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Ananalysisofthe cutting force in the hard milling process under dry and MQL conditions

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ABSTRACT
The application of sustainable cooling lubrication methods has been growing in concerns in the metal cutting field. The studies on this research direction are necessary and needed to be focued. In this paper, the main objective is to investigate the influences of cooling lubrication modes, cutting speed (V), and feed rate (f) on the cutting force F_z in the hard milling process of 60Si2Mn by using the full factorial experimental design. The main effects and interaction effects of input variables are analysed and compared to dry condition. Based on the obtained results, the MQL condition shows the better lubricating performance than dry cutting, so the cutting force F_z was significantly reduced. The cooling lubrication modes caused the most dominant effect on F_z, followed by feed rate and then cutting speed. Also, the appropriate set of factors to achieve the smallercutting force $F_z$are provided with the cutting speed V=110m/min and the feed rate f =0.08 mm/toothfor both dry and MQL conditions.
Keywords: *Hard machining; hard milling;dry; Minimum Quantity Lubrication;rapeseed oil, cutting force.*

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I. INTRODUCTION

In recent years, hard machining technology has been increasingly applied in manufacturing practices. This technology uses cutting tools with geometrically defined cutting edges (GDE) to directly cut the heat-treated steels [1]. It demonstrates the efficiency in productivity, flexibility, and environmental friendliness while ensuring dimensional accuracy and surface quality of the machined parts [2].Hard milling is one of the processes in hard machining technology and is widely applied in the mold industry. With advancements in cutting tool materials and the widespread use of CNC machine tools, hard milling can now be performed from small workshops to large production lines [2]. Because the cutting process is discontinuous, the use of flood condition faces many difficulties due to the risk of thermal shock and negative environmental impacts from the used coolants [3]. Therefore, dry hard milling is the simplest solution to overcome these problems. However, the high cutting forces and heat generated from the cutting process make it highly demanding in terms of tool material selection and cutting parameters [4]. The commonly used cutting tool materials include coated carbide, ceramics, CBN, and so on. In addition, the selection of cutting parameters plays a crucial role in achieving the efficient hard milling. The hightool wear rate and degradation of hardness and wear resistance of cutting tools have been observed in [5], which has reduced productivity and negatively affected tool life and machined surface quality. The increase of tool costs are also a factor to consider, potentially leading to a decrease in the competitiveness of hard milling technology [6]. Therefore, the use of environmentally friendly lubrication and cooling technology for hard milling is necessary.In recent years, there have been many studies applying MQL technology to hard machining processes. The research results indicate that the efficiency of the cutting process is improved in terms of cutting force and surface quality due to the good lubrication effect of MQL technology. In addition, the amount of tool wear is significantly reduced compared to dry hard milling [7]. The usage of vegetable oils as the base cutting oil for MQL technology is a solution that not only ensures lubrication but also ensures environmental friendliness [8,9]. However, the study in this direction for hard milling processes is still limited.Therefore, in this paper, the authors aim to investigate the influence of technological parameters (lubrication/cooling mode, cutting speed, and feed rate) on the cutting force in hard milling of 60Si2Mn steel (50-52HRC) under dry and MQL conditions.

II. METHODOLOGY

The hard milling experiments were conducted on VMC 85S milling center, and the set up of experimental system was shown in Figure 1.The external MQL system include the MQL nozzle, pressure regulator, air flow rate valve, and rapeseed oil.istler quartz three-component dynamometer (9257BA) was used to measure the cutting forces during the hard milling process. The APMT 1604 coated carbide inserts were selected. The samples werethe hardened 60Si2Mn steels (50-52 HRC) and theirelemental composition was shown in Table 1.

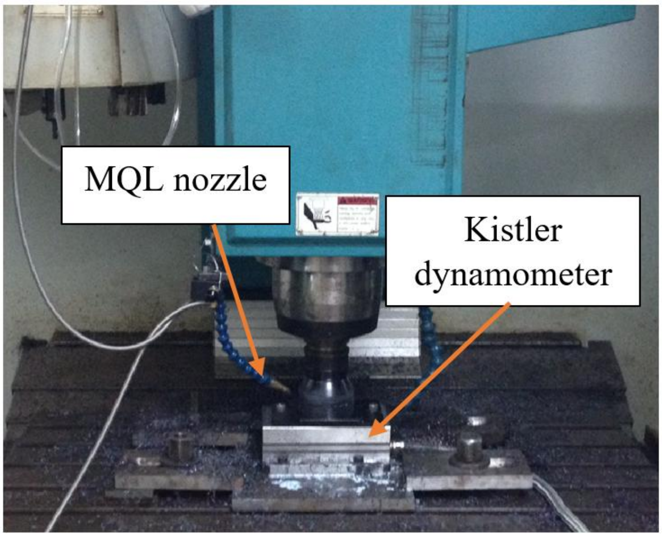

Figure 1. Set up of hard milling experiments

Table 1. Elemental composition of 60Si2Mn steels

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

The full factorial experimental design with the help of Minitab 19 software was applied to inveatigate the effects of technological parameters (cooling/lubrication modes, cutting speed, and feed rate) on the cutting force$F_z$inthe hard milling process of 60Si2Mn. The surveyed parameters and theirvalue levels/types are shown in Table 2. Table 3 presents the full factorial experimental matrix.

Table 2. Surveyed parameters and their levels/types

No.	Surveyed parameters	Symbol and Unit	Low level/Type	High level/Type	Output
1	Cooling/Lubrication modes	C/L modes	Dry	MQL	Cutting force F_z (N)
2	Cutting speed	V (m/min)	70	110	
3	Feed rate	f (mm/tooth)	0.08	0.12	

Table3. 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

III. RESULT AND DISCUSION

The experiment trials were carried out by following the full factorial experimental matrix and the cutting force component F_z was directly measured after each cutting trial. Figure 2 illustrates the main effect of the investigated variables on the cutting force F_z. It was noticeable that the cooling/lubricating modes cause the strong effects on F_z, and the MQL condition was effective in reducing the cutting force when compared to dry cutting. It proves that the better lubricating performance of MQL technique [9,10]. The increase of cutting speed from 70m/min to 110m/min contributes to reduce the cutting force. In contrast, the growing feed rate from 0.08mm/tooth to 0.12mm/tooth cause the growth of cutting force due to the increase of the cross-section cutting layer [3].

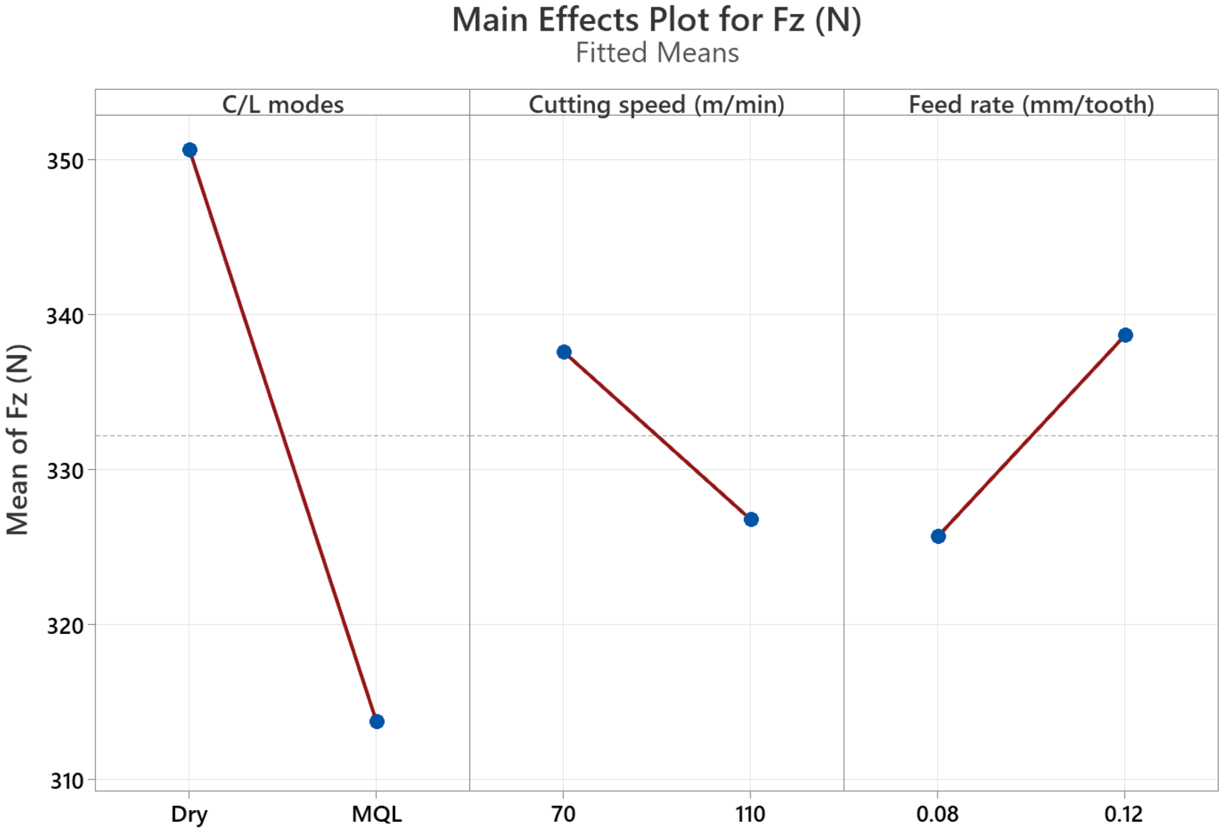

Figure 2. Main effects of the survey parameters on the cutting force F_z

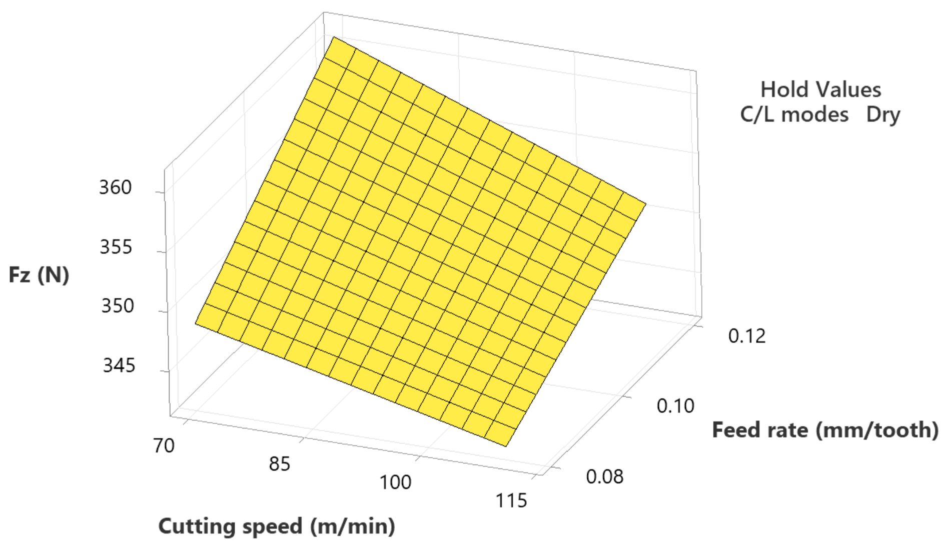

Figure 3. Interaction effectsof cutting speed and feed rate on the cutting forceF_z under dry condition

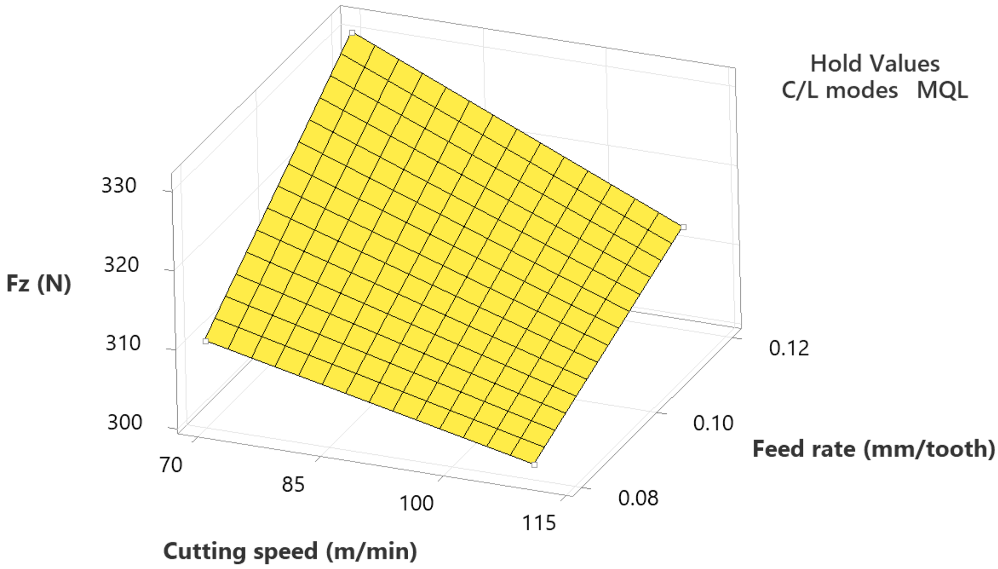

Figure 4. Interaction effectsof cutting speed and feed rate on the cutting forceF_z under MQL condition

If thedry condition is fixed, the use ofthe high level of cutting speed combined with the low feed rate will achieve the smaller cutting force F_z. Concretely,V=110m/min and f =0.08 mm/tooth are chosen to achieve the smaller F_z (Figure 3). Under MQL environment, the similar trend was observed (Figure 4).

IV. CONCLUSION

In this artcle, the effects of cutting conditons on the cutting force F_z under dry andMQL conditionusing rapeseed oil were analysed by using the full factorial experiemental design. The obtained results indicated the better lubricating effectiveness resulted from MQL method when compared to dry cutting. Hence, the cutting force F_z was significantly reduced. Among the surveyed factors, the cooling/lubricating modes had the strongest influence on the cutting force F_z, followed by the feed rate and then the cutting speed. For both dry and MQL conditions, the cutting speed V=110m/min and the feed rate f =0.08 mm/tooth are chosen to achieve the smaller F_z. In the future work, more investigations should be focused on the lubricating mechanism, tool wear and tool life.

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