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Effects of the cutting mode on surface roughness in hard turning of 90CrSi tool steel under MQL and nanofluid MQL conditions

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Abstract

The paper aims to study the effects of cooling/lubricating mode, cutting speed, and feed rate on the surface roughness R_a in the hard turning process of 90CrSi tool steel (60 ÷ 62 HRC) under pure MQL and nanofluid MQL conditions. The influences of input parameters were studied by using the factorial experimental design. The results showed that the feed rate is the most influential effect on surface roughness, followed by cooling/lubricating mode and then the cutting speed. Meanwhile, the interaction effects cause the insignificant impacts on the surface roughness R_a. Moreover, MQL technique using Al_2O_3 nano cutting oil, cutting speed of 160 m/min, and feed rate of 0.05mm/rev are the proper selection and should be used to achieve the smaller surface roughness R_a values.

Keywords: Hard Turning; Nanofluid; Al_2O_3 Nanoparticle; MQL; Cutting Speed; Feed Rate; Surface Roughness

1. Introduction

In the field of metalworking, turning is a very common machining method, especially used for manufacturing cylindrical parts. In this process, the workpiece is clamped and rotated on the lathe, while the turning tool performs a translational movement to remove excess metal and shape the part as required [1]. Turning can perform many different operations such as external cylindrical turning, internal cylindrical turning, face turning, thread turning, taper turning, and grooving, thus meeting a wide range of technical requirements in production. This method not only ensures high dimensional accuracy and surface smoothness but also offers good productivity, especially when using CNC turning machines in mass production. Thanks to its flexibility, efficiency, and high degree of automation, the turning process accounts for a significant proportion of the total volume of mechanical machining and plays a crucial role in the manufacturing industry [2].

Hard turning is a high-precision machining operation performed after the workpiece has been hardened or heat-treated to achieve the required hardness and mechanical properties. Because the material now has high hardness and wear resistance, hard turning requires the use of specialized cutting tools such as coated carbide, ceramic, or CBN tools to ensure the cutting efficiency [3]. The goal of hard turning is to remove a very small amount of material, improve dimensional accuracy, roundness, and surface smoothness, potentially achieving very low roughness and tight tolerances. Compared to traditional finishing methods such as grinding, hard turning offers advantages in flexibility, reduced setup times, and increased productivity. Dry turning is a finishing method for heat-treated steel parts (typically with a hardness of 45–65 HRC) without using coolant during the cutting process [3]. The advantages of dry turning include reduced coolant usage and handling costs, environmental friendliness, and simplified technological systems [4]. During dry turning, the heat generated is not cooled by the coolant but mainly dissipates through chips and the surrounding environment. Therefore, the strict selection of cutting parameters is necessary to avoid overheating and

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rapid tool wear [5,6]. To improve the efficiency of dry turning, the application of MQL technology has initially shown effectiveness in improving lubrication while maintaining environmental friendliness [7,8]. Nevertheless, the low cooling efficiency of MQL methods was the main disadvantage and the results were not as expected [9]. MQL using nano cutting oil is a new research direction that helps improve lubrication and cooling efficiency in the cutting zone, thereby improving the efficiency of the machining process [10,11]. However, studies in this direction for hard turning of 90CrSi tool steel are limited [12]. Hence, the authors conducted a study to evaluate the influence of lubricating/cooling mode and cutting parameters on surface roughness R_a in hard turning of 90CrSi steel.

2. Material and Method

The device setup of hard turning experiments is shown in Figure 1. The CS-460x1000 Chu Shing lathe (Pin Shin Machinery Co., LTD, Taichung city, Taiwan) was used to conduct hard turning experiments. 90CrSi steel samples were hardened to reach the hardness values ranging from 60-62 HRC. The chemical composition and mechanical properties of 90CrSi tool steel are given in Tables 1, 2. The MQL system includes MQL nozzle, pressure regulator, air flow valve, the cutting oil. The Al_2O_3 nanoparticles in size of 30 nm were suspended to soybean oil at 0.5% by weight. The prepared mixture was stirred and undergone in ultrasonic vibration for one hour to improve the homogenization of nanoparticles in the based oil [12]. The obtained nanofluid was used directly for MQL system. The surface roughness R_a was measured three times after each cut by Mitutoyo SJ-210 surface roughness tester and the average value was taken. The factorial experimental design was used to study the effects of input machining parameters (Cooling lubricating mode, cutting speed, and feed rate) on surface roughness R_a. The input variables with their levels are given in Table 3.

Table 1 Elemental composition of 90CrSi steel (wt%) according to DIN EN ISO 4957 standard

C	**Si**	**Mn**	**Ni**	**S**	**P**	**Cr**	**Mo**	**W**	**V**	**Ti**	**Cu**
0.85÷ 0.95	1.20÷ 1.60	0.30÷ 0.60	Max 0.40	Max 0.03	Max 0.03	0.95÷ 1.25	Max 0.20	Max 0.20	Max 0.15	Max 0.03	Max 0.3

Table 2 Mechanical properties of 90CrSi steel

Yield strength (Mpa)	**Tensile strength, (Mpa)**	**Elongation (%)**	**Reduction of area (%)**	**Impact strength (kJ/m^2)**
445	790	26	54	390

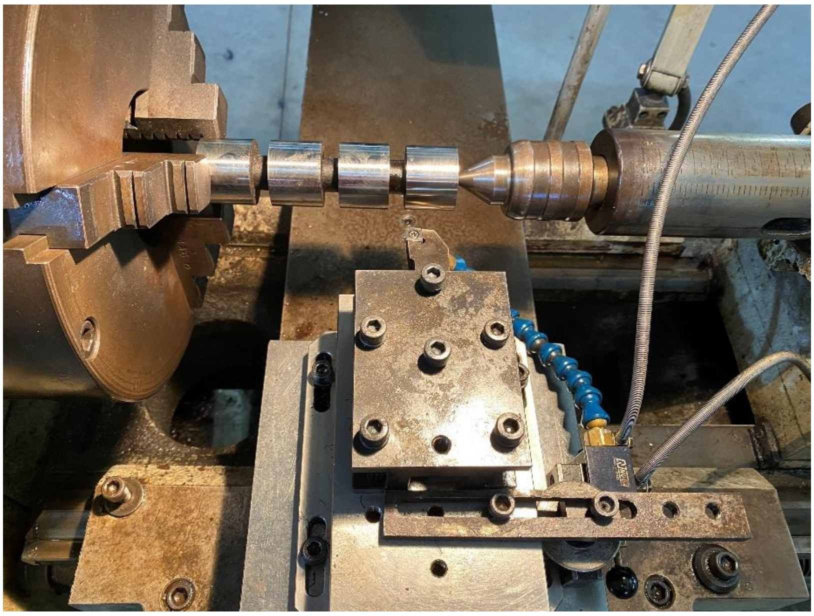

Figure 1 Setup for hard turning experiments

Table 3 Input variables and their levels

Input parameters	Low level	High level	Output parameter
Cooling/lubricating mode (C/L mode)	MQL	NF MQL	Surface roughness R_a (μm)
V (m/min)	100	160	
f (mm/rev.)	0.05	0.15	

3. Results and discussion

The experimental trials of the hard turning process were conducted by following the run order obtained from the factorial experimental matrix. The Pareto chart in Figure 2 presents the influences of each parameter and the interactive effects of the input variables on surface roughness R_a. In Figure 2, it was noticeable that the feed rate causes the strongest impact on surface roughness R_a, followed by cooling/lubricating mode and then the cutting speed. At the same time, the interactive effects have little impact on the response.

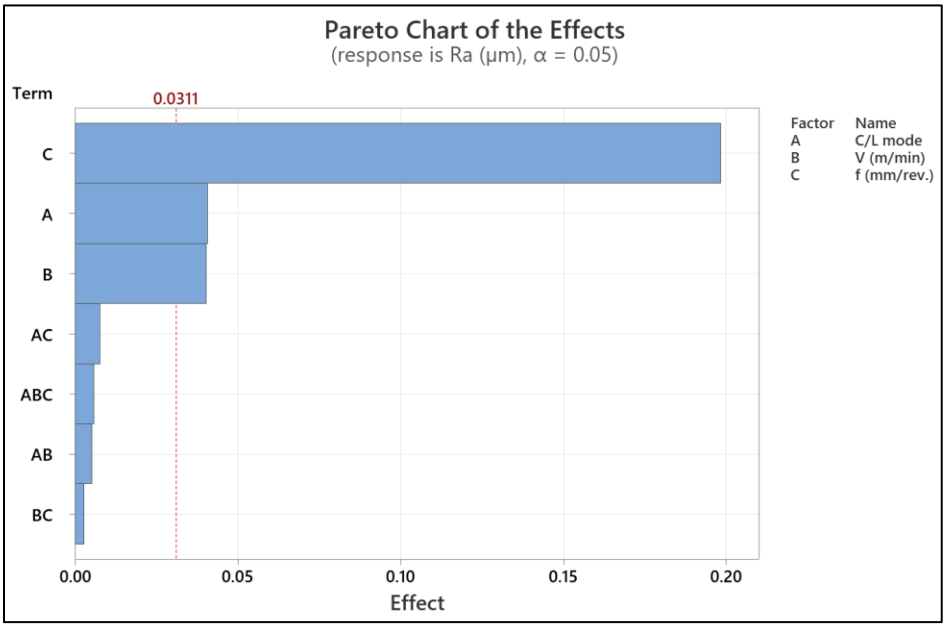

Figure 2 Pareto chart of the effects of input parameters on surface roughness R_a

The main effect of each variable is shown in Figure 3. Surface roughness R_a values grow quickly when the feed rate rises from 0.05 mm/rev. to 0.15 mm/rev, which is explained by the increase in the cutting layer [2]. At the same time, the reduction of surface roughness R_a was observed when the cutting speed increase. The rise of cutting speed from 100 m/min to 160 m/min helps to reduce the surface roughness R_a, which can be explained by the reduction of cutting forces and cutting heat [2,3]. Besides, the reduction of R_a with the use of nanofluid MQL condition links to the better lubrication performance resulted from the presence of Al_2O_3 nanoparticles [11].

Figure 4 is the graph of interaction effects of input machining parameters. The interaction effect between the cooling/lubricating mode and cutting speed causes more influences on surface roughness R_a than the other ones. From the obtained experimental results, MQL using Al_2O_3 nano cutting oil, cutting speed of 160 m/min, and feed rate of 0.05mm/rev should be selected for achieving the smaller surface roughness R_a values.

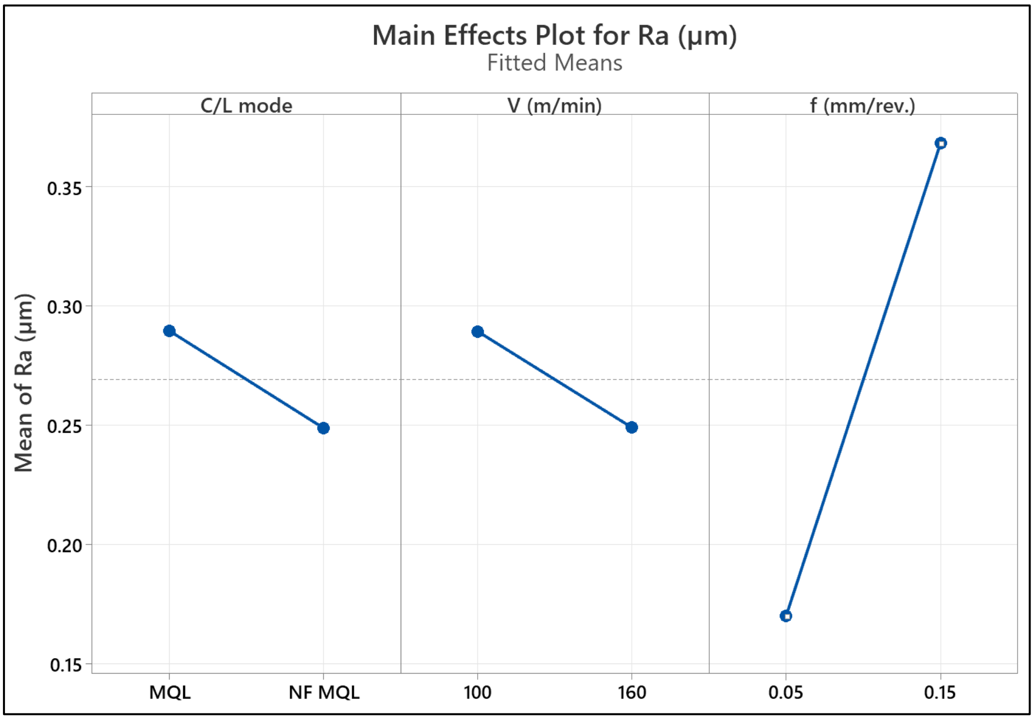

Figure 3 Main effects of input parameters on surface roughness R_a

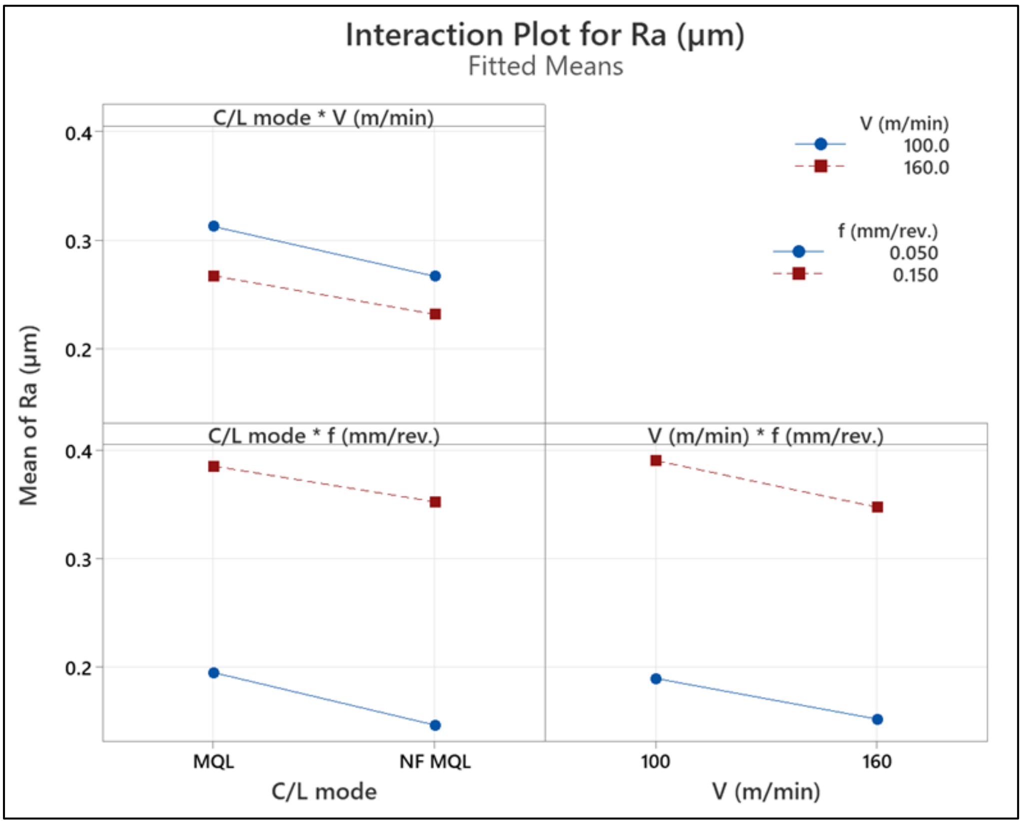

Figure 4 Interaction effects of input parameters on surface roughness R_a

4. Conclusion

In this paper, the effect of pure MQL and MQL using Al_2O_3 nano cutting oil on the surface roughness R_a in the hard turning process of 90CrSi tool steel was studied. Besides, the impacts of the cutting speed and feed rate are studied and evaluated by using the factorial experimental design. Thanks to the superior lubricating characteristic of Al_2O_3 nanoparticles, the nanofluid MQL hard turning performance was improved and provided better results in term of surface roughness R_a when compared to MQL using the based oil without nanoparticles. Regarding the main effect of each variable, the feed rate causes the strongest impact on the surface roughness R_a, followed by the lubrication/cooling mode and cutting speed. In the meanwhile, the interaction effects cause insignificant impacts on the response. To achieve the lower surface roughness R_a values, MQL using Al_2O_3 nano cutting oil, cutting speed v = 160 m/min, and feed rate f = 0.05 mm/rev should be used, which will be an important technological guideline for further research and production practice.

Compliance with ethical standards

Acknowledgments

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