA) the significance changes in setting parameters for delamination due to drilling as a controlling factor was not seen in the 4 mm drill diameter (P-value> 0.05). However, these parameters have a high contribution to the occurrence of delamination damage, this can be seen from the percentage of contributions from each parameter exceeding 15%, namely at the entry side feed rate of 22.3%, 46.7% spindle speed and on the exit side the feed rate is 15.5% and spindle speed 41.0%.

Table 10. Analysis of variance for means on diameter 4 mm

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	% contribution
Entry side						
Feed rate	0.039265	2	0.019632728	1.439209	0.338176	22.3%
Spindle speed	0.082168	2	0.041084139	3.011739	0.159251	46.7%
Error	0.054565	4	0.013641334			31.0%
Total	0.175999	8				
Exit side						
Feed rate	0.307132	2	0.153566056	0.714155	0.542989	15.5%
Spindle speed	0.81225	2	0.40612477	1.888672	0.264519	41.0%
Error	0.860128	4	0.215031889			43.5%
Total	1.979509	8	1.979509207			

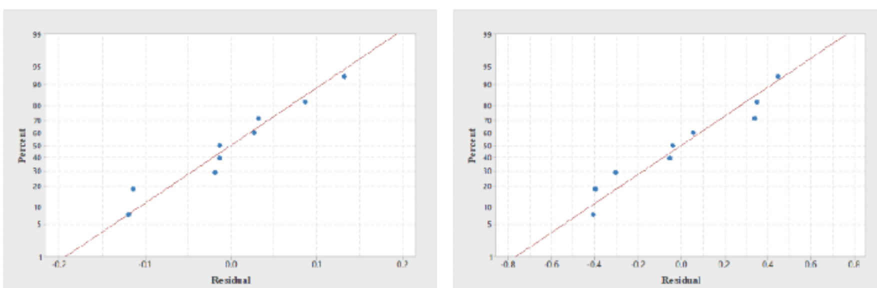
In mathematical modeling, the output performance characteristics are illustrated by the control factor correlation graph with delamination factor (Fig. 15), and are described in the regression equation as follows:

$$F_d\,\text{entry} = -1.5854 - 0.0919\cdot f_{0.10} + 0.0316\cdot f_{0.18} + 0.0604\cdot f_{0.24} + 0.1195\cdot N_{93} - 0.1144\cdot N_{443} - 0.0050\cdot N_{1420} \quad (11)$$

R^2 = 0.6900

$$F_d\,\text{exit} = -2.329 - 0.043\cdot f_{0.10} + 0\ .245\cdot f_{0.18} - 0.202\cdot f_{0.24} + 0.408\cdot N_{93} - 0.100\cdot N_{443} - 0.308\cdot N_{1420}\ \text{R2} \quad (12)$$

R^2 = 0.5655



a) entry side b) exit side

Fig.15 Normal probability plot (response is delamination factor)

Conclusions

This paper presents an experimental study of optimizing machining parameters in composite drilling reinforced by ramie woven. The significance of machining parameters was analyzed and identified using the Taguchi and ANOVA methods. Experimental planning uses L_9 orthogonal arrays with a "smaller is better" approach, where the process parameters (feed rate and spindle speed) as a controlling factors. From the results of the analysis the conclusions are as follows:

- In general, the feed rate is the machining parameter which is the main factor causing delamination damage to the drilling hole.

- The significance of the feed rate for delamination damage is more influential than the spindle speed parameter. Spindle speed even though it contributes sufficiently to delamination, but does not have a substantial effect.
- Taguchi and ANOVA designs can suggest the best combination of machining parameters to obtain drilling results with minimal delamination damage.

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References
[1] C. Kazmierski, "Growth Opportunities in Global Composites Industry, 2012 – 2017," Las Vegas, NV, 2012.
[2] F. Kahwash, I. Shyha, and A. Maheri, "Machining Unidirectional Composites using Single-Point Tools: Analysis of Cutting Forces, Chip Formation and Surface Integrity," *Procedia Eng.*, vol. 132, pp. 569–576, 2015.
[3] M. A. J. Bosco, K. Palanikumar, B. D. Prasad, and A. Velayudham, "Influence of machining parameters on delamination in drilling of GFRP-armour steel sandwich composites," *Procedia Eng.*, vol. 51, no. NUiCONE 2012, pp. 758–763, 2013.
[4] J. S. Pang, M. N. M. Ansari, O. S. Zaroog, M. H. Ali, and S. M. Sapuan, "Taguchi design optimization of machining parameters on the CNC end milling process of halloysite nanotube with aluminium reinforced epoxy matrix (HNT/Al/Ep) hybrid composite," *HBRC J.*, vol. 10, no. 2, pp. 138–144, 2013.
[5] N. S. Mohan, S. M. Kulkarni, and A. Ramachandra, "Delamination analysis in drilling process of glass fiber reinforced plastic (GFRP) composite materials," *J. Mater. Process. Technol.*, vol. 186, no. 1–3, pp. 265–271, 2007.
[6] T. sunny, J. Babu, and J. Philip, "Experimental Studies on Effect of Process Parameters on Delamination in Drilling GFRP Composites Using Taguchi Method," *Procedia Mater. Sci.*, vol. 6, pp. 1131–1142, Jan. 2014.
[7] C. C. Tsao, "Evaluation of the drilling-induced delamination of compound core-special drills using response surface methodology based on the Taguchi method," *Int. J. Adv. Manuf. Technol.*, vol. 62, no. 1–4, pp. 241–247, 2012.
[8] M. Balaji, B. S. N. Murthy, and N. M. Rao, "Optimization of Cutting Parameters in Drilling of AISI 304 Stainless Steel Using Taguchi and ANOVA," *Procedia Technol.*, vol. 25, no. Raerest, pp. 1106–1113, 2016.
[9] A. B. Chaudhari, V. Chaudhary, and P. Gohil, "Investigation of Delamination Factor in High Speed Drilling on Chopped GFRP using ANFIS," vol. 23, pp. 272–279, 2016.
[10] F. A. Ghasemi, A. Hyvadi, G. Payganeh, and N. B. M. Arab, "Effects of Drilling Parameters on Delamination of Glass-Epoxy Composites," *Aust. J. Basic Appl. Sci.*, vol. 5, no. 12, pp. 1433–1440, 2011.
[11] A. Hamdan, A. A. D. Sarhan, and M. Hamdi, "An optimization method of the machining parameters in high-speed machining of stainless steel using coated carbide tool for best surface finish," *Int. J. Adv. Manuf. Technol.*, vol. 58, no. 1–4, pp. 81–91, 2012.
[12] E. Kilickap, "Optimization of cutting parameters on delamination based on Taguchi method during drilling of GFRP composite," *Expert Syst. Appl.*, vol. 37, no. 8, pp. 6116–6122, 2010.
[13] P. J. Ross, *Taguchi Techniques for Quality Engineering*, Second. New York, NY: McGraw-Hill Professional, 1996.
[14] V. K. Vankanti and V. Ganta, "Optimization of process parameters in drilling of GFRP composite using Taguchi method," *J. Mater. Res. Technol.*, vol. 3, no. 1, pp. 35–41, 2014.
[15] C. C. Tsao and H. Hocheng, "Taguchi analysis of delamination associated with various drill bits in drilling of composite material," *Int. J. Mach. Tools Manuf.*, vol. 44, no. 10, pp. 1085–

1090, Aug. 2004.

[16] K. Palanikumar, S. Prakash, and K. Shanmugam, “Evaluation of Delamination in Drilling GFRP Composites,” *Mater. Manuf. Process.*, vol. 23, no. 8, pp. 858–864, Oct. 2008.

[17] V. N. Gaitonde, S. R. Karnik, J. C. Rubio, A. E. Correia, A. M. Abrão, and J. P. Davim, “A study aimed at minimizing delamination during drilling of CFRP composites,” *J. Compos. Mater.*, vol. 45, no. 22, pp. 2359–2368, May 2011.

Q3._An_optimization.pdf

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Dentistry, 1986
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13 B.M.Umesh Gowda, H.V. Ravindra, G.V.Naveen Prakash, P. Nishanth, G. Ugrasen. "Optimization of Process Parameters in Drilling of Epoxy Si3N4 Composite Material", Materials Today: Proceedings, 2015
Publication

%1

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%1

15 s3-eu-west-1.amazonaws.com
Internet Source

%1

16 C. C. Tsao. "Grey–Taguchi method to optimize the milling parameters of aluminum alloy", The International Journal of Advanced Manufacturing Technology, 01/2009
Publication

<%1

17 Ahmad Hamdan, Ahmed A. D. Sarhan, Mohd Hamdi. "An optimization method of the machining parameters in high-speed machining of stainless steel using coated carbide tool for best surface finish", The International Journal of Advanced Manufacturing Technology, 2011
Publication

<%1

18 Sridharan, V., N. Muthukrishnan, and S.

<%1

Deivanayagam. "Comparison of Machinability of Glass/Jute Fabric Polymer Composites", Applied Mechanics and Materials, 2013.
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27	mfr.edp-open.org Internet Source	<%1
28	C. C. Tsao. "Evaluation of the drilling-induced delamination of compound core-special drills using response surface methodology based on the Taguchi method", The International Journal of Advanced Manufacturing Technology, 2011 Publication	<%1
29	Pinho, L., D. Carou, and J. Davim. "Comparative study of the performance of diamond-coated drills on the delamination in drilling of carbon fiber reinforced plastics: assessing the influence of the temperature of the drill", Journal of Composite Materials, 2015. Publication	<%1

30	pastel.archives-ouvertes.fr Internet Source	<%1
31	C. C. Tsao. "Comparison between response surface methodology and radial basis function network for core-center drill in drilling composite materials", The International Journal of Advanced Manufacturing Technology, 2007 Publication	<%1
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33	Suleyman Neseli. "Optimization of Process Parameters with Minimum Thrust Force and Torque in Drilling Operation Using Taguchi Method", Advances in Mechanical Engineering, 2014 Publication	<%1
34	vdocuments.site Internet Source	<%1
35	maps.pme.nthu.edu.tw Internet Source	<%1
36	Ozcelik, B.. "Experimental and numerical studies on the determination of twist drill temperature in dry drilling: A new approach", Materials and Design, 2006 Publication	<%1
	pertanika.upm.edu.my	

37 Internet Source <%1

38 www.efsa.unsa.ba
Internet Source <%1

39 Kumar Abhishek, Saurav Datta, Siba Sankar Mahapatra. "Multi-objective optimization in drilling of CFRP (polyester) composites: Application of a fuzzy embedded harmony search (HS) algorithm", Measurement, 2016
Publication <%1

40 Vijaykumar Chaudhary, Piyush P. Gohil. "Investigations on Drilling of Bidirectional Cotton Polyester Composite", Materials and Manufacturing Processes, 2015
Publication <%1

41 mdpi.com
Internet Source <%1

42 ijens.org
Internet Source <%1

43 Siddharth Joshi, Krishna Rawat, A.S.S Balan. "A novel approach to predict the delamination factor for dry and cryogenic drilling of CFRP", Journal of Materials Processing Technology, 2018
Publication <%1

academic.hep.com.cn

44 Internet Source <%1

45 Submitted to National Institute of Industrial Engineering
Student Paper <%1

46 s3.amazonaws.com
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47 T. Srinivasan, K. Palanikumar, K. Rajagopal, B. Latha. "Optimization of delamination factor in drilling GFR–polypropylene composites", Materials and Manufacturing Processes, 2016
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48 archive.org
Internet Source <%1

49 ijraset.com
Internet Source <%1

50 zh.scientific.net
Internet Source <%1

51 K. Palanikumar, S. Prakash, K. Shanmugam. "Evaluation of Delamination in Drilling GFRP Composites", Materials and Manufacturing Processes, 2008
Publication <%1

52 Abhishek Aswal, Aditya Jha, Anshul Tiwari, Yashwant Modi. "CNC Turning Parameter <%1

Optimization for Surface Roughness of Aluminium-2014 Alloy Using Taguchi Methodology", Journal Européen des Systèmes Automatisés, 2019
Publication

53 ejournal.umm.ac.id
Internet Source
<%1

54 www.tci-thaijo.org
Internet Source
<%1

55 Mozammel Mia, Nikhil Ranjan Dhar. "Optimization of surface roughness and cutting temperature in high-pressure coolant-assisted hard turning using Taguchi method", The International Journal of Advanced Manufacturing Technology, 2016
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<%1

56 www.ijste.org
Internet Source
<%1

57 C. C. Tsao. "Thrust force and delamination of core-saw drill during drilling of carbon fiber reinforced plastics (CFRP)", The International Journal of Advanced Manufacturing Technology, 2007
Publication
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58 LV Pinho, D Carou, JP Davim. "Comparative study of the performance of diamond-coated
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drills on the delamination in drilling of carbon fiber reinforced plastics: Assessing the influence of the temperature of the drill", Journal of Composite Materials, 2015
Publication

59 Lecture Notes in Mechanical Engineering, 2013.
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60 hdl.handle.net
Internet Source
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61 Khurshid Alam, Ahmed Al-Ghaithi, Sujan Piya, Ashraf Saleem. "In-vitro experimental study of histopathology of bone in vibrational drilling", Medical Engineering & Physics, 2019
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---

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---

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