OPTIMIZATION OF DRILLING PARAMETERS FOR IMPROVING MATERIAL REMOVAL RATE ON TEFLON USING TAGUCHI DESIGN

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Abstract: *Now a day, objective of the manufacturing industries is to achieve the economical machining condition to increase the profit with desired quality and accuracy. Machining is an important material removal process in which materials are removed from the workpiece in the form of chips. Various machining operations like milling, grinding, drilling and turning are used in the manufacturing industries to develop the finished component with high quality. The selection of manufacturing methods depends on the production costs of the alternatives of the individual parts. Drilling operation as a mass production process is finding industrial acceptance, particularly for making hole in the materials. In drilling operation, the quality of hole is an important requirement for many industrial and home need applications. Thus, the choice of optimized drilling parameters is very important factor for controlling the quality of the drilled hole.*

Recently, Teflon material is used in the automobile, chemical, nuclear and marine industries. During the drilling process, heat is generated at the contact of the drill bit and test specimen. The experiments were conducted by the proper selection of drilling parameters to obtain better mechanical strength by using the L_{27} orthogonal array. In this experimental investigation, Teflon has been drilled by using the SAHYOG geared drilling machine with dry conditions. The optimum level of drilling parameters is great impact in the manufacturing environment. The basic drilling parameters such as spindle speed, feed rate and drill size were selected and examined at three different levels, to study the effect of drilling parameters on material removal rate. Material removal technology for the drilling operation is based on the rotation of the drill bit and the penetration of drill bit into the workpiece top face. The results of this investigation are *analysed by using the Minitab software. The present experimental work is focused on the optimization of drilling parameters using Taguchi design of experiments and the optimum level of drilling parameters are to be recommended for drilling operation.*

Keywords: Drilling, Teflon, Design of Experiments and Material Removal Rate.

1. INTRODUCTION

The important objective in the modern industries is to reduce the cost of manufacturing products with high quality in short span of time. Engineers face two main practical problems in a manufacturing process that is to determine the values of optimum process parameters that will yield the desired product quality (meet technical specifications) and to maximize manufacturing system performance using the available resources. Teflon material is a new engineering material found applications in the automobile, chemical, nuclear and marine industries. Drilling is one of the important manufacturing operations that can be carried out on number of parts for assembly work. Drilling operation can be described as a process where a multi-point tool is used for unwanted materials removal to produce a desired hole. It is an important metal cutting operations with which holes are produced in components made of metallic and non-metallic materials. Drilling operation is widely employed in manufacturing industries, but conventional drilling still remains one of the most common machining. The cylindrical holes of required diameter are cut out of the component with a cutting tool, called drill bit. It is essential to optimize quality and productivity of with respect to drilling operation as it being very common operation in manufacturing. Many researchers have worked on drilling operation. Optimum values of input parameters such as speed, feed are calculated to obtain required material removal rate (MRR) value The experiment was carried out on the basis of Taguchi's L27 orthogonal array of experiments. The input drilling parameters considered involves spindle speed, feed rate and drill diameter while the response variable of MRR is studied. Taguchi optimization technique is used for optimization of drilling parameters; ANOVA is used to find the highly influential drilling parameters that contribute to a high quality product.

2. LITERATURE REVIEW

Syed Siraj Ahmed, Prof. S. D. Ambekar investigated on experimental analysis of material removal rate in drilling of 41Cr4 by a Taguchi's Approach and concluded that statistically designed experiments based on

Taguchi method are performed using L9 orthogonal array to analyse the effect of drilling parameters on material removal rate and linear regression equations are developed to predict the values of material removal rate then the predicted values are compared with measured values. A.Navanth, T. Karthikeya Sharma conducted a study of drilling parameter of Al 2014 in radial drilling machine under dry conditions and optimizes the drilling parameters based on Taguchi method of design of experiments. They identified that a spindle speed of 200 rpm, point angle & Helix angle of 90°/15°and a feed rate of 0.36 mm/rev is the optimal combination of drilling parameters that produced a high value of S/N ratios of Hole Diameter. Mustafa Kurt, Yusuf kanak et al performed experiment on Al 2024 alloy material uses in different drilling holes on optimization of cutting parameters for surface finish and hole diameter accuracy. Lipin and Dr. P. Govindan conducted a review on multi objective optimization of drilling parameters using Taguchi methods and finalised that Taguchi method has been used to determine the main effects, significant factors and optimum machining conditions to obtain better performance characteristics. M. Sundeep, M. Sudhahar, T.T.M Kannan, P. Vijaya Kumar and N. Parthipan performed an experiment on optimization of drilling parameters on austenitic stainless steel using Taguchi's methodology and they discussed that more material removal rate occur at cutting speed 1250rpm and feed rate 0.02 mm using 8 mm drill tool. Ahamed et al. experimentally investigated the effect of drilling parameters on MRR and tool wear during the drilling of hybrid Al-5%SiCp-5%B4Cp metal matrix composites with HSS drills. Tyagi et al used Taguchi method and investigated the effect of machining parameters i.e., spindle speed, feed rate and depth of cut on the surface roughness(SR) and MRR and concluded that, the spindle speed of drilling machine tool mainly affects the SR and the feed rate largely affects the MRR.

3. METHODOLOGY

3.1. Design of Experiment (DOE):

Design of Experiment is a powerful approach to improve product design or improve process performance where it can be used to reduce cycle time required to develop new product or processes. Design experiment is a test or series of test that the input variable (parameter) of a process is change so that observation and identifying corresponding changes in the output response can be verified. The result of the process is analyzed to find the optimum value or parameters that have a most significant effect to the process.

3.2. Analysis of Variance (ANOVA)

Analysis of variance is a standard statistical technique to interpret the experimental results. It is extensively used to detect differences in average performance of groups of items under investigation. It breaks down the variation in the experimental result into accountable sources and thus finds the parameters whose contribution to total variation is significant. Thus analysis of variance is used to study the relative influences of multiple variables, and their significance. The purpose of ANOVA is to investigate which process parameters significantly affect the quality characteristic. The analysis of the experimental data is carried out using the software MINITAB 17.1 specially used for design of experiment applications. In order to find out statistical significance of various factors like speed, feed, and drill diameter, and their interactions on MRR, analysis of variance (ANOVA) is performed on experimental data.

3.3. Taguchi Method:

The Taguchi technique is a methodology for finding the optimum setting of the control factors to make the product or process insensitive to the noise factors. Taguchi's techniques have been used widely in engineering design, and can be applied to many aspects such as optimization, experimental design, sensitivity analysis, parameter estimation, model prediction, etc. Taguchi based optimization technique has produced a unique and powerful optimization discipline that differs from traditional practices. Taguchi method uses a special highly fractionated factorial designs and other types of fractional designs obtained from orthogonal arrays (OA) to study the entire experimental region of interest for experimenter with a small number of experiments. This reduces the time and costs of experiments, and additionally allows for an optimization of the process to be performed. The columns of an OA represent the experimental parameters to be optimized and the rows represent the individual trials. Traditionally, data from experiments is used to analyse the mean response. However, in Taguchi method the mean and the variance of the response (experimental result) at each setting of parameters in OA are combined into a single performance measure known as the signal-to-noise (S/N) ratio. Depending on the criterion for the quality characteristic to be optimized, different S/N ratios can be chosen:

- Smaller-The-Better
- Larger-The-Better
- Nominal-The-Best

3.3.1. Smaller – The –Better:

The Signal-To-Noise ratio for the smaller-the-better is:

S/N = –10 *log (mean square of the response)

S/N= –10 $\log_{10}$ [Σ —] ----------- (1)

3.3.2. Larger-The-Better:

The Signal-To-Noise ratio for the bigger-the-better is:

S/N = -10*log (mean square of the inverse of the response)

S/N= –10 $\log_{10}$ [– —] ----------- (2)

Where n= number of measurements in trial/row, in this case n=1, 2…, 9 and Y_i is the i^{th} measured value in a run/row. i=1, 2…

3.3.3. Nominal – The – Best:

The S/N equation for the nominal-the-best is: S/N = 10 * log (the square of the mean divided by the variance)

S/N= 10 $\log_{10}$ Σ —] ----------- (3)

4. EXPERIMENTAL SETUP

The radial drilling machine is intended for drilling on medium to large and heavy work pieces. It has a heavy round column mounted on a large base. The column supports a radial arm, which can be raised or lowered to enable the table to accommodate work pieces of different heights. The arm, which has the drill head on it, can be swung around to any position. The drill head can be made to slide on the radial arm. It consists of parts like base, column, radial arm, drill head and driving mechanism. In the present work, radial drilling machine is used to drill holes on Teflon. In this drilling operation, no coolant was used.

Figure1: Radial Drilling Machine

4.1. High Speed Steel (HSS):

Arrival of HSS in around 1905 made a break through at that time in the history of

Figure 2: HSS Cutting Tools cutting tool materials though got later superseded by many other tool materials like cemented carbides and ceramics which could machine much faster than the HSS tools. The basic composition of HSS is 18% W, 4% Cr, 1% V, 0.7% C and rest Fe.

4.2. Work Material Details:

The material used for drilling is Teflon (also called PTFE) which is in the size of 100×100×12.Polytetrafluoroethylene is a fluorocarbon-based polymer and is commonly abbreviated PTFE. It offers high chemical resistance, low and high temperature capability, resistance to weathering, low friction, electrical and thermal insulation .PTFE's mechanical properties are low compared to other plastics, but its properties remain at a useful level over a wide temperature range of -73ºC to 204ºC.It has excellent thermal and electrical insulation properties and a low coefficient of friction.

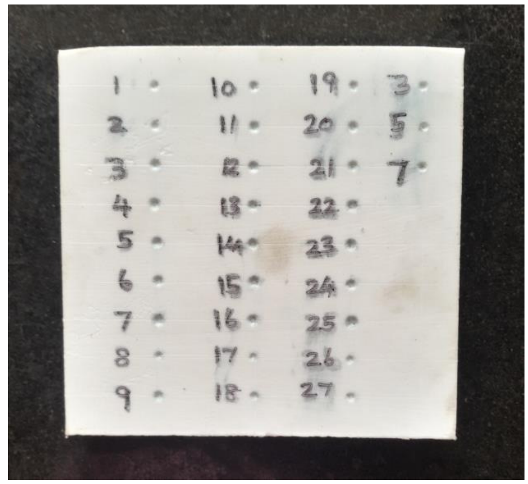


Figure 3: Teflon plate before drilling. The chemical composition of PTFE (Teflon) is 76% F and 24% C approximately.

4.3. Properties Of Teflon

This fluoroplastic family offers high chemical resistance, low and high temperature capability, resistance to weathering, low friction, electrical and thermal insulation, and "slipperiness". The melting point of Teflon is 327 °C. It is easy to mold Teflon and spin cast. It resists moisture. PTFE is a semi-crystalline polymer having non-sticky properties so that it is used in utensils. It is used in gears, bearings, and wind shield wipers

Table 1: Cutting Parameters and their levels

FACTORS	LEVEL 1	LEVEL 2	LEVEL 3
Spindle Speed (rpm)	800	1250	1850
Feed Rate (mm/rev)	0.0225	0.018	0.0157
Drill Size (mm)	3	5	7

Table 2: Process Parameters and Outcomes

Trial	Speed	Feed Rate	Drill Size	MRR	S/N
no	rpm	mm/rev	mm	gram/min	ratio
1	800	0.0225	3	0.2857	-11.0209
2	800	0.0225	3	0.2727	11.0209
3	800	0.0225	3	0.2857	11.0209
4	800	0.0180	5	0.6154	-4.0182
5	800	0.0180	5	0.6428	-4.0182
6	800	0.0180	5	0.6316	-4.0182
7	800	0.0157	7	1	0.2953
8	800	0.0157	7	1.0189	0.2953
9	800	0.0157	7	1.0914	0.2953
10	1250	0.0225	5	1.1613	1.6730
11	1250	0.0225	5	1.2	1.6730
12	1250	0.0225	5	1.2857	1.6730
13	1250	0.0180	7	1.8	5.3119
14	1250	0.0180	7	1.9091	5.3119
15	1250	0.0180	7	1.826	5.3119
16	1250	0.0157	3	0.3	-10.0211
17	1250	0.0157	3	0.3157	-10.0211
18	1250	0.0157	3	0.3333	-10.0211
19	1850	0.0225	7	3.2728	10.5752
20	1850	0.0225	7	3.5	10.5752
21	1850	0.0225	7	3.375	10.5752
22	1850	0.0180	3	0.5	-5.7171
23	1850	0.0180	3	0.5217	-5.7171
24	1850	0.0180	3	0.5333	-5.7171
25	1850	0.0157	5	1.25	-9.4346
26	1850	0.0157	5	1.2	-9.4346
27	1850	0.0157	5	1.2631	-9.4346

5. RESULTS AND DISCUSSIONS

The effect of various parameters such as cutting speed, feed, drill diameter and interaction between drill material and cutting speed were evaluated using ANOVA. A confidence interval of 95% has been used for the analysis. 27 trials were conducted in the experiment using L27 experimental design. One repetition for each of 27 trials was completed to measure Signal to Noise ratio (S/N ratio).Minitab software17.1 is used for parameters optimization. The graph no.1 shows that the relationship between spindle speed, feed rate, drill size against MRR individually. It can be found that for effective machining operation which requires larger material removal rate high values of spindle speed, feed rate and drill size are required.

The second graph shows that the relationship between percent, frequency, fitted value, observation order against Residual individually. The graph no.2 consists of four subgroups which have normal probability plot, histogram, versus fits, versus order which is called residual plot for MRR. The values in the tables are obtained from Minitab 17.1 software.

The table no.3 shows the coefficient and constant values in the regression equation and table no.4 shows that the rank given to various drilling parameters from that it is understood that drill size is the factor to be given priority and also it depends on the need of the hole .So the next priority goes to spindle speed. Thus the optimized spindle speed and feed rate is given for the recommended drill size.

5.1. Regression Equation

A statistical technique used to explain or predict the behavior of a dependent variable .the regression equation for this case is shown below.

MRR = 1.1626 + A* Spindle Speed + B *Feed Rate + C* Drill Size

Where

A - Coefficient for spindle speed

B - Coefficient for Feed rate

C - Coefficient for Drill size.

Table 3: Table for Coefficients in Regression Equation

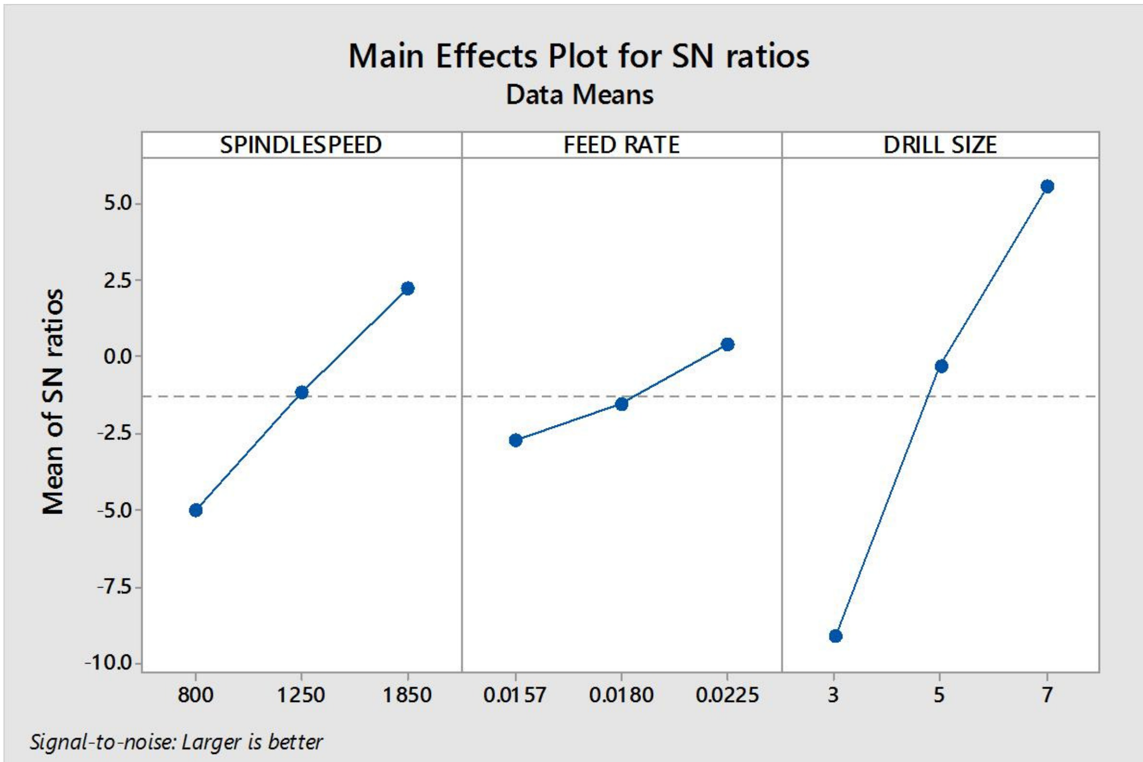
Term	Level	Coefficient		SE Coefficient	T-Value	P-Value	VIF
Constant	1	1.1626		0.0488	23.83	0.000	
Spindle Speed	800	A	-0.5133	0.0690	-7.44	0.000	1.33
	1250		0.0370	0.0690	-0.54	0.598	1.33
	1850		+ 0.5502	0.0690	3.26	0.785	1.33
Feed Rate	0.0225	B	+0.4639	0.0690	8.23	0.058	1.33
	0.018		-0.1649	0.0690	-2.39	0.027	1.33
	0.0157		-0.2990	0.0690	-4.33	0.000	1.33
Drill Size	3	C	-0.7906	0.0690	-11.46	0.000	1.33
	5		-0.1349	0.0690	-1.95	0.065	1.33
	7		+ 0.9255	0.0690	5.64	0.086	1.33

5.2. Signal to Noise ratio

Table 4: Response Table for Signal to Noise Ratios MRR - Larger is better

LEVEL	SPINDLE SPEED	FEED RATE	DRILL SIZE
1	-5.0021	-2.7198	-9.1459
2	-1.1255	-1.5325	-0.2731
3	2.2800	0.4047	5.5715
Delta	3.9025	6.7959	14.3139
Rank	2	3	1

Graph 1: Main Effects Plot for S/N ratios



5.3. Residual Plots

Graph 2: Residual Plots for S/N ratios

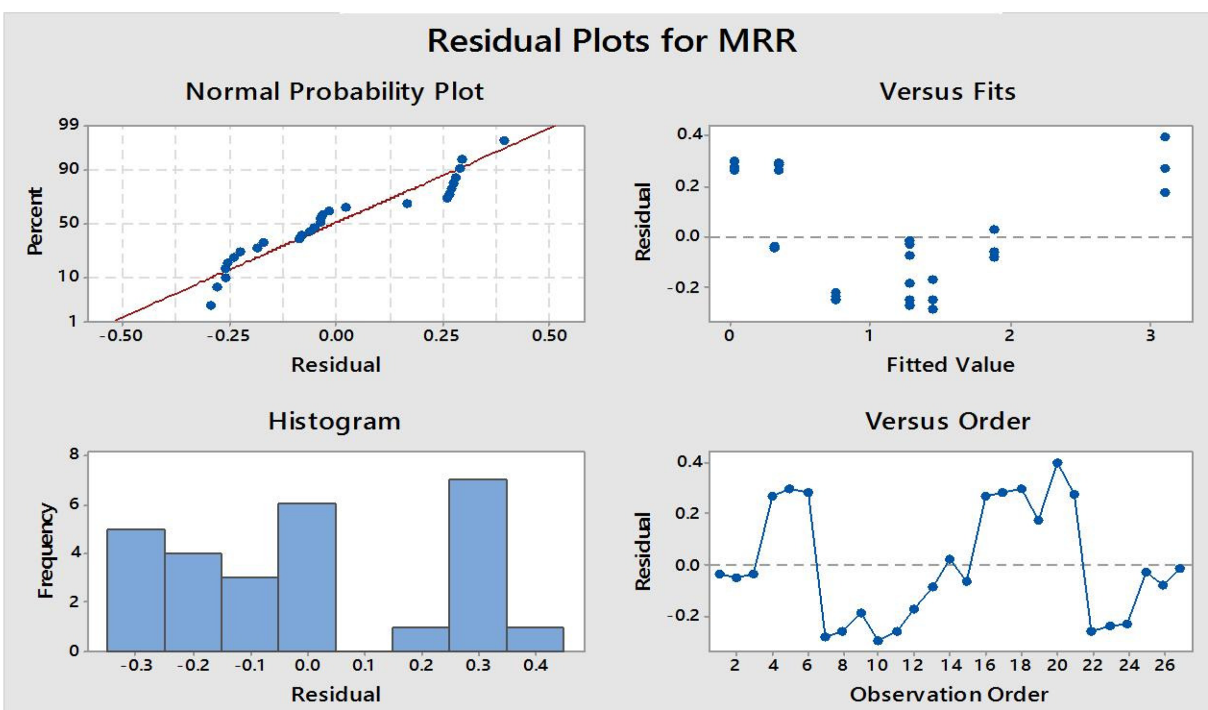


Table 5: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Spindle Speed	2	5.1083	2.55415	39.73	0.000
Feed Rate	2	2.9863	1.49317	23.23	0.000
Drill Size	2	13.4984	6.74920	104.98	0.000
Error	20	1.2858	0.06429	*	*
Lack-of-Fit	2	1.2368	0.61842	227.22	0.000
Pure Error	18	0.0490	0.00272	*	*
Total	26	22.8789		*	*

Table 6: Model Summary

S	R-square	R-square(adj)	R-square(pred)
0.253557	94.38%	92.69%	89.76%

6. CONCLUSION

The following conclusions can be obtained in drilling of Teflon (PTFE) with HSS Steel in radial drilling machine are

1. The optimum parameters for larger material removal rate (MRR) are speed =1850rpm, Feed rate = 0.0225mm/rev and drill size =7mm.
2. Drill size is the most influential factor for getting larger material removal rate.
3. The next influential factor for the recommended drill size is spindle speed and then feed rate.
4. The R-square value obtained from Minitab is 94.38% which shows nearly 5.62% errors.

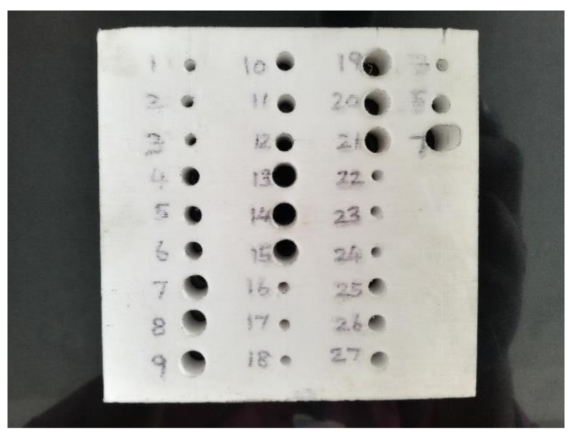


Figure-4: Teflon plate after drilling.

7. FUTURE WORK

Practically, the machining operations carried at high levels of parameters may result some abnormalities. In this case, the parameters considered for increasing MRR might results in abnormalities such as increased surface roughness ,roundness error and burr formation . Above all the abnormalities indicated, avoiding burr formation is almost impossible. The surface roughness is high for these working conditions .Since the operation is carried at dry conditions large amount of heat is produced due to the contact between tool and Teflon workpiece. It can be measured using laser temperature gun, which shows the temperature at the time of contact. Further the heat developed is more due to friction. The roundness of the drilled holes are highly affected due to the vibrations occurred during drilling operation under unavoidable conditions. Due to the occurrence of ovality in the holes drilled it is very essential to undergo the tolerance study These can be studied further in a detail manner for improving the effective machining parameters which influence the drilling operation .for getting accurate results higher level software namely SPSS is used .

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