Global Journal of Engineering and Technology Advances
eISSN: 2582-5003
Cross Ref DOI: 10.30574/gjeta
Journal homepage: https://gjeta.com/

(Review Article)

An analysis of surface roughness in the hard milling of AISI D2 tool steel under MQCL condition using nano cutting oil

Pham Quang Dong *

Department of Manufacturing Engineering, Faculty of Mechanical Engineering, Thai Nguyen University of Technology, Thai Nguyen, Vietnam.

Global Journal of Engineering and Technology Advances, 2025, 25(03), 281-285

Publication history: Received on 20 November 2025; revised on 26 December 2025; accepted on 29 December 2025

Article DOI: https://doi.org/10.30574/gjeta.2025.25.3.0361

Abstract

The paper aims to study the influences of the cutting speed, nanoparticle concentration, and feed rate on surface roughness Ra in the hard milling process under nanofluid Minimum Quantity Cooling Lubrication (MQCL) condition. Box-Behnken experimental planning design was used to formulate the experimental matrix and analyses the interaction effects among the surveyed factors. Based on the obtained results, the proper ranges of investigated variables were provided to reach the smaller surface roughness values for each specific condition. Also, the optimal set of cutting speed V=140m/min, nanoparticle concentration NC=0.3%, and feed rate f=0.01 mm/min was determined for the predicted minimal surface roughness Ra =0.107 µm, which is the useful technical guides for the further studies and machining practice.

Keywords: Hard Milling; MQCL; Nanofluid; Cutting Speed; Nanoparticle Concentration; Feed Rate; Surface Roughness

1. Introduction

Metal cutting processes continue to play a crucial role in the global industry [1]. Rapid economic growth and urbanization have led to a surge in demand for metal products. Therefore, the pressure to increase productivity while maintaining the machined surface quality is becoming a new driving force in the machining industry [2]. Hard machining technology is essentially the process, which directly cuts high-hardness materials using cutting tools with geometrically defined cutting edges [3]. This technology is increasingly being applied and contributes significantly to improving machining productivity. In hard machining technology, hard milling is a cutting process using cutting tools with multiple cutting edges to directly machine the high-hardness materials [4]. Because the cutting tools have multiple cutting edges, the productivity of hard milling is superior to hard turning and Electrical Discharge Machining (EDM) [5]. Furthermore, thanks to advances in cutting tool materials and CNC machine tools, hard milling can now be performed on from small to large production scales. Some commonly used cutting tool materials include coated carbide, ceramics, CBN, and so on.

High cutting forces and temperatures are typical characteristics of hard milling, which accelerates tool wear and negatively affect surface finish quality. In recent years, Minimum Quantity Cooling Lubrication (MQCL) technology has been researched and applied to hard milling processes, showing very positive results [6]. The lubrication and cooling effects of MQCL contribute to reducing the coefficient of friction and heat in the cutting zone, thereby improving the cutting efficiency and surface finish quality [7,8].

Furthermore, recent studies on the application of nano cutting oils as the based oils for the MQCL method have been a new research direction, improving the lubrication and cooling efficiency of this technology [7]. However, the works in

* Corresponding author: Pham Quang Dong

this direction is still limited, so the author conducted a study on the surface quality during hard milling of hardened AISI D2 steel (60-62HRC) under the MQCL condition using nano cutting oil.

2. Methodology

Box-Behnken experimental design was used to create the experimental matrix. The investigated factors include cutting speed, nanoparticle concentration, and feed rate. Their levels were given in Table 1. The output factor is surface roughness, which was measured by Surf test SJ-210 Mitutoyo (Japan). The experimental trials were carried out in Mazak vertical center smart 530C (Japan), and the experimental setup is shown in Figure 1. Table 2 shows the elemental composition of AISI D2 tool steel. The samples were hardened to reach the hardness of 60-62HRC. The APMT 1604 PDTR LT30 coated carbide inserts were used and the cutting depth was kept at 0.12mm.

Table 1 Box-Behnken experimental design with the input variables and their levels

Input variables	Unit	Low level	High level
Cutting speed, V	*m/min*	110	140
Nanoparticle concentration, NC	*%*	0.1	0.3
Feed rate, f	*mm/min*	0.01	0.03

Table 2 Elemental composition of AISI D2 tool steel

Chemical Composition (%)										
C	Si	Mn	Ni	Cr	Mo	W	V	Cu	P	S
1.4–1.6	0.4	0.6	0.5	11.0–13.0	0.8–1.2	0.2–0.5	≤0.25	≤0.25	≤0.03	≤0.03

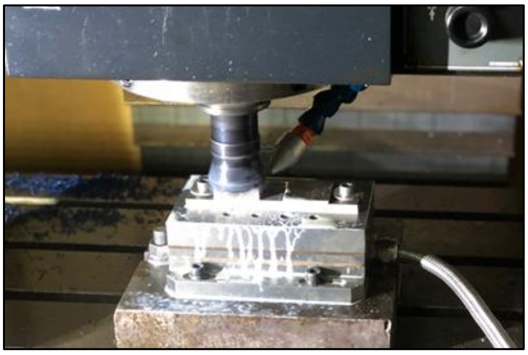

Figure 1 Experimental set up

3. Results and Discussion

The hard milling trials were conducted by following the experimental matrix, and the surface roughness Ra values were measured after each trial. The contour plot of the input factors showing the interaction effects of cutting speed and nanoparticle concentration on the surface roughness is shown Figure 2 with the feed rate f=0.02 mm/min. The use of high levels of both cutting speed and nanoparticle concentration results in the smaller surface roughness values. In detail, V=140 m/min and NC=0.3% are chosen for Ra<0.12μm.

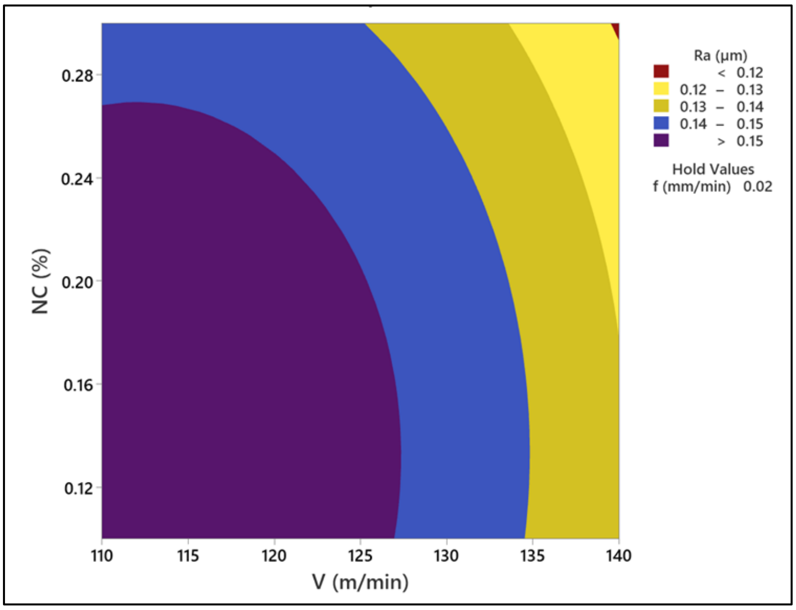

Figure 2 Contour plot of the input factors showing the interaction effects of cutting speed and nanoparticle concentration on Ra with the feed rate f=0.02 mm/min

Figure 3 is the contour plot of the interaction effects of cutting speed and feed rate on Ra with the nanoparticle concentration NC=0.2%. The use of high levels of cutting speed combined with the low feed rate brings out the smaller surface roughness values. Looking in detail, V=140 m/min and f=0.01-0.015mm/min are chosen for Ra<0.12µm.

Figure 4 is the contour plot presenting the interaction effects of nanoparticle concentration and feed rate on Ra with the cutting speed V=125 m/min. The combination of the high level of nanoparticle concentration with the low feed rate achieve the smaller surface roughness values. Specifically, NC=0.3% and f=0.01-0.011mm/min are chosen for Ra<0.12µm.

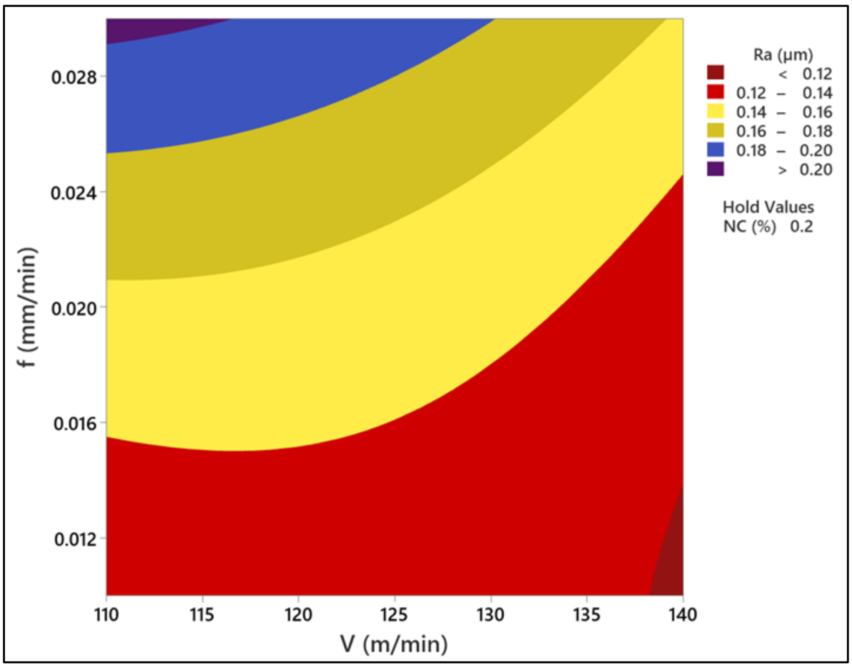

Figure 3 Contour plot of the input factors showing the interaction effects of cutting speed and feed rate on Ra with the nanoparticle concentration NC=0.2%

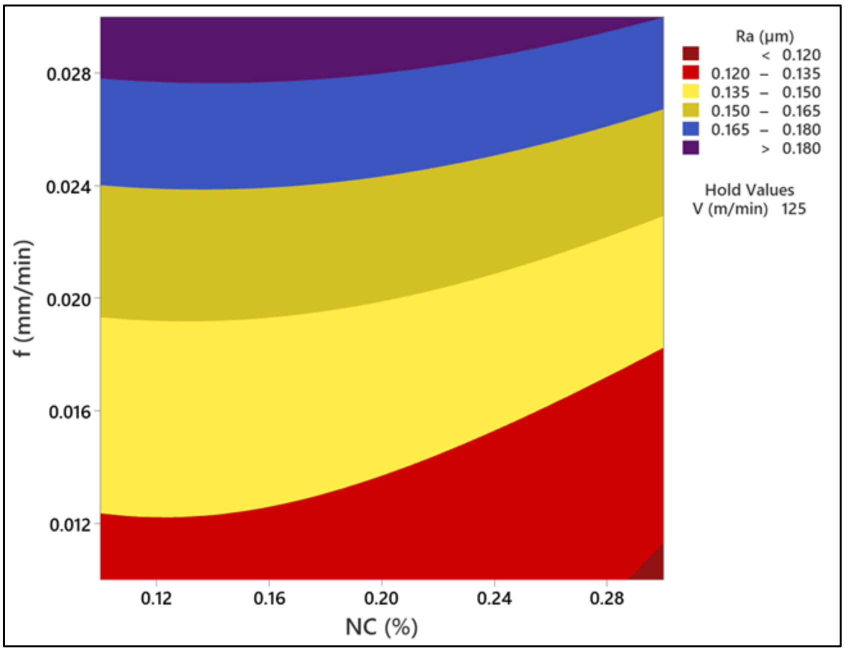

Figure 4 Contour plot of the input factors showing the interaction effects of nanoparticle concentration and feed rate on Ra with the cutting speed V=125 m/min

In order to obtain the exact values, the optimization was done and the result is shown in Figure 5. The optimal set of input variables is cutting speed V=140m/min, nanoparticle concentration NC=0.3%, and feed rate f=0.01 mm/min for the predicted minimal surface roughness Ra =0.107 µm.

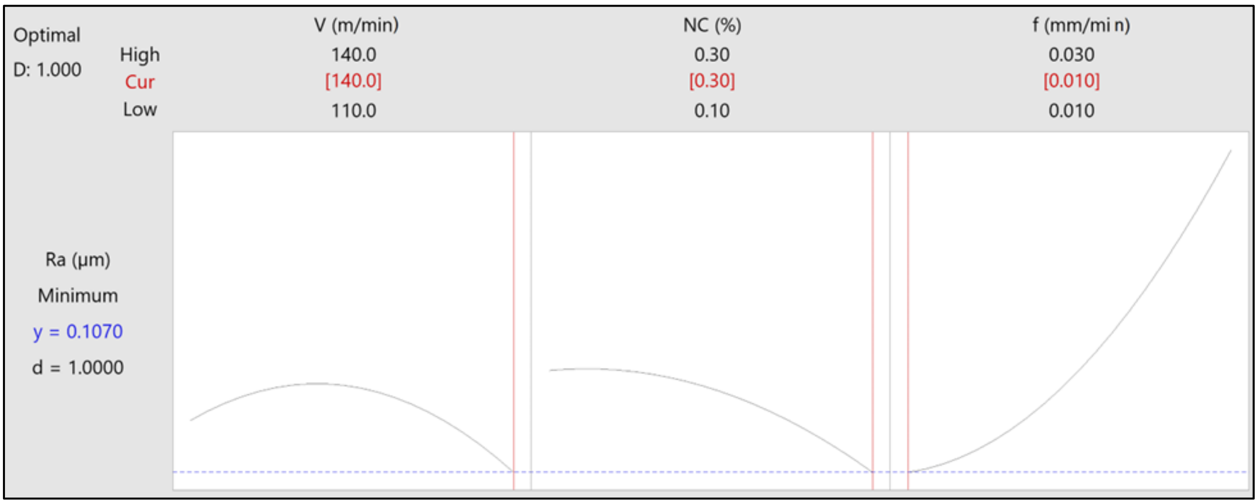

Figure 5 Optimization result for surface roughness Ra

4. Conclusion

In the presented work, the analysis of surface roughness in hard milling experiments under nanofluid Minimum Quantity Cooling Lubrication technique was made. The influence of the cutting speed, nanoparticle concentration, and feed rate on surface roughness Ra was analyzed by using Box-Behnken experimental planning design. From the obtained results, the proper ranges of investigated variables were specified to attain the smaller surface roughness values. The optimization was done to determine the optimal set of cutting speed V=140m/min, nanoparticle concentration NC=0.3%, and feed rate f=0.01 mm/min for the predicted minimal surface roughness Ra =0.107 µm. From these, the technical guidance's were provided to apply in practice and further studies.

Compliance with ethical standards

Acknowledgments

The work presented in this paper is supported by Thai Nguyen University of Technology, Thai Nguyen University, Vietnam.

References

[1] Klocke F, Brinksmeier E, Weinert K. Capability profile of hard cutting and grinding processes. CIRP Annals-Manufacturing Technology (2005) 54:22-45

[2] Le Thai Son, Tran Minh Duc, Nguyen Dang Binh, Nguyen Van Cuong; " An Investigation on Effect of Characteristics of the Made in Vietnam Peanut oil MQL on Tool life in Hard turning 9CrSi steel"; Machining and Machinability of Materials, 428 Int. J. Vol. 13, No. 4, 2013

[3] D.A Stephenson, J.S Agapiou. Metal Cutting Theory and Practice. CRC Press 2016.

[4] Halil Calıskan, Cahit Kurbanoglu, Peter Panjan, Miha Cekada, Davorin Kramar. Wear behavior and cutting performance of nanostructured hard coatings on cemented carbide cutting tools in hard milling. Tribology International 62 (2013) 215–222

[5] T. Thepsonthi, M. Hamdi, K. Mitsui. Investigation into minimal-cutting application in high-speed milling of hardened steel using carbide mills. International Journal of Machine Tools & Manufacture 49 (2009) 156–162

[6] Dong, P.Q.; Duc, T.M.; Long, T.T. Performance Evaluation of MQCL Hard Milling of SKD 11 Tool Steel Using MoS_2 Nanofluid. Metals 2019, 9, 658.

[7] Yaogang Wang, Changhe Li, Yanbin Zhang, Min Yang, Benkai Li, Dongzhou Jia, Yali Hou, Cong Mao, Experimental evaluation of the lubrication properties of the wheel/workpiece interface in minimum quantity lubrication (MQL) grinding using different types of vegetable oils, J. Clean. Prod. 127 (2016) 487–499.

[8] Radoslaw W. Maruda, Grzegorz M. Krolczyk, Mariusz Michalski, Piotr Nieslony, and Szymon Wojciechowski. Structural and Microhardness Changes After Turning of the AISI 1045 Steel for Minimum Quantity Cooling Lubrication. Journal of Materials Engineering and Performance (2017) 26: 431-438 doi:10.1007/s11665-016-2450-4.