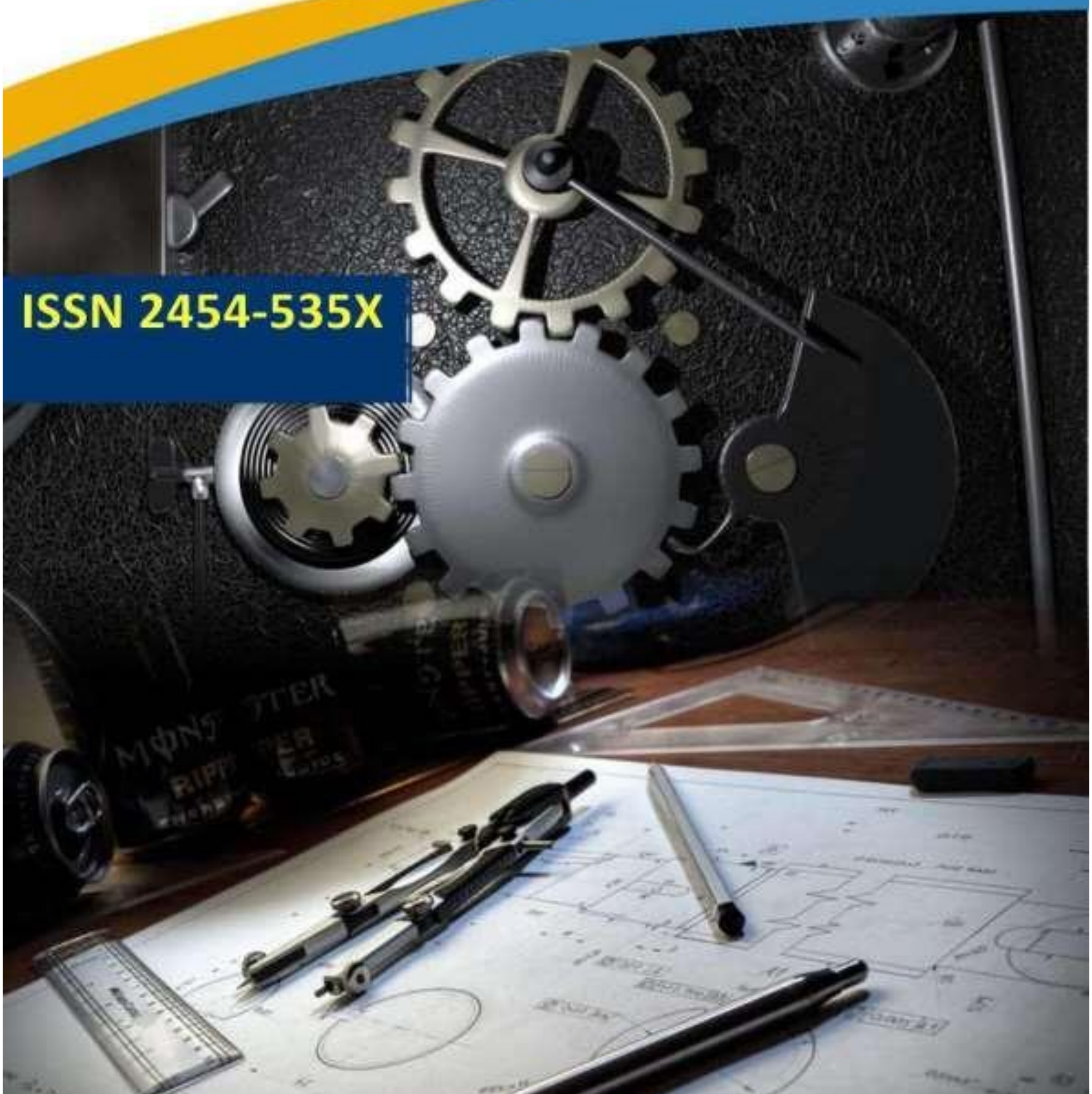
International Journal of
Mechanical Engineering Research and Technology

ISSN 2454-535X



Email ID: info.ijmert@gmail.com or editor@ijmert.net

Int. J. Mech. Eng. Res. & Tech 2017

International Journal of Mechanical Engineering Research and Technology

ISSN 2454 – 5X
www.ijmert.co
Vol.14 Issue. 1, Jan 2022

Empirical Model for Surface Roughness in Hard Milling of AISI H13 Steel Under Nanofluid-MQL Condition Based on Analysis of Cutting Parameters

Ramesh Rao.D

Thai Nguyen University of Technology, Viet Nam

thevinh8880@tnut.edu.vn

ABSTRACT: In this work, the integration of the Taguchi approach and response surface methodology (RSM) was used to assess the impact of machining parameters on surface roughness during the hard milling of AISI H13 steel using a carbide-coated (TiAlN) cutting tool under nanofluid MQL conditions. SiO2 nanoparticles were chosen to be added to CT232 cutting oil. The experiment was conducted utilizing G. Taguchi's L27 orthogonal array of DOE approach. To determine how the cutting parameters—including cutting velocity, feed rate, depth of cut, and workpiece hardness at three different levels—affect surface roughness, an investigation was conducted. In order to forecast surface roughness under nanofluid MQL conditions, an empirical model was provided. Furthermore, a multi-objective optimization was carried out to determine the maximum and minimum values of surface roughness.

KEYWORDS: surface roughness; nanofluid; MQL; SiO2 nanoparticle; Hard milling; multi-objective optimization

INTRODUCTION

Rough cuts, heat treatment (hardening), and grinding are frequently steps in the classical machining process. Numerous drawbacks of this process chain include its high cost, time commitment, and environmental concerns [1]. An efficient substitute for the conventional machining method was offered: hard machining. The process of cutting material with a hardness ranging from 40 to 70 HRC is known as hard machining [2]. Hard milling offers several advantages over traditional machining, including high cutting productivity, quick product cycles, and customizable processes. The hard milling procedure is usually used in dry cutting environments. The drawbacks of dry milling include increased tool wear and shorter tool life as a result of high

EXPERIMENT DETAILS

In this work, the blocks of AISI H13 steel has the dimensions of 200mm in length, 100mm in width and 50mm in height. The workpieces were hardened to obtain three hardness levels of 40, 45, and 50 HRC. The cutting tools used in the experiment are Φ10 TiAlN coated end mill. Each surface milled was used a fresh cutting tool. All slot milling operations were conducted under SiO2 nanofluid-based MQL condition by using CNC machine Victor V-Center-4. The surface roughness was measured by using the Sj-401 surf-test instrument of Mitutoyo Corporation. In order to reduce possible test errors, each experiment was repeated 3 times.

MQL mode was applied in hard milling of AISI H13 steel with the flow rate of 90ml/h, the air pressure of 3kg/cm2, and CT232 cutting oil of the lubricant. SiO2 added into cutting fluid has the size of 100 nm and the concentration of 2 wt%. To obtain a homogeneous dispersion and stable suspension of nanoparticles in the lubricant, the mixture of solution and nanoparticles was stirred by using a magnetic stirring device within 12 hours.

The L27 orthogonal array of Taguchi method having 27 rows and 13 columns was selected to design a set of tests. The input factors selected is the cutting parameters including cutting velocity (v), feed-rate (f), depth-of-cut (d), and hardness-of-workpiece (h). Each factor has 3 levels. Table 1 shows input factors with levels.

Table 1. Input factors with levels

Input factor	Levels		
	1	2	3

ISSN 2454 – 5X
www.ijmert.co
Vol.14 Issue. 1, Jan 2022

Cutting velocity (m/min)	40	55	70
Feed-rate (mm/tooth)	0.01	0.02	0.03
Depth-of-cut (mm)	0.2	0.4	0.6
Hardness-of-workpiece (HRC)	40	45	50

EXPERIMENTAL RESULTS AND DISCUSSIONS

The results of the roughness (Ra) obtained from the experiments and values of MRR are shown in Table 2.

Table 2. Experimental results

Runs	***V*** **(m/min)**	***f*** **(mm/tooth)**	***d*** **(mm)**	***h*** **(HRC)**	***Ra*** **(µm)**	***MRR*** **(mm^3/min)**
1	40	0.01	0.2	40	0.146	101.9108
2	40	0.01	0.4	45	0.198	203.8217
3	40	0.01	0.6	50	0.275	305.7325
4	40	0.02	0.2	45	0.167	203.8217
5	40	0.02	0.4	50	0.209	407.6433
6	40	0.02	0.6	40	0.285	611.465
7	40	0.03	0.2	50	0.253	305.7325
8	40	0.03	0.4	40	0.266	611.465
9	40	0.03	0.6	45	0.388	917.1975
10	55	0.01	0.2	45	0.132	140.1274
11	55	0.01	0.4	50	0.194	280.2548
12	55	0.01	0.6	40	0.163	420.3822
13	55	0.02	0.2	50	0.231	280.2548
14	55	0.02	0.4	40	0.2	560.5096
15	55	0.02	0.6	45	0.241	840.7643
16	55	0.03	0.2	40	0.23	420.3822
17	55	0.03	0.4	45	0.3	840.7643
18	55	0.03	0.6	50	0.401	1261.146
19	70	0.01	0.2	50	0.096	178.3439
20	70	0.01	0.4	40	0.103	356.6879
21	70	0.01	0.6	45	0.12	535.0318
22	70	0.02	0.2	40	0.151	356.6879
23	70	0.02	0.4	45	0.218	713.3758
24	70	0.02	0.6	50	0.318	1070.064
25	70	0.03	0.2	45	0.219	535.0318
26	70	0.03	0.4	50	0.369	1070.064
27	70	0.03	0.6	40	0.299	1605.096

The values of MRR in mm3/min during milling operation were calculated by the formula (1)[14].

$$MRR = \frac{d \times a_e \times V \times f \times z \times 1000}{3.14 \times D}$$

(1)

where, d is the depth-of-cut (mm), ae is the width-of-cut (mm), V is the cutting-speed (m/min), f is the feed-rate (mm/tooth), z is the flute of the cutter, and D is the diameter of the cutting tool (mm).

In current work, Minitab 17 software was used for ANOVA of the response surface. The ANOVA was conducted and shown in Table 3. As shown in Table 3, the model terms having P-value less than 0.05 show that their effect on surface roughness has statistic significant. Moreover, feed-rate is the most influential factor in Ra, which has 52.19% contribution to the model. The second most influential factor on Ra is the depth-of-cut having 23.18% contribution to the model. The result can be explained that an increase in both the depth-of-cut and feed-rate will lead to an increased chip-load, thus forming a chip in the shear-zone requiring a larger amount of energy to be expended. So, the removal of material in hard-milling is relatively difficult [15]. This

International Journal of Mechanical Engineering Research and Technology
ISSN 2454 – 5X
www.ijmert.co
Vol.14 Issue. 1, Jan 2022

conclusion is also consistent with the research of Caliskan et al. [16] and Ding et al. [17].

The quadratic mathematical model is presented in the research by using RSM for predicting the surface roughness during hard milling of AISI H13 under nanofluid MQL condition. The roughness model is indicated by the following equation (2).

$$Ra = 1.632 - 0.00691*V - 13.79*f - 0.183*d - 0.0562*h - 0.000026*V*V + 62*f*f + 0.001*d*d + 0.000496*h*h + 0.1372*V*f - 0.00384*V*d + 0.000165*V*h + 6.87*f*d + 0.183*f*h + 0.01102*d*h \quad (2)$$

The determination coefficient R-squared is 95%. It means that the model of surface roughness perfectly fit with measured data. P-value of developed model less than 0.05 indicates that the model is statisticly significant.

Table 3. ANOVA of model for surface roughness

Source	DF	Adj SS	Adj MS	F-Value	P-Value	%C
Model	14	0.170375	0.012170	16.28	0.000[a]	95
Linear	4	0.154026	0.038507	51.52	0.000[a]	85.88
V	1	0.004802	0.004802	6.42	0.026[a]	2.68
f	1	0.093600	0.093600	125.23	0.000[a]	52.19
d	1	0.041568	0.041568	55.61	0.000[a]	23.18
h	1	0.014056	0.014056	18.81	0.001[a]	7.84
Square	4	0.001354	0.000338	0.45	0.769	0.75
V*V	1	0.000200	0.000200	0.27	0.614	0.11
f*f	1	0.000232	0.000232	0.31	0.587	0.13
d*d	1	0.000000	0.000000	0.00	0.996	0
h*h	1	0.000921	0.000921	1.23	0.289	0.513
2-Way Interaction	6	0.014995	0.002499	3.34	0.036[a]	8.36
V*f	1	0.004764	0.004764	6.37	0.027[a]	2.66
V*d	1	0.001496	0.001496	2.00	0.183	0.83
V*h	1	0.001730	0.001730	2.31	0.154	0.96
f*d	1	0.002122	0.002122	2.84	0.118	1.18
f*h	1	0.000938	0.000938	1.26	0.284	0.52
d*h	1	0.001367	0.001367	1.83	0.201	0.76
Error	12	0.008969	0.000747	-	-	-
Total	26	0.179345	-	-	-	-
R-sq = 95.00%						

[a] significant

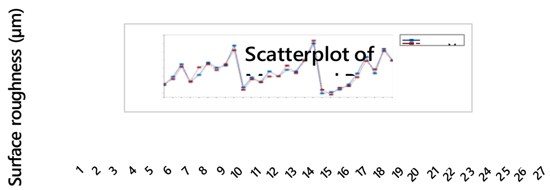


Figure 1. Comparison between measured and predicted surface roughness.

Figure 1 illustrates the comparison of roughness including measured and predicted values. As shown in Figure 1, the experimental and predicted results have a fine correlation. Therefore, the empirical model established in the study could be used to predict the roughness during hard milling of AISI H13 steel under nano-fluid MQL condition with 95% confidence intervals.

In order to obtain the minimum value of surface roughness and the maximum value of the material removal rate, the multi-objective optimization was performed based on applying a desirability function. The results of

International Journal of Mechanical Engineering Research and Technology

ISSN 2454 – 5X
www.ijmert.co
Vol.14 Issue. 1, Jan 2022

the optimization for the roughness and the material removal rate are shown in Table 4.

Table 4 The results of multi-objective optimization

Response	**Goal**	**Optimal values**				**Predicted**	**Measured**	**Error (%)**
		V	***f***	***d***	***h***			
Roughness	Min.	70	0.0207	0.6	40	0.202	0.241	16.18
MRR	Max.					1129.2	1107.52	1.96
Composite desirability = 0.67								

As shown in Table 4, the optimal cutting parameters are the cutting velocity of 70 m/min, the feed-rate of 0.0207 mm/tooth, the depth-of-cut of 0.6 mm, and the hardness of 40 HRC. According to the multi-objective optimal conditions, the surface roughness obtained is 0.202 µm and MRR obtained is 1129.2 mm3/min. With the composite desirability of 0.67, the multi-objective optimization for the roughness and the MRR is completely acceptable. A validation test was conducted to examine the accuracy of the optimization as shown in Table 4. The measured value of the roughness and the calculated value of the MRR under optimal cutting parameters are 0.241 µm and 1107.52 mm3/min, respectively. The difference between the measured value and the predicted value of Ra and MRR are expressed by the percentage error. The errors for the roughness and the material removal rate are 16.18% and 1.96%, respectively. It means that the empirical model presented by RSM can be applied for forecasting the surface roughness and the material removal rate during hard milling of AISI H13 steel under SiO2 nanofluid-based MQL condition [18-21].

CONCLUSIONS

This research has presented the study of surface roughness and the material removal rate during hard milling of AISI H13 steel under SiO2 nanofluid-based MQL condition by the combination of Taguchi method and RSM. Following conclusion may be drawn:

1. The feed-rate is the most influential factor on Ra followed by the depth-of-cut.
2. A good model for forecasting the surface roughness during hard milling of AISI H13 steel under SiO2 nanofluid-based MQL condition was established with the reliability level 95%.
3. The best cutting condition for the simultaneous combination of the minimum roughness and maximum material removal rate is the cutting velocity of 70 m/min, the feed-rate of 0.0207 mm/tooth, the depth-of-cut of 0.6 mm, and the hardness of 40 HRC.

ACKNOWLEDGMENT

This research is funded by Thai Nguyen University of Technology, Viet Nam under grant number T2019-B30.

REFERENCES

[1] T. Ding, S. Zhang, Y. Wang, and X. Zhu, "Empirical models and optimal cutting parameters for cutting forces and surface roughness in hard milling of AISI H13 steel," The International Journal of Advanced Manufacturing Technology, vol. 51, pp. 45-55, 2010.

[2] H.T. Nguyen and Q.C. Hsu, "Study on Cutting Forces and Material Removal Rate in Hard Milling of SKD 61 Alloy Steel," Journal of the Chinese Society of Mechanical Engineers, vol. 38, pp. 41-51, 2017.

[3] B. Denkena, J. Köhler, and B. Bergmann, "Development of cutting edge geometries for hard milling operations," CIRP Journal of Manufacturing Science and Technology, vol. 8, pp. 43-52, 2015.

[4] H. Schulz and T. Moriwaki, "High-speed machining," CIRP Annals, vol. 41, pp. 637-643, 1992.

[5] T.V. Do and Q.C. Hsu, "Optimization of minimum quantity lubricant conditions and cutting parameters in hard milling of AISI H13 steel," Applied Sciences, vol. 6, p. 83, 2016.

[6] A.M. Khattak, G.A. Khan, Y. Khan, M.I. Khattak, F. Jamal. "Characterization Of

International Journal of Mechanical Engineering Research and Technology
ISSN 2454 – 5X
www.ijmert.co
Vol.14 Issue. 1, Jan 2022

Soft B Separation Axioms In Soft Bi-Topological Spaces”. *Matrix Science Mathematic*, vol. 2, no. 2, pp. 11-17, 2018.

[7] Z.H. Yan. “Modeling and Kinematics Simulation of Plane Ten-Bar Mechanism of Warp Knitting Machine Based on Simcape/Multibody”. *Acta Mechanica Malaysia*, vol. 2, no. 2, pp. 15-18, 2018.

[8] N.F. Basir, S. Kasim, R. Hassan, H. Mahdin, A.A. Ramli, M.F. Md Fudzee, M.A. Salamat. “Sweet8bakery Booking System”. *Acta Electronica Malaysia*, vol. 2, no. 2, pp. 14-19, 2018.

[9] S. Tao. “Evaluation of Technology Innovation in Hubei Province”. *Engineering Heritage Journal*, vol. 2, no. 2, pp. 09-10, 2018.

[10] S. Amiril, E. Rahim, and A. Hishamudin, "Effect of nozzle distance and cutting parameters on MQL machining of AISI 1045," in Journal of Physics: Conference Series, 2019, p. 012045.

[11] T. Singh, P. Singh, J. Dureja, M. Dogra, H. Singh, and M. S. Bhatti, "A review of near-dry machining/minimum quantity lubrication machining of difficult to machine alloys," International Journal of Machining and Machinability of Materials, vol. 18, pp. 213-251, 2016.

[12] A. K. Sharma, A. K. Tiwari, and A. R. Dixit, "Progress of nanofluid application in machining: a review," Materials and Manufacturing Processes, vol. 30, pp. 813-828, 2015.

[13] T.V. Do, N.C. Vu, and Q.M. Nguyen, "Optimization of cooling conditions and cutting parameters during hard milling of AISI H13 steel by using Taguchi method," in 2018 IEEE International Conference on Advanced Manufacturing (ICAM), 2018, pp. 396-398.

[14] Y. Xuan and Q. Li, "Heat transfer enhancement of nanofluids," International Journal of heat and fluid flow, vol. 21, pp. 58-64, 2000.

[15] M. Sayuti, A. A. Sarhan, and F. Salem, "Novel uses of SiO2 nano-lubrication system in hard turning process of hardened steel AISI4140 for less tool wear, surface roughness and oil consumption," Journal of Cleaner Production, vol. 67, pp. 265-276, 2014.

[16] M. Sayuti, A. A. Sarhan, and M. Hamdi, "An investigation of optimum SiO 2 nanolubrication parameters in end milling of aerospace Al6061-T6 alloy," The International Journal of Advanced Manufacturing Technology, vol. 67, pp. 833-849, 2013.

[17] A. K. Sharma, A. K. Tiwari, A. R. Dixit, and R. K. Singh, "Investigation into performance of SiO2 nanoparticle based cutting fluid in machining process," Materials Today: Proceedings, vol. 4, pp. 133-141, 2017.

[18] Y. C. Nee, Handbook of manufacturing engineering and technology: Springer, 2015.

[19] J.A. Ghani, I. Choudhury, and H. Hassan, “Application of Taguchi method in the optimization of end milling parameters,” Journal of Materials Processing Technology, 145(1): pp. 84-92, 2004.

[20] H. Çalışkan, C. Kurbanoğlu, P. Panjan, D. Kramar, “Investigation of the performance of carbide cutting tools with hard coatings in hard milling based on the response surface methodology,” The International Journal of Advanced Manufacturing Technology, 66(5-8), pp. 883-893, 2013.

[21] T. Ding, S. Zhang, Y. Wang, X. Zhu. “Empirical models and optimal cutting parameters for cutting forces and surface roughness in hard milling of AISI H13 steel,” The International Journal of Advanced Manufacturing Technology, 51(1-4), pp. 45-55, 2010.