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Research Paper

Analysis effects of machining parameters on surface roughness in hard milling process using Taguchi method

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ABSTRACT
*This work aims to study the effects of input parameters including cutting speed (V), feed rate (f), fluid type (FT) and nanoparticle concentration (NC) on surface roughness in hard milling. Taguchi method and analysis of variance (ANOVA) were used to investigate the effects of each parameter and the interaction effect. Research results show that the efficiency of the cutting process and machinability of carbide inserts are significantly improved by using nano-cutting oil, which proves that the lubricating and cooling performance is enhanced due to the presence of nanoparticles. Besides, the feed rate has the greatest influence and the interaction effectsbetween V*f, V*NC, and FT*NC cause the great influences on the surface roughness. Furthermore, the appropriate set of parameters to achieve the minimum surface roughness includesV=110 m/min, f=26 mm/min, Emulsion base oil and NC=0.5%.*

Keywords:*Hard milling, Taguchi method, ANOVA, nano cutting oil, surface roughness.*

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I. INTRODUCTION

In the field of metal cutting, surface quality is a very important parameter that determines the quality and performance of mechanical parts. Along with the industry development, the increasing requirements for machined surface quality along with productivity are posing new challenges in the finishing process, especially steels after heat treatment. The traditional solution to cut these steels is grinding. Grinding process brings out very high dimensional accuracy and surface quality; however, this method has the main disadvantage of low productivity [1]. Besides, the use of coolant leads to environmental pollution or the cost of handling the used solutions is very expensive [2].Therefore, hard machining technology has been developed to solve this problem [3]. It is now much easier to use cutting tools with geometrically defined cutting edges such as hard turning, hard milling, and so on to directly cut heat-treated materials [4]. Thanks to the support of the development of materials technology and machine tools, hard turning or hard milling can be performed with cutting tools with very high strength, hardness and very good heat and abrasion resistance combined with high rigidity CNC machine tools from small machine shops to large factories [1].In hard machining technology, hard milling has attracted great attention of researchers and manufacturers in the mold manufacturingfield. This is an area that has been growing very rapidly in recent years. The finish milling of the mold cavity has replaced or supported the grinding and Electrical discharge machining (EDM), which has contributed to a significant improvement in productivity while ensuring accuracy and good surface quality [3]. In hard milling, the cutting process is not continuous, so the use of flood condition is easy to cause thermal shock, adversely affecting the life of the cutting tool. However, the enormous heat generated by the cutting zone accelerates tool wear [5].Therefore, it is necessary to have suitable lubricating and cooling technology to improve the efficiency of the hard milling process. In recent years, Minimal quantity lubrication (MQL) technology has been researched and developed for application to machining processes [6,7]. This method uses a minimum amount of cutting oil directly sprayed into the cutting area in the form of high-pressure mist, thus achieving high lubrication efficiency [8]. Many studies have demonstrated the effectiveness of MQL in improving cutting efficiency and machined surface quality, reducing cutting forces and tool wear. However, when applying this technology to hard machining technology, the effect is not obvious due to low cooling efficiency [9].To overcome this problem, the use of nano-cutting oil as the base oil for MQL is a new research direction and the effectiveness has been proven in improving lubrication and cooling in the cutting zone [10]. However, the studies in this direction for the hard milling process are very limited, so the authors conducted the study on the influence of parameters such as cutting speed, feed amount, type of base oil and the nanoparticle concentration onsurface roughness using Taguchi method.

II. MATERIALS AND METHOD

The experiments were carried out on VMC 85S milling center. The steel samples are 60Si2Mn steel, which was hardened to 50-52 HRC. The cutting tool was APMT 1604 carbide inserts. Al_2O_3 nanoparticles were suspended into vegetable oil with the type and concentration given in Table 1, and the obtained nano cutting fluid were used as the base oil for the MQL system.

Figure 1. The experimental device

In order to investigate the influence of technological parameters on surface roughness in hard milling, the input parameters including: cutting speed, feed rate, base oil type and nanoparticle concentrationand theirvalue levels are shown in Table 1.

Table 1. Input parameters and their levels

No.	Input parameters	Symbol	Level		
			1	2	3
1	Cutting speed, *V* (m/min)	A	110	120	130
2	Feed rate, *f* (mm/min)	B	26	35	44
3	Fluid type, *FT*	C	Soybean oil (So)	Canola oil (Co)	Emulsion (Em)
4	Nanoparticle concentration, *NC* (wt%)	D	0.5	1.0	1.5

With the survey parameters of cutting speed (A), feed rate (B), fluid type (C) and nanoparticle concentration (D) with 3 levels of values, L9experimental design was selected to analyze the influence of parameters A, B, C and D on the output factors as shown in Table 2.

Table 2. L9 experimental design

No.	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2

7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

The experimental model was set up with the aim of assessing the influence of technological parameters on the surface roughness in milling hard. The experimental set was collected and processed by Minitab 19 software, and the obtained S/N noise signal is as shown in Table 3.

Table 3. Measured surface roughness values and their corresponding S/N ratio

V (m/min)	f (mm/min)	FT	NC (%)	Ra (μm)	S/N ratio
110	26	So	0.5	0.17	15.3910
110	35	Co	1	0.265	11.5351
110	44	Em	1.5	0.297	10.5449
120	26	Co	1.5	0.291	10.7221
120	35	Em	0.5	0.193	14.2889
120	44	So	1	0.598	4.4660
130	26	Em	1	0.125	18.0618
130	35	So	1.5	0.351	9.0939
130	44	Co	0.5	0.314	10.0614

III. RESULT AND DISCUSION

3.1. Effect of input parameters to the surface roughness

Using Minitab software, analysis of variance was used for surface roughness values. The obtained results show that the average values of surface roughness with different levels for each survey parameter and the order of influence of the parameters on the value of flank wear is shown in Table 4. Among the survey parameters, the feed rate is the parameter having the strongest influence on the average value of surface roughness [4], followed by the fluid type and then the cutting speed and nanoparticle concentration.

Table 4. Response Table for Means

Level	V (m/min)	f (mm/min)	FT	NC (%)
1	0.2440	0.1953	0.3730	0.2257
2	0.3607	0.2697	0.2900	0.3293
3	0.2633	0.4030	0.2050	0.3130
Delta	0.1167	0.2077	0.1680	0.1037
Rank	3	1	2	4

The influence of the input variables on the average surface roughness valuesis shown in Figure 2. When increasing the feed rate from 26-44 m/min, the surface roughness gradually increases from 0.2 to 0.4 µm. In case of using Emulsion oil, the surface roughness is smaller than the two vegetable base oils. At the same time, the results also show that in the survey range, the surface roughness is highest atthe cutting speed of 120 m/min. When increasing the nanoparticle concentration from 0.5% to 1.0%, $R_a$increases but decreasewith the growth of NC to 1.5% [3].

Thus, based on the analysis, a set of technological parameters can be selected as follows: V=110m/min; f=26 mm/min, Emulsion base oil and NC=0.5%. Taguchi analysis also allows to evaluate the interaction effects between the survey parameters on the average surface roughness values (Figure 3).

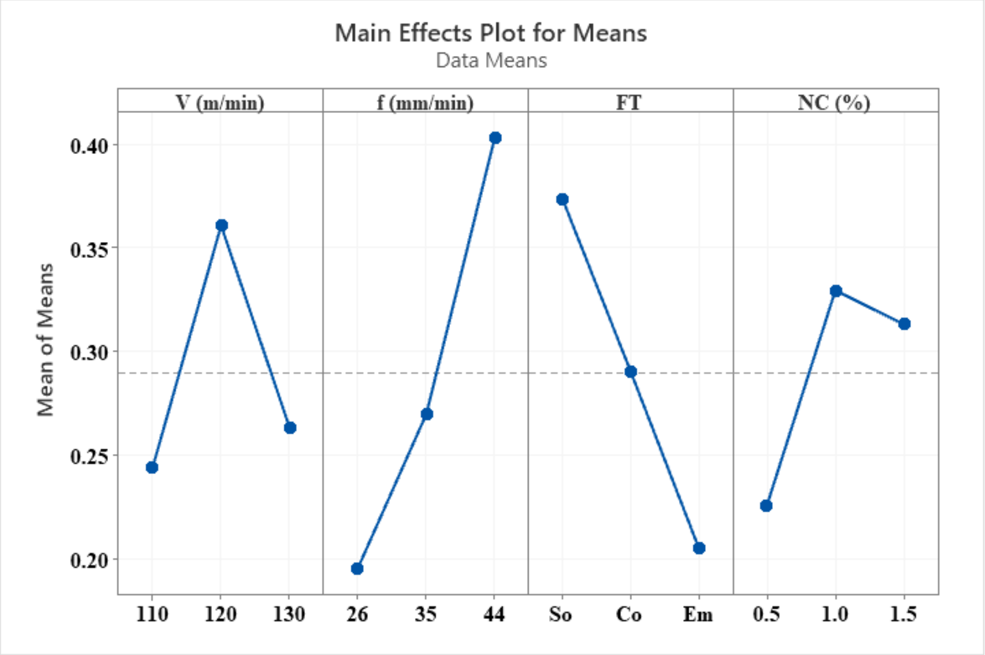

Figure 2. Influence of the survey parameters on the average surface roughness values

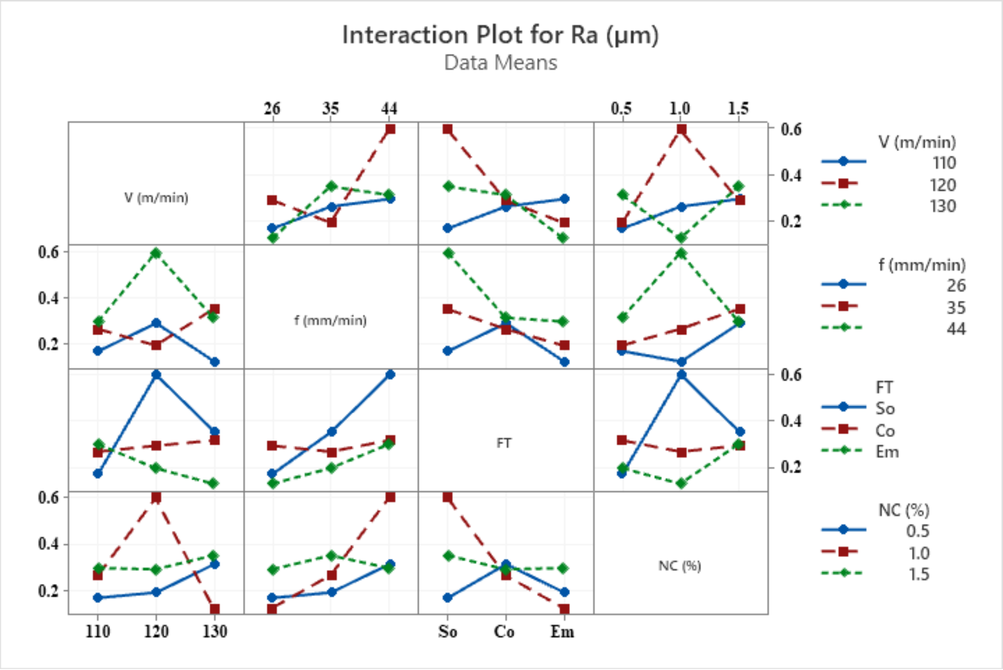

Figure 3. Interaction effects between the survey parameters on the average surface roughness values

3.2. Effect of input parameters to S/N ratios for the surface roughness

The signal-to-noise (S/N) ratio was used to evaluate the influence of survey parameters on surface roughness. The analysis results show that the signal-to-noise ratio calculated for the surface roughness with different levels for each survey parameter and the order of influence of them on the S/N ratio value of R_a is shown in Table 5. Among the investigated variables, the feed rate and the fluid type have the strongest influence on the S/N ratio of the surface roughness.

Table 5. Response Table for Signal to Noise Ratios

Level	V (m/min)	f (mm/min)	FT	NC (%)
1	12.490	14.725	9.650	13.247
2	9.826	11.639	10.773	11.354

3	12.406	8.357	14.299	10.120
Delta	2.665	6.368	4.648	3.127
Rank	4	1	2	3

The influence of the input technological parameters on the S/N ratio of the surface roughness is shown in Figure 4. The obtained results show that the S/N ratio increases rapidly when reducing the feed rate and has the largest value with the feed rate of 26 mm/min. As the nanoparticle concentration increased, the value of the S/N ratio also decreased significantly. At the same time, the value of the S/N ratio also increased sharply when changing the base oil from So - Co - Em. The S/N ratio is the smallest at cutting speed of 120 m/min. The S/N ratio of the surface roughness reached the maximum value with the parameter set of V=110 m/min, f=26 mm/min, Emulsion base oil and NC=0.5%.

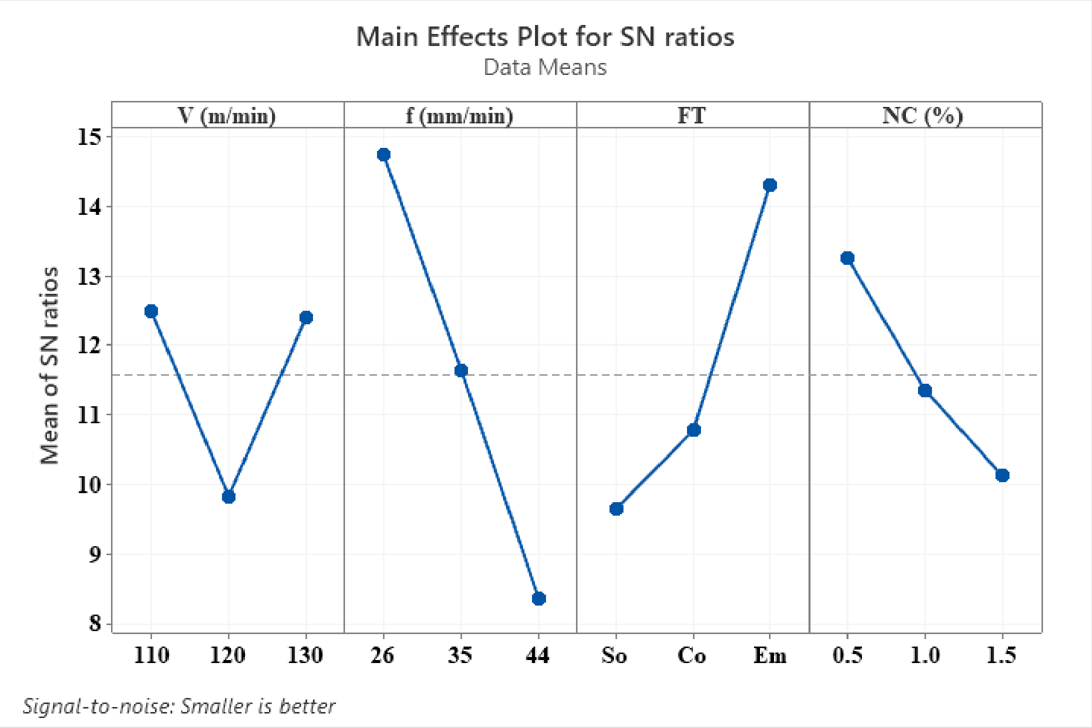

Figure 4. Influence of the input technological parameters on the S/N ratio of the surface roughness

The interaction effect between the input parameters on the S/N ratio of the surface roughness is also analyzed and shown in Figure 5. The interaction between the technological parameters strongly affects the S/N ratio of the surface roughness, especially V*f, V*NC, FT*NC interactions.

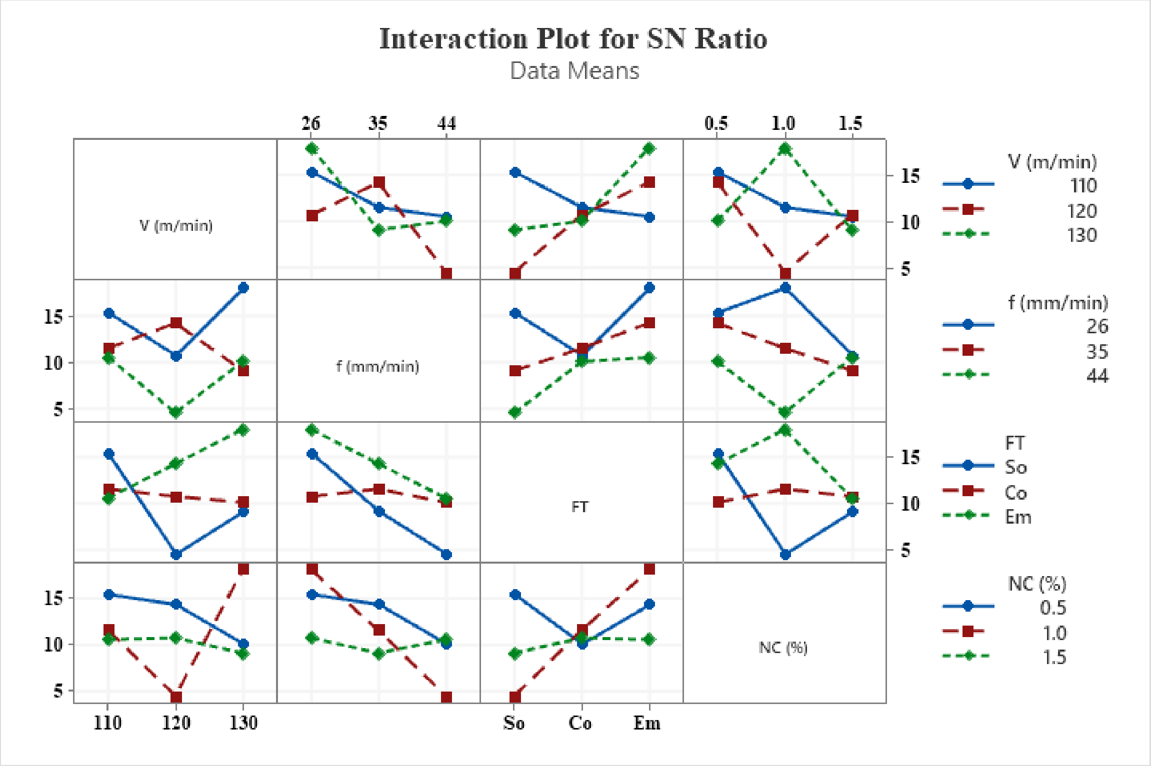

Figure 5. Interaction effect between the input parameters on the S/N ratio of the surface roughness

IV. CONCLUSION

In this article, MQL using nano-cutting oil was successfully applied to improve the efficiency of the hard milling process. The parameters of cutting speed, feed rate, fluid type, and nanoparticle concentration were studied and evaluated for the effect on surface roughness by Taguchi method. Feed rate has the greatest influence on surface roughness, followed by the fluid type and then the cutting speed and nanoparticle concentration. The obtained results also provide technological guidelines for further research and development of MQL using nano cutting oil for hard machining technology. A reasonable set of technological parameters V=110 m/min, f=26 mm/min, Emulsion base oil and NC=0.5% are suggested to achieve the minimum surface roughness. Moreover, the use of nanoparticles based on vegetable oil for MQL technology is environmentally friendly and suitable with the trend of sustainable development.

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