Prediction of Optimum Machining Parameters on Surface Roughness and MRR in CNC Drilling of AA6063 alloy using Design of Experiments

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***Abstract*—In this research, an experimental investigation of the machining parameters of Aluminium Alloy 6063 in CNC lathe machine for drilling operation using High Speed Steel (HSS) cutting tool had been carried out. In machining operation, the minimum surface roughness and maximum Material Removal Rate are important factors for the better quality of the product and production rate. Thus, the choice of optimized cutting parameters is very important for controlling the required quality. The purpose of this research is focused on the analysis of optimum cutting conditions for minimum surface roughness and maximum material removal rate in CNC milling of Aluminium Alloy 6063 by Taguchi method. Experiment have been carried out based on L16 standard orthogonal array design with three process parameters namely Spindle Speed, Feed rate, Depth of Cut. The results of the machining experiments were used to characterize the main factors affecting surface finishing and material removal rate by Signal to Noise ratio and Analysis of Variance method. The investigations exposes that the surface roughness and material removal rate were influenced by the feed rate. It was identified that the Surface roughness decreases with increase in feed rate and MRR increases with related to feed rate.**

Key Words: Aluminium Alloy 6063, CNC Drilling, Surface Roughness, MRR, Taguchi Method, ANOVA

I. INTRODUCTION

Aluminium alloys contains the typical alloying elements, such as copper, magnesium, manganese, silicon and zincand in which Aluminium (Al) is the predominant metal. Here Aluminium6063 alloy is taken as work piece material and HSS as cutting tool. The main properties of Aluminium are lightweight, strength, recyclability, corrosion resistance, durability, ductility, formability and conductivity, which make them valuable material.

Design of Experiment (DOE) is an influential method to improve manufactured goods design presentation where it can be used to decrease cycle time needed to improve new process.The Analysis of Variance is a powerful statistical tool for test of significance. ANOVA is a separation of variance ascribable to one prove of process of the variance ascribable to the other groove.

Ramesh et al [1] investigated the Surface roughness (Ra), machining time and material removal rate of EN31affect the aesthetical aspect of the final product. The experiments were carried out as per L27 orthogonal array(ANOVA) was employed by using MINITAB-16 software. The Taguchi experimental trials, shows that the feed rate was the most significant factor for improving the Metal Removal rate with contribution percentage of 85.1% and 85.7% respectively.

Kunal Sharma et al [2] this paper discussed about the performance characteristics of AISI 304 SS during CNC drilling. Factors like speed, feed and depth of cut affect the parameters such as surface roughness and ovality. L16 orthogonal array has been chosen. From the result it is concluded that feed is most effective parameter. Surface roughness increases with increases in feed and ovality increases with the increase in depth of hole. Navanth et al [3] studied the drilling parameters of AL2024 alloy at low speeds to obtain minimum surface roughness and hole diameter. L18 orthogonal array was used to conduct the experiment. ANOVA was employed to determine the most significant control factors. It was identified that a spindle speed of 300rpm, point angle & helix angle of 1300/200 and a feed rate of 0.15 mm/rev is the optimal combination of drilling parameters that produce a high value of S/N ratio.

Balakumaran et al [4] investigated the simultaneous minimization and maximization of surface roughness, machining time and material removal rate of EN31 alloy steel. Experiments were carried out by CNC lathe using chromium nitride tool bit. In this experimental investigation the Taguchi and ANOVA were used to obtain optimal drilling parameters in the drilling of EN 31 steel under wet conditions the peck increment 4.5, feed rate 0.04 and 200rpm was the most significant factor for improving the Metal Removal rate with contribution 46%.

Taguchi's Method- Taguchi defines as the quality of a product, in terms of the loss imparted by the product to the society from the time the product is shipped to the customer. Some of these losses are due to deviation of the products functional characteristic from its desired target value, and these are called losses due to functional variation. The uncontrollable factors, which cause the functional characteristics of a product to deviate from their target values, are called noise factors, which can be classified as external factors and product deterioration. The overall aim of quality engineering is to make products that are robust with respect to all noise factors. Taguchi has empirically found that the two stage optimization procedure involving

S/N ratios, indeed gives the parameter level combination, where the standard deviation is minimum while keeping the mean on target.

Theeffects of the process machining parameters are very essential.The present method of selection of parameters on desiredsurface roughness, and material removal rate (MRR) has been accomplished using Taguchi's parameter design approach. Inthis paper our objective is to minimize surface roughness and maximize the MRR.The experimental results (or data) are further transformed into a signal-to-noise (S/N) ratio. There are severalS/N ratios available depending on the type of characteristic; lower is better (LB), Nominal is best (NB) andhigher is better (HB)The characteristic that higher value represents better machining performance, such as MRR, is called Higher is better (HB). The characteristic that lower value represents better machining performance such assurface roughness, is called Lower is better (LB). Therefore, "HB" for MRR and "LB" for SF were selectedfor obtaining optimum machining performance characteristics.

For MRR (Larger is Better),

$$\text{S/N Ratio} = -10 \log \frac{1}{n} \sum_{i=1}^{n} \frac{1}{y^2}$$

For Ra (Smalleris Better),

$$\text{S/N Ratio} = -10 \log \sum_{i=1}^{n} y^2$$

Where,

y- is the observed data at "i"th trial and n -is the number of trials. From the S/N ratio, the effective parameters having influence on process results can be seen and the optimal sets of process parameters can be determined.

II. MATERIALS AND METHOD

A.Work Piece Material:

In this research work, AA6063 is used as a material. The properties of AA60663 is clearly shown in the below table 1 & 2.

TABLE I. CHEMICAL COMPOSITIONS OF AA6063

Elements	**%**
Si	0.3 – 0.6
Fe	0.15 - 0.35
Cu	0.1
Mn	0.15
Mg	0.6 - 0.9
Zn	0.15
Ti	0.1
Cr	0.05
Al	Balance

TABLE II. MECHANICAL PROPERTIES OF AA6063

Tensile Strength	220 Mpa
Elongation	5%
Proof Stress	190 Mpa

B. Experimental Setup

The experimental work was carried out on CNC turning center JOBBER XL using high speed steel drill bit. Figure 1 clearly shows the experimental set up of CNC turning center. The specifications of the machine are given in Table 3.

TABLE III. CNC TURNING CENTER SPECIFICATION

Machine Type	JOBBER XL
Year	2012
Supply Voltage	380V/415V
Control Voltage	24V D.C
Back Up Fuse	63 AMPS

Figure-1: CNC Turning Center – JOBBER XL

C.Drilling Tool

In this work, experiments were conducted using 16 - mm diameter HSS twist drill. Figure 2 clearly shows the dimensions of the drill bit.

Figure-2: HSS 16mm Drill Bit

D. Drilled Work piece Materials

The drilled 16 samples are clearly shown in the Figure 3.
Work Piece Material : AA6063
Hole Diameter : 16mm

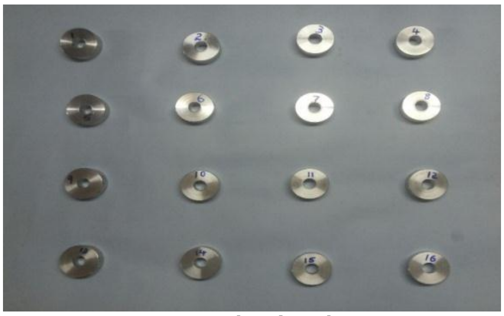

Figure-3: Machined Work piece

In this work each factor has four levels. L16 orthogonal array has be followed. The process parameters and their levels are given in the table 3.

TABLE IV. PROCESS PARAMETERS AND THEIR LEVELS

S.No	Parameters	Levels			
		1	*2*	*3*	*4*
1	Speed (rpm)	1000	1000	1200	1600
2	Feed (mm/min)	0.10	0.15	0.17	0.20
3	Depth of Cut (mm)	0.4	0.5	0.6	0.8

E. MRR and Surface roughness Measurement:

Material removal rate (MRR) has been calculated from the difference of weight of work piece before and after the experiment.

$$MRR=\frac{\pi}{4}.d^2.l mm3/min$$

Where, d= hole diameter
l= length of the work piece

The surface roughness of each specimen was tested on the surface roughness tester SJ-201(MITUTOYO Model) shown in figure 1. The surface roughness value is measured with 4mm cut-off distance and average value is taken.

Figure-3: Surface Roughness Tester SJ-201

Test.No.	Cutting Speed(rpm)	Feed Rate (mm/min)	Depth of Cut (mm)	Surface Roughness µm	S/N Ratio for Surface roughness	MRR (mm3/min)	S/N Ratio for MRR
1	800	0.1	0.4	0.50	6.08	46.2	33.29
2	800	0.15	0.5	1.33	-2.48	58.4	35.33
3	800	0.17	0.6	2.29	-7.21	63	35.99
4	800	0.2	0.8	3.55	-11.00	77.3	37.76
5	1000	0.1	0.5	0.71	2.97	49.1	33.83
6	1000	0.15	0.4	1.60	-4.08	62.2	35.88
7	1000	0.17	0.8	1.65	-4.35	65.5	36.32
8	1000	0.2	0.6	2.16	-6.68	79.4	38.00
9	1200	0.1	0.6	1.09	-0.75	57.3	35.16
10	1200	0.15	0.8	1.70	-4.59	64.2	36.15
11	1200	0.17	0.4	1.70	-4.61	66.5	36.46
12	1200	0.2	0.5	1.86	-5.37	82.7	38.35
13	1400	0.1	0.8	1.48	-3.41	58.8	35.38
14	1400	0.15	0.6	1.58	-3.99	65.5	36.32
15	1400	0.17	0.5	1.91	-5.61	78.8	37.93
16	1400	0.2	0.4	2.63	-8.40	81.7	38.24

TABLE V. Input Parameters, Material Removal Rate And S/N Ratio For MRR

III. RESULTS AND DISCUSSION

The main objective of the experiment is to optimizethe milling parameters (spindle speed, feed rate and depth of cut) to achieve lowvalue of the surface roughness and high material removal rate. The experimentaldata for the surface roughness values and thecalculated signal-to-noise ratio are shown in Table-VI. Taguchi recommends analyzing data using the S/N ratio that will offer two advantages; it provides guidance for selection the optimum levelbased on-least variation around on the average value, which closest to target, and also it offers objectivecomparison of two sets of experimental data withrespect to deviation of the average from the target.

Response table for Signal to Noise ratio of both responses are shown in Table-VI and Table-VII. Significance of machining parameters (difference between maximum and minimum values) of surface roughness and MRR indicates that feed rate is contributing towards the machining performance for lower surface roughness and maximum material removal rate.

TABLE VI. RESPONSE TABLE FOR SURFACE ROUGHNESS

Level	SPEED	FEED	DEPTH OF CUT
1	-30651	1.225	-2.753
2	-3.033	-3.786	-2.621
3	-3.831	-5.443	-4.656
4	-5.350	-7.861	-5.836
DELTA	2.317	9.086	3.215
RANK	3	1	2

TABLE VII. RESPONSE TABLE FOR MRR

Level	SPEED	FEED	DEPTH OF CUT
1	35.59	34.41	35.97
2	36.01	35.92	36.36
3	36.53	36.67	36.37
4	36.97	38.09	36.40
DELTA	1.38	3.67	0.43
RANK	3	1	2

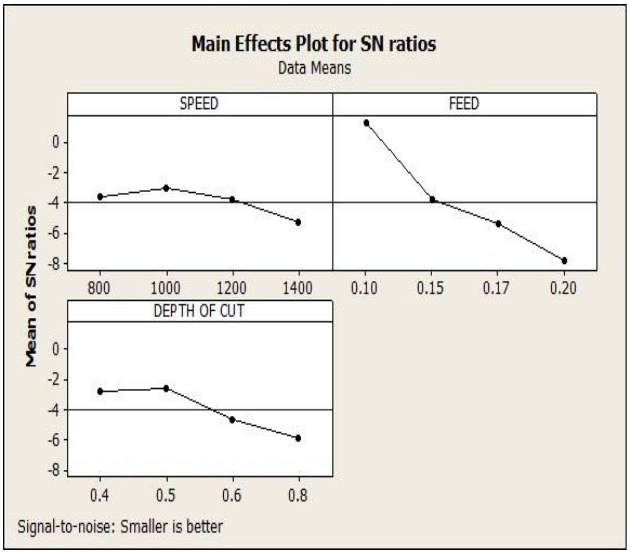

Figure-4: Main effect plots for Ra

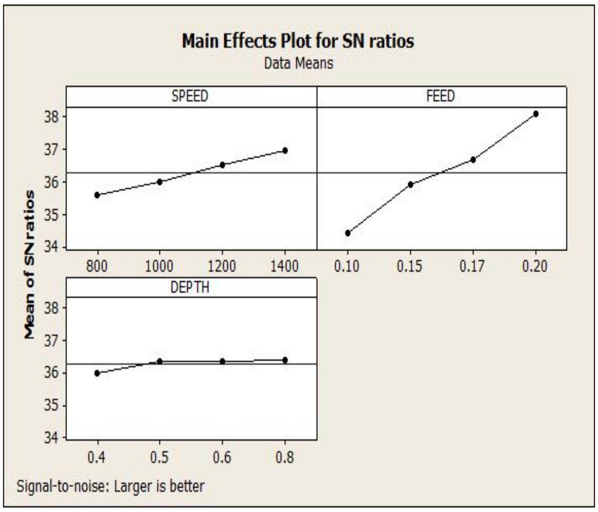

Figure-5: Main effect Plot for MRR

A.Analysis of Variance (ANOVA):

Taguchi method cannot judge and determine effect of individual parameters on entire process. Contribution of individual parameters of process can be determined using ANOVA. Minitab 17 software of ANOVA module was employed to investigate the effect of machining parameters feed, cutting speed and depth of cut.

TABLE VIII. ANOVA FOR SURFACE ROUGHNESS

Source	DF	SS	MS	F-Value	P-Value
Speed	3	0.4993	0.1664	0.89	0.497
Depth of cut	3	0.9108	0.3036	1.63	0.279
Feed	3	5.3685	1.78795	9.60	0.10
Error	6	1.1186	0.1864		
Total	15				

TABLE IX. ANOVA FOR MRR

Source	DF	SS	MS	F-Value	P-Value
Speed	3	224.72	74.91	7.23	0.020
Feed	3	1579.56	526.52	50.81	0.000
DOC	3	20.95	6.98	0.67	0.599
Error	6	62.18	10.36		
Total	15	1887.41			

From surface roughness analysis ANOVA (Table-VIII), F-value (9.60) indicates that feed rate is contributing more for minimum surface roughness. F-value (0.89) of parameter indicates that cutting speed is contributing less for minimum surface roughness. From Table V, Test No:1 has the lowest surface finish value (Ra=0.50µm). Whereas, Test no: 16 has the highest surface roughness value. (Ra=2.63 µm)

From MRR analysis ANOVA table (Table-IX), F-value (50.81) of parameter indicates that feed is contributing more for material removal rate. F-value (0.67) of parameter indicates that depth of cut is contributing less for material removal rate. From Table V, Test no: 12 has the highest material removal rate (MRR= 82.7 mm^3/min). Whereas, Test no: 1 has the lowest material removal rate (MRR=46.2mm^3/min).

IV. CONCLUSIONS

1. Taguchi method of experimental design has been applied for optimizing multi-response process parameters for CNC End Milling Al 6063 Alloy with L16 orthogonal array.
2. From Table-VI, Table-VIII, and Figure-4, Feed is the most influencing parameter for minimum surface finish which is followed by depth of cut and cutting speed.
3. From Table-V, best parameters found for minimum surface finish machining are feed rate= 0.1mm/min, cutting speed = 800rpm and depth of cut= 0.4mm.
4. From Table-VII, Table-IX and Figure-4, feed is the most influencing parameter for material removal rate which is followed by depth of cut and cutting speed.
5. From Table-V, best parameters found for maximum MRR are feed rate= 0.2mm/min, cutting speed = 1200rpm and depth of cut= 0.5mm.
6. Results obtained from Taguchi method exactly matches with ANOVA and confirmation test results are also matched with the predicted results.

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