Experimental Study and Parameter Optimization of Turning Operation of Aluminium Alloy-2014

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Abstract— In this study an experimental investigation of cutting parameters (cutting speed, feed rate and depth of cut) in turning operation of Aluminium alloy-2014 was done and influence of cutting parameters on surface roughness was studied. The machining was performed using two different tools such as carbide tool and TiN coated carbide tool. Taguchi method is used to find optimum result. Orthogonal array, signal to noise ratio and ANOVA is used to study the performance characteristic in turning operation. The result shows that better surface finish is achieve at low feed rate (0.05mm/rev), high cutting speed (314m/min) and at high depth of cut. Experimental data collected are tested with regression model and ANN technique, and a comparison study of model has been done.

Keywords— Surface Roughness, Aluminium Alloy -2014, Taguchi, Signal to Noise Ratio, ANOVA, Regression, ANN

INTRODUCTION

Nowadays the manufacturing industries are continuously challenged for achieving higher productivity and high quality products in order to remain competitive. The desired shape, size and finished, ferrous and non-ferrous materials are conventionally produced through turning. Turning is an important and widely used machining processes in engineering industries. Aluminium alloy-2014 has wide use of application especially in light aircraft which is used in landing gear struct. Due to low surface finish of the struct high friction is produced in the movement of struct. The parameters that we are dealing with in the roughness measurement area are very small which fall in the range of micrometers. But this value will affect several functional attributes of parts, such as friction, wear and tear, heat transmission, ability if distributing and holding a lubricant. The objective of this study is to find optimal solution which will give better surface finish and create a predictive model which will predict the result under any contrition within the cutting range.

LITERATURE SURVEY

Literature survey is done to explore the various process parameters of turning operation and their effect on various output responses and a thorough study of taguchi‘s optimization and ANOVA have been conducted to optimize the process parameters of this study [1-7]. The concept of prediction of results using regression model and ANN were also conducted [8-13].

3. EXPERIMENTAL SETUP AND DESIGN

All the machining processes were done with a “GALAXY MIDASC” Computer Numerical Control (CNC) turning machine with programme controller “FANUC” having 10 KW power and revolving capability of 40-4000 rev/min. For removing the buildup edge formation on the tool rake face kerosene is used as coolant, which is pumped into the work piece and tool tip interface.

3.1 Workpiece

The Aluminium alloy 2014 rod with 40mm diameter and 70 mm length is used as work piece for the study. Identification number is marked on the flat surface of the work piece from 1 to 9 which is shown in the figure no 1.

Figure No 1 Workpiece

3.2 Cutting tools

To improve the surface finish a comparison study of two tools has been conducted. Tools used for turning operation are CNMG 120404 Aluminium grade which is an uncoated carbide tool insert and YBC151 grade description: MT-TiCN + Al2O3 + TiN coated carbide insert are used. The special multi-layer coating of YBC151 offers superb wear resistance and smooth surface finish.

3.3 Output Response

Surface roughness is considered as performance characteristic that is to be evaluated. Surface roughness of work piece is measured after machining each piece with different tool using portable surface roughness tester of "MITUTOYO".

3.4 Design of Experiments

In this work, the optimum conditions for surface roughness in turning operation of Aluminium alloy-2014 is obtained by using Taguchi robust design . L9 (3^3) orthogonal array is used to conduct the experiment.

3.4.1 Selection of control factors and levels

Based on Carmita Camposeco (2014) and Ghorbani Siamak (2013), tool manufacturer recommendations and machine range, feasible range of cutting parameters for a given cutting tool–workpiece system were selected which is shown on the table 1.

Table 1 Process parameters and their levels used for experiment

Parameters	Units	Levels and values		
		1	2	3
Cutting speed	m/min	150	232	314
Feed	mm/rev	0.05	0.10	0.15
Depth of cut	mm	0.1	0.3	0.5

3.4.2 Selection of orthogonal array

The L9 orthogonal array with all values selected for the experimental run is shown in table 2. There are 9 parameter combinations that need to be tested. Each parameter combination is tested for three replications for effective error reduction and for accurate S/N ratio.

Table 2 Experimental Design

Experiment	Speed(m/min)	Feed rate (mm/rev)	Depth of Cut(mm)
1	150	0.05	0.1
2	150	0.1	0.3
3	150	0.15	0.5
4	232	0.05	0.3
5	232	0.1	0.5
6	232	0.15	0.1
7	314	0.05	0.5
8	314	0.1	0.1
9	314	0.15	0.3

4. RESULTS AND DISCUSSION

After conducting the experiment the result obtained for surface roughness for tools CNMG 120404 and YBC 151 is shown on the table 3. Better surface finish is achieved for YBC 151 insert which is coated with titanium nitride.

Table 3 Experimental result obtained

Speed (m/min)	Feed rate (mm/rev)	Depth of cut (mm)	$Ra_{CNMG\ 120404}$	Ra_{YBC151}
150	0.05	0.1	0.423	0.377
150	0.1	0.3	1.031	0.468
150	0.15	0.5	1.72	0.603
232	0.05	0.3	0.381	0.311
232	0.1	0.5	1.001	0.402
232	0.15	0.1	1.499	0.606
314	0.05	0.5	0.366	0.24
314	0.1	0.1	0.642	0.44

314	0.15	0.3	1.305	0.52

In the experiment, the desired characteristic for surface roughness is lower the better. The equation to find the S/N ratio for this characteristic is given below.

$$S/Ns = -10\log_{10}[\text{Mean of sum of squares of measured data}] \qquad (1)$$
$$= -10\log_{10}[(\sum y^2)/n]$$

Where n is the number of measurements in a trial and y is the measured value in a trial. The S/N ratio obtained for CNMG cutting tool is shown in the table 4

Table 4 S/N ratio for surface roughness

Speed (m/min)	Feed rate (mm/rev)	Depth of cut (mm)	S\N Ra (CNMG)
150	0.05	0.1	7.473192652
150	0.1	0.3	-0.265173306
150	0.15	0.5	-4.710568938
232	0.05	0.3	8.381500486
232	0.1	0.5	-0.00868155
232	0.15	0.1	-3.516032657
314	0.05	0.5	8.730378292
314	0.1	0.1	3.849299439
314	0.15	0.3	-2.312210233

The main effect values are plotted in Figure no 2 for the cutting speed, feed rate and depth of cut respectively. The main effects plot shows the influence of each level of factors and the SN ratio with maximum value is taken as the optimum values of surface roughness.

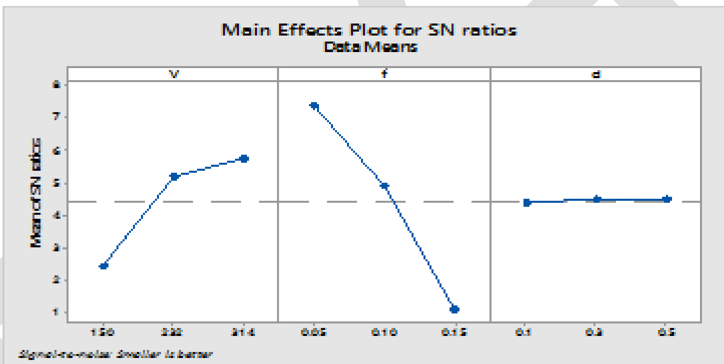

Figure no 2 Signal to noise ratio

The plot shows that as the feed rate and cutting speed increases surface roughness decreases. Depth of cut changes is negligible compared to other two factors.

Table 5 Response Table for Surface Roughness S/N Ratios

Symbol	Process Parameters	Surface roughness CNMG 120404				rank	optimum
		Mean S/N ratio			max-min		
		Level-1	Level-2	Level-3			
V	Speed	2.42792	5.19316	5.72255	3.2946320	2	314
f	Feed rate	7.36420	4.90301	1.07641	6.2877856	1	0.05
d	Depth of cut	4.37925	4.47010	4.49427	0.1150106	3	0.5

Based on the analysis of S/N ratio, shown on the table 5 response table of Signal to Noise ratios for surface roughness the optimal machining performance for the surface roughness is obtained at a cutting speed of 314 m/min (level 3), feed rate of 0.05mm/rev (level 1) and depth of cut of 0.5(level 2). In the analysis, feed rate is shown as the most influencing parameter followed by cutting speed and depth of cut.

Table 6 Analysis of variance

Source	DF	Adj SS	Adj MS	F- value	P-value	% contribution
V	2	0.10624	0.053122	35.62	0.027	24.05
f	2	0.33180	0.165902	111.24	0.009	75.11

d	2	0.00368	0.001842	1.23	0.447	0.83
error	2	0.00298	0.001491			
Total	8	0.44471				

Based on the ANOVA results in Table 6, the percentage contribution of various factors to surface roughness is identified. Here, feed rate is the most influencing factor followed by cutting speed. The percentage contribution of feed rate is 75.11%, this is because as it is well known that for a given tool nose radius, the theoretical surface roughness ($Ra=f^2/(32\times r)$) is mainly a function of the feed rate for cutting speed and depth of cut is 24.05% and 0.83% respectively. Also the probability level of depth of cut is much more than α (0.05) which indicates that depth of cut has least contribution towards surface roughness.
The optimal combination is cutting speed = 314 m/min, feed rate = 0.05 mm/rev, depth of cut =0.5mm
The S/N ratio obtained for cutting tool YBC 150 is shown on the table 7.

Table 7 Signal to Noise Ratio for Surface Roughness

Speed (m/min)	Feed rate (mm/rev)	Depth of cut (mm)	S\N Ra (TiN)
150	0.05	0.1	8.995432939
150	0.1	0.3	7.958800173
150	0.15	0.5	5.161218445
232	0.05	0.3	10.99501783
232	0.1	0.5	8.825828589
232	0.15	0.1	3.87640052
314	0.05	0.5	12.39577517
314	0.1	0.1	9.243618099
314	0.15	0.3	6.87803596

The main effect values are plotted in Figure no 3 for the cutting speed, feed rate and depth of cut respectively. The main effects plot shows the influence of each level of factors and the SN ratio with maximum value is taken as the optimum values of surface roughness. The plot shows that as the feed rate decreases surface roughness decreases. As cutting speed and depth of cut increased surface roughness decreased.

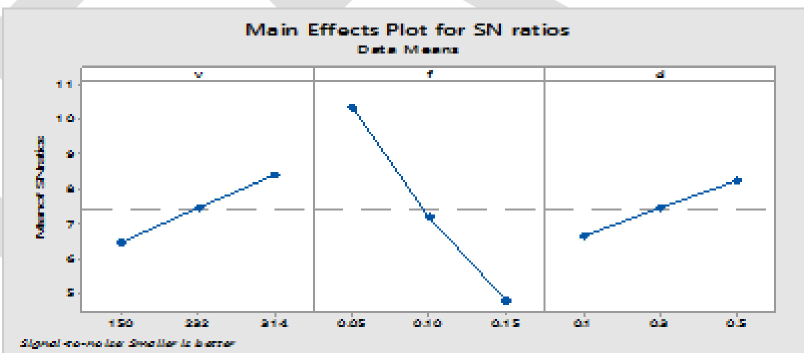

Figure no 3 S/N ratio obtained

Table 8 Response Table for Surface Roughness S/N Ratios

Symbols	Process Parameters	Surface roughness YBC 150			max-min		
		Mean S/N ratio					
		Level-1	Level-2	Level-3		rank	optimum
V	Speed	7.37181	7.899082	9.50581	2.133992555	2	314
f	Feed rate	10.7954	8.676082	5.305218	5.490190338	1	0.05
d	Depth of cut	7.3718	8.610618	8.794274	1.422456881	3	0.5

Based on the analysis of S/N ratio, shown on the response table 8 of Signal to Noise ratios for surface roughness the optimal machining performance for the surface roughness is obtained at a cutting speed of 314 m/min (level 3), feed rate of 0.05mm/rev (level 1) and depth of cut of 0.5(level3). In the analysis, feed rate is shown as the most influencing parameter followed by cutting speed and depth of cut. Based on the ANOVA results in Table 9, the percentage contribution of various factors to surface roughness is identified.

Table 9 Analysis of variance

Source	DF	Adj SS	Adj MS	F- value	P-value	% contribution
v	2	0.01025	0.00512	19.03	0.050	8.33
f	2	0.10701	0.05350	198.57	0.005	87.17
d	2	0.00555	0.00277	10.30	0.088	4.5
Error	2	0.00053	0.00026			
Total	8	0.12335				

Here, feed rate is the most influencing factor followed by cutting speed. The percentage contribution of feed rate is 87.17%, for depth of cut and cutting speed is 8.33% and 4.5% respectively. Also the probability level of depth of cut is much more than α (0.05) which indicates that depth of cut has least contribution towards surface roughness. The optimal combination is cutting speed = 314 m/min, feed rate = 0.05 mm/rev, depth of cut =0.5mm.

4.1 Regression Equation

The relationship between the factors and the performance measures were modeled by quadratic regression. The roughness Ra model is given below. Its coefficient of determination (R^2) is 98.9%.

Ra = 0.3394- 0.000271v+1.764f- 0.106d + 0.0000001 v*v + 5.20 f*f + 0.225 d*d - 0.00114 v*f - 0.000813 v*d

4.2 Verification of surface roughness through comparison test

The experimental data has been tested with the regression model and created ANN model. Model has been constructed with back-propagation algorithm with input parameters of depth of cut, cutting speed and feed rate. Output parameter is surface finish of the machined component.

Table 10 Validation of result for surface roughness

Speed	Feed rate	Depth of cut	Experimental value	Regression value	Predicted value from ANN
150	0.05	0.1	0.377	0.340	0.3916
150	0.1	0.3	0.468	0.451	0.4659
150	0.15	0.5	0.603	0.596	0.601
232	0.05	0.3	0.311	0.296	0.3165

Table 11 Validation of results of surface roughness obtained using ANN

Reading no:	Surface roughness (Ra) in experimental value (µm)	Predicted value (µm)	Error microns(µm)	Percentage error
1	0.377	0.3916	-0.0146	3.87267905
2	0.468	0.4659	0.0021	0.448717949
3	0.603	0.601	0.002	0.331674959
4	0.311	0.3165	-0.0055	1.76848875

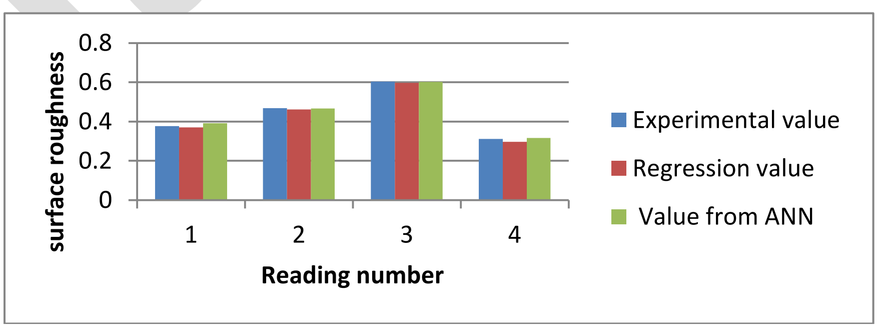

Figure no 4 Validation of result for surface roughness

After completing the experiment ANN has been used to predicted the behavior of the system within the operating range which is shown in the table 10. Average error for ANN is conducted which is given as 1.6% which is shown on the table 11. ANN model has been tested using training data and graph where plotted shown on the figure no 4. ANN is suitable tool to predict the surface roughness. From the table it shows that minimum percentage error was 0.33 and maximum of 3.87. This is a reasonable one and give ANN shows a satisfactory predicted value for surface roughness (Lin, 2003).

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CONCLUSION

In this study the effect of process parameters on surface roughness during the turning operation of Aluminium alloy-2014 under wet condition. Using signal to noise (S/N) ratio and ANOVA results the significance of cutting parameters was determined to get better surface roughness. The experimental results revealed that YBC 150 shows better surface finish compared to CNMG 120404, because Ti carbide reduces the tendency of chips to weld to the tool, decrease wear of the tool by diffusion and increase its hot hardness. Minimum Ra value obtained from the YBC 150 insert is 0.24µm and that from CNMG 120404 insert is 0.366 µm. From ANOVA it is revealed that the feed rate provides main contribution and influences most significantly on the surface roughness, and the effect of depth of cut and effect of speed provide less contribution to the surface roughness. Good surface roughness can be achieved when cutting speed and depth of cut are set nearer to their high level of the experimental range and feed rate is at low level of the experimental range. The optimized control factors settings for Ra are: V_3 (cutting speed 314 m/min), f_1 (feed rate 0.05 mm/rev), d_3 (depth of cut 0.5 mm).The results of ANN model shows close matching between the model output and the directly measured surface roughness.

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