IMPACT OF PROCESSFACTORS ON TWIST DRILL WEAR IN MACHININGGFRP COMPOSITES BY APPLYING TAGUCHI DESIGN ANALYSIS AND ANOVA TECHNIQUE

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Abstract

In recent days, the Fiber Reinforced Composites have replaced many of the engineering components and the composite material manufacturing area is experiencing substantial growth. FRC's also have replaced materials used in the civil construction area, sporting goods, automobile and aircraft parts, and boat and ship hulls. The composites in general, offermany advantages over homogenous materials like high strength to weight ratio, less weight, flexibility in design, structural and dimensional stability, corrosion and wear resistance along with low tooling cost. Because of the anisotropy in nature, machining composite materials is a complex process especially operations involved in in drilling and milling. Therefore, dry drilling operation on composite materials affects the performance of the drill tool. Hence in the present investigation, the effect of the process parameters such as spindle speed (1000, 1200 and 1500 rpm), feed rate (0.1, 0.2 and 0.3 mm/rev), drill diameter (6, 8 and 10mm) and orientation of the reinforced glass fibers (Random,Random+Stitched and Random+Rowings) on the tool wear of the HSS drill bit is studied. The experiment is designed using Taguchi's method. Measure of Signal-to-Noise (S/N) ratio was used to assess the effect of parameters on response. Relative effect of factors is assessed using ANOVA. The process parameters are optimized to reduce the tool wear.

Keywords: polymer composites, design of experiments, tool wear, analysis of variance.

Introduction

Composite Materials are extensively used in various fields of engineering applications because of their superior mechanical and tribological properties. Though composites are manufactured in single mould, secondary operations such as drilling, turning, sawing, routing and grinding, etc are required in order to give dimensional finish and to use the products in assembly. Drilling is one of the most important metal-cutting operations performed on the composite. It constitutes nearly 33% of all machining operations [3, 4]. Generally in aerospace, aircraft, and automobile industries for drilling operation on composite materials, HSS twist drills are used. It is observed that poor quality of the hole production on products leads to rejections of components estimated to about 60% which prove very costly to repair.

Tool wear depends on the thrust force and torque developed during drilling which depends on drill size, feed rate and spindle speed. Literatures shows that tool breakage, tool wear and work piece deflection are strongly dependent on cutting force. The change in drill tool geometry results in lesser material removal rate and generatespoor machined surface[5]. Tool wear leads to lowering strengthof the cutting edge, increase of tool forces as well as power consumption, increase in cutting temperatures, reduction in surface finish, loss of dimensional accuracy and productivity[6]. It has been estimated that a goodcutting tool can increase cutting speeds from 10-50%, compared to worn out tools and a reconditioned tool reduces the machine downtime by10-40% (Adam, Dr. Jin Jiang and Dr. Peter, 2004)[14].

Drill tool wear is a progressiveand a slow phenomenon when compared withthe failure of the cutting tool and cutting edge damage and breakage,whichoccur all of sudden. Thedrill tool wear starts as soon as it begins its operation, and the wear increases its rate rapidly once it becomes blunt or dull. In common, the temperature and heat distribution during machining operation, pressure difference, friction, and the stress distribution at the tool–work interface zone influence the wear patterns[7].

A number of research works reveal that the outer corner wear as the major type of wear in drilling. But practically, the significant type of wear in drilling are flank and crater wear[8]. Many investigations say that the tool wear in drilling occurs due to abrasion of tool material at lower cutting speeds in machining on metals. At the same time, the atomic diffusion is considered as the major wear mechanism for cutting tools operating at higher cutting speeds. The atomic diffusion carries the tool material along with the chipmaterial through the flow of work material along the tool work interface. This will also lead to significant reduction in tool life (Choudhury, Gangaraju, 2000)[15].

In general, the composite materials are difficult to machineBecause of inhomogeneity and anisotropy nature, and because of the abrasive nature of reinforcements. So, damage to the work piece is significant and tool will high wear at higher rate[9]. The alloyed tool steel material can withstand hardness at higher temperatures and are found to be better than high carbon and low alloy steels. Due to this observation, the research is focused on HSS drilling on composite materials.

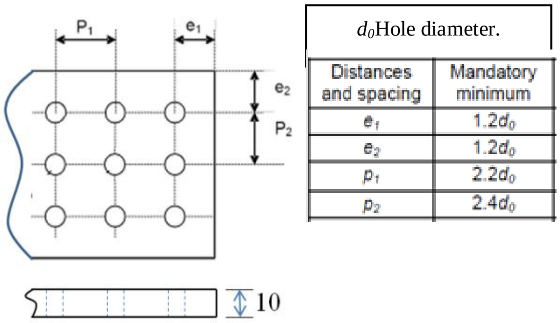
GFRP composite samplepreparation

The composite material specimens used for experimental work were manufacturedusing hand-layup procedure. The S-glass fiber matwith random, stitched and rowings fabric were used for the reinforcement.The glass fiber mats were cut according to the mould size. Isopthalic polyester resin is used as the matrix and Araldite was usedas binder and hardener material.The laminate thickness was set to 10mm and the fiber- volume fraction of the specimen was set at 0.33 (Figure 1).

Figure 1. Polymer composites with Different fabrics

Experimental Specifics

A schematic diagram of the dimensional specifications for hole spacing for the presentresearch work is shown in Figure 2.



d_0Hole diameter.

Distances and spacing	Mandatory minimum
e_1	$1.2d_0$
e_2	$1.2d_0$
p_1	$2.2d_0$
p_2	$2.4d_0$

Figure 2. Hole specifications in drilling

The holes were drilled on the GFRP laminates accordingly. The machining operations were carried out on 3 - AxisCNC Vertical Machining Center (VMC),AMS Spark machine, shown in Figure 3.

Figure 3. 3-axis CNC Vertical Machining Center

For drilling holes, the selected machining parameters (factors)and their set values (levels) are shown in Table 2.

Table 2.Factors and their set levels

Symbols	Factors	No. of Levels		
		Level 1	Level2	Level 3
A	Spindle Speed (rpm)	1200	1500	1800
B	Feed (mm/rev)	0.1	0.2	0.3
C	Drill diameter (mm)	6	8	10
D	Fabric type	Random	Random+ Strand (R+S)	Random + Rowing (R+R)

Design of Taguchi orthogonal array layout

The Taguchi orthogonal array layout helps in carrying out the optimum number of experiments which give the details regarding how all the factors affect the response parameter. The inner array consists of all the possible combinations of the controllable factors. The outer array includes the combinations of the uncontrollable factors. In the previous research works it was found that the controllable (signal) factors have high impact on the drill hole quality than that of uncontrollable (noise) factors, in the composite laminates drilling[10].There are many standard orthogonal arrays available, which are designed for a specific number of independent variables or factors and levels. According to the 4 drill process parameters (factors) and their 3 values (levels), L9 orthogonal array is selected for the present research investigation.

The experiments are conducted to understand the influence of four independent variables and their three levels on drill tool wear. Table 3 shows L9 orthogonal array as per the factors (A, B, C, and D) and their 3 levels (1, 2 and 3).

Table 3. Taguchi's L9 Orthogonal Array

Expt No	Speed	Feed	Diameter	Fabric
E1	A1	B1	C1	D1
E2	A1	B2	C2	D2
E3	A1	B3	C3	D3
E4	A2	B1	C2	D3
E5	A2	B2	C3	D1
E6	A2	B3	C1	D2
E7	A3	B1	C3	D2
E8	A3	B2	C1	D3
E9	A3	B3	C2	D1

Signal-to-Noise fraction

To evaluate the effectiveness of a design, signal to noise characteristic is used. The word signal represents the desirable component, close to its specified target value. The term noise represents the undesirable component and measures the variation of the output characteristic. The Taguchi method utilizes the Signal-to-Noise ratio (S/N) concept to display the scatter around a target value. A high value of S/N says that the effect of signal factors are higher than the effect of the noise factors. Based on the quality point of view, there are three possible quality characteristics. They are (1) smaller the better (2) nominal the betterand (3) larger the better. In the present investigation, the objective is to minimize the tool wear, so ''smaller the better'' quality characteristics is selected, whose function is given as $S/N = -10 \log_{10} (1/n\Sigma\ Y_i^2)$ wheren is the number of experiments in a trial[11, 12].

Design of Experiments

The experiments were conducted according to Taguchi's orthogonal array design. The orthogonal array was chosen based on fact that the degrees of freedom for the orthogonal array must be more than or equal to the sum of those of wear parameters or responses. In the present work, L9 orthogonal array was chosen as shown in Table 4, which has 9 rows corresponding to the number of experiments or tests.

Table 4. L9 orthogonal Array with experimentalfactors and levels

Expt No.	Spindle Speed (rpm)	Feed Rate (mm/rev)	Drill Diameter (mm)	Fabric Type
E1	1200	0.1	6	R
E2	1200	0.2	8	R+S
E3	1200	0.3	10	R+R
E4	1500	0.1	6	R+R
E5	1500	0.2	8	R
E6	1500	0.3	10	R+S
E7	1800	0.1	6	R+S
E8	1800	0.2	8	R+R
E9	1800	0.3	10	R

Experimental Technique

- Setting up the Vertical CNC machining center ready for the machining operation.
- Sizing the composite plates for performing CNC drilling for drilling 75 holes as per the specifications mentioned in table 1.
- Cleaning the drill bit using Acetone to remove impurities and atmospheric inclusions.
- Measuring weight of each drill by the high precision digital balance meter before machining.
- Creating CNC part programs for tool path generation with specific geometric codes and machining codes using different levels of spindle speed and feed for performing drilling operation.
- Perform the drilling operation to drill required number of holes (75 holes) at a time.
- Cleaning the drill bit using Acetone to remove deposited chip powders and other impurities.
- Measuring weight of each machined plate again by the digital balance meter.
- Determining tool wear by weight difference method / volume loss method (Table 5).

Experimental Results

Response (Tool Wear) Table for Means (Minitab)

Analysis of the S/N ratio

In the Taguchi method, the term 'signal' represents the desirable factor for the output or the response and the term 'noise' represents the undesirable value for the output characteristic. But from statistical point of view, the S/N ratio is the ratio of the mean to the Standard deviation. Taguchi method utilizes the S/N ratio to measure the quality characteristic deviating from the desired value. In this experiment, Smaller theBetter qualitycharacteristic is used.The smaller is better quality characteristic can be formulated asas $S/N = -10 \log_{10} (1/n\Sigma \; Y_i^2)$, where n is the numberof experiments in a trial. In this research work, n=3 and y_i is the i^{th} response value in a run. The S/N ratio values are calculated by taking the above equation as shown in Table 5.

Table 5. Tool wear values with S/N number

Expt. No.	AverageTool wear (Weight difference)(gms) (T1+T2+T3)/3	S/N Ratio
E1	2.67×10^{-4}	71.4698
E2	3.73×10^{-3}	48.5658
E3	1.89×10^{-4}	74.4708
E4	2.97×10^{-3}	50.5449
E5	7.07×10^{-3}	43.0116
E6	4.33×10^{-4}	67.2702
E7	6.8×10^{-4}	63.3498
E8	2.57×10^{-3}	51.8013
E9	5.5×10^{-4}	65.1927

Taguchi Analysis: Tool Wear versus Process Parameters (A, B, C and D)

Graphical Depiction

The experimental results and calculated values were obtained depending on the design of experiments and then the results were analyzed with the help MINITAB 16, a software developed for the design of experiment and statistical analysis of experimental data. The influence of controlled process parameters such as drill spindle speed, drill feed, drill diameter and composite fiber orientation has been analyzed. The tool wear for each factor and level is calculated. The rank of each process parameter (factors) on the tool wear was found by calculating the difference between maximum and minimum S/N number as shown in Table 6 and Table 7.

Table 6

Levels	A	B	C	D
1	64.84	61.79	63.51	60.17
2	53.61	47.79	55.04	59.73
3	60.39	69.25	60.28	58.94
Δ = Max - Min	**11.23**	**21.46**	**8.47**	**1.23**
Rank	**2**	**I**	**3**	**4**

Table 7. Response Table for S/N Ratios: Smaller

Levels	A	B	C	D
1	0.001395	0.001306	0.001090	0.002612
2	0.003491	0.004457	0.002400	0.001614
3	0.001250	0.000374	0.002646	0.001910
Δ = Max - Min	**0.002241**	**0.004083**	**0.001556**	**0.000998**
Rank	**II**	**I**	**III**	**IV**

It is evident from Table 6and Table 7 that, among these parameters, drill feed factor has significant influence on the tool wear rate. The influence of controlled process parameters on tool wear is graphically shown in Figure 4.

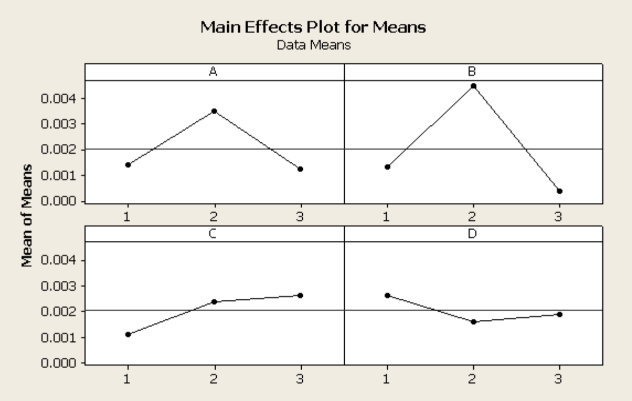


Figure 4. Graph of Main effect plot for means

Based on the analysis of S/N ratio, the optimum machining conditions result in minimum tool wear are shown in Figure 5.

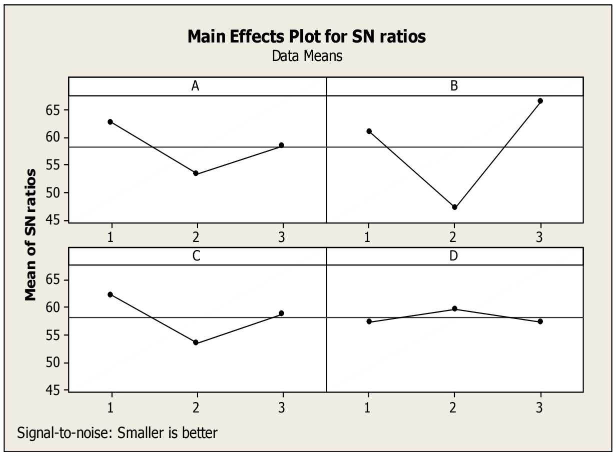


Figure 5. Graph of Main effect plot for S/N ratios

The figures clearly indicate that the first level of spindle speed (A1) and third level of drill feed (B3) and first level of drill diameter (C1) and random+strand fiber orientation (D2) are the optimum factors and levels for minimum tool wear.

It can be seen from Figure 5 that for the graph of feed rate, the slope is bigger. It means that the change in feed rate changes the tool wear rate drastically and nearly the same trend can also be seen on the graph of drill spindle speed and drill diameter.

Results of Analysis of Variance (ANOVA)

ANOVA is a statistical tool, which helps in formally testing the significance of all main factors and their interactions by comparing the mean square against an estimate of the experimental errors at specified levels. The value of total sum of squares is used to measure the influence of the factors relatively. The large value of sum of squares indicates that the factor is more influential for controlling the response.

Table 8shows the results of the analysis of variance on the wear rate for glass fiber reinforced polyester matrix composite. This analysis is carried out at 95% confidence level. The last column of the table indicates the percentage of contribution (Pr) of each factor on the response or results indicating the degree of each.

From Table 8, it is observed that the drill feed factor has greater influence or contribution towards the tool wear (Pr-F=43.51%). Hence drill feed rate is an important process parameter to be controlled carefully in the process of drill tool wear. Feed rate is followed by the influence of spindle speed (Pr-S=33.75%), drill diameter (Pr-DD=13.83%) and fiber orientation (Pr-FT=7.61%) on drill tool wear.

CONCLUSIONS

This study has applied the Taguchi method for investigating the effects of machining parameters on the tool wear of drills in the dry drilling of Glass Fiber reinforced Polymer Matrix Composites. In the drilling process, the parameters were selected by considering industrial and manufacturers requirements.

By using the Signal-to-Noise (S/N) ratio and Taguchi's optimization method along with application of ANOVA, the following conclusions can be made from the results of the drilling process of the present study:

1. The results of S/N ratio and ANOVA Software approaches for data analysis ended up with similar conclusions.
2. Statistical results show that the feed rate (B), cutting speed (A), and drill diameter (C) have significant effecton tool wear in dry drilling of Fiber Reinforced Polymer Matrix Composites with the impact percentage of 43.51%, 33.75%, and 13.83% respectively.
3. The above result concludes that the significant factors affecting the tool wear in dry drilling of Polymer Matrix
4. 4.Composites are Drill Feed followed by Drill Spindle speed, and Drill diameter respectively.
5. 5.The maximum tool wear is calculated as 7.07x10-3 gms.
6. 6.The minimum tool wear is calculated as 3.9093 x 10-4gms.
7. 7.The maximum tool wear was found for A2(spindle speed=1500rpm), B2(feed rate=0.2mm/tev), C3(drill diameter=10mm), D1(fabric type=Random).
8. 8.The application of Taguchi's analysis on the experiments of drill tool wear has shown the optimum cutting parameters as A1(spindle speed=1200rpm),B3(feed rate =0.3mm/rev), C1(drill diameter= 6mm) and D2 (fabric type=Random+Strand).

Table 8.Analysis of Variance for Tool Wear

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Pr %
Speed	2	0.0000595	0.0000595	0.0000298	231.12	0.0000	33.75
Feed	2	0.0000768	0.0000768	0.0000384	298.02	0.0000	43.51
DD	2	0.0000251	0.0000251	0.0000125	97.43	0.0000	13.83
FT	2	0.0000138	0.0000138	0.0000069	53.63	0.0000	7.61
Error	18	0.0000023	0.0000023	0.0000001			1.30
Total	26	0.0001775					100.00
R-Sq = 98.69% R-Sq(adj) = 98.11%							

References

[1.] Kalyan Kumar Chowdhury and E.V. Gijo, 2000, *"Quality Improvement through Design of Experiments: A case study"*, Quality Engineering, 12(3), pp.407-416.

[2.] Kalyan Kumar Chowdhury and E.V. Gijo, 2000, *"Role of the organized sector in developing small-sclae industries as vendors: a case study of experimental approach"*, Total Quality Management, vol-II , No-2, 171-178.

[3.] J. Paulo Davim, 2001, *"A note on determination of optimal cutting conditions forsurface finish obtained in turning using design of experiments"*, Journal of Materials Processing Technology, 116,305-308.

[4.] P.G. Benardos and G.C. Vosniakos, 2002, *"Prediction of surface roughness in CNC face milling using neural networks and Taguchi's design of experiments"*, Roboticsand Computer Integrated Manufacturing,18, 343-354.

[5.] J. Paulo Davim, 2003, *"Study of drilling metal-matrix composites based on the Taguchi techniques"*, Journal of Materials Processing Technology, 132,250-254.

[6.] Eyup Bagci et. al, 2008, *" Influence of cutting parameters on drill bit temperature in dry drilling of AISI 1040 steel material using statistical analysis"* Journal of Industrial Lubrication and Tribology, vol. 59, pp: 186-193.

[7.] S.K. Choudhury, G. Bartarya, 2004, *"Role of temperature and surface finish in predicting tool wear using neural network and design of experiments"*, Int Journal of Machine Tools &Manufacture, 43, 747-753

[8.] C C Tsao, 2004, *"Taguchi analysis of drilling quality associated with core drill in drilling of composite material"*, International Journal of AdvancedManufacturing Technology, Vol. 32, pp: 877-884.

[9.] J. Paulo Davim, Pedro Reis, C.C. Antonio, 2004, *"A study on milling of GFRP Plastics manufactured by hand lay-up*

[10.] *using ANOVA"*, Journal of Composite Structures, vol. 64, 2004, pp: 493-500.

[11.] V.N.Gaitonde, B.T. Achyutha, S.R.Karnik, B.Siddeswarappa, *"Taguchi approach with multiple performance characteristics for burr size minimization in drilling"*, Journal of Scientific and Industrial Research, 2006, (65), pp:977-988.

[12.] Palanikumar et. al., 2008, *"Evaluation of delamination in drilling of GFRPcomposites"*, Materials and Manufacturing Processes Journal, vol. 23, pp. 858-864.

[13.] Mustafa Kurt & Eyup Bagci & Yusuf Kaynak ,2009, *"Application of Taguchi methods in the optimization of cutting parameters for surface finish and hole diameter accuracy in dry drilling processes"*, Int J Adv Manuf Technol (2009) Vol 40:pp.458–469.

[14.] I.Singh, N. Bhatnagar, P. Viswanath, "Drilling of uni-directional glass fiber reinforced plastics: Experimental and finite element study", Materials and Design 29 (2008) 546–553.

[15.] Adam G. Rehorn, Jin Jiang, Peter E. Orban, and Evgueni Bordatchev, 'Modelling and experimental investigation of spindle and cutter dynamics for a high-precision machining center,' International Journal of Advanced Manufacturing Technology, 24 (11-12), pp. 806-815, 2004.

[16.] Chowdhury S.K., and Ganga Raju, Investigation into crater wear in drilling, International Journal of Machine tools and Manufacture, 40, 887-898 (2000)