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Investigation of effects of nano cutting fluid on MQCL hard milling performance of AISI D2 tool steel

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Abstract
Minimum quantity cooling lubrication (MQCL) has been considered a promising technological solution to overcome the disadvantages of minimum quantity lubrication (MQL) method. The significant improvement in cooling capacity has made this technology suitable for application in hard machining. The paper aims to experimentally study the influence of cooling condition, air pressure and air flow rate on surface roughness in hard milling of AISI D2 steel (60 HRC) with MQCL environment using coated carbide inserts. The factorial experimental design method is used to evaluate the influence of input parameters on surface roughness R_a. The experimental results show that using MoS_2 nano cutting oil for MQCL provides better machined surface quality than MQCL using cutting oil without nanoparticles. The increase of air pressure and air flow rate brings positive effects on surface roughness. Furthermore, the study also proposed a reasonable range of air pressure and air flow rate values for improving machined surface quality.

Keyword: *Hard milling; MQCL; nanofluid; air pressure; air flow rate; surface roughness*

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I. INTRODUCTION

In recent years, increasingly strict environmental regulations along with increasing requirements for the quality of machined parts have posed new challenges in the development of the metal cutting field [1]. Machining processes must now simultaneously meet many criteria, including minimizing or eliminating cutting oils. The use of cutting oil is one of the traditional solutions and is widely used in production practice. The problems of environmental pollution and negative human health effects caused by the use of industrial cutting oils are major problems that need to be resolved [2]. The complete elimination of cutting oil brings positive environmental effects, but cutting heat and high cutting force are problems that greatly affect the cutting performance [3,4]. High cutting heat and cutting force accelerate tool wear, negatively affecting the machined surface quality, especially in machining processes with harsh cutting conditions like hard milling. The research and development of hard milling has opened up new technical solutions to replace and support the finish grinding process. However, the intermittent cutting process combined with high cutting heat and cutting force makes the use of wet condition inappropriate due to thermal shock, causing chipping and breakage of cutting tools [5]. Therefore, minimal quantity lubrication technology was developed as an alternative to flood coolant technology. MQL technique delivers a small amount of cutting oil directly into the cutting zone in the form of high-pressure mist, so the lubrication effect is very good [6]. This technology has been researched and applied to the machining of alloys and un-heat heated steels [7].

The study results show positive effects in reducing cutting forces, tool wear and improving machined surface quality. When applying this technology for hard milling, the effectiveness is still not clear because the cooling ability of MQL is low [8]. To further overcome this drawback, minimal quantity cooling lubrication (MQCL) was developed as an alternative solution to overcome the low cooling capacity of MQCL [9]. However, research on MQCL and its technological parameters for hard milling process is still very limited [5]. Therefore, the author conducted a study on the effects of MQCL using cutting oil with/without MoS_2 nanoparticles, air pressure, and air flow rate on surface roughness in hard milling of AISI D2 tool steel (60 HRC) using coated carbide tools.

II. MATERIAL AND METHOD

2.1 Experimental design

Factorial experimental design with the help of Minitab 19.0 software is utilized for three input parameters including cooling condition, air pressure, and air flow rate with two levels given by Table 1.

Table 1. Factorial design with three input variables and their levels

Input variables	Low level	High level	Responses
Cooling condition	MQCL	NF MQCL	Surface roughness R_a (μm)
Air pressure (bar)	5	7	
Air flow rate (l/min)	150	250	

2.2 Experimental devices

The cutting trails were conducted on Mazak vertical center smart 530C and the setup of experimental devices is shown in Figure 1. The chemical composition of AISI D2 tool steel samples is shown in Table 1. The APMT 1604 PDTR LT30 coated carbide inserts was used (Figure 2). The water-based emulsion 5% was used as the cutting fluid for MQCL system For the case of nanofluid MQCL, the additives of MoS_2 nanoparticles with the concentration of 0.5 wt%. The cutting parameters were fixed at cutting speed V_c =100 m/min; feed rate f=0.012 mm/tooth, depth of cut of 0.12 mm. SJ-210 Mitutoyo portable surface roughness tester was used for surface roughness measurement. The values of surface roughness were measured 3 times and taken by the average value. Each experiment trial was repeated 3 times and taken by the average values.

Table 1. Chemical composition in wt% of AISI D2 tool steel

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

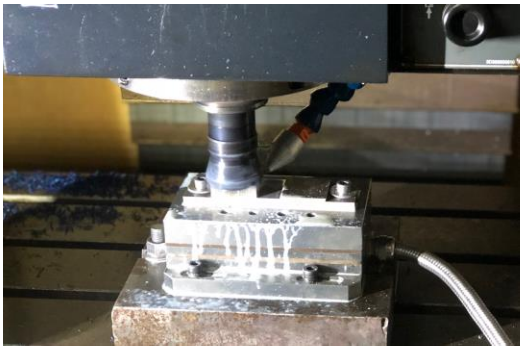

Figure 1. *Experimental set up*

Figure 2. *Milling head and carbide inserts used in the experiment*

III. RESULTS AND DISCUSSION

The cutting trials were carried out by following the factorial experimental run order, and the surface roughness values were measured after each cutting trial. From figure 3, it can be seen that the main effects of the input parameters on the surface roughness R_a. MQCL using nano cutting oil exhibits the better surface quality than MQCL using cutting oil without nanoparticles. Besides, air pressure and air flow rate have a great influence on the machined surface roughness value due to the steep slope. The increase of air pressure and air flow rate contributes to improve machined surface quality by enhancing the ability to form smaller oil droplets, the amount of oil and the ability to bring cutting oil deeper into the cutting zone [10]. The interaction effects between input parameters on surface roughness are shown in Figure 4. The interaction effects between cooling condition and air pressure have a greater influence on the response than those of between cooling condition and air flow rate as well as air pressure and air flow rate.

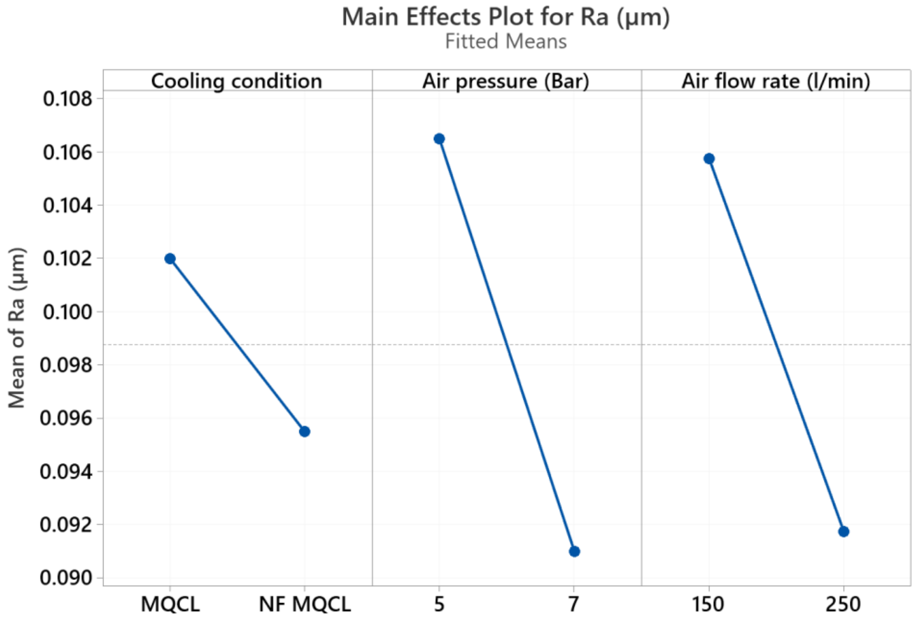

Figure 3. *Main effects of the input parameters on surface roughness R_a*

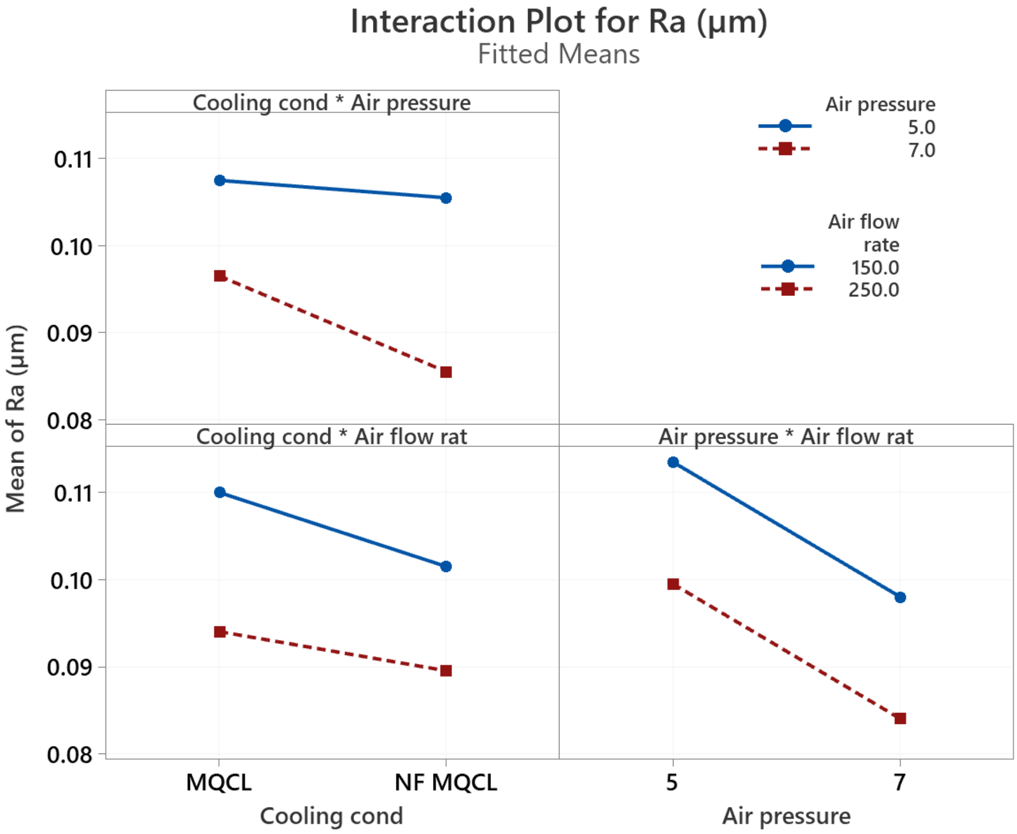

Figure 4. *Interaction effects of the input parameters on surface roughness R_a*

Figure 5 is the contour plot showing the influence of air flow rate and air pressure on surface roughness in hard milling AISI D2 tool steel (60 HRC) under MQCL condition using emulsion cutting oil without nanoparticles. It can be seen that air flow rate of 220÷250 l/min combined with air pressure of 6÷7 bar will give the smallest surface roughness R_a values (0.090÷0.095 µm).

The contour plot in Figure 6 shows the influence of air flow rate and air pressure on surface roughness in hard milling AISI D2 tool steel (60HRC) under MQCL condition using emulsion cutting oil with MoS_2 nanoparticles. It can be seen that air flow rate of 240÷250 l/min combined with air pressure of 6.7÷7 bar will give the smallest surface roughness R_a value (R_a<0.080 µm). Furthermore, the use of air flow rate at 185÷250 l/min combined with air pressure of 6÷7 bar will give the smaller surface roughness R_a values (0.080÷0.088 µm), which is smaller than those of MQCL using emulsion oil without nanoparticles (Figure 5). This proves that using nano cutting oil helped improve the lubrication performance in the cutting zone, thereby improving the machined surface quality.

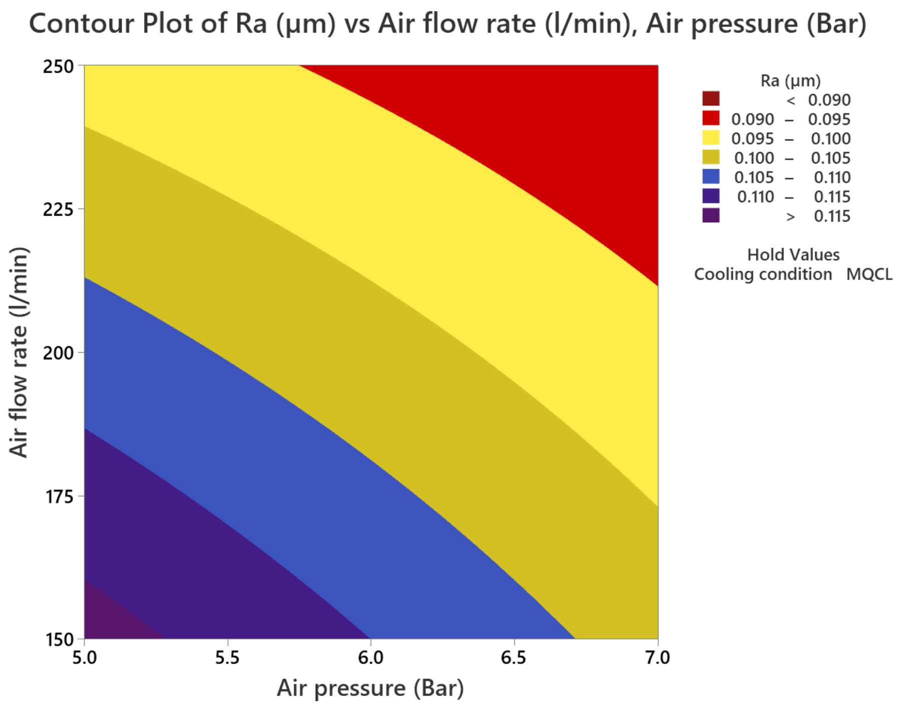

Figure 5. *Contour plot of air flow rate and air pressure on R_a in case of MQCL condition using emulsion oil without MoS_2 nanoparticles*

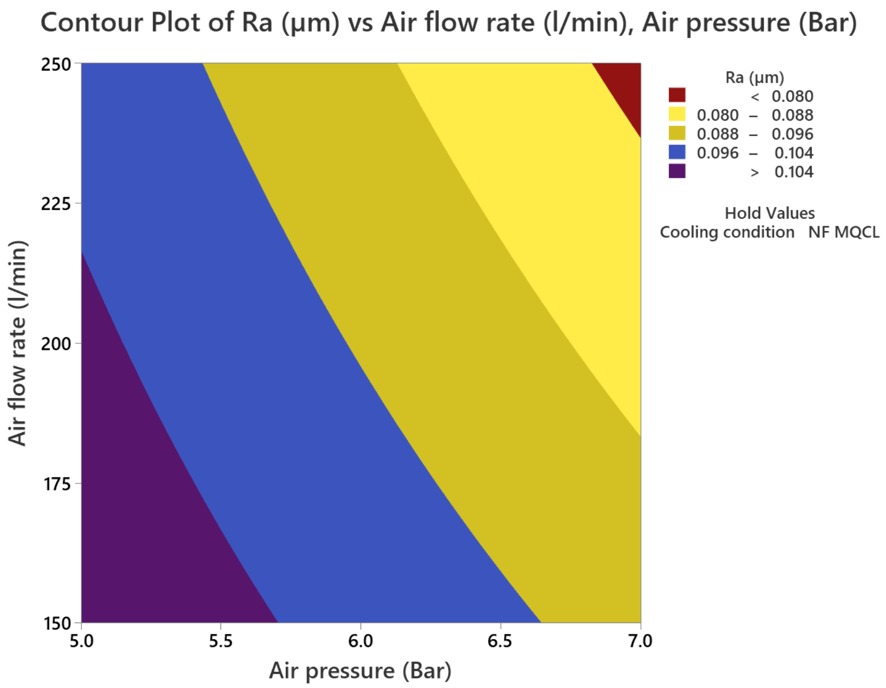

Figure 6. *Contour plot of air flow rate and air pressure on R_a in case of MQCL condition using emulsion oil with MoS_2 nanoparticles*

IV. CONCLUSION

In this article, the experimental study was conducted to evaluate the influence of cooling conditions and technological parameters of MQCL including air pressure and air flow rate on surface roughness in hard milling of AISI D2 (60 HRC) tool steel using coated carbide inserts. The obtained experimental results show that the use of MoS_2 nano cutting oil for MQCL provides better machined surface quality than MQCL using cutting oil without nanoparticles. The rise of the air pressure and air flow rate brings positive effects on the surface roughness R_a due to the improvement in the ability to form oil particles, the amount of cutting oil and the deeper penetration of cutting oil into the contact zone. Furthermore, the study also proposed the reasonable range of air pressure and air flow rate values to improve the machined surface quality and provide technical guides for further research.

Acknowledgments

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References

[1]. Pil-Ho Lee, Jung Soo Nam, Chengjun Li and Sang Won Lee. An Experimental Study on Micro-Grinding Process with Nanofluid Minimum Quantity Lubrication (MQL). International Journal of Precision Engineering and Manufacturing 13 (2012). 331-338.

[2]. Ismet Hari Mulyadi, Vincent Aizebeoje Balogun, Paul T. Mativenga. Environmental performance evaluation of different cutting environments when milling H13 tool steel. J. Clean. Prod. 108 (2015) 110–120

[3]. 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.

[4]. S. Saketi, S. Sveen, S. Gunnarsson, R. M'Saoubi, M. Olsson. Wear of a high cBN content PCBN cutting tool during hard milling of powder metallurgy cold work tool steels. Wear 332-333 (2015) 752-761.

[5]. 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.

[6]. 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.

[7]. Asif Iqbal, He Ning, Iqbal Khan, Li Liang, Naeem Ullah Dar. Modeling the effects of cutting parameters in MQL-employed finish hard-milling process using D-optimal method. Journal of materials processing technology 199 (2008) 379–390.

[8]. Y.S. Liao, H.M. Lin. Mechanism of minimum quantity lubrication in high-speed milling of hardened steel. International Journal of Machine Tools & Manufacture 47 (2007) 1660 – 1666.

[9]. 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.

[10]. Kyung-Hee Park, Jorge A Olortegui-Yumel, Shantanu Joshil, Patrick Kwonl, Moon-Chul Yoon, Gyu-Bong Lee and Sung-Bum Park. Measurement of Droplet Size and Distribution for Minimum Quantity Lubrication (MQL). International Conference on Smart Manufacturing Application (2008) 447-454.