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Machining Investigation of Hard Milling of SKD 11 Tool Steel under MQCL Using MoS_2 Nano cutting fluid

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Abstract
Environmentally friendly machining has been gained much attention from the researchers and manufacturers, in which MQCL using nano cutting fluid is a new research topic. The paper content aims to investigate the effects of cutting speed and MoS_2 nanoparticle concentration on cutting force and surface roughness in hard milling of SKD 11 tool steel (60 HRC). The obtain results show that the use of MoS_2 nano-cutting oil in MQCL has contributed to improve the lubrication and cooling efficiency, thereby improving the hard milling performance. The main effects of cutting speed and nanoparticle concentration as well as their interaction effects on the cutting force components and surface roughness have been specifically investigated and evaluated. Since then, technological guides are given to help guide further studies and select the values for practice.
Keyword: *Hard milling; MQCL; MoS_2 nanoparticles; nano cutting fluid, surface roughness, cutting force*

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I. INTRODUCTION

In recent years, increasing concerns about environmental pollution and climate change have become visible. Unusual natural disasters cause great loss of property and human life. This has prompted people to act faster and come up with innovative solutions to minimize the impact on the environment. The metal cutting field discharges a lot of waste, causing negative impacts on the environment, especially used cutting oils [1]. These oils are often released into the environment or treated at a very expensive cost. Therefore, urgent solutions are needed to reduce the use of cutting fluids or replace them with natural biodegradable oils such as vegetable oils, etc. The dry machining has been applied and developed to overcome the above problems. However, because no cutting fluid is used, in case of machining hard materials and difficult-to-cut materials [2], the heat and cutting forces generated from the contact zone are very large [3]. This accelerates tool wear, which leads to reduce tool life and adversely affects machined surface quality. Especially in machining hard materials, the selection of cutting tool becomes a crucial factor, strongly affecting the machining productivity and quality. Cutting tool materials commonly used in dry hard cutting processes are coated carbide, ceramic, CBN, and so on [4-7]. This contributes to increase the manufacturing cost. In addition, due to the enormous cutting heat, there is also the formation of white layer, which adversely affects the surface quality and durability of the machined parts.

Therefore, it is necessary to have new cooling lubrication techniques to replace flood and dry condition while ensuring environmental friendliness. There have been many solutions proposed in recent years, including MQCL technology [3]. This method shows high lubricating and cooling efficiency, which contributes to improve the cutting performance. In addition, the amount of coolant used is very small, so it still ensures environmentally friendly characteristic. The study results on this technology mainly focus on using cutting fluids having good cooling performance on the basis of MQL technology, so the cooling efficiency in machining hard materials is limited [8,9]. To improve the lubricating and cooling efficiency, the application of nano-cutting oil in MQCL is a new solution, bringing very positive effects. However, the studies on this direction is still very limited, so the author conducts the study on investigating the influence of cutting speed and MoS_2 nanoparticles concentration on cutting forces and surface roughness in hard milling of SKD 11 tool steel under MQCL condition.

II. MATERIAL AND METHOD

2.1 Experimental design

Factorial experimental design with the help of Minitab 19.0 software is utilized for two input parameters with two levels listed in Table 1.

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

Input variables	Low level	High level	Response variables
MoS_2 nanoparticle concentration, *nc* (%)	0.1	0.3	Cutting force F_x, F_y, F_z
Cutting speed, V_c (*m/min*)	110	140	Surface roughness R_a

2.2 Experimental devices

The experiments were conducted on Mazak vertical center smart 530C (Figure 1). SKD 11 tool steel samples with the hardness of 60 HRC are used, and the chemical composition is shown in Table 1. The APMT 1604 PDTR LT30 carbide inserts made by LAMINA Technologies (Sweden) was used (Figure 2). MQCL system consists of MQCL nozzle, air compressor, water-based emulsion 5% and MoS_2 nanoparticles with the grain size of 30nm. The MQCL parameters consist of: air pressure of 6 bar, flow rate at 0.5 ml/min. The depth of cut was fixed at 0.12 mm and feed rate at 0.012 mm/tooth. SJ-210 Mitutoyo (Japan) was used for measuring surface roughness. The cutting forces were directly measured during the cutting process and 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 of SKD 11 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

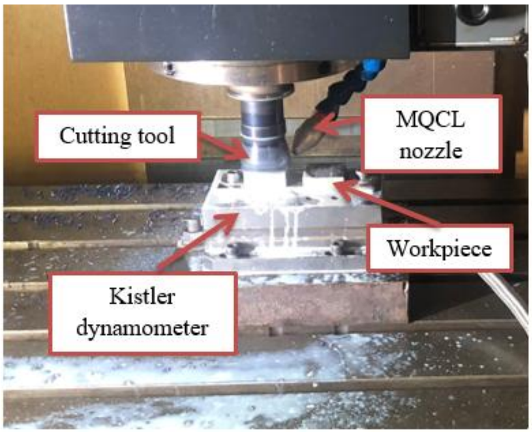

Figure 1. Experimental set up

Figure 2. Milling head and inserts

III. RESULTS AND DISCUSSION

The experiments were carried out by following the experimental design to collect and analyze the data. The main effect graphs of the input parameters are shown in Figure 3-6, and the surface plots presenting the interaction influence between the input variables on the surface roughness and the cutting force components are shown in Figure 7-10.

From Figure 3-6, it can be seen that when increasing the cutting speed from 110 to 140 m/min, the surface roughness tends to increase, but the cutting force components decrease. When increasing the concentration of MoS_2 nanoparticles from 0.1 to 0.3%, it contributes to reduce the values of surface roughness and cutting forces. The concentration of MoS_2 nanoparticles was increased to 0.3%, which means that more

MoS_2 nanoparticles are introduced into the cutting zone, thus contributing to the reduction of the friction coefficient in contact zone [3,10]. Hence, this can be clearly seen in the two force components F_y and F_z; however, the influence of the concentration of MoS_2 nanoparticles on the force component F_x is very little. Accordingly, more investigation should be made to confirm this observation.

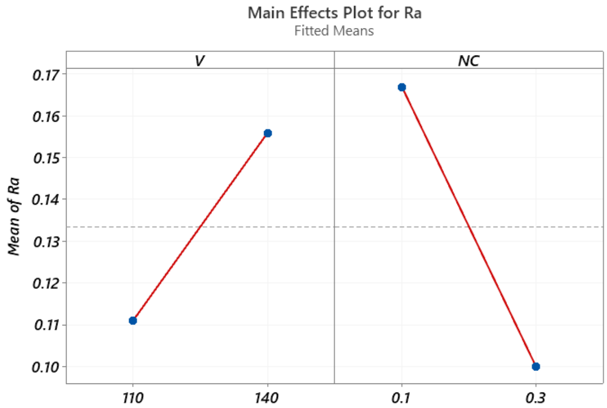

Figure 3. Main effects of cutting speed and nanoparticle concentration on R_a

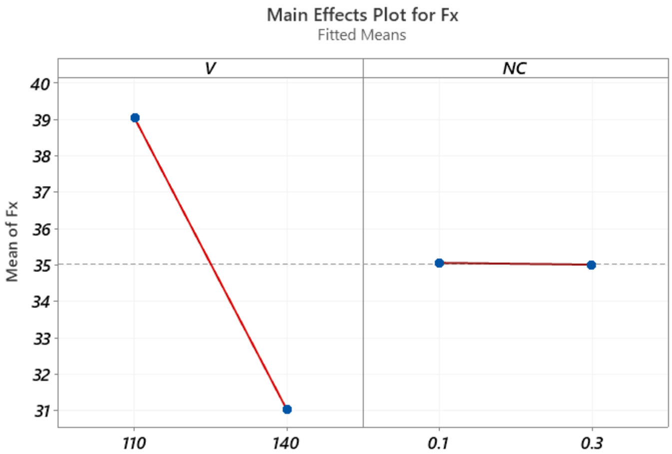

Figure 4. Main effects of cutting speed and nanoparticle concentration on F_x

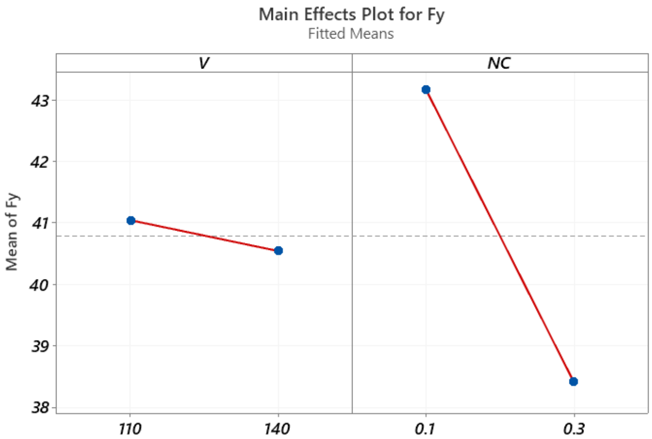

Figure 5. Main effects of cutting speed and nanoparticle concentration on F_y

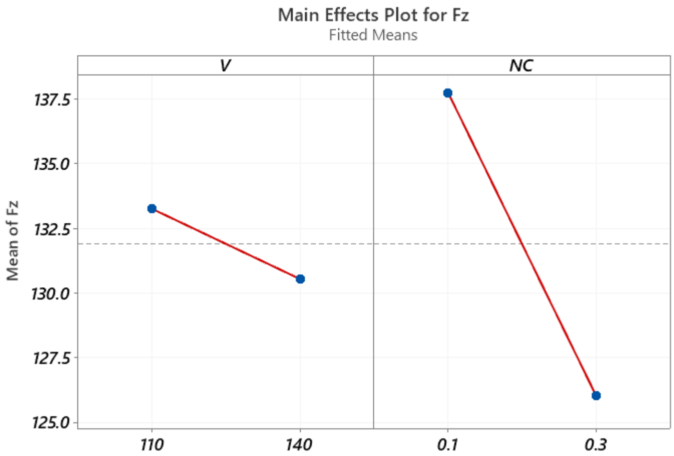

Figure 6. Main effects of cutting speed and nanoparticle concentration on F_z

From Figures 7, 9, it can be seen that the combination of high concentration of MoS_2 nanoparticles with low cutting speed will achieve the lower surface roughness and cutting force F_y. Meanwhile, for F_x, the combination of high cutting speed and low nanoparticle concentration gives the lowest values (Figure 8). Using high levels of cutting speed and nanoparticle concentration will reach the lowest F_z value (Figure 10). Through the surface plots, the interaction effects between the cutting speed and nanoparticle concentration will be clearly presented, and it will help to provide the research direction and quickly select the input parameter values to meet each specific criterion.

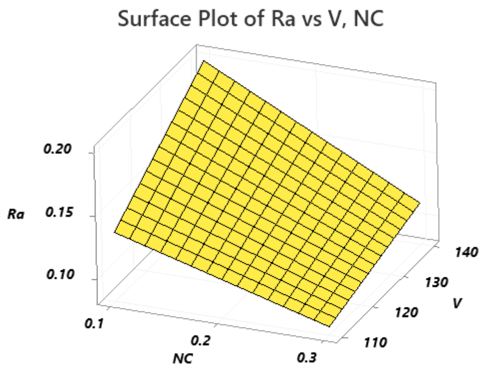

Figure 7. Surface plot of cutting speed and nanoparticle concentration on R_a

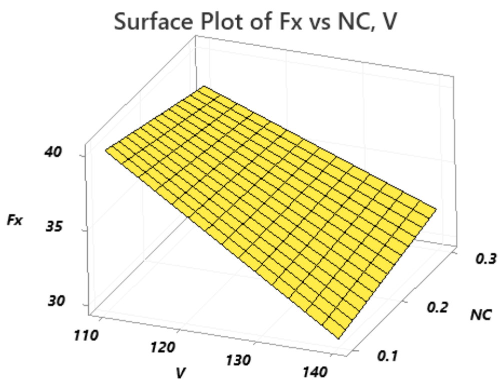

Figure 8. Surface plot of cutting speed and nanoparticle concentration on F_x

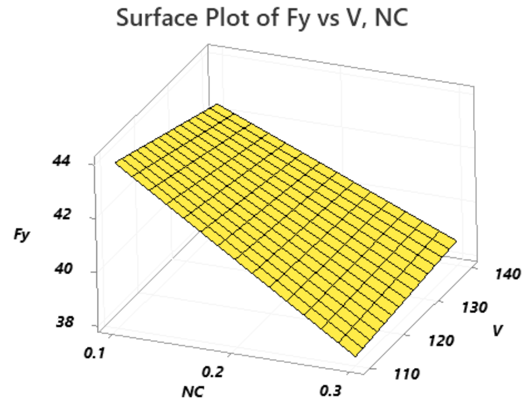

Figure 9. Surface plot of cutting speed and nanoparticle concentration on F_y

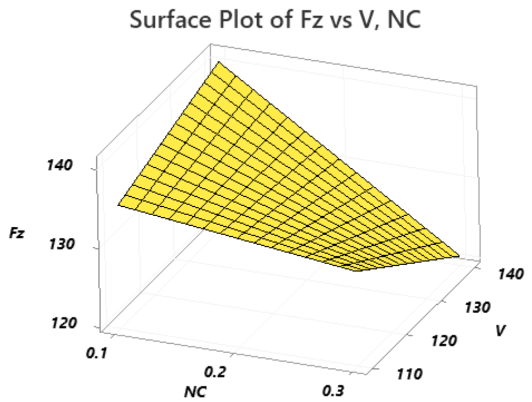

Figure 10. Surface plot of cutting speed and nanoparticle concentration on F_z

IV. CONCLUSION

In this paper, the MQCL technology using MoS_2 nano-cutting oil has been successfully applied for the hard milling of SKD 11 steel. The work content has investigated and evaluated the influence of two input parameters including cutting speed and nanoparticle concentration on cutting forces and surface roughness. The obtained results show that the use of nano-cutting oil has contributed to reduce the friction coefficient in the cutting zone, thereby improving the efficiency of the hard milling process. The study also provides technological guidelines in the selection of input parameters to achieve the output criteria including cutting force components and surface roughness.

In further research, more investigations will be concentrated on optimizing cutting speed and nanoparticle concentration. In addition to that, the influence other variables like feed rate, depth of cut and the MQCL parameters should be made.

Acknowledgments

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