SSRG International Journal of Mechanical Engineering
ISSN: 2348 – 8360 /doi:10.14445/23488360/IJME-V8I6P103
Volume 8 Issue 6, 9-12, June, 2021

Study of Oil-In-Water Emulsion Performance In MQL And MQCL Hard Milling of AISI D2 Tool Steel

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Received Date: 07 May 2021
Revised Date: 09 June 2021
Accepted Date: 21 June 2021

Abstract — *The work presents an experimental investigation on the effect of oil-in-water emulsion performance of minimum quantity lubrication (MQL) and minimum quantity cooling lubrication (MQCL) in hard milling of AISI D2 tool steel (60-62 HRC). The response parameter, including cutting force components F_x, F_y, F_z under MQL and MQCL conditions, is studied and compared. The results of this work show that machinability of coated carbide tools improves due to the better cooling and lubricating effects. MQCL shows the better results than MQL due to the superior cooling performance, from which the cutting forces, cutting temperature, and tool wear significantly reduce and therefore tool life prolongs about 57% compared to MQL condition.*

Keywords — *Hard milling, MQL, MQCL, oil-in-water emulsion, cutting force.*

I. INTRODUCTION

In the metal cutting industry, the increase in demand for productivity and product quality puts new requirements on machine tools, machining technology and cutting tools. Along with the development of the materials technology, more and more new materials are born to meet the increasingly strict requirements. The new ones could have many good such as high hardness, high ductility, good strength, etc. at the same time, but their machinability is very low, especially with traditional machining methods such as turning, milling, drilling, etc [1].

In recent years, the demand for machining difficult-to-cut materials is growing while ensuring the surface quality, especially for heat-treated steels with high hardness and strength [2]. The conventional finishing solution is grinding; however, the low productivity and the use of coolant, which causes negative effects on the environment, are the main disadvantages [3]. To overcome this problem, hard machining technology was born and developed to meet the increasing demand for higher productivity, surface quality and reduce manufacturing costs. In addition, the cutting process under dry condition, completely eliminating the cutting fluids, is considered an environmental friendliness solution, suitable with the trend of sustainable production today [3]-[5]. However, the enormous amount of heat generated from the cutting zone is a huge challenge, making the selection of cutting tools a key factor, which greatly affects machining performance. The cutting inserts for hard machining are usually required for high grade such as coated cemented carbide [6]-[8], ceramics [9], [10], (P)CBN (Polycrystalline Cubic Boron Nitride), PCD (Cubic Boron Nitride) tools [11]. However, the very high cutting temperature accelerates tool wear and reduces the life and the quality of the machined surface. In addition, it also causes the difficulty to handle and check, and adversely affects the microstructure of subsurface such as the formation of the white layer [12], [13].

Minimum quantity lubrication (MQL) and minimum quantity cooling lubrication (MQCL) technologies have been researched and applied as an alternative to dry and flood condition. The introduction of the coolant into the cutting zone in the form of oil mist under high air pressure helps to provide high lubrication efficiency and reduce the friction coefficient, thereby decreasing cutting forces, cutting temperature, tool wear and improving cutting performance, surface quality and tool life [14]-[20]. There have been many studies presenting the effectiveness of MQL in hard machining, but the low cooling capacity is the main drawback of this technology [3]. MQCL technology has been considered a solution to overcome the disadvantage of MQL technology, but the studies are still very limited [21]. In this paper, the author made an experimental study on the lubricating and cooling capacity of MQL and MQCL methods using oil-in-water emulsion for hard milling of AISI D2 steel (60-62HRC).

II. MATERIAL AND METHOD

The experimental set up is shown in Figure 1. Mazak vertical center smart 530C was used to conduct the experiments. The APMT 1604 PDTR LT30 PVD submicron carbide inserts (made by LAMINA TECHNOLOGIES) was utilized. The compressed air, air pressure regulator, and oil-in-water emulsion 5% were used for MQL and MQCL systems. Kistler quartz three-component dynamometer 9257BA was used for directly measuring cutting forces. In this study, the samples of AISI D2 tool steels with the hardness of 60-62 HRC were used. The chemical composition is shown in Table 1.

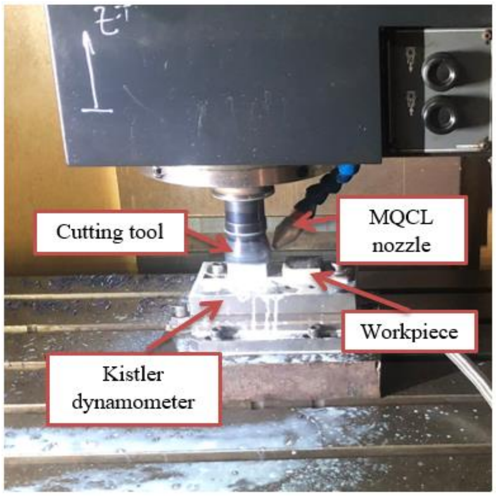

Fig 1. Experimental set up

The cutting condition is given by Table 2. The parameters of MQL and MQCL systems are air pressure of 6 Bar and flow rate of 30 ml/h. The oil mist temperature from the MQCL system based on the principle of Ranque-Hilsch vortex tube [22]-[24] is about 4–8°C. Each trial is repeated by three times under the same cutting condition and taken by the average values. Hard milling process is conducted under MQL and MQCL conditions using oil-in-water emulsion as the based fluid.

TABLE 1

Chemical composition of AISI D2 steel (According to American Society for Testing and Materials (ASTM) A681)

Element	(%)
C	1.4 – 1.6
Si	0.1 – 0.6
Mn	0.1 – 0.6
Ni	0.5
Cr	11.0 – 13.0
Mo	0.7 – 1.2
W	0.2 – 0.5
V	0.5 – 1.1
P	0.03
S	0.03

TABLE 2

Cutting condition

Cutting speed (V_c), *m/min*	110
Feed rate (*f*), *mm/tooth*	0.012
Depth of cut (*d*), *mm*	0.12
Base fluid	Oil-in-water emulsion
Cooling and lubricating condition	MQL; MQCL

III. RESULTS AND DISCUSSION

The cutting force components F_x, F_y, F_z under MQL and MQCL conditions are given by Figs. 2-4. The tool life is estimated by using the criteria of the wear land of 0.3mm [25].

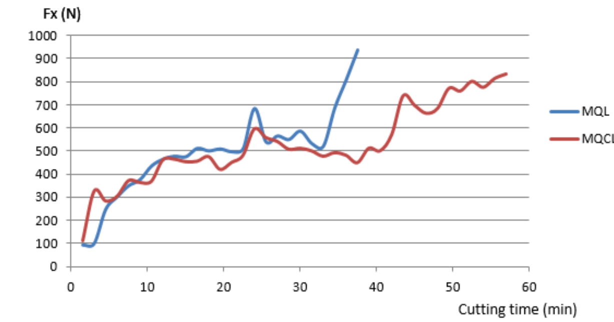

Fig. 2 Cutting force F_x under MQL and MQCL conditions

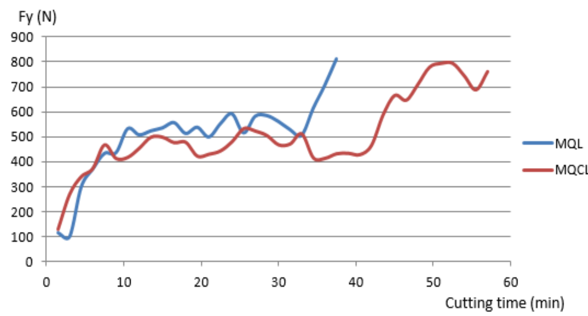

Fig. 3 Cutting force F_y under MQL and MQCL conditions

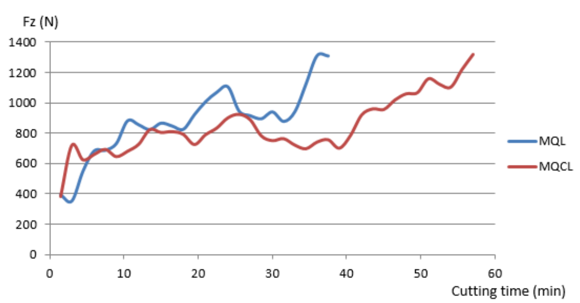

Fig. 4 Cutting force F_z under MQL and MQCL conditions

From the obtained results, it clearly indicates that the cutting forces increase with cutting time. In the first period (about 32 minutes), there is a little difference between the values of cutting force component F_x, F_y, F_z under two different techniques. However, the cutting forces under MQCL condition are lower than those under MQL, which proves the better cooling and lubricating effects of MQCL. For the cutting time after 32 minutes, the sharp distinction is clearly observed. F_x, F_y, F_z under MQL condition rapidly increase and the tool life ends at 35 minutes due to the limitation of cooling performance, so the cutting temperature goes up and accelerates the wear rate. In contrast, the values of F_x, F_y, F_z under MQCL condition tend to decrease at 40 minutes and then increase. The tool life under MQCL ends at 55 minutes, about 57% higher than that under MQL, which indicates the improvement of hard milling performance. On the other hand, the oil-in-water emulsion will increase the viscosity because of low temperature generated from MQCL nozzle, which contributes to form the oil mist in cutting zone. Hence, the friction is reduced, so the cutting forces and cutting temperature decrease and the tool life prolongs. The cutting capability of carbide inserts is improved by using MQL and MQCL conditions, which can be effectively used for machining the hardened steel with high hardness (60-62 HRC), about 20% higher than that of manufacturer's recommendations.

VI. CONCLUSIONS

The application of MQL and MQCL techniques using oil-in-water emulsion as the based fluid for hard milling of AISI D2 (60-62HRC), grouped in the difficult-to-cut materials, was investigated in terms of cutting force components F_x, F_y, F_z. The work results show the difference in cooling and lubricating effects between MQL and MQCL. The values of cutting forces increase with cutting time. Moreover, MQCL shows the better results than MQL, which is reflected by the reduction of cutting forces and longer tool life. The findings prove that cooling efficiency significantly enhances under MQCL, which encounters the enormous amount of cutting heat generated from contact zone. On the other hand, the viscosity of oil-in-water emulsion increases by applying the novel MQCL device, which can create the cool air based on the principle of Ranque-Hilsch vortex tube. This effect contributes to reduce the temperature of oil-in-water emulsion in oil mist form to about 4–8 °C, which helps to improve the lubricating performance. Hence, compared to MQL condition, the hard milling performance under MQCL condition improves, and the tool life prolongs about 57%. The machinability of the normal coated carbide inserts with low cost also improves and they can be effectively used for machining AISI D2 tool steel with high hardness (60-62HRC) in proper tool life, which is 20% higher than that of manufacturer's recommendations

In further research, more investigations will be concentrated on the based cutting fluids like vegetable oils for MQL and MQCL system aimed to sustainable production.

ACKNOWLEDGMENT

The study had the support of Thai Nguyen University of Technology, Thai Nguyen University, Vietnam

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