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A Study of the Impact of Multiple drilling parameters on Surface Roughness, Tool wear and Material Removal Rate while Drilling Al6063 applying Taguchi Technique

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Abstract— *The goal of this project is to see how different drilling parameters like spindle speed (600, 900, 1400 revolution per minute), feed rate (0.10, 0.16, 0.22 mm per revolution) and drill tool diameter (6, 8 mm) affect surface roughness, material removal rate and tool wear while drilling Al 6063 alloy with an HSS spiral drill using Taguchi method. The impact of different drilling settings on the accuracy of the drilled hole is analyzed using S/N (signal-to-noise) ratio, orthogonal arrays of Taguchi, regression analysis, and analysis of variance (ANOVA). CNC Lathe Machineis used to perform a number of experiments with the help of L_{18} orthogonal arrays of Taguchi. MINITAB 19, a commercial software tool, is used to collect and evaluate the results of the experiments. For establishing a correlation between the selected input parameters and the quality aspects of the holes made, linear regression equations are used. The experimental data are compared to the expected values, which are quite similar.*

I. INTRODUCTION

In today's modern industries, the primary goal of engineers is to produce items at a lower cost while maintaining excellent quality in a short period of time. In a production process, engineers are encountering two very basic practical issues. The first one is to identify the best combination of input parameters which will result in the required quality of the product (fulfill essential requirements), and the other one is to increase production efficiency with the existing resources. Although advanced material cutting technologies have been developed in industrial sectors, but traditional drilling is still among the most practiced mechanical operations in the aerospace, aircraft, and automotive industries. L_{18} orthogonal array of Taguchi is utilized to conduct the experiment. The significant drilling parameters are selected as rotation speed, rate of feeding and diameter of the drilling tool respectively. The best combination of all the input parameters is selected to reducethe values of the performance attributes which are mentioned above. For the optimization of these parameters, Taguchi optimization method is used. ANOVA is also used to identify the extremely effective input parameter(s) which lead to a good quality product. Point angle and Helix angle are kept standard as 118 degree and 30 degree respectively.

II. DRILLING

Making holes is among the most essential requirements in the industrial procedure. Drilling is the most popular and important hole-making method, comprising almost one third of all metal cutting operations. Drilling is the process of removing a volume of metal from a workpiece by using an instrument called "a drill" to cut a cylindrical hole.

Based on the material type, the hole's shape, the counting of samples, and the period of time it takes in finishing the work, several instruments and procedures are used for drilling. It is most commonly used in removal of material and as a pre-processing step for a variety of operations like spot facing, counter sinking, and reaming etc. A multipoint fluted end cutting tool is used to create or extend a hole at the time of cutting operation. Material is eliminated mostly in the chips shape which passes with drill's fluted shank as it rotates and penetrates into the work material. Figure 1 shows the drilling process on the job. Coolants are also used sometimes during the operation as per the requirement.

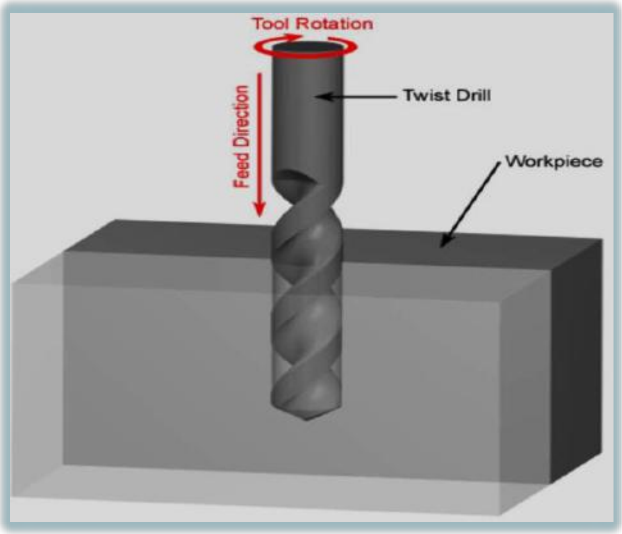

Fig.1: Drilling Operation

III. METHODS USED

TAGUCHI APPROACH

The Taguchi technique is a statistical approach for estimating the response independently with the minimum number of trials. The Taguchi method can also be used to improve product quality, It is a proven method for generating high-quality industry goods. The Taguchi technique is a powerful tool for creating processes that perform reliably and ideally across a wide range of circumstances. The utilization of carefully designed tests is required to establish the best design. Taguchi proposed a novel concept called as Orthogonal Array, which aims to minimize the number of trials by taking specific control characteristics in to consideration. The orthogonal array allows for the least number of testing.The variation from a design experiment was measured using the Taguchi method's S/N (signal-to-noise)ratio. When the mean (signal) is divided by the standard deviation (noise) then the value obtainedis known as the S/N ratio. The procedure for determining the S/N ratio varies with each experiment performed. Three characteristics values are then changed into S/N (signal-to-noise) ratio using Taguchi technique. According to the problem's objective, these three values indicate various quality characteristics."Larger is better", "Smaller is better", and "Nominal is the best" are the characteristic values of the S/N ratio. S/N ratio is estimated for every level of input parameters based on S/N analysis, with smaller being preferable.The quality characteristic employed in this study is "smaller is better" for surface roughness and tool wear but in case of material removal rate "Larger is better" is used.

Case 1: S/N ratio larger is better

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

Case 2: S/N ratio smaller is better

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

Case 3: S/N ratio nominal is best

$$SN_t = 10\log\left(\frac{\bar{y}^2}{s^2}\right)$$

Fig.2 : Characteristic values for calculating s/n ratios

DESIGN OF EXPERIMENT (DOE)

Design of Experiment is a useful method for enhancing design of the product or procedure performance, therefore it is applied for speeding up the development of new goods or processes. A design of experiment is a test or set of tests that examines the drilling parameters of the procedure in order to detect and identify equivalent changes in the system response. The output obtained from the procedure is examined in order to establish the ideal value or factors with the greatest influence.

ANALYSIS OF VARIANCE (ANOVA)

The Analysis of variance (or, ANOVA) is a strong and widely used statistical analysis tool that is based on the law of total variance. It's a programme that determines the impact of specific elements. ANOVA is a set of statistical concepts and methods used in statistics where the observed variance is divided into sections because of several independent variables. In the simplest form or sentence, Analysis of variance is a statistical analysis tool that determines if the means of several groups are just the same, and hence generalizes.

REGRESSION ANALYSIS

A series of statistical procedures utilized during mathematical modelling for evaluating the linkage among the dependent variables and one or more than one independent variables is called as Regression analysis. The very basic type of regression model is linear type model, in which we get a line (or, a more advanced linear combination) that perfectly represent the data according to a set of mathematical conditions. For prediction and forecasting, it is commonly used.

IV. EXPERIMENTAL SETUP

The current work used a CNC Lathe machine for drilling holes on Al 6063; the machine configuration is visualized in the picture below:

Fig.3: Experimental setup

WORK MATERIAL SPECIFICATION:

Work material - Al 6063

Work material dimension - $250 \times 20 \times 10$ mm^3

WORK MATERIAL PREPARATION:

With the help of a power hacksaw, the material for the job has been cut to sizes (250x20x10 mm^3)"that are required" from Aluminium alloys base stock in order to execute drilling operations on that. Table 1 shows the chemical components of the work material:

Table1: Aluminum alloy's chemical components in percentage

Al 6063 alloy	**Weight %**
Magnesium (Mg)	0.45- 0.9
Silicon (Si)	0.2 - 0.6
Iron (Fe)	0.35 (Max)
Copper(Cu)	0.10
Zinc (Zn)	0.10 (Max)
Titanium (Ti)	0.10 (Max)
Manganese(Mn)	0.10 (Max)
Chromium (Cr)	0.10
Others	0.05
Aluminium (Al)	Remaining

MEASUREMENT OF SURFACE ROUGHNESS :

The Surftest SJ-201P (Compact surface roughness testing machine) is a popular tool for determining component's shape and form. A tactile measurement principle is commonly used in profile measurement devices. On moving a stylus across the surface measures roughness, A transducer translates the movements of the stylus as it moves up and down along the surface into pulse, which is subsequently converted into a roughness value, which can be seen in a visible screen. A surface representation is often formed by combining many profiles. Figure 1 shows the Surftest SJ-201P.

Fig.4: Surftest SJ 201 P

EXPERIMENTAL DATA:

Table 2: The values of input variables

Values	Input variables		
	Tool diameter (mm) (X)	Rotation speed (rev per min) (Y)	Feed rate (mm per rev) (Z)
1	6	600	0.10
2	8	900	0.16
3	-	1400	0.22

Table 3: Experimental result for Al6063 alloy (10 mmthick plate)

Serial number	Rotation Speed(rev per min)	Feed rate (mm per rev)	Tool diameter (mm)	Roughness (Ra)µm	MRR (mm^3/min)	Tool Wear (gm)
1	1	1	1	1.43	1235	0.235
2	1	2	1	1.46	1424.7	0.762
3	1	3	1	1.49	1556.2	1.011
4	2	1	1	1.42	1865.9	0.493
5	2	2	1	1.50	2078	0.922
6	2	3	1	1.52	2228	1.267
7	3	1	1	1.25	2864.4	0.715
8	3	2	1	1.24	3007.8	1.189
9	3	3	1	1.29	3231.5	1.458
10	1	1	2	1.26	1857.1	0.288
11	1	2	2	1.30	2026.3	0.797
12	1	3	2	1.34	2239.9	1.158
13	2	1	2	1.33	2455.7	0.612
14	2	2	2	1.47	2603.4	1.095
15	2	3	2	1.50	2819.2	1.414
16	3	1	2	1.22	3076.4	0.936
17	3	2	2	1.29	3398	1.345
18	3	3	2	1.35	3612	1.723

V. ANALYSISOFRESULTS

Table4:S/N ratio's values of each outputs from the testing of Al 6063

Serial Number	Rotation Speed (rev per min)	Feed rate (mm per rev)	Tool Diameter (mm)	S/N response values for Roughness (Ra) in decibel	S/N response values for MRR (mm^3/min) in decibel	S/N response value for Tool Wear (gm) in decibel
1	1	1	1	-3.10672	61.8333	12.5786
2	1	2	1	-3.28706	63.0745	2.3609
3	1	3	1	-3.46373	63.8413	-0.0950
4	2	1	1	-3.04577	65.4178	6.1431
5	2	2	1	-3.52183	66.3529	0.7054
6	2	3	1	-3.63687	66.9583	-2.0555
7	3	1	1	-1.93820	69.1407	2.9139
8	3	2	1	-1.86843	69.5650	-1.5036
9	3	3	1	-2.21179	70.1881	-3.2752
10	1	1	2	-2.00741	65.3767	10.8122
11	1	2	2	-2.27887	66.1341	1.9708
12	1	3	2	-2.54210	67.0046	-1.2742
13	2	1	2	-2.47703	67.8035	4.2650
14	2	2	2	-3.34635	68.3108	-0.7883
15	2	3	2	-3.52183	69.0025	-3.0090
16	3	1	2	-1.72720	69.7609	0.5745
17	3	2	2	-2.21179	70.6245	-2.5744
18	3	3	2	-2.60668	71.1550	-4.7257

Graph 1: Plot for surface roughness's main effect

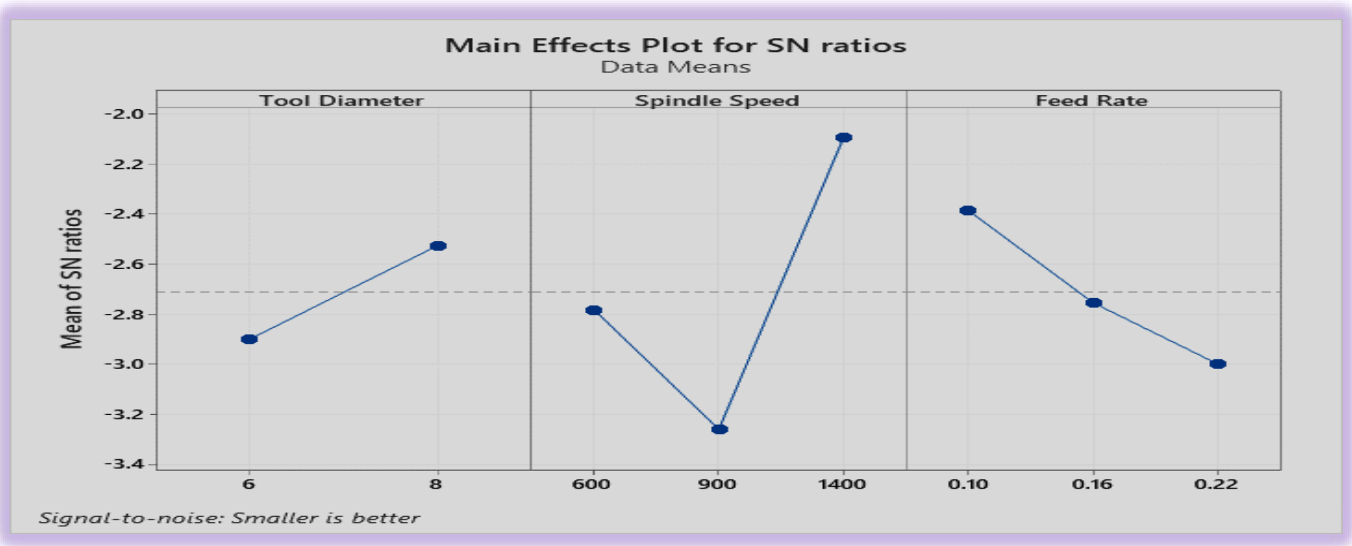

Table 5: Table containing responses for s/n ratios of surface roughness

Level	Tool Diameter (X)	Rotation Speed (Y)	Feed Rate (Z)
1	-2.898	-2.781	-2.384
2	-2.524	-3.258	-2.752
3		-2.094	-2.997
Delta	0.373	1.164	0.613
Rank	3	1	2

Table 6: Table containing responses for means of surface roughness

Level	Tool Diameter(X)	Rotation Speed (Y)	Feed Rate (Z)
1	1.400	1.380	1.318
2	1.340	1.457	1.377
3		1.273	1.415
Delta	0.060	0.183	0.097
Rank	3	1	2

Table 7: ANOVA outcome for s/n ratios of surface roughness (Ra)

Source	DF	Sum of square (S)	Variance (V)	F-ratio (F)	P-value (P)	Percentage(%)
X	1	0.6276	0.6276	5.34	0.039	8.61 %
Y	2	4.1105	2.0552	17.49	0.000	56.36 %
Z	2	1.1443	0.5721	4.87	0.028	15.69 %
Residual Error	12	1.4098	0.1175			19.33 %
Total	17	7.2922				100%

Table 8: optimal level values for roughness of Al 6063 from "Graph 1"

Input variables	Levels	Roughness response values	S/N response values
X	2	1.340	-2.524
Y	3	1.273	-2.094
Z	1	1.318	-2.384

Table 9: Validation of testing for Roughness of Al 6063 (10 mmthick plate)

	Optimal input variables	
	Estimated values	Experimented values
Level	$X_2Y_3Z_1$	$X_2Y_3Z_1$
Roughness	1.1916	1.22
S/N ratio of Roughness	-1.5799	-1.7272

Graph 2: Plot for Material removal rate's main effect

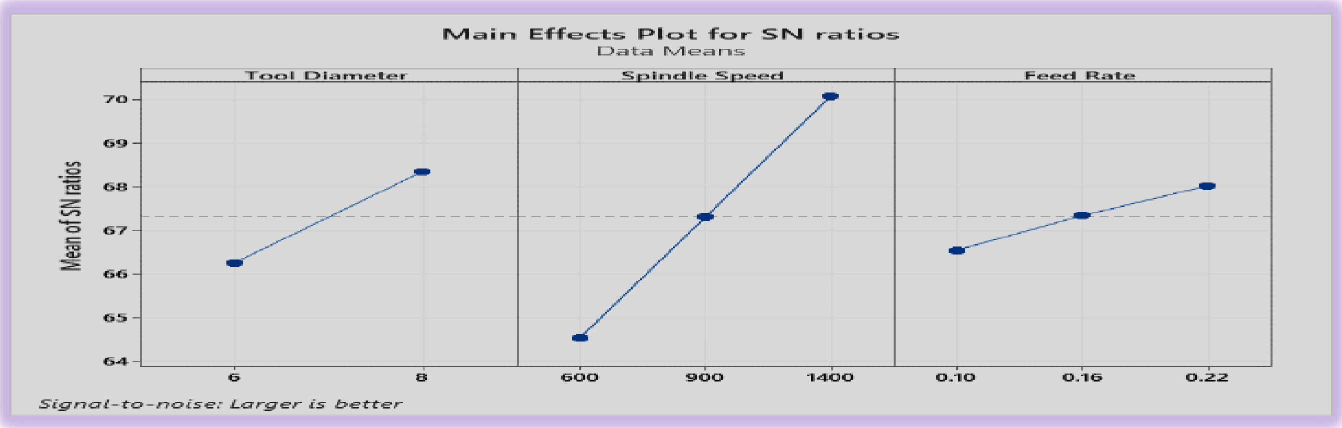

Table 10: Table containing responses for s/n ratios of MRR

Level	Tool Diameter (X)	Rotation Speed (Y)	Feed Rate (Z)
1	66.26	64.54	66.56
2	68.35	67.31	67.34
3		70.07	68.02
Delta	2.09	1.164	1.47
Rank	2	1	3

Table 11: Table containing responses for means of MRR

Level	Tool Diameter(X)	Rotation Speed (Y)	Feed Rate (Z)
1	2166	1723	2226
2	2676	2342	2423
3		3198	2614
Delta	511	1475	389
Rank	2	1	3

Table 12: ANOVA outcome for s/n ratios of Material removal rate

Source	DF	Sum of squares (S)	Variance (V)	F-ratio (F)	P-value (P)	Percentage (%)
X	1	19.637	19.637	51.30	0.000	16.04 %
Y	2	91.685	45.842	119.76	0.000	74.90 %
Z	2	6.490	3.245	8.48	0.005	5.30 %
Residual Error	12	4.593	0.3828			3.75 %
Total	17	122.405				100%

Table 13: optimal level values for MRR of Al 6063 from "Graph 2"

Input variables	Levels	MRR response values	S/N response values
X	1	2166	66.26
Y	1	1723	64.54
Z	1	2226	66.56

Table14: Validation of testing for MRR of Al 6063 (10 mmthick plate)

	Optimal input variables	
	Estimated values	Experimented values
Level	$X_1Y_1Z_1$	$X_1Y_1Z_1$
MRR	1272.51	1235
S/N ratio for MRR	62.7471	61.83

Graph 3: Plot for Tool wear's main effect

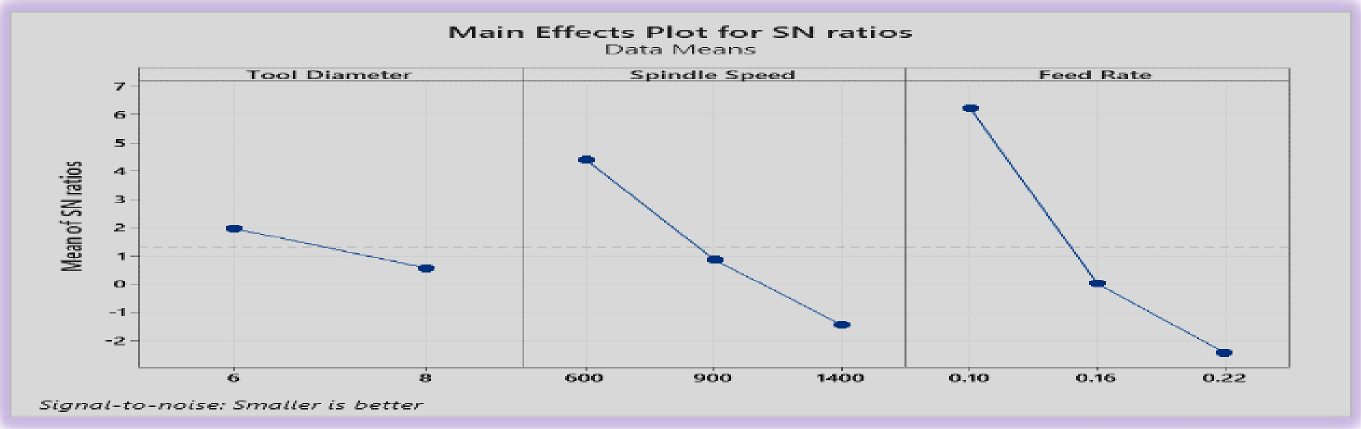

Table 15: Table containing responses for s/n ratios of Tool Wear

Level	Tool Diameter (X)	Rotation Speed (Y)	Feed Rate (Z)
1	1.975	4.392	6.214
2	0.583	0.876	0.028
3		-1.432	-2.406
Delta	1.391	5.824	8.620
Rank	3	2	1

Table 16: Table containing responses for means of Tool Wear

Level	Tool Diameter(X)	Rotation Speed (Y)	Feed Rate (Z)
1	0.895	0.708	0.546
2	1.041	0.967	1.018
3		1.227	1.338
Delta	0.146	0.519	0.792
Rank	3	2	1

Table 17: ANOVA outcome for s/n ratios of Tool Wear

Source	DF	Sum of squares (S)	Variance (V)	F-ratio (F)	P-value (P)	Percentage(%)
X	1	8.711	8.711	3.61	0.082	2.3 %
Y	2	103.213	51.607	21.40	0.000	27.31 %
Z	2	237.005	118.502	49.15	0.000	62.72 %
Residual Error	12	28.932	2.411			7.65 %
Total	17	377.860				100%

Table 18: optimal level values for Tool Wear of Al 6063 from "Graph 3"

Input variables	Levels	Tool Wear Response values	S/N response values
X	1	0.895	1.975
Y	1	0.708	4.392
Z	1	0.546	6.214

Table19: Validation of testing for Tool Wear of Al 6063 (10 mmthick plate)

	Optimal input variables	
	Estimated values	Experimented values
Level	$X_1Y_1Z_1$	$X_1Y_1Z_1$
Tool Wear	0.2141	0.235
S/N ratio for Tool Wear	12.578	10.023

Linear regression equations obtained from the above data for finding out the relationship among the specified input parameters for drilling circumstances on Al 6063. For multiple input parameters, linear type models have been generated by commercial Minitab 19 software and are presented here:

Surface Roughness(Ra) = 1.603 - 0.0300X - 0.000157Y + 0.806Z

Material removal rate = -1654 + 255.4X + 1.8306Y + 3239Z

Tool Wear = -1.215 + 0.0731X + 0.000636Y + 6.600Z

VI. CONCLUSION

In this project, Wear of the tool, Material removal rate from workpiece and Surface roughness of the sample at the entries and exits of the work material are measured using the rate of feeding, the rotation speed of the tool, and the diameter of the tool as input process parameters while drilling Al 6063 alloy with HSS spiral tool. Drilling conditions are adjusted with respect to a variety of performances in order to achieve better quality of the hole while the process of drilling of Al 6063 alloy. The Taguchi technique was employed to optimize the drilling settings. A tool dia. of 8mm, rotation speed of 1400 rev per min, and a feed rate of 0.10 mm per rev were found to be the optimal combination of drilling conditions for producing a high value of s/n ratios for the surface roughness of the hole. While A tool dia. of 6 mm, rotation speed of 600 rev per min, and a feed rate of 0.10 mm per rev were found to be the optimal combination of drilling conditions for producing high value s/n ratios for Material removal rate as well as for Tool wear too.

Several factors [including angle of the drill point, angle of helix, no. of flutes in the drill, kind of drill tool etc.] can be included in future studies to investigate that how such factors influence the quality of the sample of other types of material or alloys.

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