Optimization of Drilling Process Parameters on Surface Roughness & Material Removal Rate by Using Taguchi Method

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Abstract— The aim of this work is utilize Taguchi method to investigate the effects of drilling parameters such as cutting speed, feed and depth of cut on surface roughness and material removal rate in drilling of Aluminium alloy 7075 using HSS spiral drill. The Taguchi method, a powerful tool to design optimization for quality, is used to find optimal cutting parameters. Orthogonal arrays, the signal- to- noise ratio, the analysis of variance are employed to analyze the effect of drilling parameters on the quality of drilled holes. A series of experiments based on L16 orthogonal array are conducted using CNC vertical machining centre. The experiment results are collected and analyzed using statistical software Minitab16. Analyses of variances are employed to determine the most significant control factors affecting the surface roughness and material removal rate. ANOVA has shown that the depth of cut has significant role to play in producing higher material removal rate and cutting speed has significant role to play for producing lower surface roughness.
Keywords — AA-7075, Drilling Process, Surface Roughness, Material Removal Rate, Taguchi Method, Signal-to-Noise Ratio, ANOVA.

1. INTRODUCTION

The important goal in the modern industries is to manufacture the products with lower cost and with high quality in short span of time. There are two main practical problems that engineers face in a manufacturing process. The first is to determine the values of process parameters that will yield the desired product quality (meet technical specifications) and the second is to maximize manufacturing system performance using the available resources. Drilling operation is widely used in the aerospace, aircraft and automotive industries, although modern metal cutting methods have improved in the manufacturing industries. The surface quality is an important parameter to evaluate the productivity of machine tools as well as machined components. Hence, achieving the desired surface quality is of great importance for the functional behavior of the mechanical parts. A reasonably good surface finish is desired for improving the tribological properties, fatigue strength, corrosion resistance and aesthetic appeal of the product. Excessively better surface finish may involve more cost of manufacturing. The surface roughness and material removal rate are affected by several factors including cutting tool geometry, cutting speed, feed rate, the microstructure of the work piece and the rigidity of the machine tool. These parameters affecting the surface roughness and drilled hole qualities (roundness, cylindricality and hole diameter) can be optimized in various ways such as Taguchi method. Therefore, a number of researchers have been focused on an appropriate prediction of surface roughness and material removal rate. Aluminium Alloy 7075 are the most widely used non-ferrous materials in engineering applications owing to their attractive properties such as high strength to weight ratio, good ductility, excellent corrosion, availability and low cost. It is used for aircraft fittings, gears and shafts, fuse parts, meter shafts and gears, missile parts, regulating valve parts, worm gears, keys, aircraft, aerospace and defence applications, bike frames, all terrain vehicle (ATV) sprockets. Aluminium Alloys are soft and high strength material. Vinod kumar Vankanti, Venkateswarlu Ganta [1] Investigated the influence of cutting parameters namely cutting speed, feed, point angle, chisel edge width in drilling of glass fiber reinforced polymer composites. 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. Adem cicek Turgay Kivak [2] Studied the effects of deep cryogenic treatment and drilling parameters on surface roughness and roundness error were investigated in drilling of AISI 316 austenitic stainless steel with M35 HSS twist drills. It was found that the cutting speed had a significant effect on the surface roughness and roundness error. Pradeep kumar, P.Packiaraj [3] Presented a Taguchi method to study the influence of process parameters such as speed, feed, drill tool diameter on surface roughness, tool wear, material removal rate and hole diameter error during drilling of OHNS material using HSS spiral drill. It is found that the feed and speed are important process parameters to control surface roughness, tool wear, material removal rate and hole diameter error. Turgay Kivak, Gurcan Samtas, Adem Cicek [4] This paper presented the optimization of drilling parameters using the Taguchi technique to obtain minimum surface roughness (Ra) and thrust force. it was found that the cutting tool was the most significant factor on the surface roughness and that the feed rate was the most significant factor on the thrust force. Chandan Deep

Singh, Rajvir Singh, Swarnjeet Singh [5] In this study the parametric optimization of micro drilling has been studied by considering a number of parameters such as spindle speed, feed rate and drilling tool size on material removal rate (MRR), surface roughness, dimensional accuracy. From the result, the surface roughness are mostly influenced by spindle speed and feed rate. B.Shivapragash, K.Chandrasekaran, C.Parthasarathy [6] The presented work is focusing on multiple response optimization of drilling process for composite Al-$TiBr_2$. The results shows that the maximum feed rate, low spindle speed are the most significant factors which affect the drilling process and the performance in the drilling process can be effectively improved by using this approach. Many researchers developed many mathematical models to optimize the cutting parameters to get the maximum material removal rate and minimum surface roughness by drilling process.

2. MATERIALS AND METHOD

2.1. Work Piece Material

The work piece material used for present work was Aluminium Alloy 7075. Table 1 and Table 2 shows the chemical composition and mechanical properties of AA7075.

Table 1: Chemical Composition of AA7075

Elements	Composition %
Aluminium	89.58
Silicon	0.4
Copper	0.098
Manganese	1.41
Magnesium	0.055
Chromium	2.33
Zinc	5.95
Ferrous	0.20

Table 2: Properties of AA7075

Property	Value
Tensile Strength	572 Mpa
Yield Strength	503 Mpa
Elongation	11 %
Machinability	70 %
Density	2.81 kg/m^3

2.2. Selection of Process Parameters

In this investigation, machining process parameters like Speed, Feed and Depth of Cut of the drill were considered. According to Taguchi's design of experiments for four parameters and three levels L16 Taguchi orthogonal array was selected. The number of factors and their corresponding levels are shown in Table 3.

Table 3: Machining Parameters and Levels

Process Parameter	Levels			
	1	2	3	4
Speed (rpm)	600	800	1000	1200
Feed (mm/rev)	0.06	0.08	0.10	0.12
Depth of Cut (mm)	1.5	2.5	3.5	4.5

2.3. Methodology

2.3.1. Taguchi Approach

Taguchi method was developed by Dr. Genichi Taguchi. This method involves three stages: system design, parameter design, and tolerance design. The Taguchi method is a statistical method used to improve the product quality. The Taguchi process helps select or determine the optimum cutting conditions for drilling process. Taguchi developed a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only. The experimental results are then transformed into a signal-to-noise (S/N) ratio. It uses the S/N ratio as a measure of quality characteristics deviating from or nearing to the desired values. There are three categories of quality characteristics in the analysis of the S/N ratio, i.e. the lower the better, the higher the better, and the nominal the better. The formula used for calculating S/N ratio is given below.

Smaller the better: It is used where the smaller value is desired.

S/N Ratio $= -10 \log \frac{1}{n} \sum_{i=1}^{n} yi^2$……….(1)

Where y = observed response value and n = number of replications.

Nominal the best: It is used where the nominal or target value and variation about that value is minimum.

S/N Ratio = $-10\ log \frac{\mu^2}{\sigma^2}$……………...(2)

Where σ = mean and μ= variance.

Higher the better: It is used where the larger value is desired.

S/N Ratio = $-10\ log \frac{1}{n} \sum_{i=1}^{n} \frac{1}{yi^2}$………(3)

Taguchi suggested a standard procedure for optimizing any process parameters.

2.3.2. ANOVA (Analysis of Variance)

ANOVA is a statistical technique for determining the degree of Difference or similarity between two or more groups of data. It is based on the comparison of the average value of a common component. In this paper, Pareto ANOVA was used which measures the importance of each process parameter of the process. Pareto ANOVA is a simplified ANOVA method, which is based on Pareto principle. The Pareto ANOVA technique is a quick and easy method to analyze results of the parametric design. The Pareto ANOVA technique does not need *F*-test. This technique identifies the important parameters and calculates the percentage influence of each parameter on different quality characteristics. The use of both Pareto ANOVA technique and S/N ratio approach makes it less cumbersome to analyze the results and hence, make it fast to arrive at the conclusion. From the S/N ratios, the overall S/N ratio is expressed as

S/N Ratio = $\frac{1}{9} \sum_{9}^{1} \left(\frac{S}{N}\right) i$…………….(4)

Where, S/N- is the overall mean of S/N ratio and (S/N) is the S/N ratio for *i*th parameter

The sum of squares due to variation about overall mean is

SS = $\frac{1}{9} \sum_{i=1}^{9} \left(\left(\frac{S}{N}\right) i - \left(\frac{S}{N}\right)\right) 2$ ………(5)

Where, SS- is the sum of squares. For the *i*th process parameter, the sum of squares due to variation about overall mean is

SS_i = $\frac{1}{9} \sum_{i=1}^{9} \left(\left(\frac{S}{N}\right) i - \left(\frac{S}{N}\right)\right) 2$ ………(6)

Where, SSi- is the sum of the square for *i*th parameter and (S/N) is the average S/N ratio of *i*-th parameter of *j*-th level

% contribution = $\frac{ssi}{ss}\ x\ 100$………...(7)

Table 4: Experimental Results for MRR and Surface Roughness and Corresponding S/N Ratios

S.No	Speed (rpm)	Feed (mm/rev)	Depth of Cut(mm)	MRR (mm^3/min)	S/N Ratio	Ra (µm)	S/N Ratio
1	600	0.06	1.5	63.617	36.0719	1.17	-1.36372
2	600	0.08	2.5	235.61	47.4439	1.75	-4.86076
3	600	0.10	3.5	577.26	55.2274	1.34	-2.54210
4	600	0.12	4.5	1145.11	61.1769	1.06	-0.50612
5	800	0.06	2.5	235.61	47.4439	0.58	4.73144
6	800	0.08	1.5	113.09	41.0685	1.18	-1.43764
7	800	0.10	4.5	1272.34	62.0921	2.72	-8.69138
8	800	0.12	3.5	923.628	59.3099	1.31	-2.34543
9	1000	0.06	3.5	577.26	55.2274	1.04	-0.34067
10	1000	0.08	4.5	1272.34	62.0921	0.60	4.43697
11	1000	0.10	1.5	176.71	44.9452	0.84	1.51441
12	1000	0.12	2.5	589.04	55.4029	0.73	2.73354
13	1200	0.06	4.5	1145.11	61.1769	0.89	1.01220
14	1200	0.08	3.5	923.62	59.3101	0.97	0.26457
15	1200	0.10	2.5	589.04	55.4029	0.59	4.58296
16	1200	0.12	1.5	254.45	48.1124	1.14	-1.13810

3. RESULTS AND ANALYSIS

Minitab statistical software has been used for the analysis of the experimental work. The Minitab software studies the experimental data and then provides the calculated results of signal-to-noise ratio. The objective of the present work is to minimize surface roughness and maximize the MRR in drilling process optimization. The effect of different process parameters on material removal rate and surface roughness are calculated and plotted as the process parameters changes from one level to another. The average value of S/N ratios has been calculated to find out the effects of different parameters and as well as their levels. The use of both ANOVA technique and S/N ratio approach makes it easy to analyze the results and hence, make it fast to reach on the conclusion. Table 4 shows the experimental results for material removal rate and surface roughness and corresponding S/N ratios.

3.1. Analysis of Signal-to-Noise Ratios

Larger-the-better performance characteristic is selected to obtain material removal rate. Smaller-the better performance characteristic is selected to obtain Surface Roughness.

Table 5: Response Table for MRR

Level	Speed	Feed	DOC
1	49.98	45.49	42.55
2	52.48	52.48	51.42
3	54.42	54.42	57.27
4	51.51	56.01	57.15
Delta	**4.44**	**10.21**	**14.72**
Rank	**3**	**2**	**1**

Table 6: Response Table for Surface Roughness

Level	Speed	Feed	DOC
1	-2.3182	1.0098	-0.6063
2	-1.9358	-0.3992	1.7968
3	2.0861	-1.2840	-1.2409
4	1.1804	-0.3140	-0.9371
Delta	**4.4042**	**2.2938**	**3.0377**
Rank	**1**	**3**	**2**

From the response Table 5 and Fig.2 it is clear that depth of cut is the most influencing factor followed by feed rate and cutting speed for MRR. The optimum for MRR is cutting speed of 1000 rpm, feed rate of 0.12 mm/rev and depth of cut of 3.5 mm. From the response Table 6 and Fig.3 it is clear that cutting speed is the most influencing factor followed by feed rate and depth of cut for surface roughness. The optimum for surface roughness is cutting speed of 1200 rpm, feed rate of 0.06 mm/rev and depth of cut of 2.5 mm.

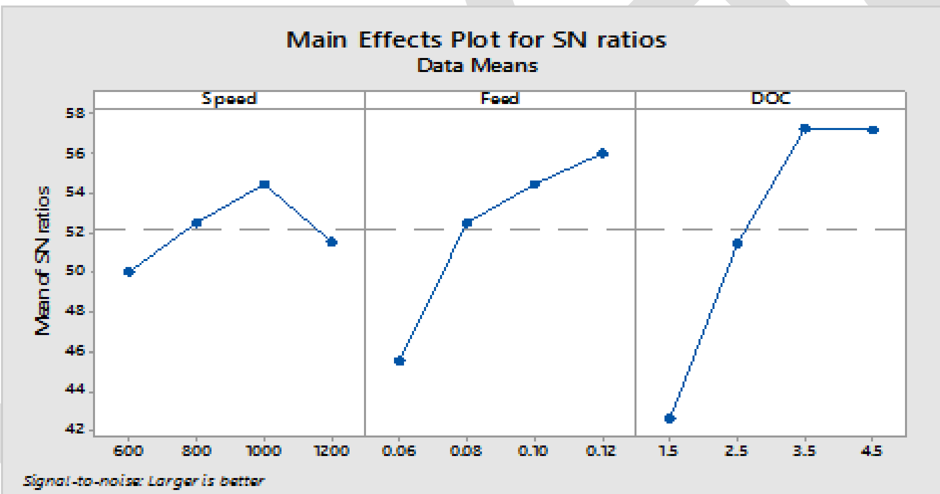

Figure 2: Main Effect Plot for MRR

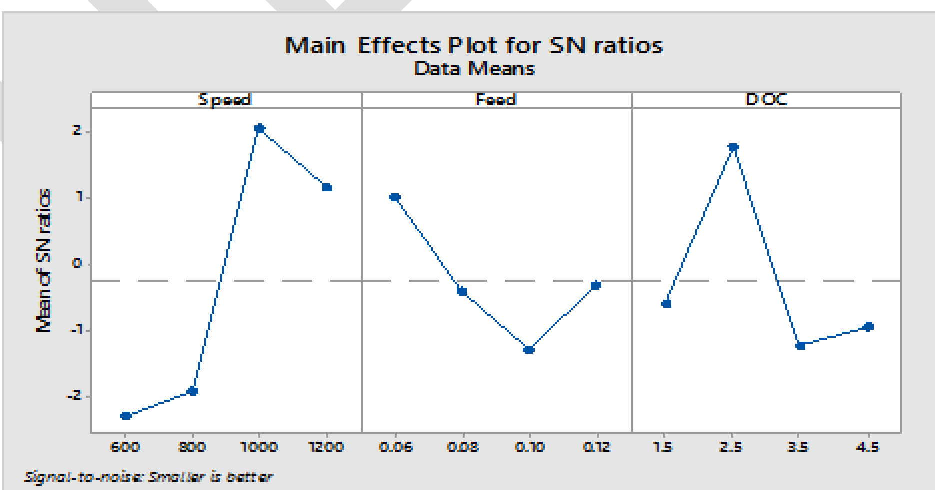

Figure 3: Main Effect Plot for Surface Roughness

3.2. Analysis of Variance (ANOVA)

Taguchi method cannot judge and determine effect of individual parameters on entire process while percentage contribution of individual parameters can be well determined using ANOVA. Using Minitab 17 software ANOVA module can be employed to investigate effect of parameters.

Table 7: ANOVA Results for MRR

Source	DOF	SS	MS	F	% CON
Speed	3	96090	32030	0.37	3.56
Feed	3	541415	180472	2.08	20.11
Doc	3	1533071	511024	5.88	56.96
Error	26	521231	86872	-	0.1936
Total	15	2691807	-	-	100
S = 294.74		**R-Sq = 80.64%**			

Table 8: ANOVA Results for Surface Roughness

Source	DF	SS	MS	F	% CON
Speed	3	1.2067	0.4022	1.08	28.68
Feed	3	0.4295	0.1432	0.39	10.20
Doc	3	0.3420	0.1140	0.31	8.12
Error	6	2.2285	0.3714	-	0.5297
Total	15	4.2067	-	-	100
S = 0.60944		**R-Sq = 47.02%**			

Table 7 & 8 shows the analysis of variance for material removal rate and surface roughness. It is observed that the depth of cut (56.96%) is most significantly influences the material removal rate followed by feed rate (20.11%) and least significant of cutting speed (3.56%). In case of Surface Roughness, speed (28.68%) is the most significant parameter followed by feed rate (10.20%) and least significant of depth of cut (8.12%). In both the cases, error contribution (0.1936%) and (0.5297%) reveals that the inter-action effect of the process parameters is negligible.

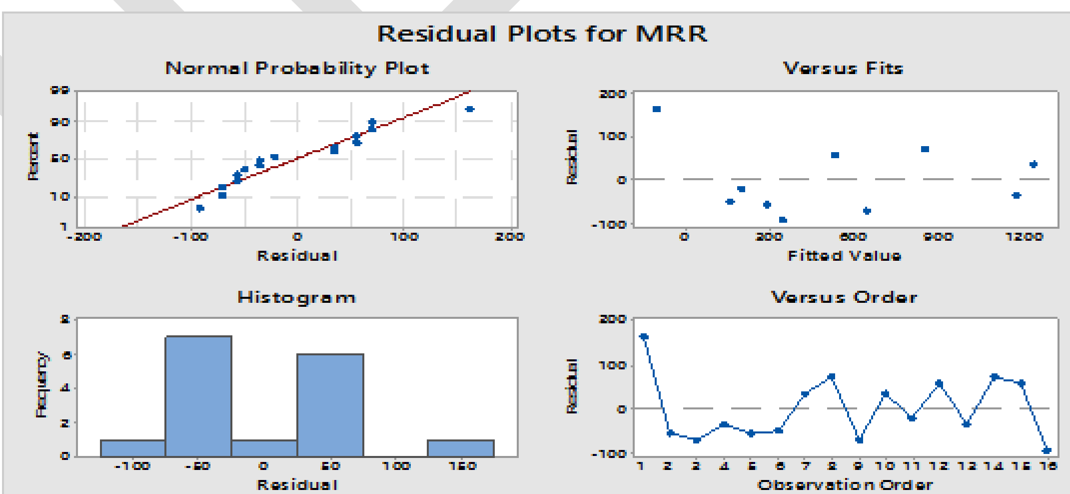

Figure 4: Residual Plot for MRR

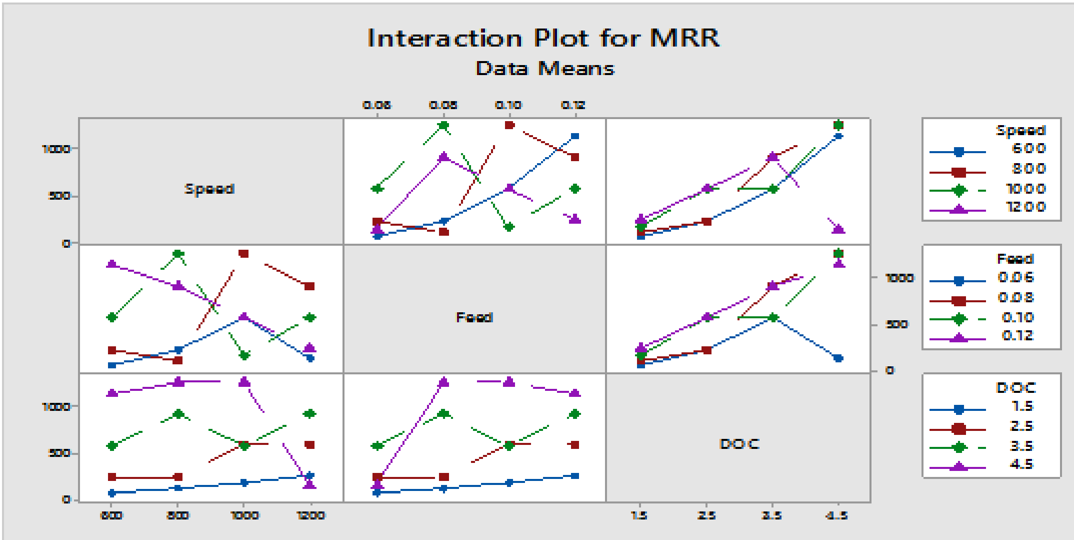

Figure 5: Interaction Plot for MRR

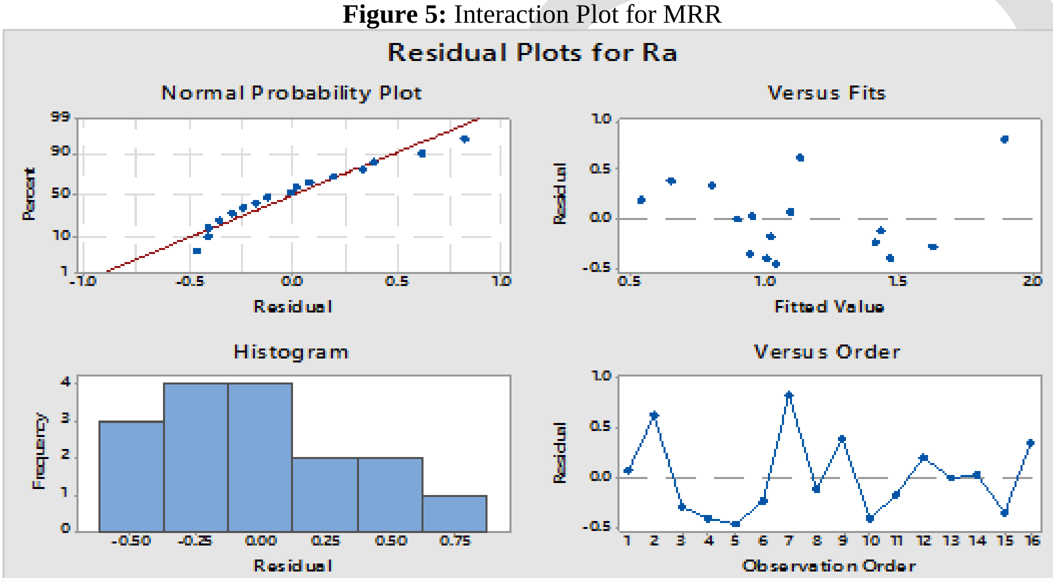

Figure 6: Residual Plot for Surface Roughness

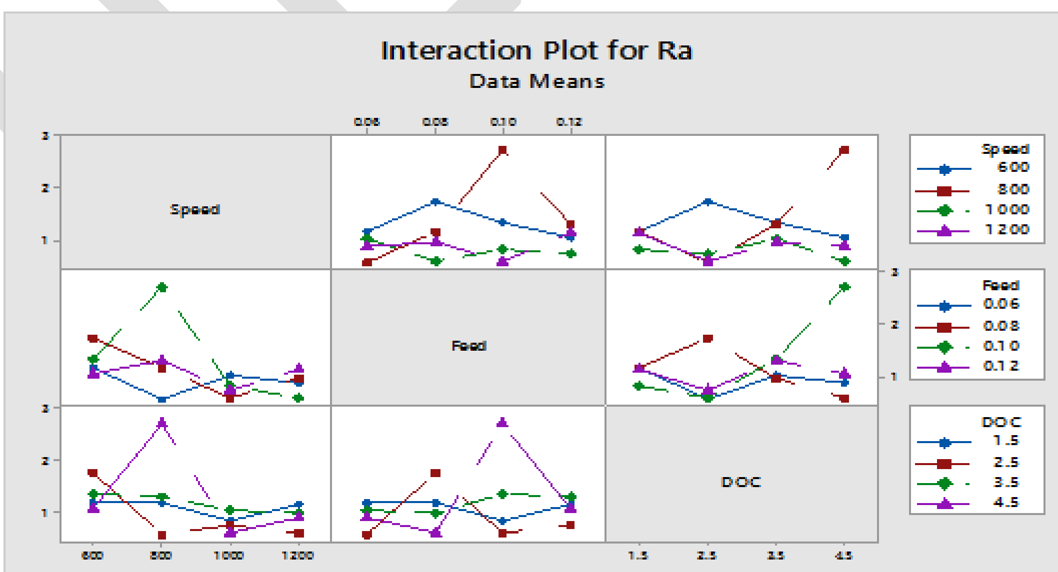

Figure 7: Interaction Plot for Surface Roughness

4. CONCLUSIONS

1. The optimum conditions obtained from Taguchi method for optimizing Material Removal Rate during drilling of Aluminium Alloy 7075 under dry condition are Cutting Speed of 1000 rpm, Feed rate of 0.12 mm/rev and Depth of Cut of 3.5 mm.
2. From response table for S/N ratio of MRR it is clear that Depth of Cut is the most significant factor influencing MRR followed by Feed rate and Cutting Speed is the least significant factor.
3. Analysis of Variances (ANOVA) for S/N ratio for MRR clearly indicates that the Depth of Cut is majorly contributing of about 56.96% in obtaining optimal MRR followed by Feed rate 20.11% and Depth of Cut 3.56%.
4. Optimum conditions for optimizing Surface Roughness are Cutting Speed of 1200 rpm, Feed rate of 0.06 mm/rev and depth of cut of 2.5 mm.
5. From response table for S/N ratio of surface roughness it is clear that Cutting Speed is the most significant factor influencing MRR followed by Feed rate and Depth of Cut is the least significant factor.
6. Analysis of Variances (ANOVA) for S/N ratio for surface roughness clearly indicates that the Cutting Speed is majorly contributing of about 28.65% in obtaining optimal surface roughness followed by Feed rate of 10.20% and Depth of Cut of 8.12 %.

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