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Investigation of rapeseed oil –based nanofluid on hard machining performance under minimum quantity lubrication environment

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Abstract
Today, the increasing demand for machining hard materials along with the requirements for ensuring environmental friendliness are putting new challenges in the metal cutting field. Therefore, the application of MQL technology using nano-cutting oil for hard machining is a new solution, attracting much attention and research. This paper aims to study the effect of Al_2O_3 nanofluid with the base oil of rapeseed oil on the cutting force components in hard milling of 60Si2Mn steel (50-52 HRC). Besides, the study also evaluated the influence of nanoparticle concentration on the cutting forces. The obtained results show that the efficiency of the hard milling process and the machinability of carbide tools are improved. The concentration of nanoparticles has a great influence on the frictional interaction in the cutting zone, and the increasing concentration of nanoparticles contributes to enhance the lubricating and cooling capacity, which helps to reduce the cutting forces.

Keyword: *Hard milling; MQL; Al_2O_3 nanoparticles; rapeseed oil, nanofluid, cutting force*

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I. INTRODUCTION

Due to the increasing demand for productivity and quality of the machined parts while ensuring the environmental protection, in recent years, new processing technologies have been developed, researched and developed, in which hard machining technology is included [1,2]. In the past, the solution for finishing heat-treated steels was mainly grinding; however, this method presents the low material removal rate [3] and besides, it use coolants, which adversely affect the environment [4]. Hard machining technology exhibits outstanding productivity and very good surface quality [5]. With the development of advanced machine tools with high rigidity and cutting tool materials, it is now much more convenient to directly machine hardened steels. However, for machining these materials in dry condition, enormous heat and large cutting forces accelerate tool wear, adversely affecting the quality of the machined surface [6]. Cutting under flood condition has low lubricating efficiency, but for hard milling, it is difficult because it easily causes thermal shock, leading to break the cutting tool [2]. Therefore, in recent years, the application of minimum quantity lubrication technology is a solution that has been proposed to research and develop as an alternative to dry and wet conditions. Studies on this technology for manufacturing processes of soft materials have brought about positive effects [7].

The application of this technology has been initially studied for hard turning and hard milling, but the effect is not really obvious due to high heat and cutting forces [8,9]. Therefore, the application of nano-cutting oil as the base oil for MQL is a new solution, which has improved the cooling lubrication efficiency in the cutting zone, thereby helping to improve efficiency and expand the application possibilities for hard cutting processes. The publications on this research direction are limited, so the authors conduct the study on the application of nano-cutting oil based on rapeseed oil, an environmentally friendly vegetable oil, for the hard milling process of 60Si2Mn steel by using carbide inserts.

II. MATERIAL AND METHOD

The hard milling experiments were carried out on CNC milling center VMS 85S (Figure 1). The workpiece were 60Si2Mn steel (50-52 HRC), and the chemical composition is shown in Table 1. The carbide inserts with the designation of APMT 1604 PDTR LT30 made by LAMINA Technologies (Sweden) was used. MQL system consists of MQL nozzle, air compressor, rapeseed oil and Al_2O_3 nanoparticles. The MQL parameters consist of air pressure of 6 bar, flow rate at 0.23-0.25 ml/min. The cutting condition was shown in Table 2 fixed at 0.2 mm. Kistler quartz three-component dynamometer (9257BA) was used for measuring

cutting forces. The values of cutting forces were directly measured during the cutting process. The nano cutting oil was formulated by suspending Al_2O_3 nanoparticles in rapeseed oil with three different nano concentration (0.5%, 1.0%, and 1.5%).

Table 1. Chemical composition of 60Si2Mn steel

Element	C	Si	Mn	P	S	Cr	Ni	Fe
Weight (%)	0.56-0.64	1.50-2.00	0.60-0.90	≤0.035	≤0.035	0.35max	0.35max	Rest

Table 2 – Cutting conditions

Cutting parameters	Value
Cutting velocity	110 m/min
Feed rate	0.12 mm/tooth
Depth of cut	0.2 mm

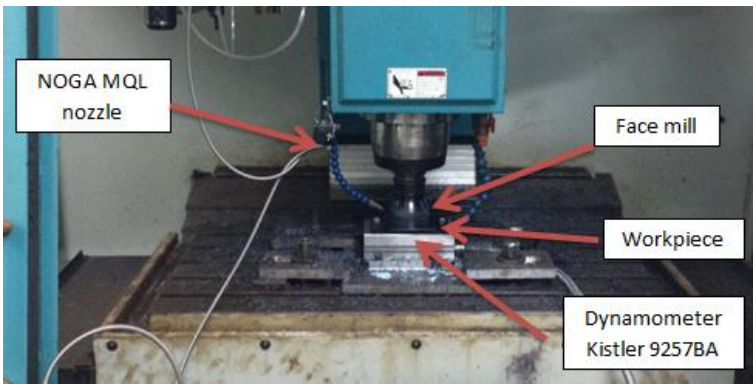

Figure 1. Experimental set up

III. RESULTS AND DISCUSSION

The cutting trials were done three times and the obtained data of cutting force components was collected and shown in Figure 2-4. In Figure 2, it can be seen that in case of increasing the concentration of nanoparticles in rapeseed oil from 0.5% to 1.0%, there is no significant difference in the cutting force F_x; however, the cutting force components F_y, F_z have decreased significantly (Figures 3,4). When the Al_2O_3 nanoparticle concentration rises from 1.0% to 1.5%, all the cutting force components much decreased. This can be explained that Al_2O_3 nanoparticles have high hardness and near-spherical morphology as well as good thermal conductivity, so the growing concentration of nanoparticles in rapeseed oil has contributed to enhance thermal conductivity of the base oil.

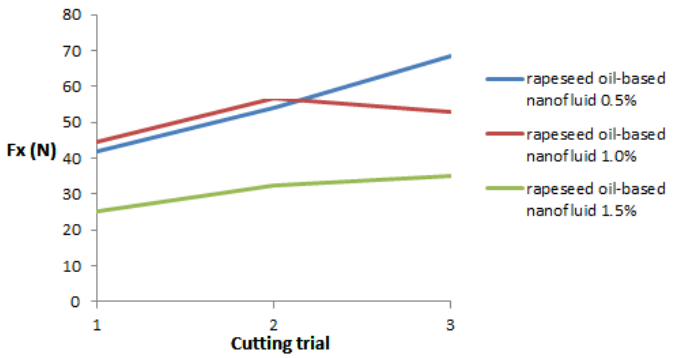

Figure 2. The cutting force F_x with different nanopartilce concentrations

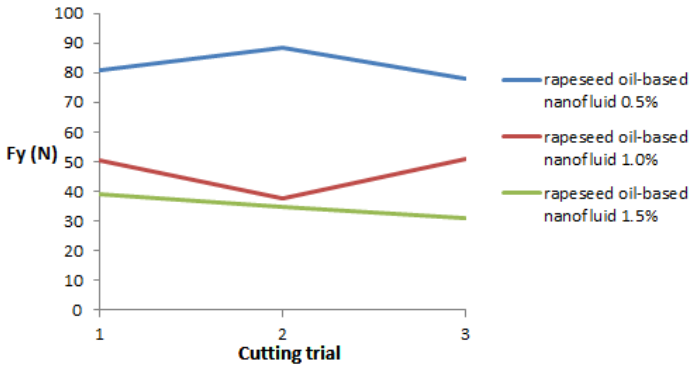

Figure 3. The cutting force F_y with different nanopartilce concentrations

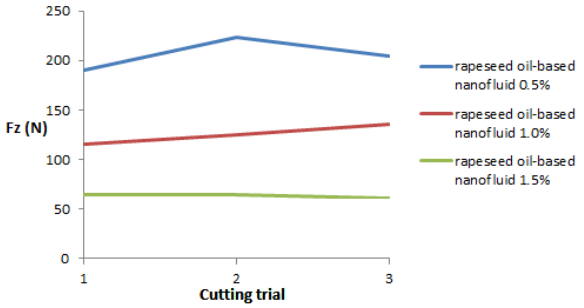

Figure 4. The cutting force F_y with different nanopartilce concentrations

Moreover, more nanoparticles are introduced into the cutting zone, acting as ball rollers, which contribute to reduce the friction coefficient in the contact faces, thereby decreasing cutting heat and cutting forces. In addition, the concentration of 1.0 - 1.5% is appropriate for Al_2O_3 nanoparticles [4]. The normal cutting force F_y and the tangential force F_z play the very important roles in hard milling because F_y has a direct effect on the machining dimensional error and flank wear, while the tangential force F_z has a great influence on the wear on rake face and main cutting edge. Therefore, increasing the concentration of nanoparticles in the base cutting oil has contributed to reduce the values of the cutting forces, thereby improving the machinability and tool life.

IV. CONCLUSION

In this paper, the MQL technology using Al_2O_3 rapeseed-based nano cutting oil has been successfully applied for hard milling of 60Si2Mn steel (50-52 HRC). The influences of nanoparticle concentration on cutting forces was investigated and evaluated. The machinability of carbide tools was improved due to the enhancement of cooling and lubricating performance of Al_2O_3 nano cutting oil under MQL environment. The lubricating and cooling properties of rapeseed oil were increased, which will provide the environmentally friendly alternative solution for the base cutting fluid of MQL method. Moreover, the applicability of rapeseed oil was expanded to hard milling process, which is a step toward to sustainable machining.

Acknowledgments

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