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Optimization of Cutting Parameters in Drilling of Epoxy Resin Composite Material using Taguchi's Technique

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Abstract: -- **Drilling is one of the oldest and the most widely used of all machining processes, comprising about one third of all metal-machining operations. Drilling of composite materials is an important and current topic in modern researches on manufacturing processes. Currently, the use of composite materials has increased in various areas of science and technology due to their special physical and mechanical properties such as high specific strength, stiffness and fatigue strength. The quality of the drilled hole depends on the factors such as, speed, feed rate, tool geometry etc. The efficient and economic machining of the materials is required for the desired dimensions and surface finish. Taguchi technique is a powerful tool in experiment design and it provides a simple, efficient and systematic approach for optimization, quality and cost. The methodology is valuable when the design parameters are qualitative and discrete. Taguchi's Orthogonal Array based on Robust design is one of the important techniques, which is used for optimization of input parameters of drilling. In this paper, an attempt has been made to optimize the drilling parameters using the Taguchi's technique which is based on the Robust design. Experiments are carried out on machining the various % weight of Si3N4 in Epoxy Resin - Si3N4 Composite (ERC) materials, using the HSS tool for various cutting conditions. The input process parameters considered during experiments are viz, % weight of Si3N4, Speed, Feed, diameter of drill bit and machining time. The response variables measured for the analysis are surface roughness, delamination, circularity, cylindricity and tool wear. Analysis has been done through various steps like calculating degrees of freedom, physical layout and total response layout up to ANOVA. After the confirmation experiment, it was observed that, optimized parameters have given best results, so these parameters can be used to achieve the good surface roughness, less delamination, better circularity, cylindricity and less tool wear than before.**

Keywords: ***Taguchi's technique, ANOVA, ERC, HSS.***

INTRODUCTION

Composite materials are increasingly used in various fields of science and engineering due to their unique properties such as high stiffness, lightweight, good corrosive resistance, low thermal expansion, etc. The PMC constituents of reinforcement, matrix, hardner. The selection of reinforcement involves silicon nitride (Si3N4) and matrix involves epoxy resin (LY556), and hardener has epoxy hardner. The material had been prepared based on the 3 composites 0%, 6% and 10 % weight. The number indicates the amount of reinforcement added to the mixture of matrix and hardner. The polymer matrix composites are extensively used in the pharmaceutical industries and medical appliances. They are significantly used in the aeronautical industries specifically in landing gears in the aircraft, cockpit of the aircraft. The preparation involves taking matrix as epoxy resin and reinforcement as carbon fiber and also silicon nitride and hardner as epoxy hardner.

Some of the researchers have attempted to know the effect of speed and feed on delamination behaviour of composite materials by conducting drilling experiments using Taguchi's L25, orthogonal array and Analysis of Variance (ANOVA) by using three different tools namely twist drill, end mill and kevlar drill. Results of these experiments revealed that increasing the spindle speed and reducing feed rate can reduce the delamination within limits of specified speed and feed rates. Too low feed rate and too high spindle speed can also increase the delamination [1]. The influence of the cutting parameters, such as cutting speed and feed rate, and point angle on delamination produced when drilling a GFRP composite were investigated. The damage generated associated with drilling GFRP composites were observed, both at the entrance and the exit during the drilling. They revealed that feed rate and cutting speed were the most influential factor on the delamination respectively. The best results of the delamination were obtained at lower cutting speeds and feed rates [2]. An effective approach for the optimisation of drilling parameters with multiple performance characteristics based on the Taguchi method with grey relational analysis analyzed. The drilling parameters such as spindle speed and feed rate are optimised with consideration of multiple performance characteristics, such as thrust force, workpiece surface roughness and delamination factor. The analysis of grey

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relational grade indicates that feed rate is the more influential parameter than spindle speed. The results indicate that the performance of drilling process can be improved effectively through this approach [3]. A new comprehensive approach to select cutting parameters for damage-free drilling in CFRE composite material was presented. A plan of experiments was performed in an autoclave Carbon Fiber Reinforced Plastic (CFRP) laminate. The drilling was carried out using High Speed Steel (HSS) and Cemented Carbide (K10) drills. The correlation was obtained by multiple linear regressions. Finally, confirmation tests were performed to make a comparison between the results foreseen from the mentioned correlation [4]. The cutting parameters (cutting velocity and feed rate) under specific cutting pressure, thrust force, damage and surface roughness in Glass Fiber Reinforced Plastics (GFRP's) were studied. A plan of experiments, based on the techniques of Taguchi, was established considering drilling with prefixed cutting parameters in a hand lay-up GFRP material. The ANOVA was performed to investigate the cutting characteristics of GFRP's using Cemented Carbide (K10) drills with appropriate geometries. The specific cutting pressure decreases with the feed rate and slightly with the cutting speed, and the thrust force increases with the feed rate. The damage increases with both cutting parameters, which means that the composite damage is bigger for higher cutting speed and for higher feed [5].

Prediction and evaluation of delamination factor in use of twist drill, candle stick drill and saw drill were presented. The approach is based on Taguchi's method and the ANOVA. An ultrasonic C-Scan to examine the delamination of CFRP laminate is used. The experiments were conducted to study the delamination factor under various cutting conditions. The experimental results indicate that the feed rate and the drill diameter are recognized to make the most significant contribution to the overall performance. The correlation was obtained by multi-variable linear regression and compared with the experimental results [6]. An experimental investigation were carried out for a full factorial design performed on thin CFRP laminates using K20 carbide drill by varying the drilling parameters such as spindle speed and feed rate to determine optimum cutting conditions. They have analysed delamination while drilling CFRP at high spindle speeds using Artificial Neural Network (ANN) and concluded that spindle speed, feed rate and point angle of the drill affect the delamination of the drilled hole. It was proposed that a combination of high spindle speed, low feed rate and low point angle would minimize damages that occur due to delamination. The hole quality parameters analysed include hole diameter, circularity, peel-up delamination and push-out delamination. ANOVA was carried out for hole quality parameters and their contribution rates were determined. Genetic Algorithm (GA) methodology was used in the multiple objective optimization to find the optimum cutting conditions for defect free drilling. Tool life of the K20 carbide drill was predicted at optimized cutting speed and feed [7]. The experimental investigation that examines the theoretical predictions of critical thrust force at the onset of delamination and compares the effects of these different drill bits was studied. The results confirm the analytical findings and are consistent with the industrial experience. Ultrasonic scanning is used to evaluate the extent of drilling-induced delamination. The allowable feed rate without causing delamination is also increased. The analysis can be extended to examine the effects of other future innovative drill bits [8]. Experiments were carried out as per the Taguchi's L9 orthogonal array was used to study the influence of various combinations of process parameters on hole quality. ANOVA test was conducted to determine the significance of each process parameter on drilling. The results indicate that feed rate is the most significant factor influencing the thrust force followed by speed, chisel edge width and point angle; cutting speed is the most significant factor affecting the torque, speed and the circularity of the hole followed by feed, chisel edge width and point angle. This work is useful in selecting optimum values of various process parameters that would not only minimize the thrust force and torque but also reduce the delimitation and improve the quality of the drilled hole. The optimization of cutting process parameters viz., cutting speed, feed, point angle and chisel edge width in drilling of GFRP composites using the application of Taguchi method [9]. A non-contact non-destructive technique for measuring and determining the extent of delamination in composite materials was studied. The approach developed consists of utilizing a shadow moire laser based imaging technique. This technique allows the assessment of the degree of delamination resulting from the machining processes necessary for final set-up and assembly. Mechanical drilling has been implemented on Carbon Fiber Reinforced Epoxy (CFRE) composites. The effects of cutting variables (feed and speed) on the delamination size in mechanical drilling of CFRE composites have been investigated [10].

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II. EXPERIMENTAL WORK

The experiments were conducted on an automatic drilling machine tool. The control factors were chosen based on review of literature, experience and some preliminary investigations. Different settings of controllable factors such as % volume of Si3N4, Cutting speed, Feed rate, Diameter of drill bit and Machining time were used in the experiments as shown in Table 1.

Table 1 Machining settings used in experiments

Control Factors		Level		
		I	II	III
A	%wt. Si_3N_4	0	6	10
B	Speed	360	490	680
C	Feed	0.095	0.190	0.285
D	Dia. of drill bit	6	8	10
E	Machining Time	30	60	90

III. RESULTS AND DISCUSSIONS

Experiments were conducted for various cutting speed, feed rate, drill diameter, machining time and various % volume of Si3N4. Ra, circularity, cylindricity, tool wear and delamination were measured. Process parameters are optimized with consideration of multiple performance characteristics, such as workpiece surface roughness, circularity, cylindricity, tool wear and delamination. The verification experiments are conducted using the optimized process parameters and compared with the results obtained from the initial set of readings.
Data obtained after measuring the response variables like surface roughness, circularity, cylindricity, tool wear and delamination for Si3N4 ERC material are tabulated in Table 2 and Table 3.

Table 2. L_{27} orthogonal array

Run	%wt. Si_3N_4	Speed	Feed Rate	Dia. of DB	Machining time
1	0	360	0.095	6	30
2	0	360	0.190	8	60
3	0	360	0.285	10	90
4	0	490	0.095	8	60
5	0	490	0.190	10	90
6	0	490	0.285	6	30
7	0	680	0.095	10	90
8	0	680	0.190	6	30
9	0	680	0.285	8	60
10	6	360	0.095	8	90
11	6	360	0.190	10	30
12	6	360	0.285	6	60
13	6	490	0.095	10	30
14	6	490	0.190	6	60
15	6	490	0.285	8	90
16	6	680	0.095	6	60
17	6	680	0.190	8	90
18	6	680	0.285	10	30
19	10	360	0.095	10	60
20	10	360	0.190	6	90
21	10	360	0.285	8	30
22	10	490	0.095	6	90
23	10	490	0.190	8	30
24	10	490	0.285	10	60
25	10	680	0.095	8	30
26	10	680	0.190	10	60
27	10	680	0.285	6	90

Table 3. Machining performances using L_{27} orthogonal array

Run	Ra (µm)	TW (mm)	Fd (mm)	Cir (mm)	Cyl (mm)
1	4.619	0.14	1.024	0.115	0.106
2	5.118	0.180	1.035	0.057	0.073
3	4.387	0.19	1.023	0.085	0.062
4	5.064	0.09	1.034	0.053	0.052
5	3.645	0.11	1.004	0.116	0.068
6	6.975	0.13	1.016	0.139	0.090
7	3.604	0.12	1.007	0.322	0.204
8	5.644	0.16	1.018	0.080	0.070
9	3.171	0.14	1.026	0.087	0.068
10	2.163	0.11	1.024	0.115	0.089
11	2.537	0.10	1.012	0.099	0.086
12	1.738	0.10	1.036	0.152	0.123
13	13.39	0.20	1.051	0.067	0.068
14	6.846	0.19	1.098	0.080	0.068
15	4.467	0.23	1.054	0.040	0.045
16	3.805	0.18	1.015	0.386	0.259
17	5.960	0.17	1.005	0.109	0.095
18	2.717	0.19	1.006	0.084	0.072
19	3.171	0.16	1.025	0.080	0.095
20	3.694	0.16	1.050	0.034	0.042
21	4.319	0.17	1.020	0.064	0.058
22	1.564	0.18	1.007	0.119	0.075

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23	1.335	0.17	1.005	0.173	0.095
24	5.071	0.18	1.002	0.129	0.091
25	7.999	0.13	1.069	0.048	0.038
26	9.044	0.17	1.062	0.030	0.061
27	6.371	0.19	1.062	0.052	0.044

Observations on Ra, Tool wear and Delamination

From the Fig. 1, Fig. 2 and Fig. 3, the main effect plots for Si_3N_4 ERC material that, the factor drill dia has largest effect on the surface roughness as the response variable. The optimum level for a factor is the level that gives the highest value of η in the experimental region. Fig. 1 shows that, the surface roughness of the material decreases with the increase in %wt. of Si_3N^4 from 0% to 10%, it decreases with the increases in the speed from 360 rpm to 680 rpm and it decreases with the increase in the machining time from 30 sec to 90 sec. From the Fig. 1 clearly shows that, the surface roughness rapidly increased with the increase in feed rate from 0.095 mm/rev to 0.190 mm/rev and further it is decreased with the increase in feed rate 0.190 mm/rev to 0.285 mm/rev. The surface roughness increases with the increase the drill dia. 6 mm to 8 mm.

The factor % weight of Si_3N_4 has largest effect on the surface roughness as the response variable. From the Fig. 2, tool wear increases with the increase in %wt. of Si_3N_4 from 0% to 10%, the Tool wear decreases with the increase in the speed from 360 to 680 rpm. The Tool wear increases with the increase in feed rate from 0.095 to 0.190mm/rev, further tool wear decreases with the increase in feed rate from 0.190 to 0.285mm/rev., tool wear increases with increase in the dia of drill bit from 6 to 10 mm, tool wear increases with increases in the machining time from 30 to 60 seconds.

The factor feed rate has largest effect on the surface roughness as the response variable. From the Fig. 3 it is observed that, The Delamination (Fd) of the material decreases with the increase in % weight of Si3N4 from 0 to 6%, further it will increases with the increases in the % weight of Si_3N_4 from 6 to 10%. The Delamination (Fd) of the material increases with the increases in the speed from 360 to 680rpm. Delamination (Fd) decreases with the increase in feed rate from 0.095 to 0.285mm/rev., the drill dia increases the Delamination (Fd) value also increases. The Delamination (Fd) increases with increases in machining time from 30 to 60 seconds, further it will decreases with the increases in the machining time from 60 to 90 seconds.

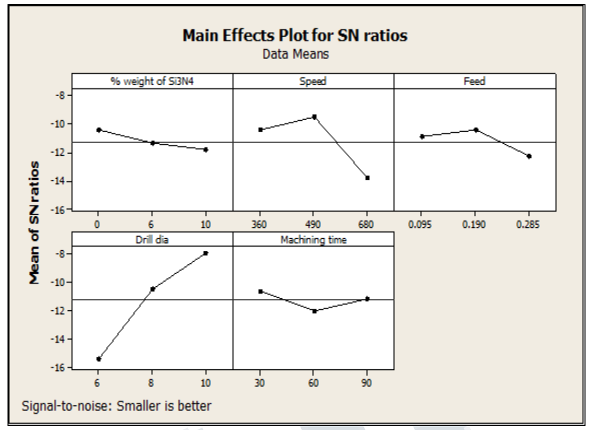

Fig. 1. Main effects plot for surface roughness

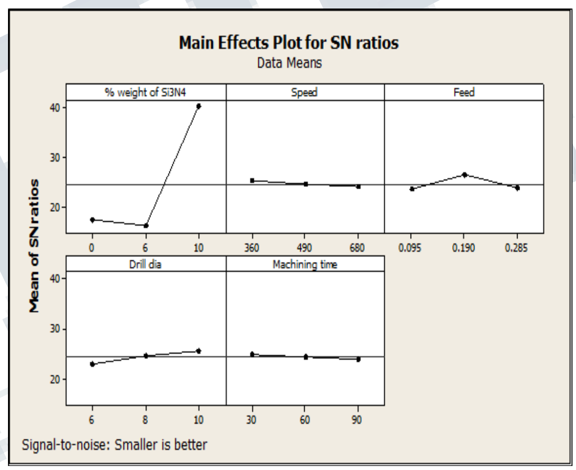

Fig. 2. Main effects plot for tool wear

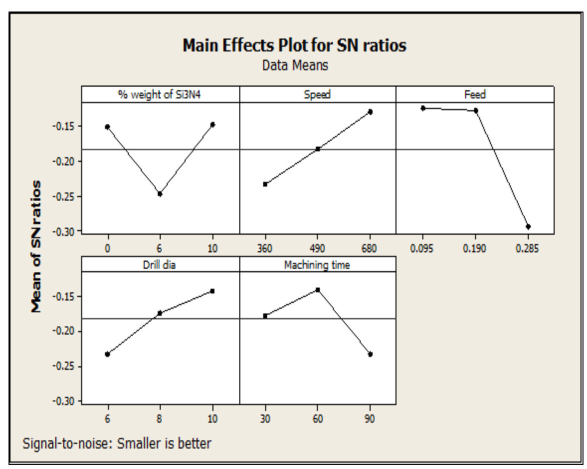

Fig. 3. Main effects plot for delamination

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The purpose of conducting ANOVA is to determine the relative magnitude of the effect of each factor on the objective function η and to estimate the error variance. The largeness of a factor effect relative to the error variance can be judged from the F column. The larger the F value, the larger the factor effect is compared to the error variance. Referring to the ANOVA, the drill dia has more effect on the response variable for surface roughness, % weight of Si3N4 which effects more on tool wear and feed rate has larger effect delamination. This can also be seen from the main effect plot shown in the Fig. 1. Based on this, the value of F in the ANOVA, the rank to the each factor or the magnitude is given.

Observations on circularity and cylindricity

From the Fig. 4 the main effect plots for Si_3N_4 ERC material that, the factor drill dia has largest effect on the circularity as the response variable. The optimum level for a factor is the level that gives the highest value of η in the experimental region. From the above Fig. 4 it is clear that, the deviation of the Circularity decreases with the increase in % weight of Si_3N_4 from 0 to 6%, further it will increases with the increasing of % weight of Si_3N_4 from 6% to 10%. The deviation of the Circularity of the material decreases with the increase in the speed from 360 to 490rpm, further it will increases with the increase in speed from 490 to 680rpm. The deviation of the Circularity of the material decreases with the increase in the feed rate from 0.095 to 0.190 mm/rev, further it will increases with the increase in feed rate from 0.190 to 0.285 mm/rev. The deviation of the Circularity decreases with increase in the dia of drill from 6 to 10 mm. As the machining time increases from 30 to 60 seconds the deviation of circularity value decreases.

From the Fig. 5 the main effect plots for Si3N4 ERC material that, the factor % weight of Si_3N_4 bit has largest effect on the cylindricity as the response variable. The optimum level for a factor is the level that gives the highest value of η in the experimental region. From the Fig. 5 it is clear that, the deviation of the cylindricity decreases with the increase in % weight of Si_3N_4 from 0 to 6%, further it will increases with the increasing of % weight of Si_3N_4 from 6% to 10%. The deviation of the cylindricity of the material decreases with the increase in the speed from 360 to 680 rpm. The deviation of the cylindricity of the material increases with the increase in the feed rate from 0.095 to 0.285 mm/rev. The deviation of the cylindricity decreses with increase in the dia of drill from 6 to 10 mm. As the machining time increases the deviation of cylindricity value decreases.

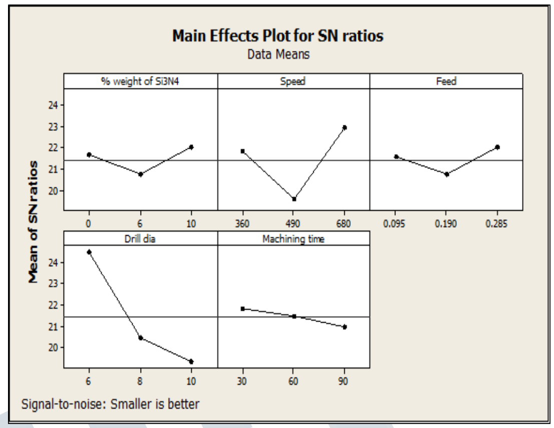

Fig. 4. Main effects plot for circularity

Referring the ANOVA, the factor dia. of drill bit has more effect on the response variable for circularity and the factor %wt. of Si3N4 has more effect on cylindricity. This can also be seen from the main effect plot shown in the Fig. 4 and Fig. 5. Based on this, the value of F in the ANOVA, the rank to the each factor or the magnitude is given.

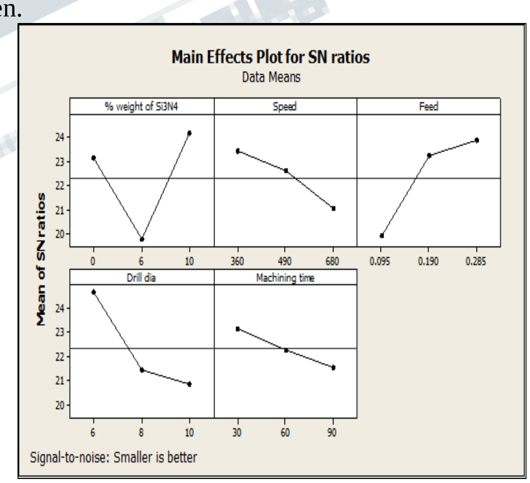

Fig. 5. Main effects plot for cylindricity

Verification experiment

Conducting a verification experiment is to verify that the optimum conditions suggested by the matrix experiment do indeed give the projected improvement. If the observed S/N ratios under the optimum conditions are close to their respective predictions, then one can conclude

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that the additive model on which the matrix experiment was based is a good approximation of the reality. Then, adopt the recommended optimum conditions for the process or product, as the case may be. In the drilling process case study, parameters are optimized and are tabulated in the previous sections. The confirmation run was conducted taking these optimized parameters for the Si_3N_4 ERC materials considered in the case study. The results obtained from the confirmation runs are tabulated in the below Table 3.

Form the Table 3 one can observe that, the optimized parameters have considerable effect on the response variables surface roughness, tool wear, delamination, circularity and cylindricity for Si_3N_4 ERC material. The surface roughness was 4.619µm for initial settings of parameters and the value has been reduced to 2.3µm after setting parameters to optimized values. Similarly, the tool wear and delamination was 0.12 mm and 1.024 mm for initial settings of parameters and after setting parameters to optimized values, the value has been reduced to 0.11 mm and 1.010 mm respectively. Similarly circularity is improved from 0.115 mm to 0.057 mm and cylindricity is also improved from 0.106 mm to 0.055 mm.

Table 3 Results of verification experiment

Parameters	Initial Parameter Readings					Optimized Parameter Readings				
	Ra (µm)	Fd (mm)	Cir (mm)	Cyl (mm)	TW (mm)	Ra (µm)	Fd (mm)	Cir (mm)	Cyl (mm)	TW (mm)
% weight of Si_3N_4	0	0	0	0	0	0	10	10	10	10
Speed	360	360	360	360	360	490	680	680	360	360
Feed	0.095	0.095	0.095	0.095	0.095	0.190	0.285	0.285	0.285	0.190
Dia. of DB	6	6	6	6	6	10	10	6	6	10
Machining time	30	30	30	30	30	30	60	30	30	30
Response obtained	4.619	1.024	0.115	0.106	0.12	2.3	1.010	0.057	0.055	0.11

CONCLUSION

The present study was concerned with drilling of various %wt. of Si3N4. The experiments were performed based on Taguchi's L27 orthogonal array. The input parameters were %wt. Si3N4, cutting speed, feed rate, diameter of drill bit and machining time, and the response variables were surface roughness, tool wear, delamination, circularity and cylindricity. After the experiment conducted, response variables were tabulated and analysis was conducted. Single objective optimization was performed based on Taguchi's technique. After the process parameters are optimized, ANOVA was performed to determine the relative magnitude of the each factor on objective functions.

The following are the important conclusions drawn from the present work.

i. Statistical analysis of data pertaining to tool wear has shown that the lower cutting speed (360rpm), high feed rate (0.285mm/rev) and higher drill diameter (10mm) is required to minimize the tool wear.

ii. Relatively higher cutting speed (680 rpm), lower Feed rate (0.285 mm/rev) and higher drll diameter of (10mm) are required to avoid the delamination effect.

iii. ERC material has to be drilled with high cutting speed (680 rpm), high feed rate (0.285mm/rev) and lower drill diameter of (6mm) to sustain circularity deviation within the limits.

iv. Relatively lower cutting speed (490 rpm), lower feed rate (0.190 mm/rev) and higher drill diameter of (10mm) are required to obtain good surface finish.

v. ERC material has to be drilled with lower cutting speed (360rpm), high feed rate (0.285mm/rev) and lower drill diameter (6mm) are required to minimize the cylindricity deviation.

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After the confirmation experiment, it was concluded that, the optimized parameters have shown good results, so these parameters can be used to achieve good surface finish, minimum tool wear, lower delamination, circularity and cylindricity than before.

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REFERENCES

[1] Tom sunny, J.Babu and Jose Philip, "Experimental studies on effect of process parameters on delamination in drilling GFRP composites using Taguchi method", Materials science, Vol. 6, pp. 1131-1142, 2014.

[2] Kilickap E, "Optimization of cutting parameters on delamination based on Taguchi method during drilling of GFRP composite" Expert Systems with Applications, Vol. 37, pp. 6116–6122, 2010.

[3] Palanikumar K, "Experimental investigation and optimisation in drilling of GFRP composites", Measurement, Vol. 44, pp. 2138–2148, 2011.

[4] J.P.Davim and Pedro Reis, "Study of delamination in drilling carbon fiber reinforced plastics (CFRP) using design experiments", composites structures, Vol. 59, pp. 481-487, 2003.

[5] J.paulo Davim, Pedro Reis and C.Conceicao Antonio, "Experimental study of drilling glass fiber reinforced plastics (GFRP) manufactured by hand lay-up", composites science and technology, Vol. 64, pp. 289-297, 2004.

[6] C.C.Tsao and H.Hocheng, "Taguchi analysis of delamination associated with various drill bits in drilling of composite material", International journal of machine tools and manufacture, Vol. 44, pp. 1403-1416, 2004.

[7] Vijayan Krishnaraj, A.Prabukarthi,Arun Ramanathan and J.P.Davim, "optimization of machining parameters at high speed drilling of carbon fiber reinforced plastic (CFRP) laminates", composites, Vol. 43, pp. 1791-1799, 2012.

[8] H.Hocheng and C.C. Tsao, "Effects of special drill bits on drilling-induced delamination of composite materials", International journal of machine tools and manufacture, Vol. 46, pp. 1403-1416, 2006.

[9] Venkateswarlu Ganta and Vinod Kumar Vankantia, "Optimization of process parameters in drilling of GFRP composite using Taguchi method", Journal of Materials Research and Technology, Vol. 3, pp. 35-41, 2014.

[10]T.V. Rajamurugan and K. Shanmugam, "Analysis of delamination in drilling glass fiber reinforced polyester composites ", Materials and Design , Vol. 45, pp. 80–87, 2013.

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