Pemodelan matematika untuk proses bubut pada baja menggunakan metodologi permukaan respons (*Response Surface Methodology*)

Mathematical modeling for turning on steels using Response Surface Methodology

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Abstrak

Meningkatnya permintaan untuk memperbesar produktivitas dengan biaya produksi rendah, menuntut untuk dilakukannya pemesinan yang cepat dengan mempertimbangkan umur pahat dan kekasaran permukaan yang berpatutan untuk digunakan pada proses pemesinan. Dalam penelitian ini dilakukan eksperimen penentuan umur pahat high speed steel (HSS) dan kekasaran permukaan benda kerja baja carbon. Model matematika untuk kondisi pemotongan yang optimum untuk parameter bebas kecepatan potong dan gerak makan didapat dengan bantuan metodologi permukaan respons (*Response Surface Methodology*) (RSM) yang dilakukan menggunakan paket piranti lunak Design Expert 8.0.2. Hasil yang didapat adalah menurunnya kekasaran permukaan dengan naiknya kecepatan potong sebaliknya terjadi kenaikan gerak makan berakibat pada naiknya kekasaran permukaan. Sedangkan untuk umur pahat didapat penurunan baik pada kenaikan kecepatan potong maupun gerak makan. Kondisi pemotongan optimum didapatkan melalui model matematika empirik yang dihasilkan.

Kata-kata kunci: Pahat potong HSS; umur pahat; keausan pahat, kekasaran permukaan, Response Surface Methodology (RSM).

Abstract

Increasing demand to enlarge low cost productivity requires high speed machining and takes the use of reasonable tool life and surface roughness into consideration. In this study, machining test was conducted using high speed steel on carbon steel to investigate tool life and surface roughness. Mathematical models of optimum cutting condition for independent variables cutting speed and feed rate were generated according to Response Surface Methodology (RSM) using software package the Design Expert 8.02. The experimental results indicated that the increase of cutting speed decreases the surface roughness. In contrary, the increase of feed rate affected on increasing of the surface roughness. Meanwhile, the decrease of tool life was revealed when cutting speed and feed rate were increased. In this case, the optimum cutting condition was calculated using generated empirical mathematical model.

Keywords: High speed steel (HSS); Tool life; Wear, Surface roughness, Response Surface Methodology (RSM).

Introduction

The term of machinability is used to describe the ease with which a work material is machined under a given set of cutting conditions. A prior knowledge of a work material is important to the production engineer so that he/she can plan its processing efficiently. In earlier work machinability has been defined as the response of a metal to machining which gives long tool-life under, otherwise equal conditions when compared with other material, provides good surface finish, produces well broken chips, gives uniform dimensional accuracy of successive parts, produces each part at the lowest overall cost, and requires lower power consumption in removing a given quantity of chips (Dabnun, et al., 2005).

Neseli et al. (2011), Palanikumar (2007), Mukherjee & Ray (2006) reviewed the earlier works on response surface methodology, which has been used in modeling of tool life, surface roughness, and in other machining processes.

According to Noordin, et al. (2004), design and methods such as factorial design, response surface methodology (RSM) and Taguchi methods are now widely use in place of one-factor–at-a-time experimental approach which is time consuming and exorbitant in cost. Moreover, this computation can be observed in machining processes especially to improve a good quality surface (Aouici et al., 2012; Bernardos & Vosniakos, 2003; Lin et al., 2007).

Nowadays, carbon steel materials have become an economic alternative to other materials in industrial applications. Only few researchers paid an attention to the finding of optimum cutting condition on cabon steel using response surface methodology. The aim of this study is, therefore, to focus on the prediction and optimization for tool life and surface roughness during turning of carbon steel.

Apparatus and Experimental Methods

Workpiece and tool materials

The workpiece material was carbon steel ST 37 in form of round bars with 34 mm diameter and 250 mm cutting length. This steel is recomended for general purpose industrial application.

To perform the tests, the high speed steel cutting tools with 10 x 10 x 100 mm in dimension, were used as shown in Figure 1.

Figure 1. High Speed Steel Cutting Tools

Experimental Design

The response surface methodology (RSM) is a procedure able to determine a relationship between independent input process variables and output data (dependent variables or process response) (Montgomery, 2001; Aouici et al., 2012). In the current study, the relationship between the input, called the cutting conditions (cutting speed V_c, feed rate f) and the output Y define as a machinability aspect (tool life or surface roughness) was calculated using Design Expert 8.02 according to Design of Experiments (DOE) as shown in Figure 2. This design is well known as Central Composite Design (CCD).

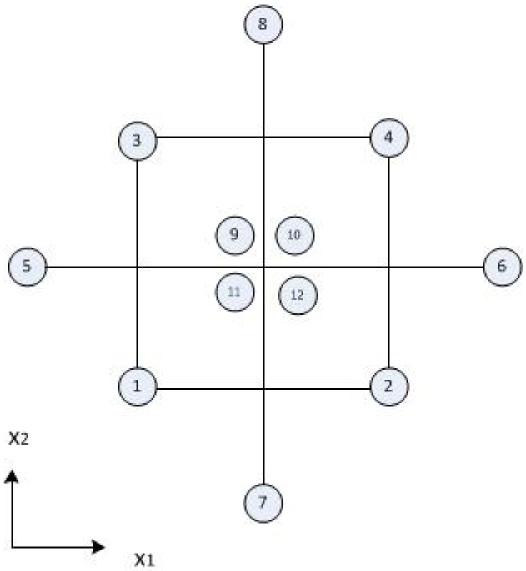

Figure 2. The Central Composite Design

Experimental Works

Turning experiments were conducted in wet condition using a universal lathe MAIER & Co Austria type Maximat V13 as shown in Figure 3. which involved 12 trials and the response variables measured were tool life and surface roughness.

The cutting condition of the tests were tabulated in the following Table 1

Table 1. Experimental cutting conditions

Standard	Cutting speed V_c (m/min)	Feed rate f (mm/rev)
1	60	0.04
2	140	0.04
3	60	0.06
4	140	0.06
5	43.43	0.05
6	156.57	0.05
7	100	0.03
8	100	0.07
9	100	0.05
10	100	0.05
11	100	0.05
12	100	0.05

Figure 3. A universal lathe MAIER & Co Austria type Maximat V13

The surface roughness of the turned surface was measured using a portable surface roughness tester TR 200 (Krissbow), as shown in Figure 4. On the other hand, the tool life was measured using a microscope loop. For each experimental trial, a new cutting edge was used. Due to the limited number of inserts available, each experimental trial was not repeated, except those at the center point of CCD. In this case, it was assumed that the error occured at center point will also take place on others designed points. As far as possible the trials were performed in a random fashion.

Figure 4. A Surface roughness tester TR200 Krisbow

Results and Discussion

The results from the machining trials performed are shown in Table 2. These results were input into the Design Expert 8.02 for further analysis using the designed experimental points as shown in Table 1. Without performing any transformation on the response, examination of the fit summary output revealed that the quadratic model is statistically significant for both responses and therefore it will be used for further analysis. This can be shown from ANOVA in Table 3 and Table 4. In addition it is proven also from the insignificant lack of fit that occurred in generating the mathematical empirical models.

Table 2. Experimental results

Standard	Cutting speed V_c (m/min)	Feed rate f (mm/rev)	TL (min)	Ra (μm)
1	60	0.04	0.363	1.43
2	140	0.04	0.050	1.03
3	60	0.06	0.238	1.72
4	140	0.06	0.033	1.68
5	43.43	0.05	0.450	1.43
6	156.57	0.05	0.048	0.95
7	100	0.03	0.165	0.98
8	100	0.07	0.059	1.74
9	100	0.05	0.100	011
10	100	0.05	0.088	1.16
11	100	0.05	0.095	1.05
12	100	0.05	0.089	1.08

Table 3. ANOVA of tool life experiments

ANOVA for Response Surface Quadratic Model
Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	0.20	5	0.040	395.48	< 0.0001	significant
A-Speed	*0.15*	*1*	*0.15*	*1472.52*	*< 0.0001*	
B-Feed	*0.011*	*1*	*0.011*	*106.29*	*< 0.0001*	
AB2.916E-003	*1*	*2.916E-003*	*29.10*	*0.0017*		
A:0.037	*1*	*0.037*	*365.25*	*< 0.0001*		
B:3.249E-004	*1*	*3.249E-004*	*3.24*	*0.1219*		
Residual	6.013E-004	6	1.002E-004			
Lack of Fit	*5.073E-004*	*3*	*1.691E-004*	*5.40*	*0.0999*	*not significant*
Pure Error	*9.400E-005*	*3*	*3.133E-005*			
Cor Total	0.20	11				

Table 4. ANOVA of surface roughness experiments

Response 2 Ra
ANOVA for Response Surface Quadratic Model
Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	0.95	5	0.19	12.61	0.0039	significant
A-Speed	*0.16*	*1*	*0.16*	*10.32*	*0.0183*	
B-Feed	*0.50*	*1*	*0.50*	*33.24*	*0.0012*	
AB0.032	*1*	*0.032*	*2.14*	*0.1937*		
A:0.071	*1*	*0.071*	*4.72*	*0.0728*		
B:0.23	*1*	*0.23*	*15.34*	*0.0078*		
Residual	0.091	6	0.015			
Lack of Fit	*0.079*	*3*	*0.026*	*6.83*	*0.0744*	*not significant*
Pure Error	*0.012*	*3*	*3.860E-003*			
Cor Total	1.04	11				

In following, the mathematical models for both responses were described by Equation 1 and Equation 2.

Equation 1

$$Y_{TL} = 0.093 - 0.140x_1 - 0.036x_2 + 0.027x_1x_2 + 0.076x_1^2 + 7.125\times10^{-3}x_2^2$$

Equation 2

$$Y_{Ra} = 1.07 - 0.14x_1 + 0.25x_2 + 0.090x_1x_2 + 0.110x_1^2 + 0.190x_2^2$$

From Equation 1, which is illustrated in Figure 5, it revealed that increasing the cutting speed and feed rate affected the decreasing of tool life.

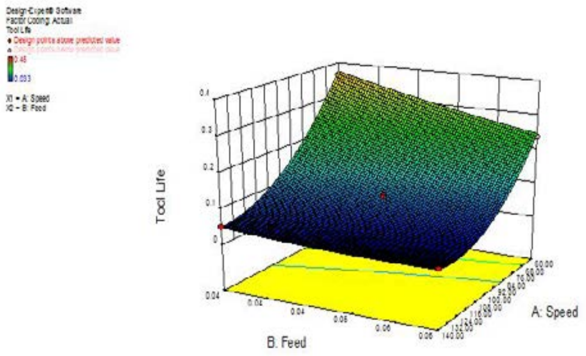

Figure 5. A3D Contour of tool life mathematical model

In contrary to the tool life, the surface roughness model revealed that increasing of the feed rate is followed by increase of the machined surface roughness.

Similar results were also found by Sahin et al. (2005) and Oktem et al. (2005).

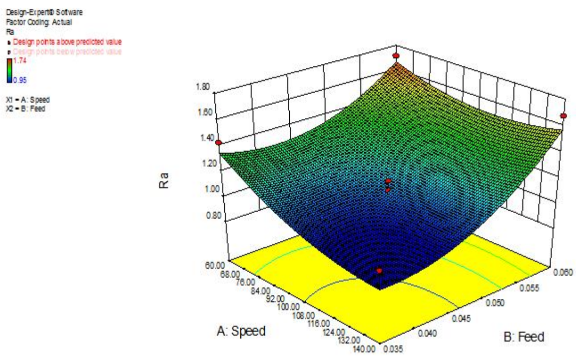

Figure 6. A 3D-Contour of surface roughness mathematical model

Table 5. Optimization for maximum tool life

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A:Speed	is in range	60	140	1	1	3
B:Feed	is in range	0.035	0.06	1	1	3
Tool Life	maximize	0.033	0.45	1	1	3

Solutions

Number	Speed	Feed	Tool Life	Desirability	
1	60.00	0.04	0.375053	0.820	Selected
2	60.00	0.04	0.364665	0.795	
3	60.00	0.05	0.283091	0.600	

Table 6. Optimization for minimum surface roughness

Constraints

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A:Speed	is in range	60	140	1	1	3
B:Feed	is in range	0.035	0.06	1	1	3
Ra	minimize	0.952	1.741	1	1	3

Solutions

Number	Speed	Feed	Ra	Desirability	
1	120.00	0.04	0.94	1.000	Selected
2	125.00	0.04	0.91	1.000	
3	130.50	0.04	0.90	1.000	
4	140.00	0.04	0.89	1.000	
5	129.00	0.04	0.90	1.000	

Table 7. Optimization for maximum tool life combined with minimum surface roughness.

Constraints

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A:Speed	is in range	60	140	1	1	3
B:Feed	is in range	0.035	0.06	1	1	3
Tool Life	maximize	0.033	0.45	1	1	3
Ra	minimize	0.952	1.741	1	1	3

Solutions

Number	Speed	Feed	Tool Life	Ra	Desirability	
1	60.00	0.04	0.351599	1.30	0.655	Selected
2	60.00	0.04	0.352286	1.30	0.655	

One of the most important aims of experiments related to manufacturing is to achieve the desired tool life and surface roughness of the optimum cutting conditions. To this end, the response surface optimization is an ideal technique for determination of the best combination for cutting conditions.

From Table 5 and Table 6, it was shown that the optimum cutting condition for turning carbon steel were the combination of V_C = 60 m/min, f = 0.04 mm/rev and V_C = 120 m/min, f = 0.04 mm/rev for maximum tool life of 0,375 min and minimum surface roughness of 0.94 µm, respectively.

In the other hand, Table 7 figured out the optimization according to the general purpose of industries, which desired to have maximum tool life in combination with minimum surface roughness. The results shows that the optimum cutting condition, which fulfills this, is achieved when V_C = 60 m/min, f = 0.04 mm/rev used in turning of carbon steels.

Conclusions

Mathematical model for tool life and surface roughness have been developed to correlate the important machining parameters in turning of carbon steel. The experimental design is of central composite design and the two important input variables considered for the present study are cutting speed and feed rate. The influences of all turning parameters on the tool life and surface roughness have been analyzed based on the developed mathematical model. The following conclusions are drawn based on this study.

1. The increasing the cutting speed and feed rate affected the decreasing of tool life.
2. The surface roughness model showed that increasing of the feed rate is followed by increase of the machined surface roughness.
3. The combination of V_C = 60 m/min, f = 0.04 mm/rev resulted on the maximum achieved tool life and the minimum surface roughness.

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