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Effects of MQL and MQCL Parameters on Surface Roughness in Hard Milling of SKD 11 Tool Steel

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Abstract
This paper presents the empirical research on the effects of technological parameters of the two methods MQL and MQCL on surface roughness in hard milling SKD11 tool steel. The factorial experiment design is used to evaluate the influence of each input parameter. The obtained results show that the investigated factors have very little influence on the surface roughness values. This result also provides technology guides for further studies to improve the surface quality of hard milling. In addition, the influence of the parameters is also evaluated in detail.

Keywords — *MQL, MQCL, hard milling, hard machining, difficult-to-cut material, surface roughness*

I. INTRODUCTION

SKD11 is a high-carbon and high-chromium alloy tool steel widely used to make long-life high-precision cold-work dies. SKD11 tool steel has good wear resistance and size ability. After heat treatment, it can reach high hardness (60-62 HRC), making this type of alloy steel suitable for many industrial applications.

Due to its high chromium content and high hardness, this steel is grouped in difficult-to-cut materials [1]. The traditional solution for finishing is grinding and EDM. However, these two processes' main disadvantages are very low productivity, high machining cost, and low flexibility with complex shapes. In addition, the grinding process also adversely affects the environment by using a large amount of cutting fluids to cool the cutting zone [2].

Hard machining technology was developed to be a solution to overcome these problems. This technology uses cutting tools having geometrical cutting edges to machine directly on high hardness materials (typically 45 HRC or more) [3]. The advantages of hard machining technology are outstanding productivity, high flexibility, and machine parts with complex shapes. In addition, the use of coolant during machining makes this technology eco-friendly. The hard machining methods include hard turning, hard milling, hard drilling, and so on. Hard milling is a machining process that attracts the special attention of scientists and manufacturers [4]. However, the amount of heat generated from the cutting zone is very large, so the selection of cutting tools must be directed to the inserts made of materials with high hardness, good heat resistance, and abrasion: coated carbide, ceramic CBN, and so on. This has narrowed the applicability and increased production costs. Large cutting temperature also accelerates the tool wear rate, affecting the tool life, machined surface quality [5-7].

To improve the hard milling process's efficiency, many solutions have been proposed and studied, such as using MQL and MQCL techniques, or using nanofluid, and so on [8-11]. Due to the many factors affecting the cutting efficiency, these are new research approaches, so it is necessary to have further studies to evaluate and give guidance to develop hard milling technology. This paper aims to investigate the effects of spraying methods (MQL and MQCL), fluid types (emulsion and soybean oil), based fluid with/without nanoparticles, airflow pressure, airflow rate on surface roughness in hard milling of SKD 11 steel.

MATERIAL AND METHOD

A. Design of experiment

Minitab 18 software is used for designing the experiment. The experiment is carried out by following the factorial design 2^{k-p}, resolution III, with five variables (k =5) and two for each variable (p=2). The factorial design $2^{5-2}_{III} = 8$ is chosen. The experiment's design is shown in Table 1, and each trial is repeated 3 times under the same cutting parameters.

Table 1. The investigated variables and their levels in the factorial design 2^{k-p}

No	***Investigated variables***	***Low (-1)***	***High (+1)***	***Response variable***
1	Fluid type (x_1)	Emulsion	Soybean oil	Surface roughness R_a.
2	Spraying method (x_2)	MQL	MQCL	
3	Nanoparticles (x_3)	Yes	No	
4	Airflow pressure (x_4), Bar	5	7	
5	Airflow rate (x_5), l/min	150	250	

B. Experimental devices

The experimental setup is shown in Figure 1. Mazak vertical center smart 530C (Japan) is used to conduct the experiments. Tool holder type with the designation SHIJIE BAP 400R-50-22-4T. APMT 1604 PDTR LT30 PVD submicron carbide inserts are utilized. The samples are SKD 11 sheets of steel (56 HRC) with 90 mm × 48 mm × 50 mm. The chemical composition of SKD 11 steel (according to JIS G4404:1983) is given in Table 2. SJ-210 Mitutoyo made by Japan is used for measuring surface roughness.

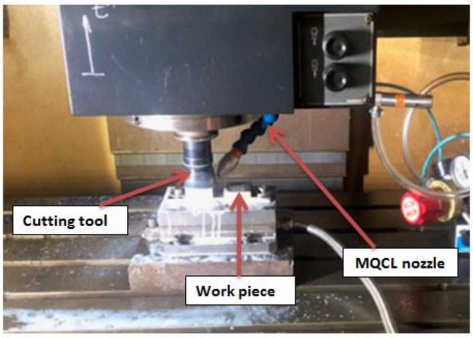

Fig 1. Experimental setup

Table 2. Chemical composition of SKD 11 steel (According to JIS G4404:1983).

Chemical Composition (%)										
C	**Si**	**Mn**	**Ni**	**Cr**	**Mo**	**W**	**V**	**Cu**	**P**	**S**
1.4–1.6	0.4	0.6	0.5	11.0–13.0	0.8–1.2	0.2–0.5	≤0.25	≤0.25	≤0.03	≤0.03

III. Results and discussion

The experiments are carried out with test run order, and the values of surface roughness R_a are measured, as shown in Table 3.

Table 3. Design of the experiment with test run order and output in term of surface roughness

Std Order	*Run Order*	x_1	x_2	x_3	x_4	x_5	R_a (μm)
1	15	Emulsion	MQL	No	7	250	0.084
2	16	Soybean oil	MQL	No	5	150	0.089
3	13	Emulsion	MQCL	No	5	250	0.11
4	3	Soybean oil	MQCL	No	7	150	0.106
5	4	Emulsion	MQL	Yes	7	150	0.093
6	6	Soybean oil	MQL	Yes	5	250	0.111
7	1	Emulsion	MQCL	Yes	5	150	0.107
8	10	Soybean oil	MQCL	Yes	7	250	0.106
9	7	Emulsion	MQL	No	7	250	0.113
10	8	Soybean oil	MQL	No	5	150	0.092
11	5	Emulsion	MQCL	No	5	250	0.077
12	9	Soybean oil	MQCL	No	7	150	0.079
13	12	Emulsion	MQL	Yes	7	150	0.085
14	2	Soybean oil	MQL	Yes	5	250	0.108
15	11	Emulsion	MQCL	Yes	5	150	0.069
16	14	Soybean oil	MQCL	Yes	7	250	0.094

Minitab 18 software is used with significance level $\alpha = 0.05$. The regression models of surface roughness R_a is given by Equation 1 with R^2 equal to 25.01%. Pareto chart evaluates the influence of the investigated variables on surface roughness, Ra shown in Figure 2. The effects of factors on R_a are given in Figure 3.

$$R_a = 0.0756 + 0.00294\, x_1 + 0.0061\, x_2 + 0.00144\, x_3 - 0.00019\, x_4 + 0.000104\, x_5 - 0.00094\, x_2 * x_3 - 0.000039\, x_2 * x_5 \quad (1)$$

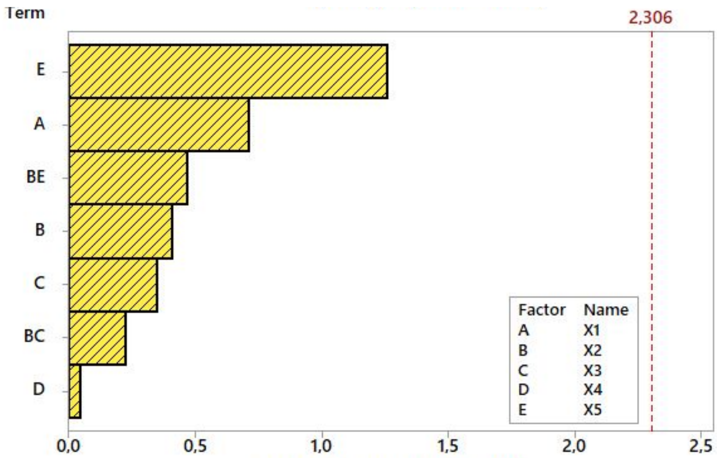

Figure 2. Pareto chart to evaluate the effects of investigated factors on surface roughness R_a

The reference line was 2.306, and the standardized effect value of the investigated factors did not exceed to the right of this line, which means that these factors had very little effect on surface roughness R_a. This result is suitable for theory and practice. The main reason is that, in finish hard milling, the values of surface roughness R_a are small, and the surface texture depends mainly on the geometrical printing factor such as scratches. These values are less affected by the dynamic causes of the cutting process. However, the technology methods applied to improve the surface roughness values bring out a little change but are very meaningful in finish machining.

The effects of investigated factors on surface roughness R_a are shown in Figure 3. The achieved surface roughness R_a is very good (R_a = 0.09 ÷ 0.10 µm), equivalent to that of the grinding process.

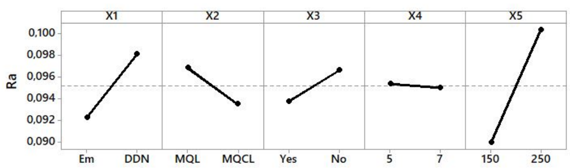

Figure 3. The effects of investigated factors on surface roughness R_a

The effect of the fluid type: Emulsion oil gives better results because it has a small viscosity, which is easy to form oil mist to penetrate the cutting zone. On the other hand, it also has a higher ignition temperature than that of soybean oil, so this kind of fluid is more suitable for hard machining materials.

The influence of the spraying methods: MQCL gives better results than MQL. The reason is that MQCL has a better cooling effect. Moreover, the viscosity depends on the temperature. At low temperatures, the viscosity of the fluid increases and thus improves lubricating performance.

Effects of nanoparticles: The based fluid having nanoparticles is better than the pure one because MoS_2 nanoparticles contribute to increasing the viscosity and the thermal conductivity of the based fluid, which improves the cooling and lubricating effects.

Effect of airflow pressure: The airflow pressure in the investigated range has a small influence on the surface roughness.

Effect of airflow rate: In the investigated range, it is better to use a small air flow rate.

IV. CONCLUSIONS

Experimental studies are conducted to evaluate the effects of input machining parameters, including spraying method, fluid type, the effect of nanoparticles, airflow pressure, airflow rate on surface roughness in hard milling of SKD 11 steel. Factorial design of the experiment is used. The results show that the input machining parameters have very little influence on surface roughness values because the surface roughness in finish milling depends mainly on geometrical printing. Therefore, this result is completely consistent with theory and practice.

Besides, considering each factor's effect, it has been shown that the use of the combination of the MQCL method with emulsion-based nanofluid helps to improve lubricating and cooling in the cutting zone, which contributes to the improvement of machined surface quality.

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