Study on Surface Roughness in Milling of Aluminum 6060 using Taguchi's Approach

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ABSTRACT:

The work and study presented in this paper aims to investigate the effect of the cutting speed, feed rate and depth of cut on surface roughness, in CNC milling of Aluminum (6060) in dry condition. The effect of cutting condition (cutting speed and feed rate) on surface roughness were studied and analyzed. Design of experiments were conducted for the analysis of the influence of the machining parameters on the surface roughness by using Taguchi design and then followed by optimization of the results using Analysis of Variance to find minimum surface roughness. The speed was identified as the most influential process parameter on surface roughness. The optimum surface roughness was reached when the feed rate and depth of cut were set as low as possible.

Keywords: Surface Roughness, CNC Milling, Optimization, Taguchi Techniques, Aluminium

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I. INTRODUCTION

The drastic increase of consumer needs for quality metal cutting related products (more precise tolerance and better surface finish) has driven the metal cutting industry to continuously improve quality control of the metal cutting processes. The quality of surface roughness is an important requirement of many work pieces in machining operations. Within the metal cutting processes, the milling process is one of the most fundamental metal removal operations used in the manufacturing industry. Surface roughness, which is used to determine and evaluate the quality of a product, is one of the major quality attributes of a machining product. Surface roughness of a machined product could affect several of the product's functional attributes such as contact causing surface friction, wearing, light reflection, heat transmission, ability of distributing and holding a lubricant, coating and resisting fatigue. Therefore, surface roughness is one of the important quality aspects in milling operations.

Hence, there is a need to optimize the process parameters in a systematic way to achieve the output characteristics/responses by using experimental methods and statistical models. In order to obtain better surface roughness, the proper setting of cutting parameters is crucial before the process takes place. The aim of organization of this paper is to optimize the process parameters for minimum surface roughness in CNC milling process for Aluminium 6060.

II. EXPERIMENTAL Material

Work Piece Material: Aluminum 6060 was selected as the work material. It is one of the most extensively used of the 6000 series aluminum alloys. This standard structural alloy, one of the most versatile of the heat-treatable alloys, is popular for medium to high strength requirements and has good toughness characteristics. Applications range from transportation components to machinery and equipment applications to recreation products and consumer durables. It is widely used for producing automotive components by milling process. The different alloying elements present in this alloy are shown in the table 1.

Components	% by weight
Aluminium	97.9 to 99.3%
Chromium	0.05% max
Copper	0.1% max
Iron	0.1 to 0.3%
Magnesium	0.35 to 0.6%
Manganese	0.10%
Silicon	0.3 to 0.6%
Titanium	0.1% max
Zinc	0.15% max

Table 1 Composition of work material

It has excellent corrosion resistance to atmospheric conditions and good corrosion resistance to sea water. This alloy also offers good finishing characteristics and responds well to anodizing. Alloy 6060 is easily welded and joined by various commercial methods. For screw machine applications, alloy 6060 has adequate machinability characteristics in the heat-treated condition.

Experimental plan

The experimental work was carried out on CNC milling. The specifications of the machine are given in Table 2

Title	Description	Unit
Capacity	Length	998.98 mm
	Width	1009.65 mm
	Height	1329.18 mm
Machine Size	Foot print	914.40 x 609.60 mm
	Weight	532.97 kg
Spindle	Maximum Speed	4000RPM
	Motor Rating	1.5kw
	Maximum Torque	30Nm
Travel Axis	Table Travel X Axis	558.80mm
	Saddle Travel Y Axis	330.20mm
	Head Travel Z Axis	292.10mm

Table2: Machine Specification

The surface roughness of machined surface has been measured by a Surface Roughness Measuring instrument. The Surtronic 3+ is a portable, self-contained instrument for the measurement of surface texture and is suitable for use in both the workshop and laboratory. Parameters available for surface texture evaluation are: Ra, Rq, Rz (DIN), Ry and Sm. The parameter evaluation and other functions of the instrument are microprocessor based. The measurement results are displayed on LCD screen and can be output to an optional printer or computer for further results.

Design of Experiment

Taguchi's parametric design is the effective tool for robust design. It offers a simple and systematic qualitative optimal design to a relatively low cost. Taguchi method of off-line (Engineering) quality control encompasses all stages of product/process development. However the key element for achieving high quality at low cost is Design of Experiments. In this paper, Taguchi's approach is used to analyze the effect of process parameters like cutting speed, feed and depth of cut on Surface Roughness of Aluminium 6060 work material while milling it on a CNC milling machine to obtain an optimal setting of these parameters that may result in good surface finish. The process parameters and their values at three levels are given in Table 4.

Parameters	Level 1	Level 2	Level 3
Speed (RPM)	1500	1800	2000
Depth of Cut (mm)	0.25	0.50	0.75
Feed (mm/rev.)	0.12	0.18	0.24

Table 3 Process parameters with their value at three levels

Analysis of variance was used for analyzing the results obtained. Analysis of variance is used in the analysis of comparative experiments, those in which only the difference in outcomes is of interest. The statistical significance of the experiment is determined by a ratio of two variances. This ratio is independent of several possible alterations to the experimental observations. Adding a constant to all observations does not alter significance. Multiplying all observations by a constant does not alter significance. So in analysis of variance, statistical significance results are independent of constant bias and scaling errors as well as the units used in expressing observations.

III. RESULTS AND DISCUSSION

The pieces of work material were set so as to conduct milling process three times on a single work piece while calculating the average roughness value, simultaneously by the stylus of the measuring instrument. To more closely replicate typical finish milling processes and to avoid excessive vibrations due to work place dimensional inaccuracies and defects, each work piece was rough-cut just prior to the measured finish cut. Thus simultaneously we could choose the machining zero required for generating cutting profile with reference to our work piece dimensions. On each piece, there were three different values of feed at one depth of cut and at a single speed. Surtronic 3+ instrument, used for surface roughness measurement, has a pick-up with a skid which is used to travel automatically through a drive motor. Thus such travel would at least require a distance of at least 8 mm. Thus we require appropriate surface travel distance on turned aluminum work piece. These dimensions were taken so as to keep travel the stylus on the best surface. The obtained results were analysed using Minitab software and all the values are shown in the Table 4.

S. No	Speed (RPM)	Doc (mm)	Feed (mm/rev.)	Ra (µm)	Rz (µm)
1	1500	0.25	0.12	0.559	4.350
2	1500	0.25	0.18	1.516	6.996
3	1500	0.25	0.24	1.890	8.310
4	1500	0.50	0.12	0.684	4.336
5	1500	0.50	0.18	0.957	5.603
6	1500	0.50	0.24	1.755	9.786
7	1500	0.75	0.12	0.671	4.786
8	1500	0.75	0.18	1.137	9.810
9	1500	0.75	0.24	3.080	12.900
10	1800	0.25	0.12	0.533	3.420
11	1800	0.25	0.18	0.773	4.820
12	1800	0.25	0.24	2.523	12.000
13	1800	0.50	0.12	0.688	4.393
14	1800	0.50	0.18	1.090	8.110
15	1800	0.50	0.24	2.383	1.560
16	1800	0.75	0.12	0.782	4.310
17	1800	0.75	0.18	1.493	7.383
18	1800	0.75	0.24	1.646	7.916
19	2000	0.25	0.12	0.554	3.183
20	2000	0.25	0.18	1.448	7.493
21	2000	0.25	0.24	2.176	9.083
22	2000	0.50	0.12	0.657	4.346
23	2000	0.50	0.18	1.793	8.183
24	2000	0.50	0.24	2.316	1.370
25	2000	0.75	0.12	0.721	5.120
26	2000	0.75	0.18	1.445	6.920
27	2000	0.75	0.24	1.836	9.500

The main effects plot for Means and SN Ratios are shown in Fig. 1 and Fig. 2 respectively. They show the variation of individual response with three parameters i.e. speed, feed and depth of cut separately. In the plot x-axis represents the value of each process parameter and y-axis is response value. Horizontal line indicates the mean of

the response. The main effect plots are used to determine the optimal design conditions to obtain the optimal surface finish.
It is evident from Fig. 3 that Ra is minimum at the second level of speed (A), first level of depth of cut (B) and first level of feed (C). In Fig. 2, the main effect plot for SN ratios of the Surface roughness is shown. Signal-to-Noise ratio of common interest for optimization for surface roughness is smaller the better.

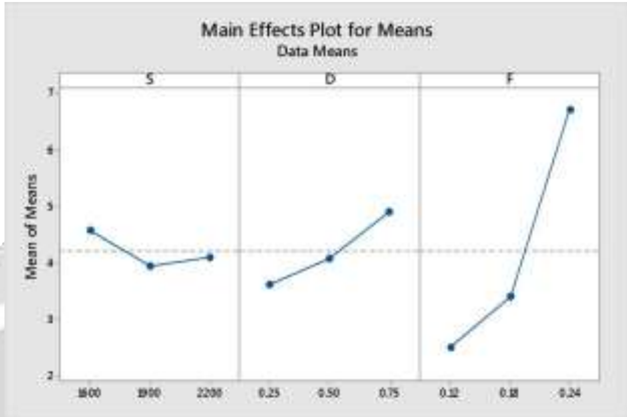

Fig. 1: Main Effects Plot for Means

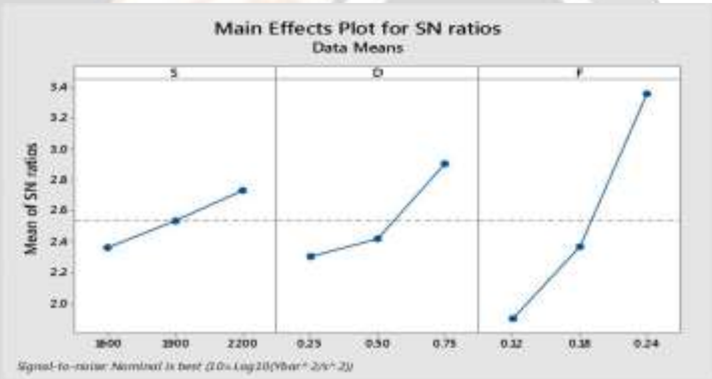

Fig. 2: Main Effects Plot for Means

In order to quantify the influence of process parameters and interactions on the selected machining characteristic, analysis of variance was performed as given in Table 5 and Table 6.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
S	2	0.2256	0.20256	0.10128	2.11	0.322
D	2	0.61077	0.61077	0.30539	6.35	0.136
F	2	3.33902	3.33902	1.66951	34.71	0.028
Residual Error	2	0.09620	0.09620	0.04810		
Total	8	4.24856				

Table 5: Analysis of Variance for SN Ratios

Estimated Model Coefficients for SN ratios

S = 0.2193 R-Sq = 97.7% R-Sq (adj) = 90.9%

Source	DF	Seq SS	Adj SS	Adj MS	F	P
S	2	0.3718	0.3718	0.1859	0.95	0.512
D	2	0.8364	0.8364	0.4182	2.14	0.318
F	2	10.6115	10.6115	5.3058	27.17	0.036
Residual Error	2	0.3906	0.3906	0.1953		
Total	8	12.2104				

Table 6: Analysis of Variance for SN Ratios

Estimated Model Coefficients for Standard Deviation

S = 0.4419 R-Sq = 96.8% R-Sq (adj) = 87.2%

It is evident that speed, depth of cut and feed are significant at 95% confidence level and thus affects mean value and variation around the mean value of the Ra. The speed is most significant and thus affects the mean value of the Ra. Next significant factor is depth of cut followed by feed. The response table for signal noise ratios and for means has been given in Table 7 and Table 8 respectively. The response tables explain that feed is dominant factor followed by depth of cut and speed.

Level	S	D	F
1	2.365	2.308	1.901
2	2.537	2.419	2.371
3	2.732	2.908	3.362
Delta	0.367	0.600	1.461
Rank	3	2	1

Table 7: Response Table for signal to Noise Ratios

Level	S	D	F
1	4.575	3.627	2.501
2	3.938	4.084	3.420
3	4.105	4.906	6.697
Delta	0.637	0.637	1.279
Rank	3	2	1

Table 8: Response Table for signal to Noise Ratio

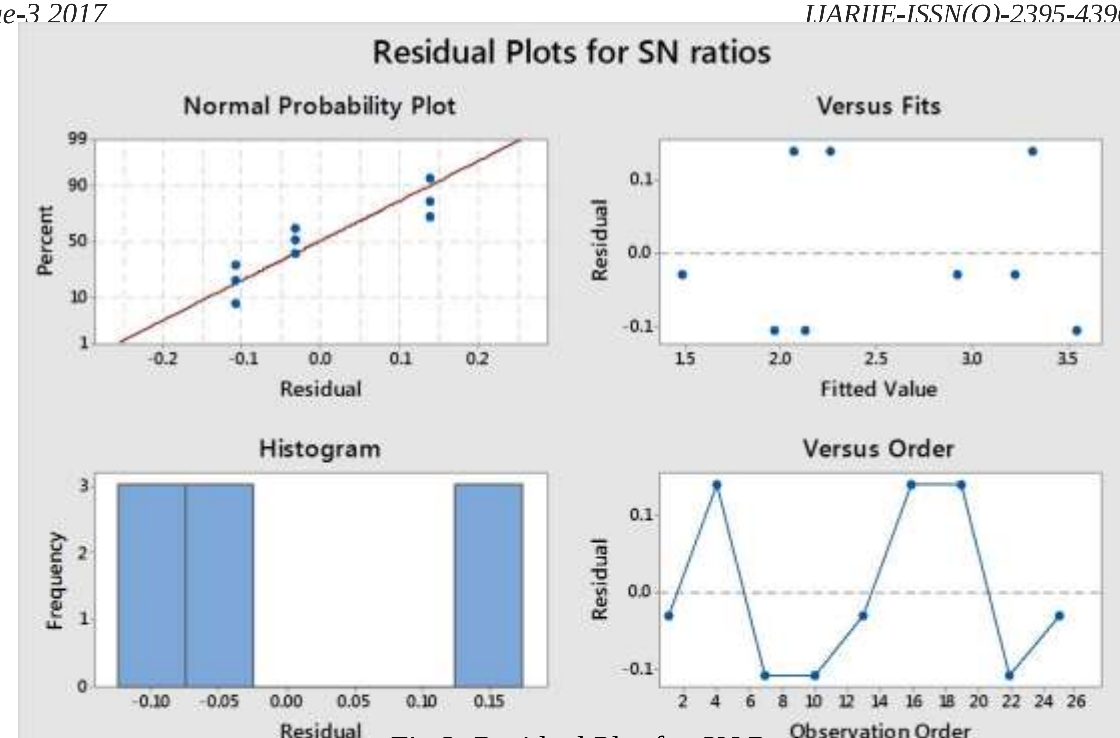

Fig 3: Residual Plot for SN Ratio

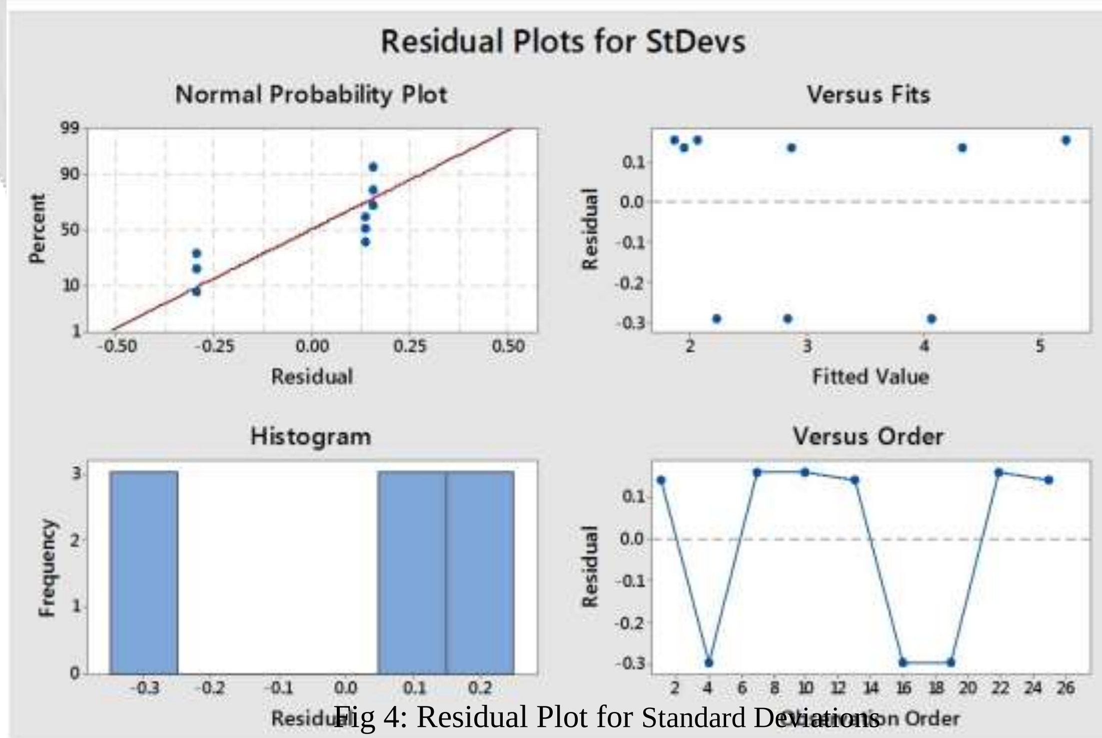

Fig 4: Residual Plot for Standard Deviations

The diagnostic checking has been performed through residual analysis for the developed model. The residual plots for SN Ratios and Standard Deviations are shown in Fig. 3 and Fig. 4 respectively. These generally fall on a straight line implying that errors are distributed normally.

It can be concluded that all the values are within the control range, indicating that there is no obvious pattern and unusual structure and also the residual analysis does not indicate any model inadequacy. Hence these values yield better results in future predictions.

IV.CONCLUSIONS

This work presented an experimentation approach to study the impact of machining parameters on surface roughness. A Systematic approach was provided to design and analyze the experiments, and to utilize the data obtained to the maximum extent. The following are conclusions drawn based on the experimental investigation conducted at three levels by employing Taguchi technique to determine the optimal level of process parameters. CNC Milling gives better results, as speed and feed can be set at any value within a specified range, according to the requirement, compared to a conventional machine in which only some fixed values can be selected. Better results have been obtained in terms of design of experiment techniques such as Taguchi using MINITAB software. Increase in cutting speed decreases the surface roughness up to a certain extent, but as speed increases beyond a certain limit, the surface roughness increases. Increase in feed rate adversely affects the surface finish slightly, but a large increase deteriorates surface finish to a large extent. Analysis of variance and F-test reveals that the speed is dominant parameter followed by depth of cut and feed. The optimal combination process parameters for the work piece under consideration with regards to minimum surface roughness or maximum surface finish is obtained at speed 1800 rpm, depth of cut 0.25 mm and feed rate 0.12 mm/rev.

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