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Using RSM and GA to Predict Surface Roughness Based on Process Parameters in CNC Turning of AL7075-T6

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ABSTRACT: Surface roughness is a common indicator of the quality characteristics for machining processes. The machining process is more complex, and therefore, it is very hard to determine the effects of process parameters on surface quality in all turning operations. The present work deals with the study and development of a regression model to predict surface roughness in terms of geometrical parameter, nose radius of cutting tool TNMG insert and machining parameters, cutting speed and cutting feed rate for machining AL7075-T6, using Response Surface Methodology (RSM). The surface roughness of machined surface was measured by Mitutoyo Surftest SJ201. The second order mathematical model in terms of machining parameters was developed for predicting surface roughness. The adequacy of the model was checked by employing ANOVA. The direct and interaction effects were graphically plotted which helps to study the significance of these parameters on surface roughness. An attempt has also been made to optimize the surface roughness prediction model using Genetic Algorithm (GA) to optimize the objective function.

KEY WORDS: Surface roughness, CNC turning, AL7075-T6, nose radius, Response Surface Methodology, Genetic algorithm, optimization.

I. INTRODUCTION

Turning is the basic machining process that involves material removal from cylindrical parts using a single point cutting tool to obtain the required dimension.

Surface roughness is an important index of quality for a turned component. The factors responsible for surface roughness are not only limited to machining parameters (cutting speed, feed, depth of cut) and tool geometry (nose radius, rake angle, face angle), but also includes tool wear, tool material, tooling errors, operator skill, machining environment and so on. Surface roughness has greater impact on the performance of machined parts such as fatigue behavior, corrosion resistance, creep life etc. and also influences production costs.

Several researches are in progress to optimize the process parameters in machining to improve manufacturing efficiency and to cut down production costs. Various optimization techniques and sequential algorithms have been used by researchers to determine the optimum set of input parameters to attain the desired output in turning process.

Response Surface Methodology (RSM) [1, 5 & 6] is a statistical method that explores the relationship between several influencing variables and one or more response variables. RSM uses data acquired from experimental designs to develop a mathematical model that helps in the prediction of response value for a given set of input parameters.

Genetic Algorithm [3, 7 & 10] is an optimization technique, based on the mechanics of natural selection and natural genetics. Input parameters are encoded as genes by binary encoding to apply GA in an optimization process. A set of genes (randomly selected) is combined together to form chromosomes, which are used to perform the basic mechanisms in GA, such as crossover and mutation. Through successive iterations, individuals are randomly selected as parents for the next generation until the evolution of an optimal solution.

In this paper, a second order mathematical model is developed using RSM to predict the surface roughness in turning operation for known values of tool nose radius, cutting speed and feed rate. These process parameters are optimized using genetic algorithm to obtain minimum surface roughness. The experiments are conducted on Al7075 – T6 Aluminum alloy jobs using TNMG inserts in JYOTHI CNC Lathe. Al7075 has high strength and excellent corrosion resistance among the available aluminum alloys, which enable it to be used in aerospace and defense equipment.

Even though numerous researches have been made to find the optimal machining parameters, this work is aimed to optimize the cutting parameters (speed and feed) as well as tool nose radius simultaneously at constant depth of cut. The validation of the model to achieve optimum response has proven its potential to be used in practical applications.

II. LITERATURE SURVEY

K. Bouacha et al. [1] investigated the effect of workpiece hardness and cutting speed on the cutting forces for different values of the tool wear to delimit the working parameters in hard turning. J. P. Davim et al. [2] analyzed the effects of feed rate, cutting speed and depth of cut on average roughness and maximum peak to valley height by developing ANN models in turning of free machining steel using cemented carbide tools. M. Durairaj & S. Gowri [3] performed Micro turning with full factorial experiments and developed a Non-linear regression model to represent relationship between input and output variables.

E. Liasi et al. [4] presented an integrated model for turning process to focus on the effects of random excitations that result from material micro hardness variations that enhances the surface finish. A.J. Makadia & J.I. Nanavati [5] developed a quadratic surface roughness prediction model in turning of AISI 410 steel under various cutting conditions. S. Neseli et al. [6] applied RSM on the turning of AISI 1040 steel with Al2O3/TiC tool to develop a mathematical model of the surface roughness (Ra) so as to investigate the influences of cutting tool geometry parameters.

A. Del Prete et al. [7] estimated the surface roughness using experimental data by formulating a RS model based on RBF (Radial Basis Functions) methodology for predicting surface roughness values in milling Al7075-T6. T. G. A. Raj & V. N. N. Namboothiri [8] investigated the optimum process parameter for surface roughness on the turning of SS420 material. An IGA approach was applied to predict the influence of tool geometry and cutting parameters. C.J. Rao et al. [9] studied the influence of speed, feed and depth of cut on cutting force and surface roughness for a predefined combination of material and tool under the given set of machining conditions.

P.V.S. Suresh et al. [11] made a two-stage effort to obtain a surface roughness model by surface response methodology, and optimization of the model by Genetic Algorithms, which was a fairly useful method of obtaining process parameters in order to attain the required surface quality. S. Xie et al. [12] proposed a novel approach combining genetic algorithm (GA) with a pass enumerating method to minimize the unit production cost (UC) in multi-pass turnings using bound adjustment of optimized variants (BAOV) method to represent the chromosome to reduce the number of infeasible individual during evolution.

III. EXPERIMENTAL SETUP

The plan of the current work is briefly presented as follows

1. Identification and selection of influential process parameters that have an impact on the surface roughness of the turned component.
2. Determination of the upper and lower limits for each parameter.
3. Development of experimental design matrix for conducting the experiments.
4. Conducting the experiments to determine the roughness value for different combinations of input parameters.
5. Development of mathematical model to predict the surface roughness based on experimental data acquired from experiments using Response Surface Methodology.

Table 1 Composition of Al7075

Element	Mn	Si	Cr	Cu	Fe	Zn	Mg	Ti	Al
Composition %	0.3	0.4	0.18-0.3	1.2-2	0.5	5.1-6.1	2.1-2.9	0.2	88.11-90.87

Table 2: Factor level for the parameters

parameters	Factor levels				
	-1.682	-1	0	1	1.682
Nose radius, r (mm)	0.4	0.6	0.8	1	1.2
Cutting speed, Vc (rpm)	2000	2500	3000	3500	4000
Feed, fz (mm)	0.05	0.1	0.15	0.20	0.25

Figure 1 Experimental setup of CNC Turning and Surface Roughness Measurement

6. Validation of the developed model using ANOVA.

7. Analysis of the effect of input parameters on the response (surface roughness) from the coefficients of the model.

8. Determination of optimum input parameters to attain minimum surface roughness using Genetic Algorithm.

The experiments were performed in JYOTI CNC lathe using TNMG carbide inserts on Al7075 cylindrical rods of 20mm diameter and 50mm in length. The chemical composition of the workpiece element (Al7075) is shown in Table 1.

The experiment involves three parameters viz. tool nose radius, cutting speed and feed, each at five levels which is a 5^3 factorial design. The factor levels and the coded values for the parameters are shown in Table 2.

The Surface Roughness of each turned component is measured using Mitutoyo Surftest – 201 apparatus. The experimental setup is shown in Figure 1. The roughness is determined from the average of roughness values measured over the circumference of the turned surface.

IV. MODEL DEVELOPMENT

Table 3: Experimental design matrix with measured and predicted roughness values

Runs	r	V_c	f_z	O_v	P_v	% error
1	-1	-1	-1	0.87	0.88	0.78
2	1	-1	-1	0.91	0.86	-5.06
3	-1	1	-1	1.25	1.30	4.18
4	1	1	-1	0.67	0.65	-3.11
5	-1	-1	1	2.73	2.81	2.94
6	1	-1	1	1.42	1.39	-2.36
7	-1	1	1	3.48	3.55	1.84
8	1	1	1	1.48	1.49	0.79
9	-1.682	0	0	3.09	2.97	-3.63
10	1.682	0	0	1.19	1.23	3.02
11	0	-1.682	0	0.91	0.91	0.47
12	0	1.682	0	1.31	1.35	3.00
13	0	0	-1.682	0.35	0.37	5.03
14	0	0	1.682	2.77	2.71	-2.34
15	0	0	0	1.13	1.16	2.49
16	0	0	0	1.22	1.16	-4.98
17	0	0	0	1.10	1.16	5.38
18	0	0	0	1.19	1.16	-2.58
19	0	0	0	1.12	1.16	3.49
20	0	0	0	1.17	1.16	-0.92

$$R_a = \begin{bmatrix} 1.15609 - 0.51571r + 0.11860v_c + 0.69463f_z + 0.34314r^2 \\ +0.13866f_z^2 - 0.16300rv_c - 0.36600rf_z + 0.08400v_c f_z \end{bmatrix} \quad (1)$$

Table 4 ANOVA result for the mathematical model

Response	DF	Lack of fit	Pure error	F ratio		adequacy
				Model	Standard	
Roughness	9	5	5	2.99	4.77	Adequate

The design matrix for the experiment, observed roughness, O_v value and the predicted roughness values, P_v along with the corresponding percentage error are shown in Table 3. MINITAB 16 software is used to analyze the central composite experimental design and to perform the analysis of variance[10]. The predicted values of roughness are obtained using Regression equation developed from the observed values for the design combination.

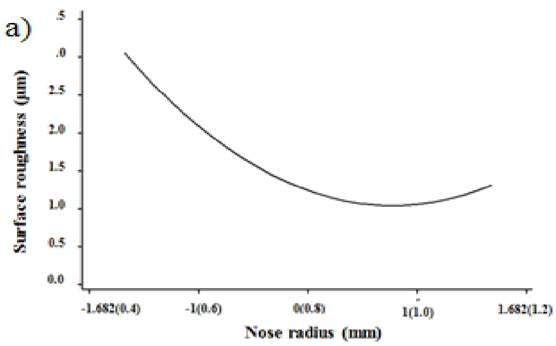
The regression mathematical model for surface roughness developed using the coefficients is shown in equation 1.This equation provides prediction of surface roughness in terms of cutting parameters.

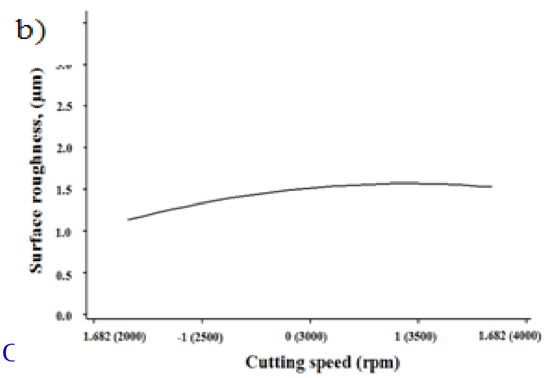
ANOVA is performed to confirm the adequacy of the model. The result of ANOVA is presented in Table 4. The F ratio of the model is less than the standard value and hence, the model is adequate at a confidence level of 95%.

V. RESULTS AND DISCUSSIONS

The impact of input machining parameters on surface roughness is analysed using the developed mathematical model.

Main effect of the parameters





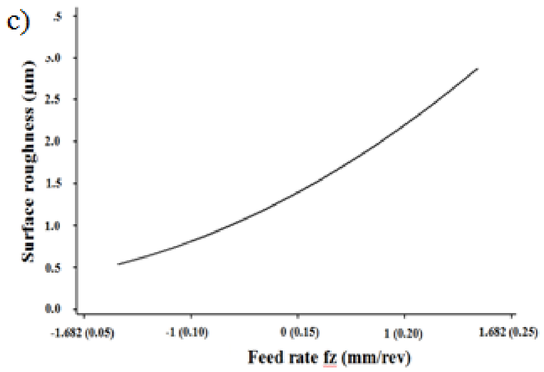


Fig 2 Main Effect of Parameters a) Tool Nose Radius b) Cutting Speed c) Feed Rate

The direct effect of each individual machining parameter on surface roughness is identified by keeping all input values at the middle level except the parameter under study. The main effects of all the three input parameters are shown in Figure 2.

It can be seen that with the increase of tool nose radius, roughness minimizes gradually until the radius is 1mm. Above this radius, roughness tends to increase. Increasing cutting speed tends to increase the surface roughness. This can be attributed to the fact that with increasing speed, temperature at the point of conact increases which results in plastic deformation. By increasing the feed rate, roughness continues to increase and therefore minimum roughness can be achieved at low feed rates. The cause for increase in roughness is at increased feed rate, vibration of tool causes poor surface finish.

Interaction effect of parameters

Interaction effects are the impacts created by the combined effects of multiple input parameters on the response, other than the effects produced by them individually.

The effects of interaction between the input parameters are shown in Figure 3. It is found that the interaction between nose radius and feed rate has maximum impact on the response (surface roughness) compared to other interaction effects. Therefore surface finish can be improved by minimizing feed rate and increasing the nose radius.

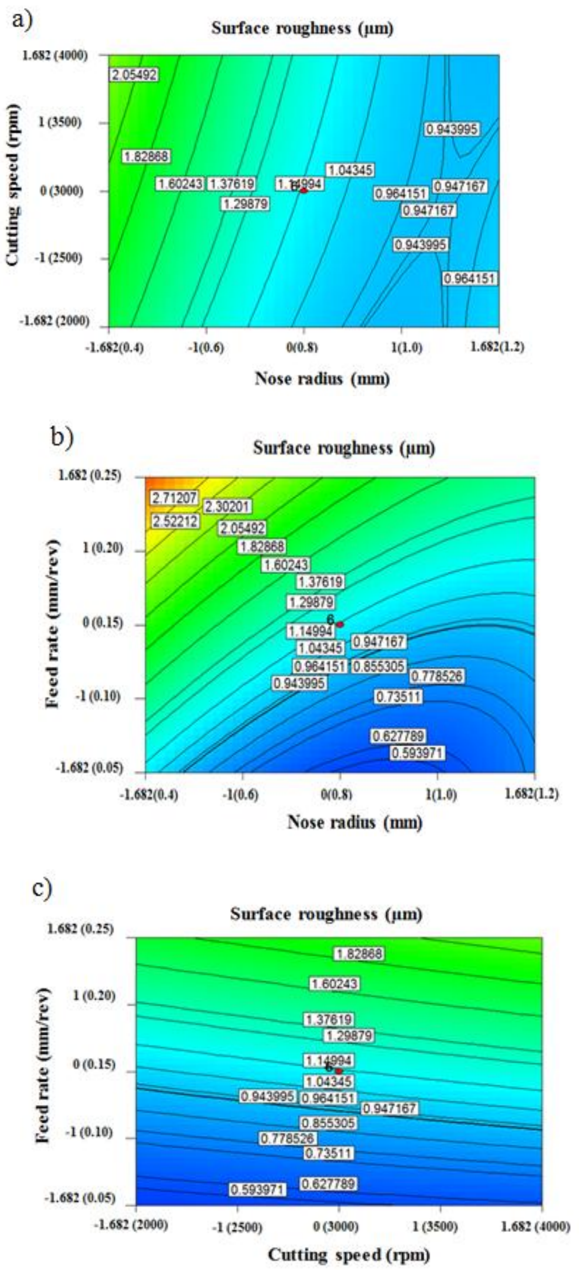


Fig 3 Interaction Effects of input Parameters a) Nose Radius and Cutting Speed b) Nose Radius and Feed Rate c) Cutting Speed and Feed Rate

Model validation

The proposed mathematical model is validated by comparing the predicted roughness values with the observed values of surface roughness.

The comparison of the response values is represented in Figure 4. It is found that the predicted roughness values match closely with the observed values to a reliability of 99.69%.

Also the adequacy of the model is investigated by

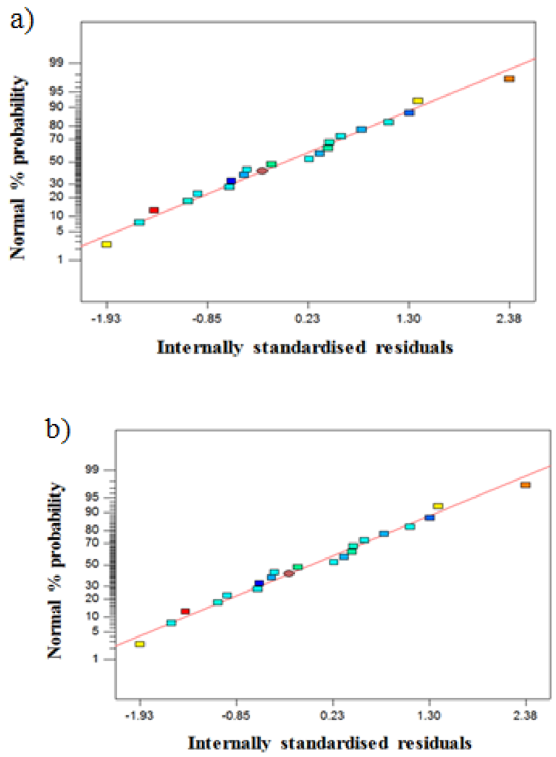


Fig 5 Model Validation a) % Probability Vs Residuals b) Residuals Vs Runs

examination of residuals. Residuals are the difference between the predicted and observed values of the response. The residuals are analyzed for normality and the plot of residuals versus predicted values of response for each run. For the model to be adequate, the normality test should result in a straight line and the residuals plotted against each run should not follow any structured pattern. Figure 5 a) and Figure 5 b) represents the examination of residuals.

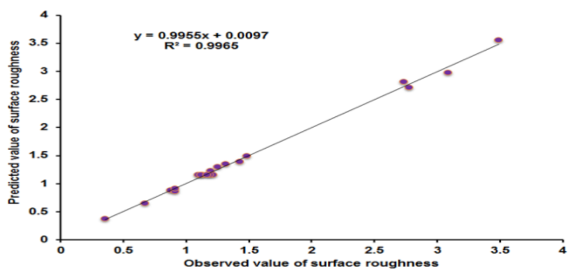


Fig 4 Observed Values Vs Predicted Values

Model optimization

The mathematical model is optimized using Genetic Algorithm to determine optimum values of input parameters to achieve minimum surface roughness. Since the objective is to attain minimum surface roughness, this is a minimization problem. The minimization objective function is shown in Figure 6.

Genetic algorithm is based on the mechanism of natural selection and natural genetics, which simulates the biological progression method. Through binary encoding, the cutting conditions are encoded as genes to apply the GA technique.

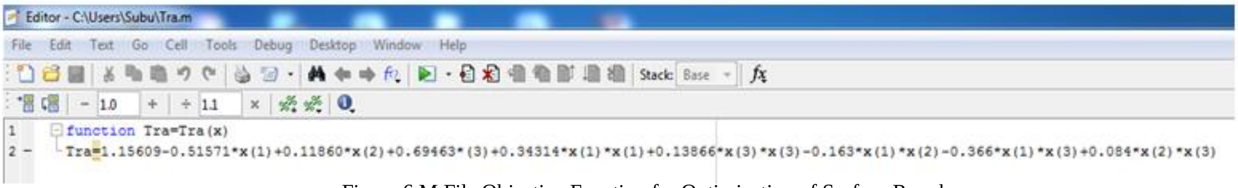


Figure 6 M File Objective Function for Optimization of Surface Roughness

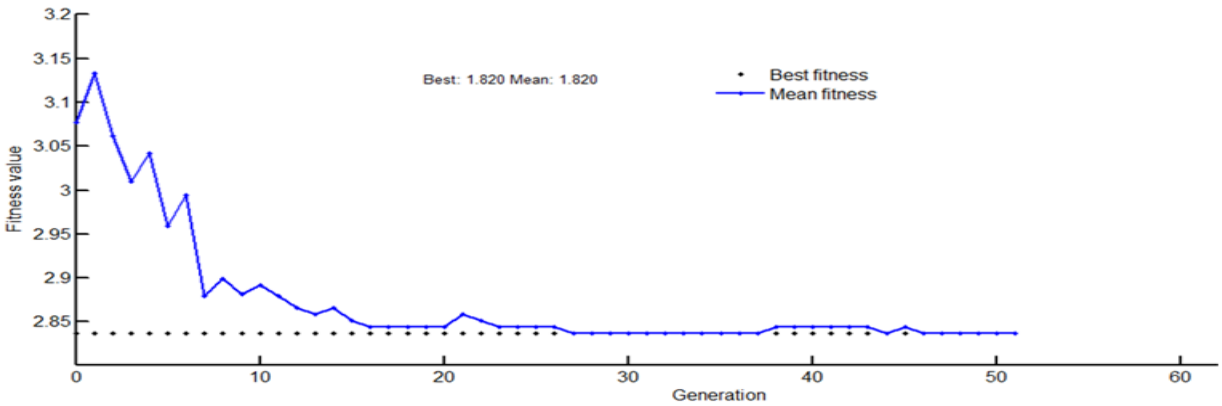


Figure 7 Optimization of Surface Roughness with Subsequent Generations

Genes combine to form chromosomes. Randomly selected chromosomes represent a population. The chromosomes undergo crossover and mutation to produce new generation, of which the best individuals survive, while others are rejected. This process continues until a new generation with the best fitness characteristics is evolved. For the current application, the best minimum roughness value is attained at the 51st iteration and the optimum values of input parameters are identified as r = 1mm, v_c = 3500rpm and f_z = 0.1mm. The optimization history is represented in Figure 7.

VI. CONCLUSION

In this paper, response surface methodology is applied to develop a second order mathematical model that can be used to predict the surface roughness value for known values of tool nose radius, cutting speed and feed rate in CNC turning. The adequacy of the model is examined using ANOVA. The direct and interaction effect of the input parameters are also analysed. Also the mathematical model is optimized using Genetic Algorithm to attain minimum surface roughness. The predicted values of roughness are found to match closely with the observed values.

This work will be useful for individuals in production engineering to achieve minimum surface roughness in turning operations. Also it will assist in determining the levels of input parameters to be established for achieving the desired surface roughness.

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