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An Investigation on Effects of Minimum Quantity Lubrication Technique on Surface Roughness in the Hard Milling Process

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ABSTRACT: The main objective of this paper is to study the effects of input parameters including the cooling lubrication modes, cutting speed (V), and feed rate (f) on surface roughness in hard milling. The full factorial experimental design is used to investigate the main effects of each parameter and the interaction effect. The obtain results show that the efficiency of the cutting process under MQL environment is significantly improved when compared to dry cutting, which proves the better lubricating performance of MQL. Besides, the feed rate and the interaction effects between the cooling lubrication modes and cutting cause the great influences on the surface roughness. Furthermore, the appropriate sets of parameters to achieve the smaller surface roughness are provided with V=70-80m/min and f =0.08 – 0.086 mm/tooth for dry condition and V=90-110m/min and f =0.08 – 0.092 mm/tooth for MQL mode.

KEYWORDS: Hard machining, hard milling, Minimum Quantity Lubrication, vegetable oil, surface roughness.

1. INTRODUCTION

Metal cutting processes play the important roles in the mechanical engineering industry, because they can create almost all the shapes from simple to complex ones with high dimensional accuracy and surface quality [1]. They are also capable of processing many different types of materials and creating complex parts that are difficult to create with other processing methods. In the modern production, especially with the development of CNC machines, the machining processes contribute to improve the productivity, accuracy and product quality, thereby becoming an important foundation of many industries such as precision mechanics, automobiles, aviation or electronics [2]. Coming along with the trend of green and sustainable machining, the cutting methods also have new motivations in minimizing negative impacts on the environment. One of the main causes of environmental pollution is the use of industrial cutting oils with wet/flood condition [3]. The used industrial cutting oils become a serious problem for the environment if discharged directly. At the same time, the cost of collecting and treating them is also very expensive, increasing the manufacturing cost [2]. However, cutting oils are still necessary in lubricating and cooling the contact zones. Dry machining, which means the complete elimination of cutting oils, has been widely applied in industrial production. This technology shows environmental friendliness, but the selection of cutting tool material and cutting parameters plays a very important role. High heat and cutting forces are common problems in dry machining, especially when machining difficult materials such as hardened steels [2,4]. The high heat and cutting forces generated from the cutting zone cause the reduction in the hardness and wear resistance of the cutting tool, accelerating tool wear and reducing its tool life [5,6]. Therefore, the application of environmentally friendly cooling lubrication technologies is becoming an urgent need.

In recent years, MQL technology has emerged as a suitable candidate to meet the requirements of cooling lubrication in the cutting zone while ensuring environmental friendliness [7]. The application of vegetable oils or biodegradable oils for MQL technology is a promising research direction. Many studies have shown the effectiveness in improving the efficiency of the machining process compared to dry and flood cutting. The improvement in the machined surface quality when machining with MQL mode is reported in [8]. In the study on the performance of MQL machining [9], the cutting force was reduced and the tool life was improved. However, the studies on the application of MQL technology for hard milling are still limited. Therefore, this study aimed to investigate the effect of MQL technology using rapeseed oil on the surface quality in the hard milling process of 60Si2Mn steel. The results were compared with dry mode to evaluate the effectiveness of MQL technology.

2. METHODOLOGY

The VMC 85S milling center was used to implement the experimental trials. The external MQL system include the MQL nozzle, pressure regulator, air flow rate valve, and rapeseed oil. The APMT 1604 coated carbide inserts and hardened 60Si2Mn steel samples (50-52 HRC) were used for hard milling experiments.

Figure 1. Experimental set up

The full factorial experimental design was used to study the effects of technological parameters (cooling/lubrication modes, cutting speed, and feed rate) on the surface roughness R_a in the hard-milling process of 60Si2Mn. The input parameters and their value levels/types are shown in Table 1. The experimental matrix was shown in Table 2.

Table 1. Input parameters and their levels

No.	Input parameters	Symbol and Unit	Low level/Type	High level/Type	Response
1	Cooling/Lubrication modes	C/L modes	Dry	MQL	Surface roughness R_a (µm)
2	Cutting speed	*V* (m/min)	70	110	
3	Feed rate	*f* (mm/tooth)	0.08	0.12	

Table 2. Full factorial experimental matrix

StdOrder	RunOrder	CenterPt	Blocks	C/L modes	Cutting speed (m/min)	Feed rate (mm/tooth)
3	1	1	1	Dry	110	0.08
6	2	1	1	MQL	70	0.12
4	3	1	1	MQL	110	0.08
1	4	1	1	Dry	70	0.08
2	5	1	1	MQL	70	0.08
8	6	1	1	MQL	110	0.12
5	7	1	1	Dry	70	0.12
7	8	1	1	Dry	110	0.12

3. RESULT AND DISCUSION

The experiment was conducted by following the experimental matrix and the surface roughness values R_a were measured after each cutting trial. The values of surface roughness were measured 3 times and the average values were taken. Figure 2 shows the main effect of the investigated parameters on the surface roughness R_a. It can be seen that the MQL mode gives better efficiency than dry cutting due to the better lubrication performance [9]. The feed rate has a great influence on R_a. When the feed rate f is increased from

0.08mm/tooth to 0.12mm/tooth, the surface roughness values R_a increase sharply. In contrast, the surface roughness values R_a decrease when the cutting speed V is increased from 70m/min to 110m/min. The interaction effects between the investigated variables are shown in Figure 3. It can be clearly seen that the cooling lubrication modes and cutting speed have a larger interaction effect than the remaining interaction effects.

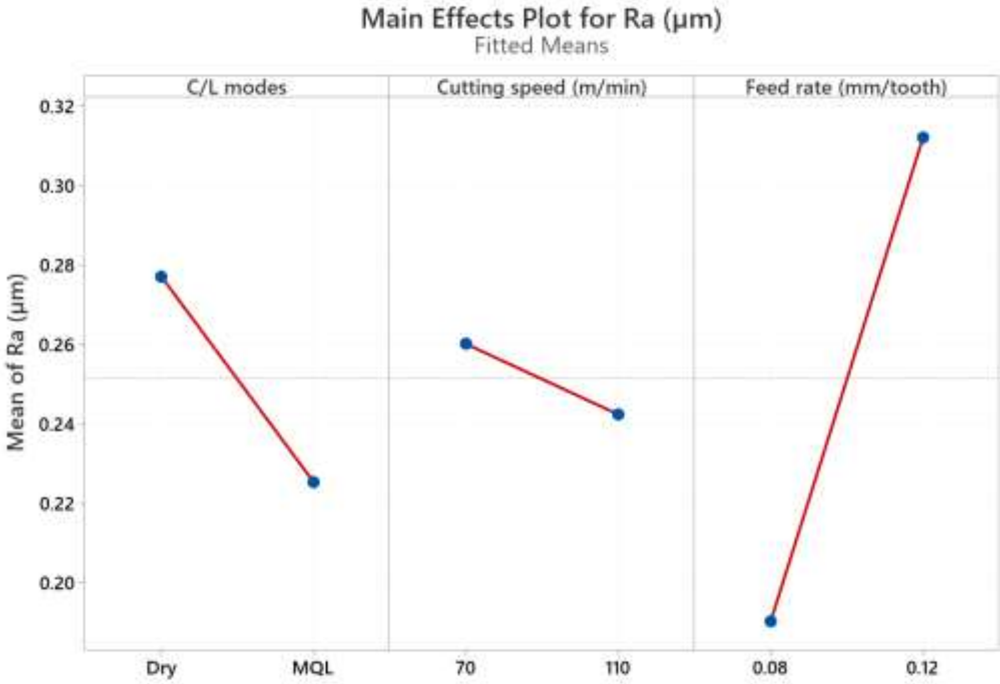

Figure 2. Main effects of the survey parameters on the surface roughness R_a

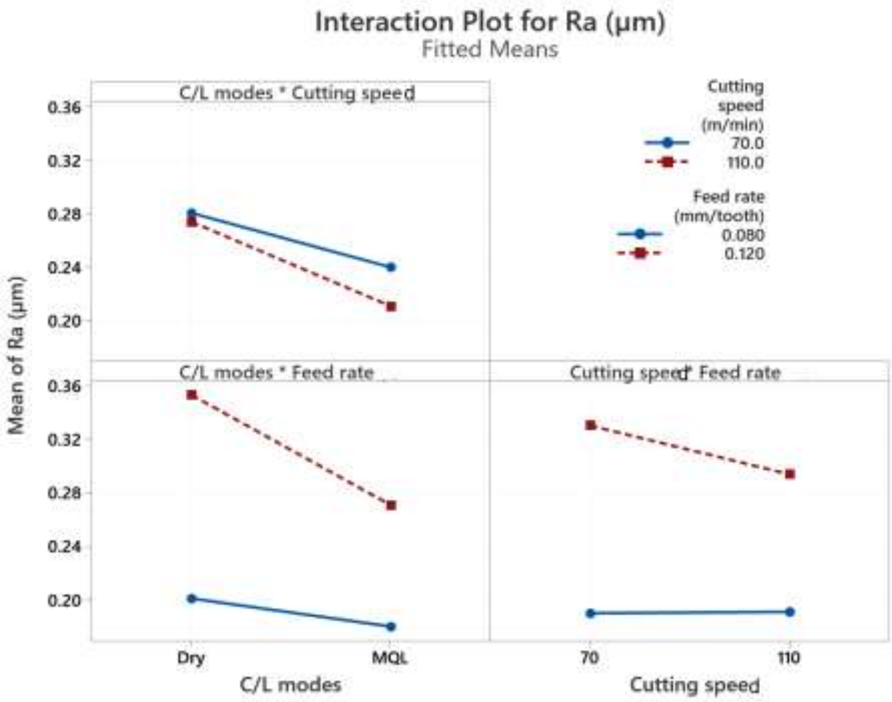

Figure 3. Interaction effects between the survey parameters on the surface roughness R_a

In the dry condition, the use of the low level of cutting speed combined with low feed rate will achieve the smaller surface roughness values. Specifically, V=70-80m/min and f =0.08 – 0.086 mm/tooth are chosen to achieve R_a <0.2µm (Figure 4).

Under MQL environment, the high cutting speed combined with the low feed rate will get the smaller surface roughness values. Looking in detail, V=90-110m/min and f =0.08 – 0.092 mm/tooth are chosen to reach R_a <0.18µm (Figure 5).

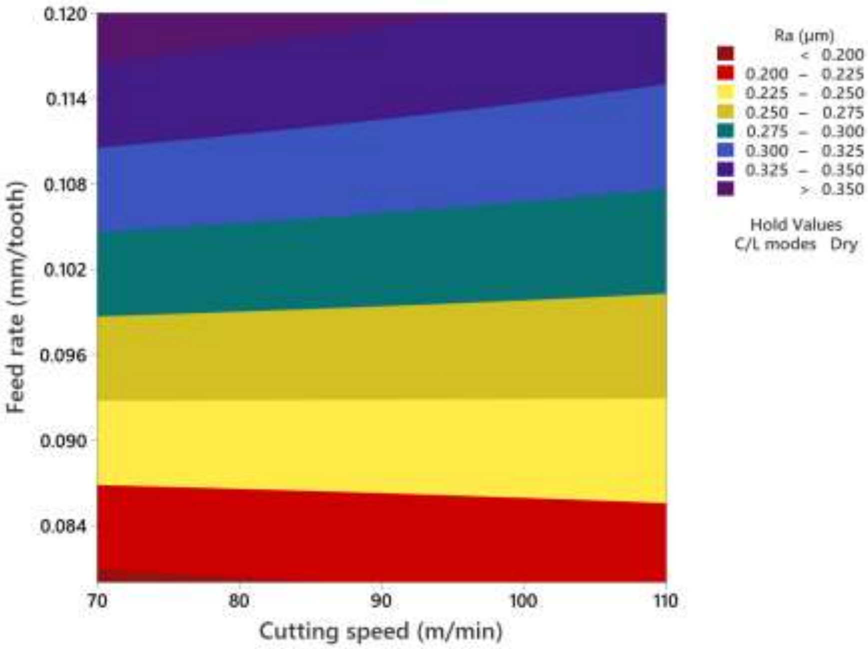

Figure 4. Contour plot of the effects of the investigated parameters on R_a under dry condition

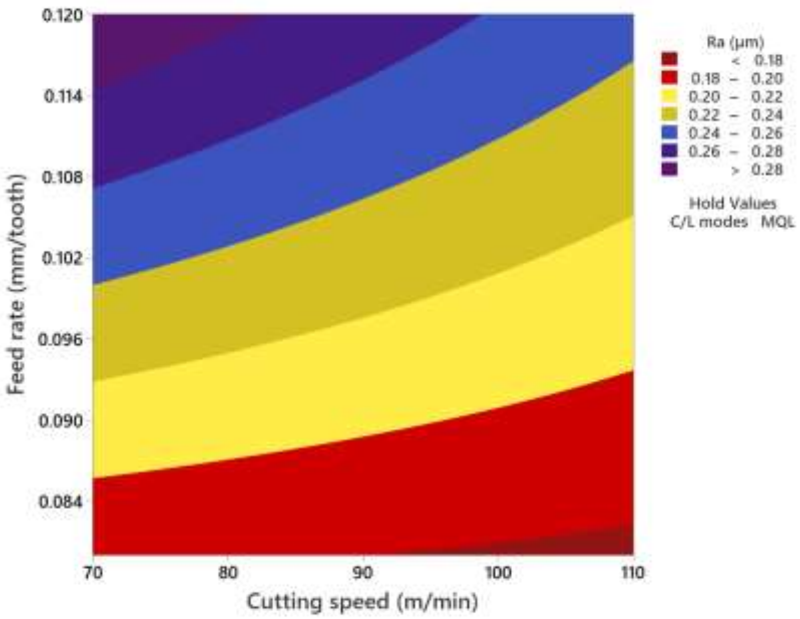

Figure 5. Contour plot of the effects of the investigated parameters on R_a under MQL condition

4. CONCLUSION

In the presented work, the MQL technique using vegetable oil was successfully applied to improve the hard milling efficiency. The effects of the input parameters (the cooling lubrication modes, cutting speed, and feed rate) on surface roughness R_a were studied and evaluated by using the full factorial experimental design. Based on obtained results, hard milling under MQL condition brings out the better surface quality when compared to dry cutting due to the superior lubricating effect. The feed rate causes the most dominant influence on surface roughness. Besides, the technological guidelines for further research and application of dry and MQL hard milling were provided. For dry condition, V=70-80m/min and f =0.08 – 0.086 mm/tooth are selected to achieve R_a <0.2µm. For MQL mode, V=90-110m/min and f =0.08 – 0.092 mm/tooth are chosen to reach R_a <0.18µm.

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