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Optimization of Surface Roughness and Material Removal Rate of Aluminium Alloy Using Taguchi Method

[1]Prasad Kumar C M, [2]Hemanth Kumar T R, [3]S N Lakshmi Narasimhan
[1]PG scholar, [2]Associate Professor, [3]Professor and HeadMechanical engineering, Sri Siddhartha Institute of Technology, Tumakuru, India
Corresponding Auther: Prasad Kumar C M

ABSTRACT
Machining involves many process parameters. To achieve accurate dimensions, good surface quality and to maximize metal removal rate, the turning parameters contributes significantly. The aim of this research is to optimize the cutting parameters like cutting speed, feed and depth of cut to minimize surface roughness and to maximize the material removal rate in turning of aluminium alloy. Three types of cutting tools viz. HSS tool, carbide tool and polycrystalline diamond tool are used for the turning operations. The experiments were carried out using Taguchi design of experiments with L_{27} orthogonal array. The Analysis of means is employed to analyze the performance characteristics in turning operation of aluminium alloy. Response variables measured for the analysis of surface finish and the material removal rate.
Keywords: Cutting force, Surface roughness, Material removal rate, Orthogonal array, Taguchi method, Cutting tools.

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I. INTRODUCTION

Surface topography is of great importance in specifying the function of manufactured product. A significant proportion of component failure starts at the surface, due to an isolated manufacturing discontinuity of the surface quality. Surface roughness is the most important parameter to describe the surface integrity. In the manufacturing industry, surface roughness must be within convinced limits. Therefore, measuring surface roughness is vital to quality control of machining work piece. In metal cutting and manufacturing industries, surface finish of a product is very crucial in determining the quality. Good surface finish not only assures quality, but also reduces manufacturing cost. Surface finish is important in terms of tolerances, it reduces assembly time and avoids the need for secondary operation, thus reduces operation time and leads to overall cost reduction. Good quality turned surface is significant in improving fatigue strength, corrosion resistance and creep life. Higher material removal rate (MRR) and lower the cutting forces are the needs of industry to cope up with mass production in shorter time. Higher MRR can be achieved by increasing the process parameters such as cutting speed, feed, nose radius and depth of cut. The effect of cutting parameters reflected on the surface roughness and dimensional deviation of the product.

Taguchi method is used for conducting the design of experiments which are based on well defined guidelines. This method uses a special set of arrays called orthogonal arrays. These standard arrays stipulate the way of conducting the minimal number of experiments which could give the full information of all the factors that affect the performance parameters. In Taguchi method the design parameters (factors that can be controlled by designers) and noise factors (factors that cannot be controlled by designers such as environmental factors) are considered influential on the product quality. Analysis of means is used to take both mean and variability of the experimental result into account. The surface roughness and material removal rate versus cutting speed, feed and depth of cut; of analysis of means predict the quality characteristics of the process to be optimized.

II. LITERATURE REVIEW

M.Naga Phani Sastry et. al., conducted an experiment to determine process parameters during turning operations (cutting speed, feed and depth of cut) which resulted in an optimal value of surface roughness and maximum material removal rate while machining Aluminium bar with HSS tool. Mathematical model was developed to determine the MRR [1]

Md.Tayab Ali et. al., they conducted an experimental approach to study the effect of input parameters on the surface roughness and MRR. The signal-to-noise ratio and Analysis of variance are employed to study the performance characteristics in CNC turning operation. Optimal values of process parameters for desired performance characteristics are obtained with identification of most significant factor. [2]H.K.Dave et. al., the different turning tests were performed by them on different grades of EN materials using two different inserts of carbide cutting tools. The optimum cutting conditions were analyzed here to get the lowest surface roughness and maximum material removal rate in CNC turning of different grades of EN materials by Taguchi method. [3]

Mohd Abbas et. al., have studied the effects machining parameters using Taguchi method in CNC lathe machine on AL 1070 specimen with carbide tool material. From the experimental results, it is evident that the surface roughness and material removal rate increases as feed increases. Study has revealed that the surface roughness by large is influenced by cutting environment and the kind of tool. [4]

Borse et. al., focused on optimizing the turning parameters based on Taguchi method to minimize surface roughness and maximize the material removal rate by using SAE 52100 steel with carbide inserts. Results of this study indicate that the feed is mostly influencing the surface roughness of the machined surface. [5]

Nithyanandhan investigated the effect of process parameters on the surface finish and material removal rate (MRR) to obtain the optimal setting of process parameters. The Analysis of Variance (ANOVA) is also used to analyse the influence of cutting parameters during machining. In this work, AISI 304 stainless steel work pieces are turned on conventional lathe by using tungsten carbide tool. Results revealed that the feed and nose radius are the most significant process parameters on work piece surface roughness. However, depth of cut and feed are the significant factors on material removal rate. [6]

Ravi Aryan et. al., designed the experiments using Taguchi method to optimize the cutting parameters for surface roughness and material removal rate in the turning process to obtain the optimal setting for the process parameters and Analysis of variance is used to analyse the influence of cutting parameters while turning the Al-alloy 6082. [7]

Ranganath M.S et. al., conducted several work and research on Al 6061 alloy, their aim is to investigate the effect of cutting speed, feed and depth of cut on the surface roughness in CNC turning. The effect of cutting condition on surface roughness were studied and analysed. The design of experiments was conducted to analyze the influence of turning parameters on the surface roughness by using Taguchi method and ANOVA. [8]

III. EXPERIMENTAL DETAILS

3.1 Test Material

Aluminium 2014 alloy is a high strength structural component for aircraft, military vehicles and bridges, weapons manufacture, automotive industry cylinder, piston manufacture and structural applications. AA-2014 is used for conducting the experiments. The composition of AA-2014 is depicted in Table 1.

Table 1: Composition of AA-2014

Element	Si	Fe	Cu	Zn	Mn	Mg	Ti	Cr	Other	Al
Wt.%	0.69	0.25	4.02	0.02	0.65	0.44	<0.01	<0.02	<0.12	Remainder

3.2 Cutting Tools

The turning tools used for this experiment are viz. High speed steel tool (HSS), Carbide tool tip, Poly-crystalline diamond tool tip that are brazed to HSS E19 tool holder material.

3.3 Process Parameters

The three cutting parameters with three different levels are experimentally constructed for the machining operation. Table 2 indicates the values of process parameters and their levels used for the experiments.

Table 2: Process Parameters and Levels

Cutting Parameters	Level 1	Level 2	Level 3
Cutting Speed(rpm)	384	598	938
Feed (mm/rev)	0.0625	0.125	0.1875
Depth of Cut(mm)	0.2	0.3	0.4

3.4 Experimental Procedure and Details

Experiments were conducted based on Taguchi method and as per L_{27} orthogonal array with considering three controllable factors and three levels as shown in Table 2. In the present research, three different tools were used to turn the AA2014 material and after that the performance characteristics like surface roughness and material removal rate are analyzed to predict the optimum value. After each experimental run, the reduced diameter of work piece and the surface roughness of work piece were measured, surface roughness is measured by Mitutoyo surface roughness tester. The considered value for surface roughness (R_a) was taken as the average value from three trials during experiment. Using average diameter, feed, depth of cut and cutting speed values the material removal rate is calculated for all the experimental runs by using below mentioned formula.

$MRR = 3.142 \times D_{avg} \times f \times d \times N \quad mm^3/min$

Where, D_{avg} = Average diameter between diameter of the work piece before machining and after machining in mm.

f = Feed in mm/rev.

d = Depth of cut in mm.

N = Cutting speed in rpm.

An attempt has been made to assess the factors influencing surface roughness and material removal rate on turning operation. The machining parameters selected for a turning operation is an important procedure in order to achieve high performance. So the best parameter is to judge the quality of turned product is surface roughness which is very important for product. The aim of the research is to minimize the surface roughness and increase the material removal rate; it can be accomplished towards the optimization of cutting parameters. An experimental study has to be conducted to come out with a best possible outcome. The important three machining parameters considered are depth of cut, cutting speed and feed. The experiments were carried out using Taguchi method, the design of experiment has to be implemented to select cutting speed, feed and depth of cut that could result in a better quality product. The response table and response graph for each level of machining parameters are obtained from the Taguchi method and the optimum levels of machining parameters are selected.

The aim of this research is to determine the process parameters which maximize material removal rate and to achieve minimum surface roughness. Larger-the-better quality characteristic is used for material removal rate, as larger MRR values represent better. Smaller-the-better quality characteristic is used for surface roughness, as smaller surface roughness values represent improved or better productivity

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Table 3: Experimental Result for HSS, Carbide and PCD Tools

Exp. Run	Cutting Speed (rpm)	Feed (mm/rev)	Depth of Cut (mm)	HSS Tool		Carbide Tool		PCD Tool	
				MRR mm^3/min	R_a µm	MRR mm^3/min	R_a µm	MRR mm^3/min	R_a µm
1	1	1	1	599.34	1.41	600.1	1.28	600.55	0.54
2	1	1	2	885.21	1.29	887.7	1.83	888.61	0.68
3	1	1	3	1154.65	1.26	1160.68	2.07	1160.68	0.77
4	1	2	1	1132.33	2.24	1141.07	3.40	1140.77	0.80
5	1	2	2	1671.8	2.34	1686.73	3.89	1686.27	0.96
6	1	2	3	2178.99	2.52	2201.91	3.78	2201.31	1.46
7	1	3	1	1600.31	5.25	1620.22	5.87	1620.22	0.95
8	1	3	2	2357.71	5.93	2388.25	6.28	2390.96	0.91
9	1	3	3	3059.45	6.16	3002.44	7.06	3116.46	1.10
10	2	1	1	933.59	1.02	763.31	1.51	933.35	0.74
11	2	1	2	1378.54	1.21	1123.47	2.07	1379.59	0.93
12	2	1	3	1799.06	1.37	1457.1	2.25	1804.7	3.60
13	2	2	1	1765.71	2.15	1786.38	4.30	1775.11	5.19
14	2	2	2	2607	2.31	2630.95	3.68	2623.2	5.35
15	2	2	3	3400.84	2.37	3422.45	3.90	3423.38	5.45
16	2	3	1	2502.01	4.05	2518.22	4.92	2520.33	9.50
17	2	3	2	3686.43	4.41	3718.14	5.08	3719.2	9.44
18	2	3	3	4796.87	4.79	4849.01	5.75	4850.42	9.81
19	3	1	1	1465.86	0.80	1242.61	1.70	1462.91	1.42
20	3	1	2	2170.06	0.58	1833.52	2.02	2155.69	1.57
21	3	1	3	2840.36	0.72	2390.18	3.30	2807.2	1.44
22	3	2	1	2791.73	1.30	2343.76	3.29	2751.94	4.82
23	3	2	2	4119.07	1.26	3457.06	3.17	4061.6	5.05
24	3	2	3	5369.79	1.38	4498.89	4.09	5297.58	4.76
25	3	3	1	3951.08	3.54	3303.44	5.18	3896.93	9.54
26	3	3	2	5828.82	3.66	4865.64	5.34	5752.56	9.53
27	3	3	3	7592.71	3.59	6315.1	5.75	7495.46	8.92

IV. RESULT AND DISCUSSION

MINITAB18 statistical software was used for the experimental analysis. The effect of different process parameters on material removal rate and surface roughness are calculated and plotted, which are mentioned at Fig 1 to 6.

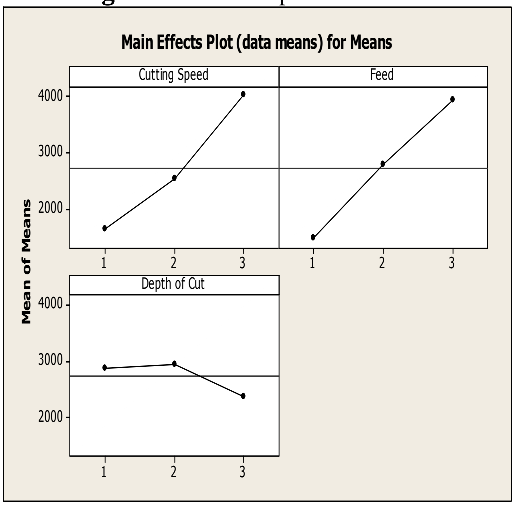
4.1 HSS Tool

Taguchi Analysis: MRR versus Cutting Speed, Feed, Depth of Cut

Table 4: Response Table for Means

Level	Cutting Speed (S)	Feed (F)	Depth of Cut (D)
1	1627	1470	2878
2	2541	2782	2941
3	4014	3931	2363
Delta	2388	2461	578
Rank	2	1	3

Fig 1: Main effect plot for Means



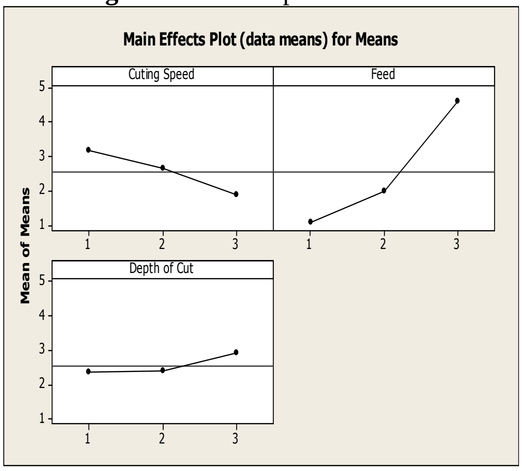
From Table 4, it is clear that feed is the most influencing factor followed by cutting speed and depth of cut for MRR. The optimum value for MRR is predicted from Fig 1, i.e. cutting speed of 938 rpm, feed of 0.1875 mm/rev and depth of cut of 0.3 mm.

Taguchi Analysis: R_a versus Cutting Speed, Feed, Depth of Cut

Table 5: Response Table for Means

Level	Cutting Speed (S)	Feed (F)	Depth of Cut (D)
1	3.156	1.073	2.350
2	2.631	1.986	2.388
3	1.870	4.598	2.919
Delta	1.286	3.524	0.569
Rank	2	1	3

Fig 2: Main effect plot for Means



From Table 5, it is clear that feed is the most influencing factor followed by cutting speed and depth of cut for surface roughness. The optimum value for surface roughness is predicted from Fig 2, i.e. cutting speed of 938 rpm, feed of 0.0625 mm/rev and depth of cut of 0.2 mm.

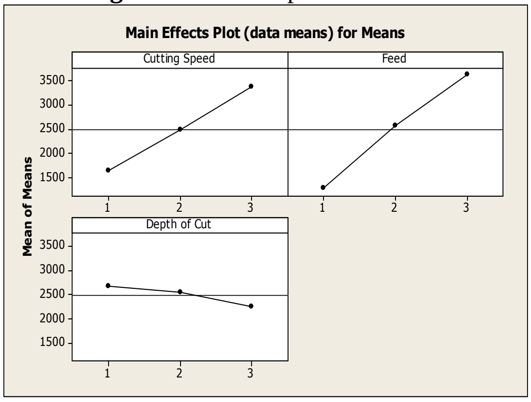
4.2 Carbide Tool

Taguchi Analysis: MRR versus Cutting Speed, Feed, Depth of Cut

Table 6: Response Table for Means

Level	Cutting Speed (S)	Feed (F)	Depth of Cut (D)
1	1632	1273	2670
2	2474	2574	2540
3	3361	3620	2257
Delta	1729	2347	413
Rank	2	1	3

Fig 3: Main effect plot for Means



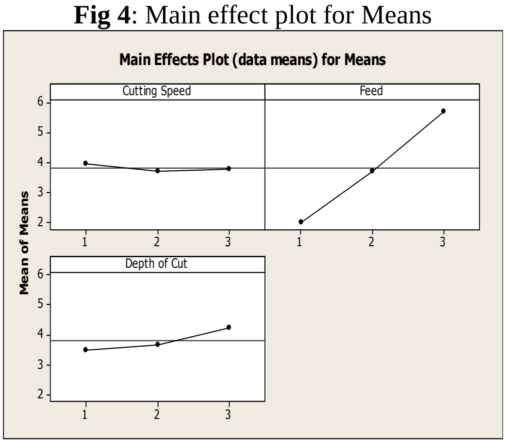
From Table 6, it is clear that feed is the most influencing factor followed by cutting speed and depth of cut for MRR. The optimum value for MRR is predicted from fig 3, i.e. cutting speed of 938 rpm, feed of 0.1875 mm/rev and depth of cut of 0.2 mm.

Taguchi Analysis: R_a versus Cutting Speed, Feed, Depth of Cut

Table 7: Response Table for Means

Level	Cutting Speed (S)	Feed (F)	Depth of Cut (D)
1	3.940	2.003	3.498
2	3.718	3.722	3.686
3	3.760	5.692	4.234
Delta	0.222	3.689	0.737
Rank	3	1	2

Fig 4: Main effect plot for Means



From Table 7, it is clear that feed is the most influencing factor followed by depth of cut and cutting speed for surface roughness. The optimum value for surface roughness is predicted from Fig4, i.e. cutting speed of 598 rpm, feed of 0.0625 mm/rev and depth of cut of 0.2 mm.

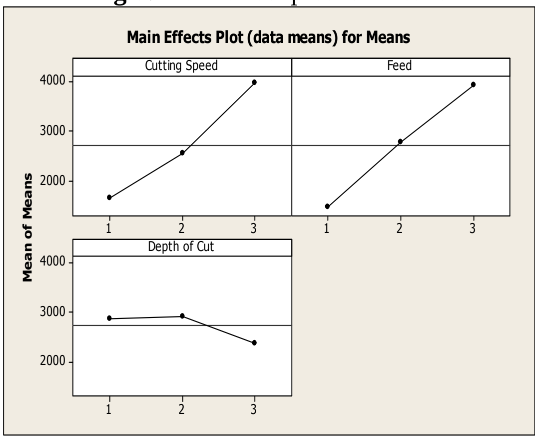
4.3 PCD Tool

Taguchi Analysis: MRR versus Cutting Speed, Feed, Depth of Cut

Table 8: Response Table for Means

Level	Cutting Speed (S)	Feed (F)	Depth of Cut (D)
1	1645	1466	2872
2	2559	2773	2921
3	3965	3929	2375
Delta	2320	2463	546
Rank	2	1	3

Fig 5: Main effect plot for Means



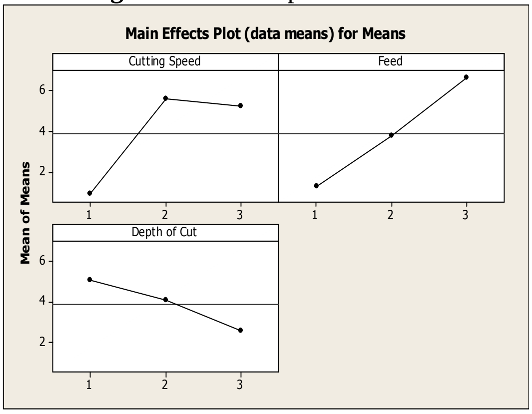
From Table 8, it is clear that feed is the most influencing factor followed by cutting speed and depth of cut for MRR. The optimum value for MRR is predicted from Fig 5, i.e. cutting speed of 938 rpm, feed of 0.1875 mm/rev and depth of cut of 0.3 mm.

Taguchi Analysis: R_a versus Cutting Speed, Feed, Depth of Cut

Table 9: Response Table for Means

Level	Cutting Speed (S)	Feed (F)	Depth of Cut (D)
1	0.9078	1.2989	5.0411
2	5.5567	3.7600	4.0533
3	5.2278	6.633	2.5978
Delta	4.6489	5.3344	2.4433
Rank	2	1	3

Fig 6: Main effect plot for Means



From Table 9, it is clear that feed is the most influencing factor followed by cutting speed and depth of cut for surface roughness. The optimum value for surface roughness is predicted from Fig 6, i.e. cutting speed of 384 rpm, feed of 0.0625 mm/rev and depth of cut of 0.4 mm.From Fig 9 and 10 it is clear that the HSS tool is the most suitable tool for minimized surface roughness and maximized material removal rate with maximum speed when compared to Carbide and PCD tools.

Fig 7: Comparison b/w tools for Surface Roughness

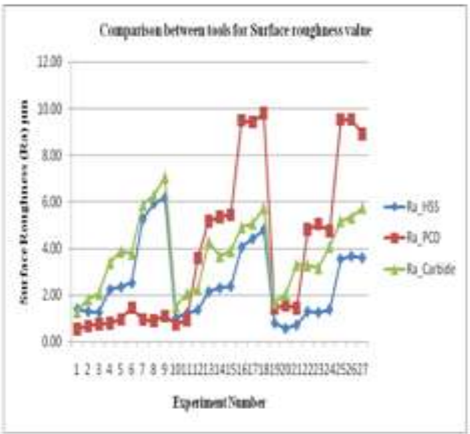
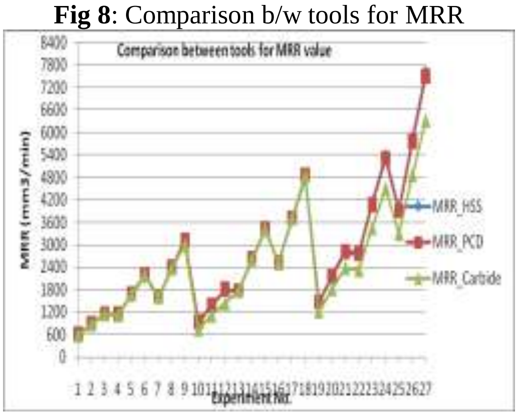


Fig 8: Comparison b/w tools for MRR



Discussion on material removal rate:

The highest material removal rate can be achieved by setting both the cutting speed and feed parameters are at 1st level. The cutting speed and feed parameters are kept constant for all the cutting tools. The depth of cut at intermediate level for HSS and PCD tool yields highest material removal rate. The depth of cut at 3rd level for carbide tool yields highest material removal rate.

Discussion on surface roughness:

The good surface roughness can be achieved by setting feed at 1st level for all the cutting tools, cutting speed at 3rd level for HSS tool, PCD tool and intermediate level for carbide tool gives the good surface roughness, depth of cut at 1st level for HSS tool, carbide tool and depth of cut at 3rd level for PCD tool gives the good surface roughness.

V. CONCLUSIONS

Material Removal Rate

For optimizing material removal rate during turning operation of AA-2014 from different turning tools are carried out and from which the HSS tool is best one when compared to carbide and PCD tools because the material removal rate is about 4 % more with cutting speed of 938 rpm, feed of 0.1875 mm/rev and depth of cut of 0.3 mm.

Surface Roughness

For optimizing surface roughness during turning operation of AA-2014 from different turning tools are carried out and from which the carbide tool is best one when compared to HSS and PCD tools because the surface roughness is 0.25 microns less with cutting speed of 938 rpm, feed of 0.0625 mm/rev and depth of cut of 0.2mm.

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