

# Mathematical modeling for turning on steels using Response Surface Methodology

*By* Amrifan Saladin Mohruni

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

### Mathematical modeling for turning on steels using Response Surface Methodology

A.S. Mohruni<sup>a</sup>, D. Suparman<sup>a</sup>

<sup>a</sup>Mechanical Engineering Department  
Faculty of Engineering,  
Sriwijaya University,  
Indralaya, 30662 OI-Indonesia

Tel. +62-711-580062 Fax. +62-711-58041

E-mail : [mohrunias@yahoo.com](mailto:mohrunias@yahoo.com), [mohrunias@unsri.ac.id](mailto:mohrunias@unsri.ac.id)

#### 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).

#### 1

#### 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 efficient. 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. (11), 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 carbon 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 recommended 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 5. This design is well known as Central Composite Design (CCD).

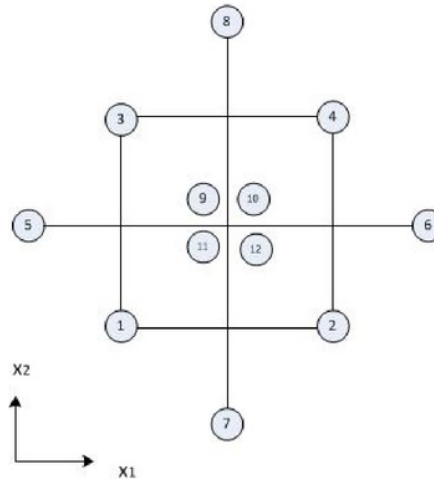


Figure 2. The Central Composite Design

**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 (Krisbow), 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 occurred 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 ( $\mu\text{m}$ )
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	0.11
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	Significant
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	365.23	< 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-003	3	3.133E-003			
Cor Total	0.20	11				

**Table 4.** ANOVA of surface roughness 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	Significant
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	13.34	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**

$$Y_{TL} = 0.093 - 0.140x_1 - 0.036x_2 + 0.027x_1x_2 + 0.076x_1^2 + 7.125 \times 10^{-3}x_2^2$$

**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.

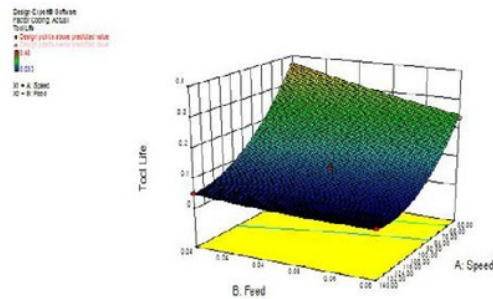


Figure 5. A3D Contour of tool life mathematical model

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).

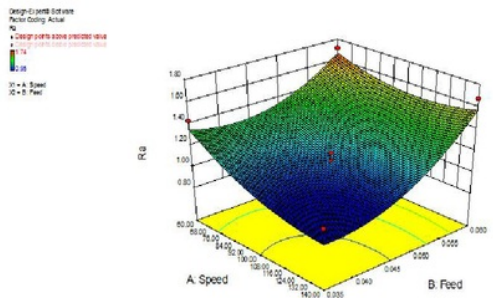


Figure 6. A 3D-Contour of surface roughness mathematical model

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	Selected
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

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	Selected
1	120.00	0.04	0.04	1.000	Selected	
2	125.00	0.04	0.04	1.000		
3	130.50	0.04	0.04	1.000		
4	140.00	0.04	0.04	1.000		
5	129.00	0.04	0.04	1.000		

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

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	Selected
1	60.00	0.04	0.351599	1.30	0.655	Selected	
2	60.00	0.04	0.352286	1.30	0.655		

4

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  $\mu$ m, 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.

3

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.

**References**

- Aouici, H., Yallese, M.A., Chaoui, K. & Mabrouki, T., Analysis of surface roughness and cutting force components in hard turning with CBN tool: prediction model and cutting condition optimization, *Measurement*, Vol. 45, 344-353 (2012).
- Benardos, P.G. & Vosniakos, G.C., Predicting surface roughness in machining: a review, *International Journal of Machine Tools & Manufacture*, Vol. 43, 8333-844 (2003).
- Dabnun, M.A., Hashmi, M.S.J. & El-Baradie, M.A., Surface roughness prediction model by design of experiments for turning machinable glass-ceramic (Macor), *Journal of Material Processing Technology*, Vol. 164-165, 1289-1293 (2005).
- Lin, S.Y., Cheng, S.H. & Chang, C.K., Construction of a surface roughness prediction model for high speed machining, *Journal of Mechanical Science and Technology*, Vol. 21, 1622-1629 (2007).
- Montgomery, D.C., *Design and Analysis of Experiments*, 5<sup>th</sup> editions, New York, Wiley (2001).
- Mukherjee, I. & Ray, P.K., A review of optimization techniques in metal cutting processes, *Computer and Industrial Engineering*, Vol. 50, 15-34 (2006).
- Neseli, S., Yaldiz, S. & Turkes, E., Optimization of tools geometrie parameters for turning operations based on the response surface methodology, *Measurements*, Vol. 44, 580-587 (2011).
- Noordin, M.Y., Venkatesh, V.C., Sharif, S., Elting, S. & Abdullah, A, Application of response surface methodology in describing the performance of coated carbide tools when turning AISI 1045 steel, *Journal of Material Processing Technology*, Vol. 145, 46-58 (2004).
- Oktem, H., Erzurumlu, T. & Kurtaran, H., Application of response surface methodology in the optimization of cutting conditions for surface roughness, *Journal of Material Processing Technology*, Vol. 170, 11-16 (2005).
- Paiva, A.P., Ferreira, J.R. & Balestrassi, P.P., A multivariate hybrid approach applied to AISI 52100 hardened steel turning optimization, *Journal of Material Processing Technology*, Vol. 189, 26-35 (2007).
- Palanikumar, K., Modelling and analysis for surface roughness in machining glass fibre reinforced plastics using response surface methodology, *Materials & Design*, Vol. 28, 2611-2618 (2007).
- Sahin, Y. & Motorcu, A.R., Surface roughness model for machining mild steel with coated carbide tool, *Materials & Design*, Vol. 26, 321-326, (2005).

# Mathematical modeling for turning on steels using Response Surface Methodology

ORIGINALITY REPORT

23%

SIMILARITY INDEX

## PRIMARY SOURCES

- 1 Mohamed A. Dabnun, M.S.J. Hashmi, M.A. El-Baradie. "Surface roughness prediction model by design of experiments for turning machinable glass–ceramic (Macor)", *Journal of Materials Processing Technology*, 2005  
Crossref 121 words — 7%
- 2 [eprints.utm.my](http://eprints.utm.my)  
Internet 85 words — 5%
- 3 Palanikumar, K.. "Modeling and analysis for surface roughness in machining glass fibre reinforced plastics using response surface methodology", *Materials and Design*, 2007  
Crossref 80 words — 4%
- 4 Süleyman Neşeli, Süleyman Yıldız, Erol Türkeş. "Optimization of tool geometry parameters for turning operations based on the response surface methodology", *Measurement*, 2011  
Crossref 48 words — 3%
- 5 [www.iie.istanbul.edu.tr](http://www.iie.istanbul.edu.tr)  
Internet 35 words — 2%
- 6 Hamdi Aouici, Mohamed Athmane Yallese, Kamel Chaoui, Tarek Mabrouki, Jean-François Rigal. "Analysis of surface roughness and cutting force components in hard turning with CBN tool: Prediction model and cutting conditions optimization", *Measurement*, 2012  
Crossref 26 words — 1%

Noordin, M.. "Application of response surface methodology in

7 describing the performance of coated carbide tools when turning AISI 1045 steel", Journal of Materials Processing Tech., 20040101

Crossref

23 words — 1%

8 Dass, Kali, and S. R Chauhan. "Machinability Study of Titanium (Grade-5) Alloy Using Design of Experiment Technique", Engineering, 2011.

Crossref

10 words — 1%

EXCLUDE QUOTES ON

EXCLUDE MATCHES < 2%

EXCLUDE BIBLIOGRAPHY ON