Optimization of Surface Roughness in CNC Turning of Aluminum Alloy ENAC 43400 using Taguchi Method

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Abstract— In Computer Numerical Control (CNC) turning technology, Surface roughness is a one of the most important parameter. The aim of the work is, to obtain the optimum process parameters of turning process (cutting speed, feed rate and depth of cut) which results in an optimal of surface roughness for machining aluminum alloy ENAC43400, as a work piece material with carbide cutting tool in a CNC lathe machine. The effect of various cutting parameter for surface roughness of ENAC 43400 work material in turning operation L9 orthogonal array based Taguchi optimization technique is used for optimization of process parameters of CNC. The surface roughness is measured by using the surface roughness tester (Mitutoyo surftest-SJ210). Design of experiments (DOE) were conducted for the analysis of the effective turning parameters on the surface roughness by using Taguchi design and then optimize these results using Analysis of Variance (ANOVA), to find the optimal value of surface roughness. The feed rate and depth of cut values are set as low for the result of optimum surface roughness whereas speed was the most influential process parameter.

Key words: CNC Lathe, Surface Roughness, Regression analysis, Taguchi, Design of Experiments, ANOVA

I. INTRODUCTION

The aim of the modern industries is to manufacture low cost, good quality products in short time. The aluminium alloys are used in various engineering applications like structural, cryogenic, food processing, oil and gas process industries etc. because of light weight and high tensile strength. Therefore the desired finish surface is usually specified and the appropriate processes are selected to reach the required quality [1].

Surface roughness is commonly considered as a major manufacturing goal for turning operations in many of the existing research works. The machining process on a CNC lathe is programmed by speed, feed rate and cutting depth, which are frequently determined based on the machine performance where the product characteristics are not guaranteed to be acceptable. Therefore, the optimum turning conditions have to be accomplished. It is mentionedthat the tool nose run-off will be the performance of the machining process [2].

Parameter optimization for surface roughness is a hardsolving issue because of the interactions between the parameters. Problems related to the enhancement of the product quality and production efficiency can always be related to the optimization procedures [3]. One of the best method to control the product quality at the product design stage is Taguchi's method.

In the present work to determine the optimum machining parameters for CNC Lathe machine turning operation for optimization of surface roughness the Taguchi's method is used for the machining aluminum alloy ENAC43400 as a work piece material. For the three factors (cutting speed, feed, depth of cut) Taguchi's L9 orthogonal array is used. Analysis of variance (ANOVA) is used to determine the influence of parameters which significantly affect the responses. The effects of the process parameters such as feed rate (f), cutting speed (v) and depth of cut (d) on surface roughness parameters is also analyzed in this investigation [4].

The number of surface roughness prediction models available in literature is very limited [5].Salah Gasim Ahmed [6] developed an empirical surface roughness model for commercial aluminum, based on metal cutting results from factorial experiments. The model includes the feed, depth of cut and spindle speed.Basim A. Khidhirand Bashir Mohamed et al. [7] investigate the effect of cutting speed feed and the depth of cut on surface roughness. It was found that the good surface roughness is obtained with a higher cutting speed, a minimum feed rate, and a lower depth of cut.Mahamani et al.[8] studied tool wear, surface roughness and cutting force in the turning of Al-6061-6% TiB2 in-situ metal matrix composite using GRA. Ramanujam et al. [9] also used desirability function analysis for optimizing multiple performance characteristics namely surface roughness and power consumption in turning Al-15%SiCp metal matrix composites.

II. EXPERIMENTAL PART

A. Work Material

The work piece material is aluminum alloyENAC43400 in the form of round bars of 40 mm diameter and length of 150 mm axial cutting length. The composition of material is.

Element	CU	Si	Fe	Mn	Mg	Zn	Ni	Pb	Ti	Sn
Wt %	0.081	9.76	0.36	0.08	0.35	0.13	0.001	0.023	0.016	0.012

Table 1: Chemical composition of ENAC43400 aluminum alloy

Surface roughness is measured using an automatic digital POCKET SURF EMD-1500.

B. Experimental Observations and Detail

In the present work, three machining parameters are selected as control factors, and each parameter is designed to have three levels, denoted 1, 2, and 3. The experimental design was according to an L'9 array based on Taguchi method. The use of Taguchi orthogonal array reduces the number of experiments. A set of experiments designed using the Taguchi method is conducted to investigate the relation between the process parameters and response factor. Minitab 16 software is used for optimization and graphical analysis of obtained data.

By performing OVAT analysis and studying research papers, it is found that cutting speed, feed rate and depth of cut are influencing parameters on Surface Finish. According to OVAT analysis following input parameters namely cutting speed, feed rate and depth of cut are selected by keeping other process parameters constant at minimum level which is less influencing on surface finish [10].

Parameters	Units	Level 1	Level 2	Level 3
Speed (V)	Rpm	3447	3513	3579
Feed (F)	mm/rev	0.05	0.053	0.056
DOC(D)	Mm	0.3	0.35	0.40

Table 2: Selection of Levels from OVAT Analysis

Expt No.	Speed (rpm)	Feed rate (mm/rev)	Depth of cut (mm)	Avg. Surface Roughness (μm)
01	3447	0.050	0.30	0.955
02	3447	0.053	0.35	1.285
03	3447	0.056	0.40	1.545
04	3513	0.050	0.35	0.748
05	3513	0.053	0.40	0.918
06	3513	0.056	0.30	1.118
07	3579	0.050	0.40	0.731
08	3579	0.053	0.30	0.771
09	3579	0.056	0.35	1.241

Table 3: Results from Design of Experiments and calculations

III. REGRESSION MODEL

Based on the experimental data, statistical regression analysis enabled to study the correlation of process parameters with the surface roughness. Non-linear regression model is examined; acceptance is based on high to very high coefficients of correlation calculated. The coefficients of regression model can be estimated from the experimental results. The effects of these variables and the interaction between then were included in this analyses and the developed model is expressed as in interaction equation. The unknown coefficients are determined from the experimental data. The model made to represent surface roughness depicts that cutting speed, feed depth of cut, and their interaction are the most influencing parameters in order of significance. The final response equation for surface roughness is given in equation 1.1 [11].

$$RA = 5.5418 - 0.00263131\,S + 81.6667\,F + 1.16667\,D$$

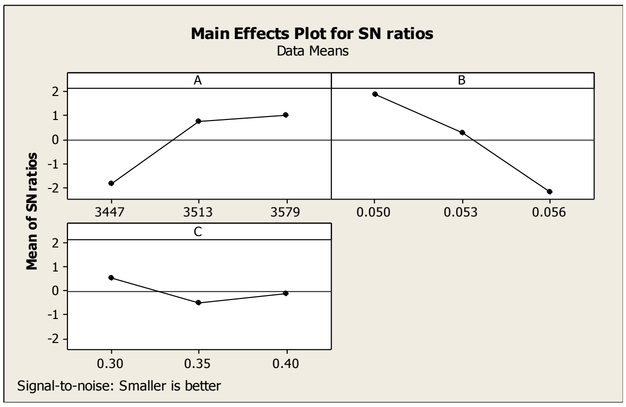

Fig. 1: Main Effects Plot for SN ratios

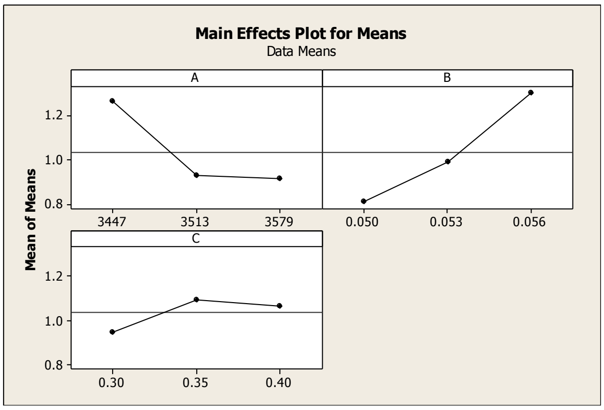

Fig. 2: main Effects Plot for Means

IV. ANALYSIS OF VARIANCE (ANOVA)

Table 4 indicates the ANOVA for surface roughness. The purpose of the ANOVA is to determine the process parameters which significantly affect the performance characteristics. It is found that the cutting speed, feed rate, depth of cut and their interactions are the significant cutting parameters for affecting the surface roughness. The ANOVA table for the model depicts the value of Coefficient of determination R-sq , which signifies that how much variation in the response is explained by the model. The higher of R-Sq, indicates the better fitting of the model with the data. However,. It is important to check the adequacy of the fitted model, because an incorrect or under-specified model can lead to misleading conclusions. The model adequacy checking includes the test for significance of the regression model, model coefficients, and lack of fit, which is carried out subsequently using ANOVA is presented in table 5. The residual error is the sum of pure and lack-of-fit errors. The fit summary recommended that the model is statistically significant for analysis of surface roughness. In the table, all the p-value values are significant. Moreover, the mean square error of pure error is less than that of lack-of-fit. The final model tested for variance analysis (F-test) indicates that the adequacy of the test is established [6].

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Speed	2	0.23216	0.23216	0.11608	267.88	0.004
Feed	2	0.36860	0.36860	0.18430	425.31	0.002
Depth of cut	2	0.03487	0.03487	0.01743	40.23	0.024
Error	2	0.00087	0.00087	0.00043		
Total	8					

Table 4: Anova Table for Ra

S = 0.0208167 R-Sq = 99.86% R-Sq(adj) = 99.46%

V. COMPARISON BETWEEN PREDICTED AND EXPERIMENTAL RESULTS

Table 5 indicates the comparison between predicted Ra mean and experimental Ra mean. A good agreement between predicted value and experimental value of Ra mean is being observed.

Trial No	Predicated Ra mean value (μm)	Experimental Ra mean values (μm)
1	0.90501	0.955
2	1.208344	1.285
3	1.511678	1.545
4	0.789677	0.748
5	1.093011	0.918
6	1.221344	1.118
7	0.674345	0.731
8	0.802678	0.771
9	1.106011	1.241

Table 5: Comparison Between Predicted And Experimental Results

VI. CONCLUSION

The final conclusions arrived, at the end of this work are as follows:

1) The increase in cutting speed produces better surface finish (i.e., surface roughness reduces). The surface roughness decreases from level one to level three with depth of cut, whereas with increase in feed rate the surface roughness increases.
2) The present investigation has focused on surface roughness prediction and analysis during the turning of Aluminium alloy ENAC43400 using carbide inserts. Design of experiments (DOE) were conducted for the analysis of the effective turning parameters on the surface roughness by using Taguchi design and then optimize these results using Analysis of Variance (ANOVA) to find the optimal value of surface roughness. The following conclusions can be drawn from this study: Theminimum surface roughness in this process was obtained for Aluminium alloy ENAC43400 workpiece by turning at 3579rpm speed, 0.050 feed and 0.40 depth of cut with Ra 0.731 μm
3) The value of the performance characteristics obtained from confirmation experiment is within the 95% confidence interval of the predicted optimum condition.
4) Hence it is concluded that feed rate has significant effect on surface roughness and the next significant factor is speed and depth of cut.

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