Engineering and Technology Journal e-ISSN: 2456-3358
Volume 09 Issue 05 May-2024, Page No.- 3887-3892
DOI: 10.47191/etj/v9i05.03, I.F. – 8.227

An Experimental Investigation of the Effects MQL Using Nanofluids on Surface Roughness of Hard Milling Process

Tran Minh Duc[1], Tran The Long*[2]
[1,2] Department of Manufacturing Engineering, Faculty of Mechanical Engineering, Thai Nguyen University of Technology, Thai Nguyen, 250000, Vietnam

ABSTRACT: High cutting force and cutting heat are challenging problems that need to be overcome for the hard milling process. Minimum quantity lubrication (MQL) has been shown to be effective and suitable for use in hard milling due to the improving lubrication in the cutting zone. The content presented in this article is to investigate MQL using emulsion cutting oil with/without Al_2O_3 nanoparticles for hard milling of 60Si2Mn steel (50-52 HRC) using carbide tools. Factorial experimental design is used to evaluate the cooling condition, cutting speed and feed rate on surface roughness. Experimental results show that feed rate has the greatest influence on surface roughness among the parameters investigated, followed by cooling mode and cutting speed. MQL technique using nano cutting oil gives better machined surface quality than MQL using pure cutting oil, which has proven that the additives of Al_2O_3 nanoparticles to the base cutting oil has improved cooling and lubrication capability. Furthermore, the applicability of MQL method is expanded to apply for hard milling.

KEYWORDS: Hard milling; minimum quantity lubrication; nanofluid; surface roughness; emulsion; Al_2O_3 nanoparticles.

1. INTRODUCTION

In today's industrial industry, metal cutting processes still play a key role because of their advantages that are difficult to replace with any method. High dimensional accuracy and high surface quality, as well as the ability to create diverse surfaces from simple to complex ones can be achieved in machining [1]. The general principle of the traditional machining process is to use cutting tools with a higher hardness than the work material hardness. Cutting force and cutting heat generated from the cutting zone are the main causes that affect the efficiency of the cutting process and the tool life, so cutting oils are commonly used in production practices to lubricate and cool the cutting zone [2]. However, the current use of cutting oil is mainly in flood coolant, so the amount of oil used is large and the ability to bring oil deeply into the cutting zone are limited [3]. Besides, the treatment of used cutting oil is very expensive with many strict regulations, which causes the increase in manufacturing costs. Along with the current trend of sustainable production, the use of industrial cutting oils is an urgent problem, so it is necessary to reduce, eliminate or switch to environmentally friendly oils. Therefore, many lubrication and cooling technology solutions have been researched and developed such as minimum quantity lubrication, minimum quantity cooling lubrication, minimum quantity cooling, and so on. Among the proposed methods, minimal quantity lubrication has been researched and developed for application in industrial production and has so far brought many positive effects compared to flood coolant technology. MQL is a method of introducing a small amount of cutting oil into the cutting zone in the form of high-pressure mist, so the oil droplets can penetrate deeply into the cutting zone and provide high lubrication efficiency [4]. The experimental study on the influence of MQL on the turning efficiency is presented in [5]. The obtained results show that the reduction in cutting force and tool wear was reported when compared with dry and wet conditions. However, when MQL is applied to cut hard materials, due to high cutting force and enormous cutting temperature, the effectiveness is not as expected because low cooling ability is the main drawback [6,7]. The use of nano cutting oil is a new technological solution, attracting much attention from researchers around the world, and has been developed to overcome this problem. The additives of nanoparticles into the base cutting oil for the MQL method has not only improved the lubrication and cooling properties of the based oil but also created additional lubrication mechanisms in the cutting zone [8-10]. However, the application of this technology to the hard milling process is still limited, so the authors conducted a study on the effects of nano cutting oil on the hard milling process of 60Si2Mn steel (50-52HRC) with MQL technique using coated carbide inserts. The input parameters investigated include cooling conditions (MQL and nanofluid MQL), cutting speed and feed rate, while the output parameter is surface roughness R_a.

2. METHOLOGY

The experiment was implemented on Maximart VMC 85S CNC milling machine and the device setup is shown in Figure 1. Coated carbide insert with the designation of APMT 1604 PDTR LT30 was used for the experiment (Figure 2). The cooling lubrication system consists of MQL nozzle, air compressor, pressure regulating valve, air flow regulating valve, emulsion oil, Al_2O_3 nanoparticles (Figure 3). MITUTOYO SJ-210 portable surface roughness tester is used to measure surface roughness R_a. R_a values were measured 3 times after each cuting trial and the average value was taken. The workpiece samples are 60Si2Mn steel (50-52 HRC) with the chemical composition shown in table 1. The depth of cut is fixed at 0.2 mm. The factorial experimental design was used with input parameters and output parameters given in Table 2.

Table 1 – Chemical composition in wt% of 60Si2Mn steel

C	**Si**	**Mn**	**P**	**S**	**Cr**	**Ni**	**Fe**
0.56-0.64	1.50-2.00	0.60-0.90	≤0.035	≤0.035	0.35max	0.35max	Rest

Table 2 – Factorial experimental design

Input parameters	**Low level**	**High level**	**Response**
Cooling condition	MQL	NF MQL	Surface roughness R_a (μm)
Cutting speed (m/min)	110	130	
Feed rate (mm/tooth)	0.1	0.2	

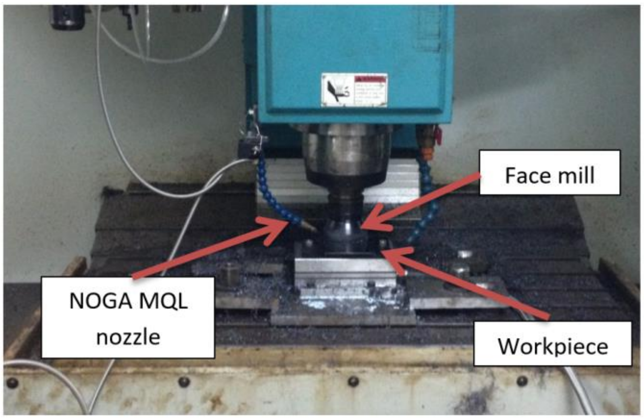

Figure 1. The experimental set up

Figure 2. APMT 1604 PDTR LT30 carbide inserts

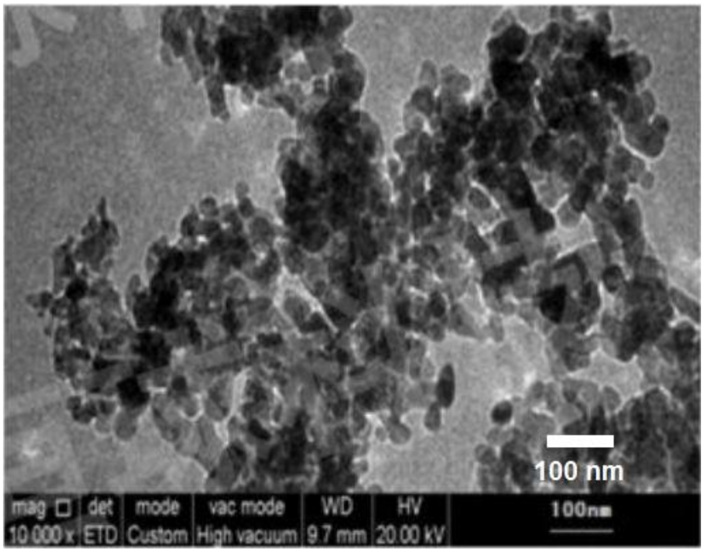

Figure 3. SEM image of Al_2O_3 nanoparticles

3. RESULTS AND DISCUSSION

The hard milling experiments were carried out by following the factorial experiment design and each experiment was repeated 3 times with the same cutting parameter, and then the average value was taken. In Figure 4, Pareto chart shows the influence of input parameters on surface roughness R_a. It can be seen that the feed rate has the greatest influence on machined surface roughness [3], followed by the cooling condition. Besides, cutting speed has a negligible effect on surface roughness value.

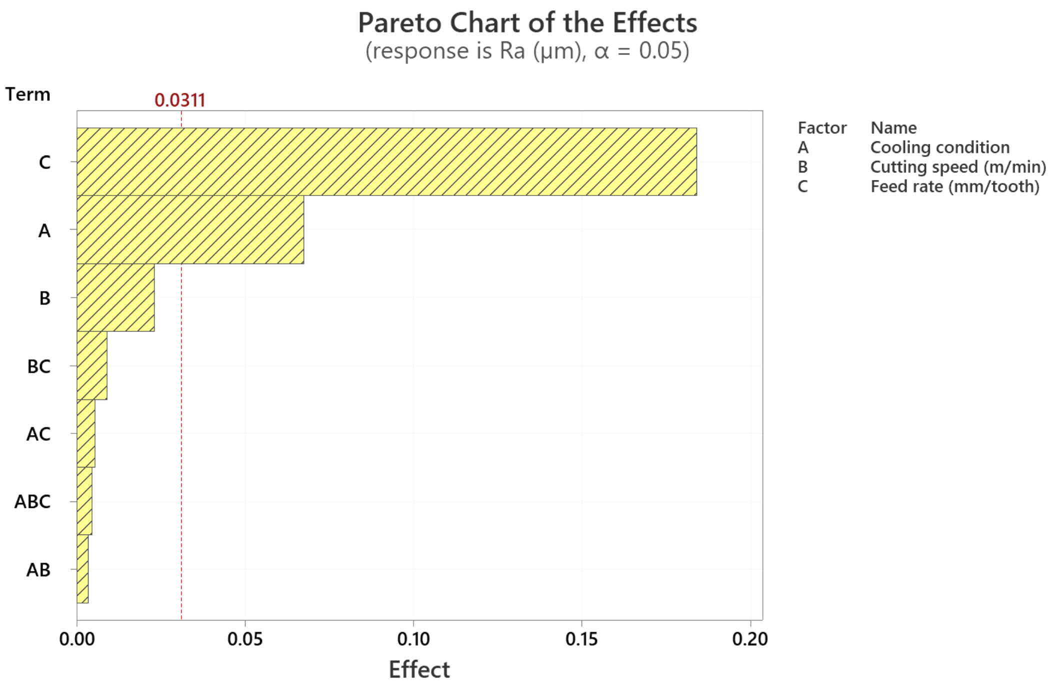

Figure 4. Pareto chart of the effects of input variables on surface roughness R_a

The main effects of input parameters on surface roughness R_a is shown in Figure 5. It can be noticable that for the growing feed rate, the surface roughness R_a increases sharply, which is reflected by the steep slope of the graph. MQL using Al_2O_3 nano cutting oil provides higher machined surface quality than MQL using cutting oil without nanoparticles due to better lubrication ability in the cutting zone [11,12]. Besides, when cutting speed increases, surface roughness decreases slightly [3].

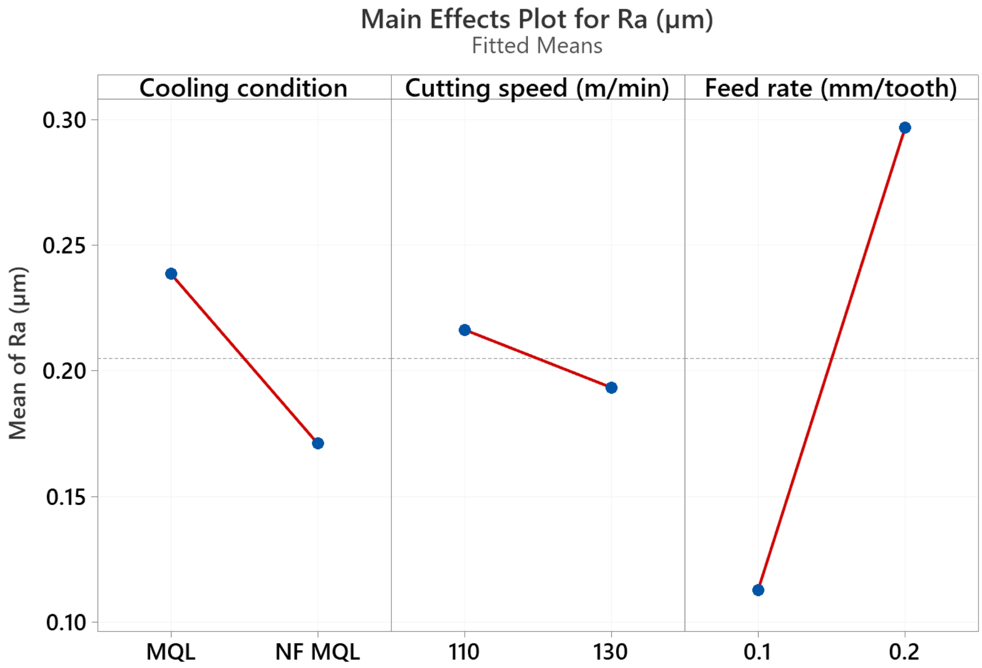

Figure 5. Main effects of input variables on surface roughness R_a

The surface plot in Figure 6 shows the interaction effect of cutting speed and feed rate on surface roughness under MQL environment using cutting oil without nanoparticles. It can be seen that the combination of cutting speed at a high level of 130 m/min and feed rate at a low level of 0.1 mm/tooth will give the smallest surface roughness R_a values.

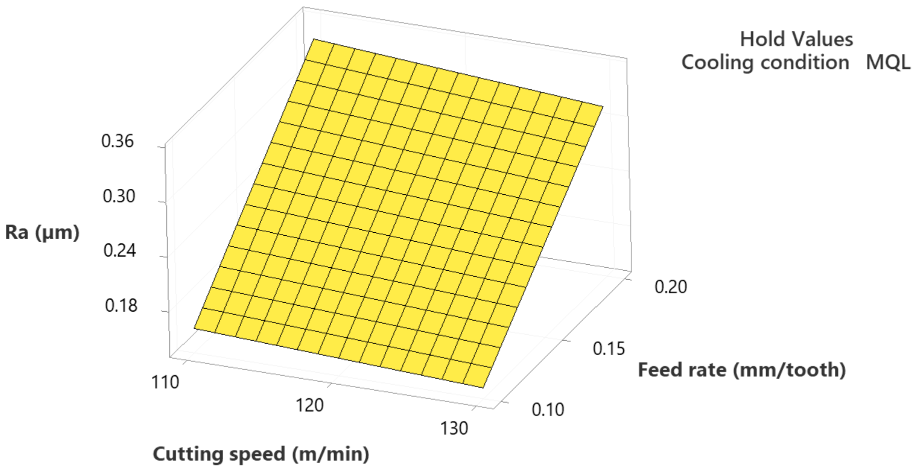

Figure 6. Surface plot of the effects of input variables on surface roughness R_a for MQL condition

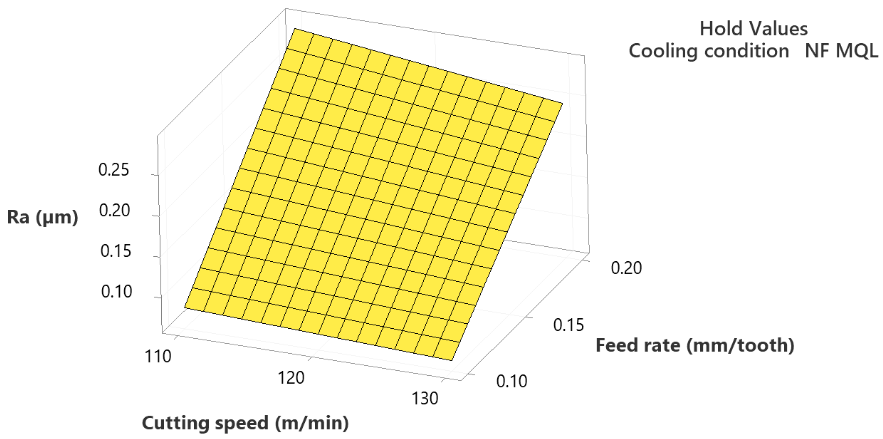

Figure 7. Surface plot of the effects of input variables on surface roughness R_a for NF MQL condition

The surface plot in Figure 7 shows the interaction effect of cutting speed and feed rate on surface roughness under MQL condition using Al_2O_3 nano cutting oil. It can be noticed that the combination of cutting speed at 130 m/min and feed rate of 0.1 mm/tooth will give the smallest surface roughness R_a, but the R_a values are lower than those in MQL using pure cutting oil in Figure 6.

4. CONCLUSION

In this article, minimum quantity lubrication method using emulsion cutting oil with/without Al_2O_3 nanoparticles was successfully applied for the hard milling process of 60Si2Mn steel (50-52 HRC) using coated carbide tools. The effects of cooling condition, cutting speed and feed rate on surface roughness R_a are studied and evaluated. Experimental results indicate that the use of alumina nano cutting oil has improved machined surface quality compared to the cutting oil without nanoparticles due to the improvement of lubrication capability compared to base cutting oil. Among the surveyed parameters, feed rate is the parameter that has the greatest influence on machined surface roughness. Besides, using high cutting speed combined with low feed rate under MQL condition using nano cutting oil gives better surface roughness values.

ACKNOWLEDGMENTS

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

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