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PREDICTION AND ANALYSIS OF SURFACE ROUGHNESS OF AISI 4140 STEEL IN TURNING PROCESS

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Abstract

In this paper, a quadratic model was developed for the prediction of surface roughness in turning process of AISI 4140 steel using Response Surface Methodology (RSM) with rotatable Central Composite Design (CCD). The relationship between the surface roughness and cutting conditions was analyzed. In the development of predictive models, cutting speed, feed rate and depth of cut were considered as model variables and surface roughness was considered as a response variable. The results showed that, cutting speed and feed rate have the most significant effect on surface roughness.

Key Words: Turning, Surface roughness, Analysis of variance, Central composite design

1. Introduction

The surface quality is an important parameter to evaluate the productivity of machine tools as well as machined components. Hence, achieving the desired surface quality is of great importance for the functional behaviour of the mechanical parts. Surface quality is generally associated with surface roughness. The surface roughness of machined parts is known to have considerable effect on some properties such as wear resistance and fatigue strength. A proper cutting condition is extremely important task becuse these determine surface quality of manufacured parts. It is necessary to employ theoretical models making it feasible to do predictions in function of operation conditions[1-3].

In machinibility studies, statistical design of experiments such as factorial design and RSM with CCD are used quite extensively. These methods have been used by some researchers for prediction the surface roughness in terms of various cutting parameters during machining of different materials. For example, Sahin and Motorcu [1] machined the hardened AISI 1040 steel at different machining conditions and modeled the surface roughness by using RSM. Sahin and Motorcu [2] developed the surface roughness model in terms of main cutting parameters such as cutting speed, feed rate and depth of cut, using RSM. Kopac and Bahor [3] examined the changes in surface roughness of AISI 1060 and AISI 4140 steels and analyzed the effect of cutting parameters by using RSM. Noordin et al. [4] developed the empirical models such as linear and quadratic functions by using RSM to predict surface roughness when turning AISI 1045 steel. Mansour et al.[5] studied a surface roughness model that utilizing RSM for milling steel in dry condition. Choudhury and El-Baradie [6] developed surface roughness prediction model in turning of high strength steel by factorial design of experiments. Arbizu and Perez [7] presented a surface roughness prediction model using RSM to determine surface quality in turning processes. Erzurumlu and Oktem [8] developed RSM and an neural network model to predict surface roughness values error on mold surfaces. Ozel and Karpat [9] used regression and neural network for predictive modeling of surface roughness and tool wear in hard turning. In this study, a quadratic model for the surface roughness was developed using RSM with CCD. Main cutting parameters such as cutting speed, feed rate and depth of cut were considered as model variables, surface roughness was considered as a response variable.

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2. Material and Method

The cutting experiments were carried out a industrial type of CNC lathe. HSS tool was used for the machining of AISI 4140 steel bars with cutting fluid. These bars of 30 mm diameter and 200 mm in length were prepared. Test samples were trued, centered and cleaned by removing a 1 mm depth of cut from the outside surface, prior to actual machining tests. Three replications of each cutting conditions were conducted resulting in a total of 60 tests. Input parameters of the models are cutting speed, feed rate and depth of cut. Output parameter of the models is the corresponding surface roughness. The level of used factors was selected for the general applications. Factors and levels for CCD) are given in Table 1. A Mahr Perthometer-M1 type of portable surface roughness tester was used for measuring surface roughness.

Table 1. Factors and levels for CCD

Factors/Levels	**-1.68**	**-1**	**0**	**+1**	**+1.68**
Cutting speed (m/min)	16	47	92	137	167
Feed rate (mm/rev)	0.032	0.1	0.2	0.3	0.368
Depth of cut (mm)	0.160	0.5	1	1.5	1.840

1. Data analysis and discussion of results

The arrangement and the results of the 20 experiments carried in this study based on CCD rotatable design are shown in Table 2. The comparisons of experimental results with the RSM predictions have been depicted in terms of percentage absolute error. In the prediction of surface roughness values the average absolute errors for RSM is found to be 3.18%.

Table 2. Experimental and predicted surface roughness values for CCD

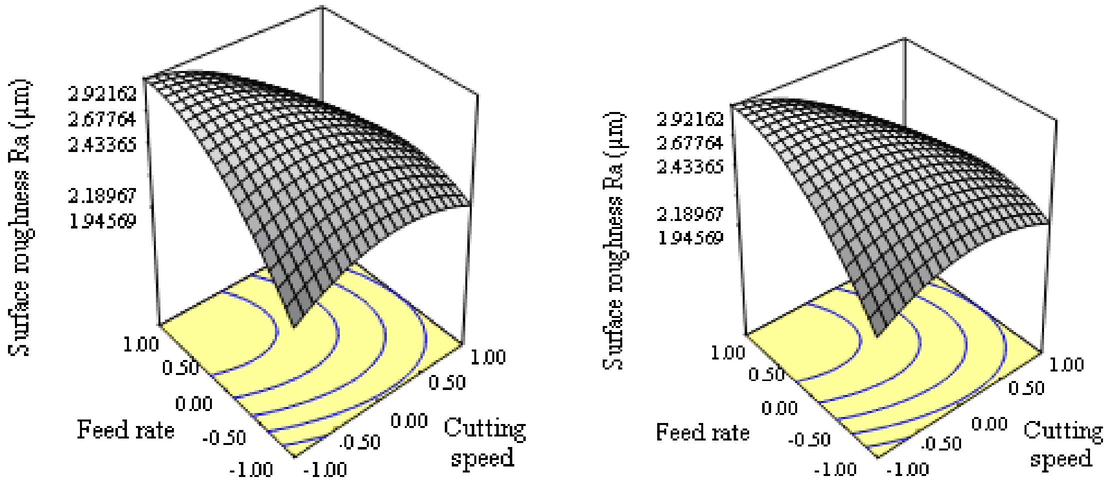
Run	Cutting speed (m/min)	Feed rate (mm/rev)	Depth of cut (mm)	Actual $R_a(\mu m)$	Predicted $R_a(\mu m)$
1	47	0.1	0.5	1,60	1.64
2	137	0.1	0.5	2,20	2.24
3	47	0.3	0.5	2,47	2.66
4	137	0.3	0.5	2,14	2.14
5	47	0.1	1.5	1,91	2.00
6	137	0.1	1.5	1,77	1.68
7	47	0.3	1.5	2,84	2.90
8	137	0.3	1.5	1,40	1.46
9	16	0.2	1	2,62	2.44
10	167	0.2	1	1,70	1.74
11	92	0.032	1	1,67	1.67
12	92	0.368	1	2,48	2.34
13	92	0.2	0.160	2,51	2.40
14	92	0.2	1.840	2,17	2.14
15	92	0.2	1	2,72	2.68
16	92	0.2	1	2,74	2.68
17	92	0.2	1	2,64	2.68
18	92	0.2	1	2,70	2.68
19	92	0.2	1	2,51	2.68
20	92	0.2	1	2,74	2.68

Quadratic regression equation was developed for predicting surface roughness within selected experimental conditions using RSM. Regression equation can be expressed in Equation 1.

$$R_a = 2.68 - 0.21X_1 + 0.20X_2 - 0.078X_3 - 0.21X_1^2 - 0.24X_2^2 - 0.14X_3^2 - 0.28X_1X_2 - 0.23X_1X_3 \quad (1)$$

where x_1 is cutting speed, x_2 is feed rate, x_3 is depth of cut.

The established equation indicates that cutting speed and depth of cut have negative influence on surface roughness. However, feed rate has positive influence on the surface roughness. The surface roughness of AISI 4140 steel decreases with increasing cutting speed and depth of cut whereas increases with increasing feed rate. The relationship between cutting speed and feed rate is shown in Fiqure 1 (a), the relationship between cutting speed and depth of cut is shown in Fiqure 1 (b).



(a) (b)

Figure 1. 3D surface graphs for surface roughness

It can be realized that the combination between high cutting speed and high feed rate results in a considerable reduction in surface roughness and also between high cutting speed and high depth of cut results in a considerable reduction in surface roughness. Input factors (cutting speed, feed rate and depth of cut) are given as coded factors in Figure 1. Coded factors (-1, -0.5, 0, 0.5,1) can be transform to actual factors. Minimum surface roughness values were obtained from three dimensional graph. The response surface plot (Fig.1.a) indicates that the minimum surface roughness is at about 137 m/min and 0.3mm/rev. The response surface plot (Fig.1.b) indicates that the minimum surface roughness is at about 137 m/min, and 1.5 mm.

The analysis of variance is used to check the adequacy of the predictive model. An ANOVA table shows a significant influence of machining parameters and its interaction on the surface roughness [10]. The ANOVA table for the quadratic model is given in Table 3.

As seen in Table 3, cutting speed has the most significant effect on the surface roughness, followed by feed rate and lastly depth of cut. All the squared terms and among interaction term cutting speed - feed rate and cutting speed - depth of cut appears to be highly significant.

Table 3. The ANOVA table for the quadratic model

Source	SS	DF	MS	*F*- value	p- value
Model	3.75	9	0.42	25.29	< 0.0001
x_1	0.60	1	0.60	36.29	< 0.0001
x_2	0.55	1	0.55	33.19	< 0.0002
x_3	0.0.83	1	0.083	5.01	0.0491
x_1^2	0.62	1	0.62	37.72	0.0001
x_2^2	0.81	1	0.81	49.43	< 0.0001
x_3^2	0.30	1	0.30	18.14	0.0017
x_1x_2	0.62	1	0.62	37.74	0.0001
x_1x_3	0.43	1	0.43	25.97	0.0005
x_2x_3	0.007813	1	0.007813	0.47	0.5067

We consider a measure of the model's overall performance is referred to as the coefficient of determination and denoted by R^2 . In the prediction model, R^2 is obtained equal to 95 %. The R^2 value indicates that the cutting parameters explain 95% of variance in surface roughness.

4. Conclusion

In this study, the statistical methods such as ANOVA and RSM with CCD were applied to analyze the experimental data. A quadratic model was developed for the prediction and analysis of the relationship between the cutting parameters and surface roughness in turning process of AISI 4140 steel. The value of *p* obtained from ANOVA table for the term of model is less than 0.05 indicates that it is considered to be statistically significant. This value showed that, the quadratic model fits well to the experimental results. ANOVA results indicated that cutting speed and feed rate and depth of cut are the significant parameters. Eventhough their quadratic effects are significant and among interaction term cutting speed - feed rate and cutting speed - depth of cut appears to be significant. The surface roughness of AISI 4140 steel decreases with increasing cutting speed and depth of cut whereas increased with increasing feed rate. The predicted values was found similar to the actual values. The average absolute error between actual and predicted values was calculated as 3.18 % sufficiently low to confirm the high predictive power of model. Experimental results showed that prediction model can be effectively used to predict the surface roughness from the cutting process.

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