Experimental Investigation to Optimize process Parameters in Drilling Operation for Composite Material

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Abstract - *This paper discusses the influence of cutting parameters in drilling of Delrin material. The experiments are conducted to study the effect of drill diameter, point angle, spindle speed, feed rate and depth of cut on material removal rate using HSS twist drills. In this thesis, the input parameters considered are point angle, tool diameter, spindle speed, feed rate and depth of cut. Different combinations of the above parameters are considered to get the maximum material removal rates using L12 orthogonal array in Taguchi method. The parameters are drilling diameter of cutting tool - 6mm, 10mm, point angle – 118° & 120°, Speed – 800rpm, 1200rpm, Feed Rate – 30mm/min, 50mm/min and depth of cut – 0.5mm, 1mm.Theoretical calculations are done to calculate to verify the Material Removal Rate (MRR) and calculating time taken has been calculated by the experiment. Experiments are conducted on CNC milling machine using Taguchi design of experiments a model is developed with the drilling parameters. The experimental results were analyzed using MINITAB V19. By observing the Taguchi results to optimize parameters for time taken for drilling, the optimum speed is 1200rpm, feed rate is 50mm/min, depth of cut is 0.5mm, tool angle is 118^0 and drill diameter is 6mm. Signal-to-Noise (S/N) ratio is employed to analyze the effect of drilling parameters on the quality of the drilled holes.*

Key Words: DOE, S/N ratio, Taguchi method, drilling Operation, composite material

1. INTRODUCTION

Composite materials are widely used in the diverse applications such as aircraft, automobile, sporting goods, marine vessels, audio equipment etc. Because of its unique properties such as specific strength, fatigue strength, strength to weight ratio and corrosion resistance Machining of Delrin material is essential for all applications.

Drilling using twist drill is the most commonly employed operation of secondary machining for fiber reinforced materials. However, composite laminates are regarded as hard-to-machine materials, which results in low drilling efficiency and undesirable drilling-induced delamination. For rivets and bolted joints, damaged-free and precise holes must be drilled in the components to ensure high joint strength and precision. However, some special characteristics of composite laminates such as non homogeneous, anisotropic, and highly abrasive and hard reinforced fibers, result in them difficult to machine. Among the problems caused by drilling, delamination is considered the major damage. It was reported that, in aircraft industry, the rejection of parts consist of composite laminates due to drilling-induced delamination damages during final assembly was as high as 60.

1.1 Literature Review

Biren Desai [1] et.al studied an application of the full factorial design for optimizing the cutting parameters in drilling operations performance measures circularity and hole size. From this research, following conclusions could be reached with an optimum amount of response. P. Ghabezi, and M. Khoranb A [2] studied in their investigation the experiment is carried out to analyze two criterions of delamination and uncut fiber factors in the drilling of PVC foam composite sandwich panels. The effect of cutting speed, feed rate and tool diameter on the hole quality is analyzed. The mean values of DF and UCFF versus different cutting parameters for PVC core materials. R.M. Kulkarni [3] et al in their experimental studies of drilling of glass fibre reinforced plastic laminates dispersed with 0, 4 and 8 wt% carbon black employing a sensitive drilling machine were undertaken. Design of experiments provided an experimental plan of L27 orthogonal array by considering carbon black % weight, spindle speed, Feed rate, drill point angle and drill material as factors. J Baboo and Tom Sunny [4] has presented an application of the Taguchi method for the delamination study of drilling of GFRP composites. The analysis of experimental results is carried out using Taguchi's orthogonal array and analysis of variance. The level of the best of the cutting parameters on the drilling induced delamination is determined by using ANOVA. The drilling induced delamination increases with spindle speed (1000rpm-2500rpm) and decreases with feed rate (100mm/min to 400mm/min). The results for very low feed rate i.e., 50mm/min and high spindle speed 300rpm show the opposite trend. In both the cases delamination factor increased instead of decreasing. The reason for higher delamination at spindle speed 3000rpm may be, when the drill speed increases, the thrust force increases because severe heat generation in the drilling area leads to softening of the fiber and matrix. S. Madhavan and S. Balasivanadha

Prabu [5] studied for correlating the drilling parameters with respect to thrust force a second order response surface model has been developed. The developed model is significant at 95% confidence level, which shows that the developed model can be effectively used for drilling of CFRP composites within the range of the process parameters. Analysis of variance for the developed model revealed that the type of drill and the feed rate are the dominant factors that influence the thrust force. Thrust force recorded for HSS drill was high when compared to Carbide. Since the hardness of HSS tool is less than the Carbide drill. Medium cutting speed and feed rate provided optimum thrust forces irrespective of the drills used. Significant reduction in cost and timing can be achieved by using this response surface model K. Sabeel Ahmed and Amith Kumar S. [6] studied The effect of drilling parameters (feed, speed) and filler (SiC and Al2O3) composition on thrust force, torque, delamination factor and hole quality of ceramic particles filled jute/epoxy composites was experimentally investigated. Based on their analysis both thrust force and the torque increases with the increase in feed at all speeds. Pradeep Mishra, [7] et al studied in their Experimental work to optimize and analyzed process parameters namely point angle (deg), spindle speed (RPM) and feed (mm/Rev) in drilling operation of mild steel. In this work, experiments were carried out as per the Taguchi experimental design and an L9 orthogonal array was applied to study the influence of various combinations of process parameters for MRR. ANOVA (Analysis of variance) test was conducted to determine the percentage of contribution for each process parameters on drilling. Yogendra Tyagi, [8] et al studied the drilling of mild steel with the help of CNC drilling machine operation with Tool use high speed steel by applying Taguchi methodology has been reported. The Taguchi method is applied to formulate the experimental layout to ascertain the Element of impact each optimum process parameters for CNC drilling machining with drilling operation of mild steel. A L9 array, taguchi method and analysis of variance (ANOVA) are used to formulate the procedure tried on the change of parameter layout. The available material study in focuses optimization of CNC Drilling machine process parameters to provide good surface finish as well as high material removal rate (MRR). Abhishek Dubey, [9] et al studied in their work successfully demonstrated the application of Taguchi based Grey relational analysis for optimization of process parameters in end milling of EN31 steel. They conclude that the highest Grey relational grade of 1.0000 was observed for the experimental Process, of the average Grey relational grade, which indicates the combination of control factors. The order of importance for the controllable factors to the minimum surface roughness, in sequence, is the feed rate, depth of cut, spindle speed and pressurized coolant jet. Vijayan Krishnaraj [10] et al studied in their experimental results of effect of cutting parameters on the cutting forces and hole quality. Feed rate has a greater influence on thrust force, push-out delamination and diameter of the hole. While lower feed rates reduce thrust force and push-out delamination, higher feed rates result in holes closer to the nominal diameter. Spindle speed is one of the major determinants of the circularity of the drilled hole. J.P. Davim and Pedro Reis [11] studied on delamination when, drilling of CFRPs, The helical flute K10 drill promotes less damage on the composite laminate than the four-flute carbide (K10) drill, i.e., the delamination factor (F_d) is smaller. The helical flute K10 drill, presents a better performance, than helical flute HSS drill, i.e., the carbide drill is the better choice for drilling CFRP. S.R. Karnik, [12] et al studied to analyze the effects of process parameters on delamination factor in high speed drilling of CFRP materials, the experiments were carried out as per full factorial design plan to create a database. Three drilling parameters, namely spindle speed, feed rate and point angle were considered for delamination analysis. The delamination prediction model was developed using multi- layer feed forward ANN, trained using EBPT algorithm. Krishnamoorthy [13], et al studied in their experiment drilling of CFRP composite is carried out with the input drilling parameters considered as spindle speed, point angle and feed rate, and the response obtained are thrust force, torque, delamination at the entry and exit of the hole and eccentricity. The drilling parameters are optimized with respect to multiple performances in order to achieve a good quality of holes in drilling of CFRP composite.

2. DESIGN OF EXPERIMENT

A calculatedly set of experiments, within which all parameters of interest a varied over a such vary, could be a far better approach to get systematic information. Mathematically speaking, such an entire set of experiments need to provide desired results. Typically the quantity of experiments and resources (materials and time) needed a prohibitively giant. Typically the experimenter decides to perform a set of the entire set of experiments to avoid wasting on time and money but, it doesn't simply lend itself to understanding of science behind the development. The analysis isn't terribly simple (though it's going to be simple for the mathematician/statistician) and therefore effects of varied parameters on the discovered information don't seem to be pronto apparent. In several cases, significantly those within which some optimization is needed, the strategy doesn't purpose to the most effective settings of parameters.

2.1 TAGUCHI TECHNIQUE

Dr. Taguchi of Nihon Telephones and Telegraph Company, Japan has developed a way supported "ORTHOGONAL ARRAY" experiments which supplies abundant reduced "variance" for the experiment with "optimum settings "of management parameters. Therefore the wedding of style of Experiments with optimization of management parameters to get BEST results is achieved within the Taguchi technique. "Orthogonal Arrays" (OA) offer a group of well balanced (minimum) experiments and Dr. Taguchi's Signal: to: Noise ratios (S/N), that area unit Log functions of desired output, function objective functions for optimization, facilitate in information analysis and prediction of optimum results.

2.2 TAGUCHI TECHNIQUE TREATS OPTIMIZATION ISSUES IN 2 CLASSES

Static Problem: Generally, a method to be optimized has many management factors that directly decide the target or desired worth of the output. The optimization then involves determinative the simplest management issue levels so the output is at the target worth. Such a retardant is referred to as a "Static problem".

Dynamic Problem: If the merchandise to be optimized features a signal input that directly decides the output, the optimization involves determinative the simplest management issue levels so the "input signal output" magnitude relation is highest to the required relationship. Such a retardant is named as a "Dynamic problem".

3. EXPERIMENTAL WORK

3.1 Material

The materials used Delrin (acetal homopolymer) is the ideal material in parts designed to replace metal. It combines low-friction and high-wear resistance with the high strength and stiffness such applications require. It provides a wide operating temperature range (-40 ˚C to 120 ˚C) and good color ability. Compared to acetal copolymer, Delrin(acetal homopolymer) offers higher tensile strength, stiffness, creep and fatigue resistance, and significantly higher impact resistance. The combination of these excellent mechanical properties in a single material allows for thinner, lighter-weight parts and shorter molding cycles with potential cost reductions.

3.2 Preparation

Drilling operations are conducted on the Delrin (acetal homopolymer) material with 6mm and 10mm diameter drills with 118˚ and 120˚ point angles, Speed – 800rpm, 1200rpm, Feed Rate – 30mm/min, 50mm/min and depth of cut – 0.5mm, 1mm.The initial size of Delrin (acetal homopolymer) material is 115*86*10mm.Cutting tool material is HSS. On a CNC machine for drilling, final product is as shown n figure 3.1 and then optimized using MINITAB software.

Fig 3.1 Final component

Table 1: Time taken for drilling and Martial removal rate (MRR) for different parameters

JOB NO.	SPEED (rpm)	FEED RATE(mm/ min)	DEPTH OF CUT (mm)	TOOL ANGLE	TOOL DIAMETER (mm)	Time (sec)	MRR (mm^3/ min)
1	800	30	0.5	118	6	17	848.23
2	800	30	0.5	118	6	17	848.23
3	800	30	1	120	10	12	2356.19
4	800	50	0.5	120	10	10	3926.99
5	800	50	1	118	10	11	3926.99
6	800	50	1	120	6	20	1413.71
7	1200	30	1	120	6	15	848.23
8	1200	30	1	118	10	14	2356.19
9	1200	30	0.5	120	10	12	2356.19
10	1200	50	1	118	6	15	1413.71
11	1200	50	0.5	120	6	14	1413.71
12	1200	50	0.5	118	6	20	3926.99

4. RESULTS AND DISCUSSION

4.1. S/N ratio

In the Taguchi method, the term ‚signal‘ represents the desirable value (mean) for the output characteristic and the term ‚noise‘ represents the undesirable value (standard deviation, SD) for the output characteristic. Therefore, the S/N ratio is the ratio of the mean to the SD. Taguchi uses the S/N ratio to measure the quality characteristic deviating from the desired value. There are several S/N ratios available, depending on the type of characteristic; lower is better (LB), higher is better (HB), and nominal is best (NB)

Lower the better: measured data and ideal value is expected to be as small as possible.

$$SN_S = -10log\left(\frac{1}{n}\sum_{i=1}^{n} Y_i^2\right)$$

Higher the better: The larger-the-better characteristic should be non-negative, and its most desirable value is infinity.

$$S = \sqrt{\sum_{i=1}^{n}\frac{(Y_i - \overline{Y})^2}{n-1}}$$

Nominal the best: This case arises when a specified value is most desired, meaning that neither a smaller nor a larger value is desirable.

$$SN_L = -10log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{Y_i^2}\right)$$

Table 2: S/N Ratio results for Time taken for different parameters

JOB NO.	SPEED (rpm)	FEED RATE(mm/min)	DEPTH OF CUT (mm)	TOOL ANGLE	TOOL DIAMETER (mm)	Time (sec)	S/N Ratio
1	800	30	0.5	118	6	17	-38.0618
2	800	30	0.5	118	6	17	*
3	800	30	1	120	10	12	-39.0849
4	800	50	0.5	120	10	10	-36.9020
5	800	50	1	118	10	11	-37.5012
6	800	50	1	120	6	20	-37.3846
7	1200	30	1	120	6	15	-35.5630
8	1200	30	1	118	10	14	-36.1236
9	1200	30	0.5	120	10	12	-355.8478
10	1200	50	1	118	6	15	-34.8073
11	1200	50	0.5	120	6	14	-33.6248
12	1200	50	0.5	118	6	20	-35.1175

Table 3: S/N Ratio results for MRR for different parameters

JOB NO.	SPEED (rpm)	FEED RATE(mm/min)	DEPTH OF CUT (mm)	TOOL ANGLE	TOOL DIAMETER (mm)	MRR (mm^3/min)	S/N ratio
1	800	30	0.5	118	6	848.23	58.5659
2	800	30	0.5	118	6	848.23	*
3	800	30	1	120	10	2356.19	67.4398
4	800	50	0.5	120	10	3926.99	71.8768
5	800	50	1	118	10	3926.99	71.8768
6	800	50	1	120	6	1413.71	63.0028
7	1200	30	1	120	6	848.23	58.5659
8	1200	30	1	118	10	2356.19	67.4398
9	1200	30	0.5	120	10	2356.19	67.4398
10	1200	50	1	118	6	1413.71	63.0028
11	1200	50	0.5	120	6	1413.71	63.0028
12	1200	50	0.5	118	6	3926.99	71.8768

From Table 2 shows the best performance the optimum Speed is 1200rpm, optimum feed rate is 50mm/min, optimum Depth of cut is 0.5mm, the optimum Tool Angle is 118^0, and the optimum Tool Diameter is 6mm.From Table 3 shows the best performance the optimum Speed is 800rpm, optimum feed rate is 50mm/min, optimum Depth of cut is 0.5mm, optimum Tool Angle is 118^0 and optimum Tool Diameter is 10mm.

4.2 Main effect plots for different values of S/N ratios

The main effects plot for S/N ratio values for time of drilling is shown in Fig 1. Spindle speed of 1200rpm produced optimum feed rate is 50mm/min, optimum Depth of cut is 0.5mm, the optimum Tool Angle is 118^0, and the optimum Tool Diameter is 6mm.

Main effects plot for S/N ratio values for MRR is shown in Fig 2 is optimum Speed is 800rpm, optimum feed rate is 50mm/min, optimum Depth of cut is 0.5mm, optimum Tool Angle is 118^0 and optimum Tool Diameter is 10mm.

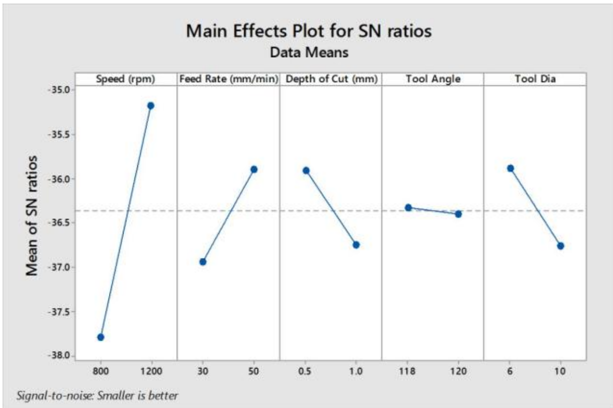

Fig 1 Main effects plot of for S/N ratio values of Time taken

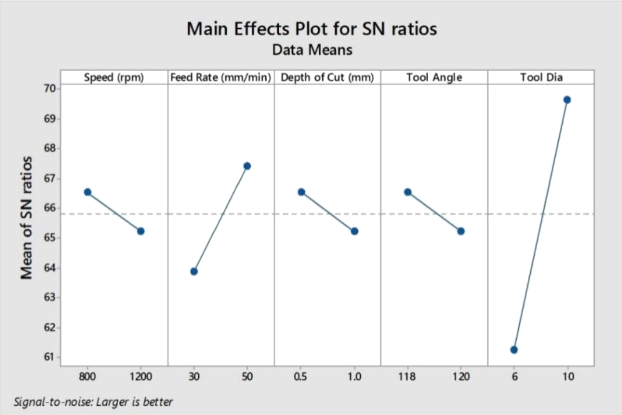

Fig 2 Main effects plot of for S/N ratio values of MRR

4. CONCLUSIONS

Different combinations of the point angle, tool diameter, spindle speed, feed rate and depth of cut, are considered to get the maximum material removal rates using L12 orthogonal array in Taguchi method. The parameters are drilling diameter of cutting tool - 6mm, 10mm, point angle – 118^0& 120^0, Speed – 800rpm, 1200rpm, Feed Rate – 30mm/min, 50mm/min and depth of cut – 0.5mm, 1mm.

From the experimental results and Taguchi results, the following conclusions can be made:

- The important parameters affecting time taken for drilling are Speed, Feed Rate & drill dia. and for MRR are drill diameter & Feed Rate. So it can be concluded that tool angle and depth of cut do not affect time and MRR.
- By observing the Taguchi results to optimize parameters for time taken for drilling, the optimum speed is 1200rpm, feed rate is 50mm/min, depth of cut is 0.5mm, tool angle is 118^0 and drill diameter is 6mm.
- Optimize parameters for MRR, the optimum speed is 800rpm, feed rate is 50mm/min, depth of cut is 0.5mm, tool angle is 118^0 and drill diameter is 10mm.
- By observing the results, the stresses are more for 118^0 angle and 6mm diameter. The results are less when drilling Derlin material.

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