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OPTIMIZATION OF MACHINING PARAMETERS FROM MINIMUM SURFACE ROUGHNESS IN TURNING OF AISI 52100 STEEL

[1]MOHAMMED IRFAAN, [2]BHUVNESH BHARDWAJ

[1]Lecturer, Department of Mechanical Engineering, Adigrat University, Ethiopia, E-mail: irfaanprof@gmail.com

[2]Assistant professor, Department of Mechanical Engineering, Suresh Gyan Vihar University, India, E-mail: b_bhardwaj24@rediffmail.com

ABSTRACT

Metal machining has been a very important process is manufacturing. Machining conditions play a vital role in estimating the performance of machining operations. It have long been recognized that the machining conditions, such as cutting speed, feed and depth of cut affect the performance of the operations in great extent.

The objective of the present work is to analyse the effects of the machining parameters in turning on the surface roughness parameters of AISI 52100 steel. It is quietly used in bearing in rotating machinery. The design of experiments based on response surface methodology with three numeric factors(cutting speed, feed rate and depth of cut) five level central composite rotatable design have been used to develop relationships for predicting surface roughness.

The surface roughness parameters were measured using surface roughness tester (SJ 210). The design expert software has been used for the analysis. A quadratic model and linear model have been developed which indicates that interaction is present between the machining parameters (speed, feed and depth of cut). Model adequacy tests were conducting using ANOVA table and the effects of various parameters were investigated and presented in the form of contour plots and

3 D surface graphs. Numerical optimization was carried out considering all the input parameters within range so as to minimize the surface roughness.

The optimal value obtain are cutting speed 259.46 m/min, feed 0.20 mm/rev, depth of cut 0.35 mm. the finding of this study would be beneficial to manufacturing industries where surface finishing plays very important role.

1. INTRODUCTION

Machining parameters such as speed, feed and depth of cut play a vital role during machining. These have a major effect on the quantity of production, cost of production and production rate hence their carful section assumes significance.

Metal cutting is one of the most significant manufacturing processes in material removal. Metal cutting can be defined as the removal of metal from a work piece in the form of chips in order to obtain a finished product with desired size,shape and surface roughness. There are different methods of metal cutting such as turning, milling etc.

Turning is one of the commonest among these methods. Turning is the process of machining external cylindrical and conical surfaces (Nalbant et al. 2006). In this process the work material will held in the chuck of a lath and rotated. The tool is held rigidly in a tool post and moved at a constant rate along the axis of the bar, cutting away a layer of metal to form a profile.

In manufacturing industries, manufactures focus on both the quality and productivity. To increase the productivity, computer numerically control (CNC) machine tools have been implemented during the past decade. Surface roughness is one of the most important parameters to determine the quality of product. The mechanism behind the formation of surface roughness is very dynamic, complicated and process dependent. Several factors influenced the surface roughness obtained in a CNC turning operation. These can be categorized as controllable factors (Spindle speed, feed rate and depth of cut) and uncontrollable factors (tool geometry and material properties of both tool and work pieceZhange et al. 2006).

Ferrous metal are widely used in manufacturing industries. Among the various ferrous materials the AISI 52100 is quite popular main engineering materials in various industries such as bearing industries.

The aim of present study is to develop surface roughness prediction model using response surface methodology (RSM) based on centre composite rotatable design (CCRD). An attempt has also been to analyse the effect of machining conditions on surface roughness during turning of AISI 52100 steel with carbide inserts.

2. EXPERIMENTAL STUDY

The experimental set up for example: details of CNC turning centre, work piece, cutting inserts, coolant and surface roughness measurement.

2.1 INTRODUCTION

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The response surface methodology is applied to determine the optimal turning parameters to achieve minimum surface roughness parameters value for AISI 52100 steel under varying machining conditions.

2.2 EXPERIMENTAL DETAILS

Experimental details contain about the study of CNC turning centre, cutting insert, coolant and surface roughness measuring instrument.

2.2.1 CNC turning centre

Turing operations were carried out on Pushkar 200, Make HMT Pvt. Ltd. The CNC machining centre equipped with continuously variable spindle speed up to 5000 rpm, and 15 kW motor drive was used for experimentation. A picture of machining centre is shown in fig 2.1

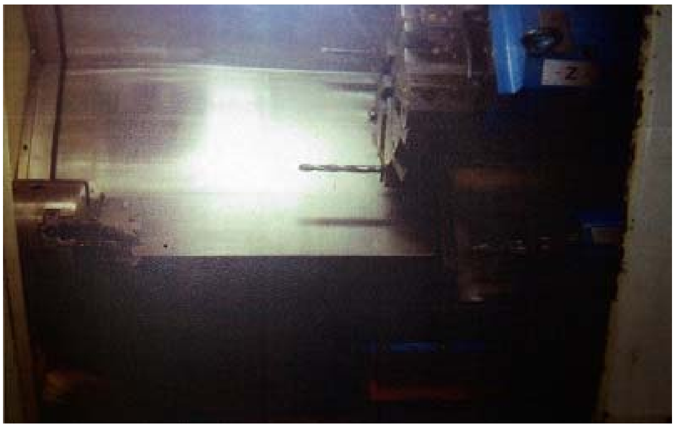

Fig 2.1: picture of machining centre

2.2.2 Cutting Insert

Coated carbide tool performs better than uncoated carbide tools. Because of this reason, commercially used coated carbide for turning steel was used in this research for turning. The cutting inserts used for experimentation was WNMG 089404 MF - 2 with grade TP2500 manufactured by seco tools. The pictorial view of cutting insert is shown in fig 2.2

Figure 2.2: WNMG 089404 MF – 2 TP2500

2.2.3 Work Piece

The machining experiments were performed on AISI 25100 steel. All the pieces used in experimentation were 40 mm in diameter and 60mm in length as shown in fig 2.3

2.2.4 Coolant

Coolant has been used in all the experiments SUPERCUT cutting oil by SHELL COMPANY has been used in the ratio of 20:1 i.e. 20 litters of cutting oil in it. Physical properties of cutting oil are summarized in table 1

Table 1 Physical properties of SUPERCUT – cutting oil

Appearance	Amber Clear Liquid
Solubility	Soluble Giving Stable Milky Emulsion
Storage Stability	Good
pH of 5% conc.	9.1

2.3 DESIGN OF EXPERIMENTS

Number of experiments required, mainly depends on the approach adopted for design of experiment. In this work, the design suggested by CCRD has been implemented for the experiments. The machining parameters and their levels are shown in table 2. Complete design layout for experiments is summarized in table 3 and experimental results are summarized in table 4. This demonstrates a total of 20 runs required for complete experimentation. Twenty experiments constitute 2factorial point, six central point and six axial points.

Table 2: Factors and levels of independent variable according to response surface methodology.

Symbol	Cutting Parameters	Unit	Levels				
			$-\alpha$	-1	0	+1	$+\alpha$
A	Cutting speed	m/min	100	140.54	200	259.46	300
B	Feed rate	mm/ rev	0.10	0.20	0.35	0.50	0.60
C	Depth of cut	mm	0.10	0.20	0.35	0.50	0.60

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Table 3 Complete design layout

Std	Run	Factor 1A: Cutting Speed	Factor 2B : Feed Rate	Factor 3C : Depth Of Cut
5	1	140.54	0.201	0.498
18	2	200	0.35	0.35
20	3	200	0.35	0.35
17	4	200	0.35	0.35
13	5	200	0.35	0.1
4	6	259.46	0.498	0.201
6	7	259.46	0.201	0.498
10	8	300	0.35	0.35
11	9	200	0.1	0.35
14	10	200	0.35	0.6
3	11	140.54	0.498	0.201
1	12	140.54	0.201	0.201
15	13	200	0.35	0.35
19	14	200	0.35	0.35
8	15	259.46	0.498	0.498
2	16	259.46	0.201	0.201
12	17	200	0.6	0.35
16	18	200	0.35	0.35
9	19	100	0.35	0.35
7	20	140.54	0.498	0.498

2.4 SURFACE ROUGHNESS MEASUREMENT

Surface roughness is defined as the very fine irregularities of the surface texture that usually result from the inherent action of the machining process or material conditions. There are many parameters used related of surface roughness in literatures. The most accepted parameter are centre line average (CLA) surface roughness values (R_a), root - mean – square roughness (R_q) and maximum peak to valley roughness (R_t). Mathematically, in this study, surface roughness of finish – turned work pieces was measured by making use of a portable surface roughness tester (SJ 210) made by Milutoyo according to ISO 97 R and the measurements were repeated three times. The average of three values is taken as final value of surface roughness for particular trial. Cut – off length for roughness measurements was set to be 0.8 mm

Figure 2.4: Surface Roughness Measurement

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Table 4 surface roughness measurement results

Run	R_a (μm)	R_q(μm)	R_t(μm)
1	1.823	2.105	11.771
2	2.817	3.56	12.735
3	3.231	3.833	13.761
4	3.13	3.782	14.218
5	2.476	3.275	12.054
6	3.442	5.346	17.522
7	1.423	1.962	7.933
8	1.722	2.178	9.737
9	0.602	0.96	3.852
10	2.632	3.14	12.237
11	5.239	6.6	20.197
12	1.872	2.118	6.648
13	2.716	3.441	13.269
14	2.736	3.775	13.999
15	3.243	4.363	16.617
16	1.41	1.923	7.868
17	6.21	7.6	22.608
18	2.903	3.418	12.158
19	3.613	4.413	12.579
20	4.809	5.8	18.769

3. RESULTS AND DISCUSSIONS

The mathematical modelling, analysis of variance (ANOVA) and optimization of machining parameters for minimum surface roughness parameters. Optimization has been carried out by studying various plots, contour plots and 3D surface graphs.

3.1 INTRODUCTION

The complete results of the 20 experiments performed as per the experimental plan are shown in Table 2, along with the run order selected at randomly. These results were input into the Design Expert 8.0.4.1 software for further analysis.

3.2 ANALYSIS FOR R_A (AVERAGE ROUGHNESS PARAMETER)

After the examination of fit summary as shown in table 5, output revealed that the quadratic model is statistically significant for R_a and therefore it will be used for further analysis.

Table 5 Fit summaries for roughness parameters R_a

Source	Sum of squares	Degree of freedom	Mean square	F value	P – value Prob> F	
Linear	2.271	11	0.206	4.544	0.0536	
2FI	1.434	8	0.179	3.946	0.0736	Suggested Aliased
Quadratic	0.575	5	0.115	2.532	0.1655	
Cubic	0	0				
Pure Error	0.227	5	0.0454			

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3.2.1 Mathematical Models For R_a (average roughness parameter)

Final equation in terms of Coded Factors

R_a = 2.77-0.54*A + 1.44*B – 0.31*A*B + 0.20*B^2

Final equation in terms of Actual Factors

$$R_a = -0.17771 + 3.25999E - 003 * Cutting\ speed + 10.50800 * Feed\ rate - 0.035369 * Cutting\ speed * Feed + 8.91221 Feed\ rate^2$$

3.2.2 ANOVA analysis

ANOVA is commonly used to perform test for significant of the regression model, test for significance on individual model coefficients and test for lack – off – fit of model. This analysis was carried out for a significance level of $\alpha = 0.05$, i.e. for a confidence level of 95%. Table 6 represents the ANOVA table for the reduced quadratic model for surface roughness parameter R_a by selecting the backward elimination procedure to automatically reduce the terms that are not significant.

Table 6 Resulting ANOVA table for quadratic model for R_a

Source	Sum of squares	Degree of freedom	Mean square	F value	P – value prob> F	
Model	33.601	4	8.400	108.738	<0.0001	S
A – cutting speed	4.015	1	4.015	51.978	<0.0001	
B – feed rate	28.234	1	28.234	365.485	<0.0001	
AB	0.782	1	0.782	10.121	0.0062	
B^2	0.569	1	0.569	7.367	0.0160	
Residual	1.159	15	0.077			
Lack of fit	0.932	10	0.093	2.051	0.2215	NS
Pure error	0.227	5	0.045			
Core total	34.760	19				

Std dev.	0.278	R – squared	0.967
Mean	2.902	Adj R –squared	0.958
C.V.%	9.576	Pred R – squared	0.912
PRESS	3.074	Adeq R – Precision	34.801

It shows that the value of Prob>F for model is 0.0001 which is less than 0.05, that indicates that model is significant, which is desirable as it indicates that the terms in the model have a significant effect on the response. In the same manner, The value of Prob>F for main effect of speed and feed, and two level interaction of speed and feed, and second order effect of feed are less than 0.05 so these terms are significant model terms. The value of Prob>F for lack – of – fit is 0.2215, which is greater than 0.05 that indicates that lack of fit is insignificant. If the model does not fit the data well, this will be significant. The non- significant lack of fit is desirable.

The R^2 value (the measure of proportion of total variability explained in the model) is equal to 0.967 or close to 1, which is desirable. The adjusted R2 value is equal to 0.958; it is particularly useful when comparing models with differentnumber of terms. The result show that the adjusted R2 value is very close to the ordinary R2 value. Adequate precision value is equal to 34.801; a ratio greater than 4 is desirable which indicates adequate model discrimination. Adequate precision value compares the range of the predicted values at the design points to the average prediction error.

3.2.3 Influence of cutting parameters on surface roughness (R_a)

The contour plot for the response surface parameter R_a at 0.35 mm depth of cut is shown in Fig 3.2.3 (a)

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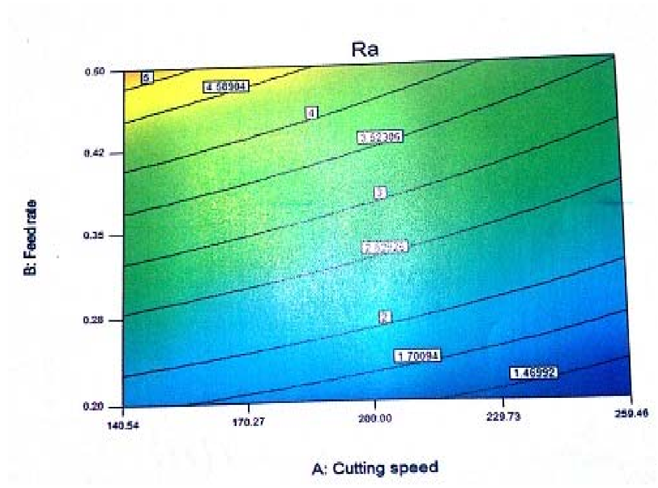

Fig 3.2.3(a) Ra contour in feed – speed at depth of cut 0.35 mm

It is clear from the plot that at constant speed, the surface roughness increases as the feed rate increases because higher feed rate traverses the work piece too speedily resulting in deteriorated surface quality and also high feed increase the chatter, which leads to higher surface roughness. Also, at constant feed rate, the surface roughness decreases as the cutting speed increase resulting in better surface quality.

The 3D surface graph for surface roughness R_a is shown in Fig 3.2.3(b) and curve have curvilinear profile in accordance to the quadratic model fitted. From the graph it is clear that as the cutting speed increases surface roughness decreases, on the other hand as feed increases surface roughness increases.

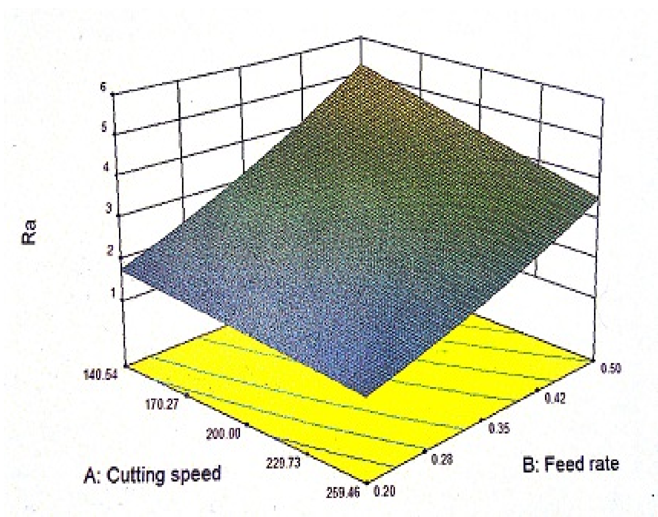

Fig 3.2.3 (b) 3D surface graph for surface roughness parameter R_a at depth of cut 0.35mm

From the both plot 3.2.2 (a) & 3.2.3(b) it is clear that the minimum surface roughness R_a (1.297μm) is achieved at low level of feed (0.20 mm/rev.) and high level of cutting speed (259.46 m/min)

4. CONCLUSION

The important conclusions drawn from the present work are summarized as follows:

1. Out of three parameters, feed seems to be the most significant and influential machining parameters that affect the surface roughness parameters (R_a) followed by cutting speed.
2. The depth of cut has insignificant influence on the surface roughness parameters.
3. The mathematical model developed clearly show that surface roughness increases with increasing the feed but decreases with increasing the cutting speed.
4. The results of AVOVA and the confirmation runs verify that the developed mathematical models for surface roughness parameters show excellent fit and provide predicted value of surface roughness that are close to the experimental values, with a 95 per cent confidence level.
5. The model can be used for direct evaluation of R_a under various combinations of machining parameters during turning of AISI52100 steel.
6. Percentage contribution of feed on surface roughness parameters i.e. R_a = 84.027 and percentage contribution of cutting speed on surface roughness parameters R_a = 11.949 have been found, which clearly indicate that feed is the dominant factor affecting the surface roughness parameters.

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