Investigation of air pressure, air flow rate, and nanoparticle concentration in MQCL drilling of Hardox 500 steel

Pham Quang Dong[1,*], Dao Thi Tuyet Nhung[2], and Nguyen Thuan[1]

[1]*Faculty of Mechanical Engineering, Thai Nguyen University of Technology, Thai Nguyen, 250000, Vietnam*

[2]*Thai Nguyen University of Technology, Thai Nguyen, 250000, Vietnam*

Abstract: *The work presents the experimental study on the effectiveness of MQCL technology using Al_2O_3 nano-cutting oil when drilling Hardox 500 steel, a difficult-to-cut material. The Box – Behnken experimental design was applied to evaluate the influence of parameters including air pressure, air flow rate and nanoparticle concentration on the axial cutting force F_y and surface roughness R_a. The obtained results show that the investigated parameters have greater influences on the axial cutting force than the surface roughness. The study also gives some technological guidelines to achieve the desired smaller cutting force or surface roughness values.*

Keywords: *MQCL, drilling, surface roughness, cutting force, air pressure, air flow rate, nano cutting oil, Hardox 500 steel.*

1. Introduction

Hardox 500 steel produced by SSAB, SWEDEN [1] has been widely used in industrial production in recent years. Commercial hardox 500 steel has been fully heat-treated with fairly high hardness, high strength, high toughness and good wear resistance. According to the company's recommendations, it is recommended to use Hardox 500 steel in the fully heat-treated state provided by the company, so there should be no additional heat processing.

However, Hardox 500 steel is classified as a difficult-to-cut material [2]. When cutting this type of steel, the cutting force and cutting heat are often very large, and the severe tool wear is also the problem, seriously affecting the economic and technical efficiency [3-6]. Because Hardox 500 steel is widely used in industry, it is necessary to have solutions to improve economic and technical efficiency by using machining processes.

Among the proposed solutions, Minimum Quantity Cooling Lubrication (MQCL) is a novel technique that has attracted a lot of attention of researchers around the world because a minimum amount of low-temperature coolant is sprayed directly into the cutting zone in the mist form. The study on the effect of graphite nanofluid with vegetable oil as the based oil for hard turning under MQCL condition was reported in [7]. The obtained results revealed that the turning performance significantly improved due to the reduction of the friction created by nanoparticles combined with cooling enhancement created by MQCL environment. The experimental investigation of MQCL technique using MoS_2 nanofluid in hard milling of SKD 11 tool steel indicated that the enhancement of cooling and lubricating performance is reported by using MoS_2 nanofluid, from which the white layer formation and burn marks significantly reduce, and therefore the surface quality improves [8].However, there are very few studies on the application of MQCL using nano-cutting oils for machining difficult-to-machine materials. Besides, the effectiveness of this method has been proven especially for machining methods with closed spaces like drilling [3]. In this article, the authors investigated the influence of technological parameters of MQCL technique including air pressure, air flow rate, and Al_2O_3nanoparticle concentration when drilling Hardox 500 steel.

2. Material And Method

The experiment was carried out on a Vertical center smart 530C - Mazak corporation and the experimental set up is shown in Figure 1. Multi Drill MDS127SK (Sumitomo Electric Industries, Japan) carbide tool was used. MQCL nozzle was used with the rice bran oil containing 1.0 wt.% Al_2O_3nanoparticles. Measurement devices include SJ-210 Mitutoyo for surface roughness and Kistler quartz three-component dynamometer 9257BA for cutting forces. Hardox 500 sample (49÷50 HRC) with the dimensions of 150mm ×100mm ×15 mm were used. The chemical composition and mechanical properties of Hardox 500 steel are shown in Table 1, 2. To ensure uniform distribution of Al_2O_3 nanoparticles 1.0 wt%. in the base fluids of rice bran oil, the nanofluid is placed in Ultrasons-HD ultrasonicator for 1 hours with 600W ultrasonic pulses at 40 kHz and directly used for MQCL systems [3]. The cutting condition was fixed with cutting speed of 15 m/min and feed rate of 0.02 mm/rev.

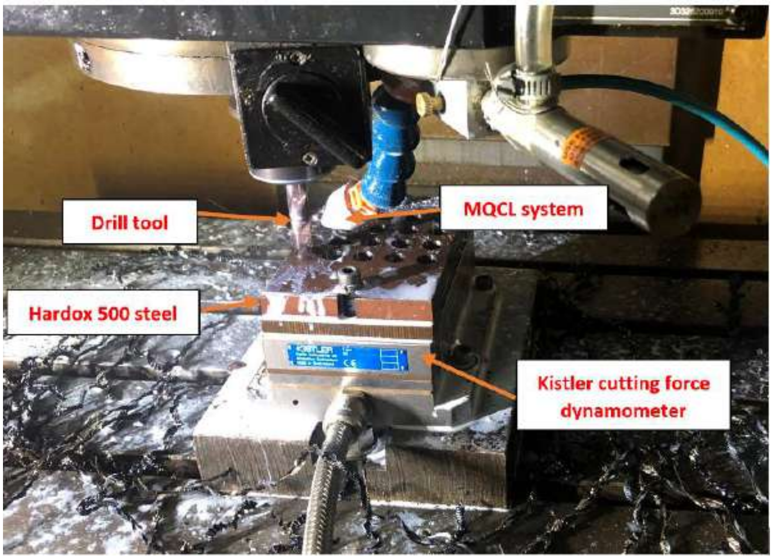

Figure 1. Experimental set up

Table 1. Chemical composition of Hardox 500 steel

Element	C	Si	Mn	P	S	Cr	Ni	Mo	B
Weight *(%)*	0.3	0.7	1.6	0.025	0.01	1.5	1.5	0.6	0.005

Table 2. Mechanical property of Hardox 500steel

Toughness *(MPa)*	Tensile strength*(MPa)*	Elongation *(%)*	Hardness *(HBW)*	Hardness *(HRC)*
1250	1400	10	470 - 530	49 - 50

The Box - Behnken experimental design with the support of MINITAB 19 software was used to investigate the effect of air pressure, air flow rate, and nano concentration on the surface roughness $R_a$and axial cutting force F_y. The input parameters and their levels are given in Table 3.

Table 3. Input cutting parameters and their levels

Input cutting parameters	**Symbol**	**Low level**	**High level**	**Response**
Air pressure	p (Bar)	4	6	Surface roughness R_a (μm); axial cutting force F_y (N)
Air flow rate	Q (l/min)	100	200	
Nanoparticle concentration	NC (%)	0.2	1.0	

3. Results and Discussion

The experiment was carried out according to the experimental plan and the measured surface roughness R_a and axial force $F_y$are given in Table 4. The cutting force is measured directly from the cutting process, while the surface roughness was measured 3 times after each cutting trial and taken by the average values.

Table 4. Factorial experimental design and the measured surface roughness R_a and thrust force F_y

StdOrder	RunOrder	PtType	Blocks	p (Bar)	Q (l/min)	NC (%)	Ra (μm)	Fy (N)
2	1	2	1	6	100	0.6	0.184	520.5
12	2	2	1	5	200	1	0.168	500.3
4	3	2	1	6	200	0.6	0.154	480.6
11	4	2	1	5	100	1	0.203	530.6
1	5	2	1	4	100	0.6	0.223	550.5
3	6	2	1	4	200	0.6	0.197	524.5
15	7	0	1	5	150	0.6	0.185	510.3
8	8	2	1	6	150	1	0.202	513.3

StdOrder	RunOrder	PtType	Blocks	p (Bar)	Q (l/min)	NC (%)	Ra (µm)	Fy (N)
7	9	2	1	4	150	1	0.236	530.6
5	10	2	1	4	150	0.2	0.256	560.5
9	11	2	1	5	100	0.2	0.25	556.2
14	12	0	1	5	150	0.6	0.248	540.5
6	13	2	1	6	150	0.2	0.228	538.6
10	14	2	1	5	200	0.2	0.186	530.2
13	15	0	1	5	150	0.6	0.182	512.5

Pareto charts with significance level α = 0.05 shows the limit line of the hypothetical rejection area for surface roughness R_a and axial cutting force F_y. The variables whose histograms all exceed the right of the limit line are the dominant factors. Those whose histogram lies to the left of the limit line have little influences.

The limit line of the surface roughness R_a has a coordinate of 2.571 (Figure 2), and the investigated factors are air flow pressure (A), air flow rate (B), the nanoparticle concentration (C) and their interaction effects of these factors have little influences on the surface roughness values of the machined surface. Meanwhile, these three variables all have the great influences on the axial cutting force F_y, in which, the air flow rate has the greatest influence, followed by the air pressure and nanoparticle concentration (Figure 3). The interaction effects of these variables have little effects on the axial cutting force F_y [9].

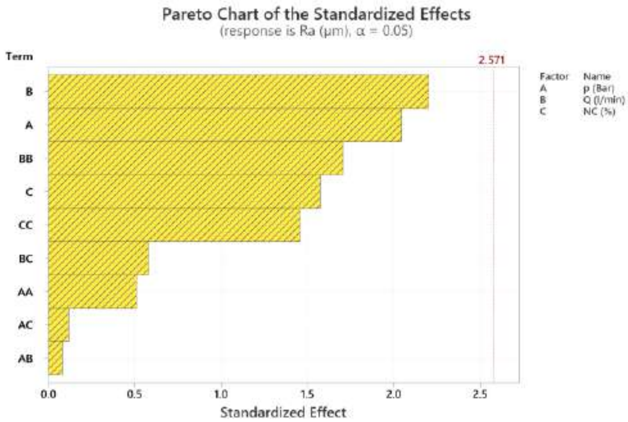

Figure 2. Pareto chart of air pressure, air flow rate, and nano concentration effects on surface roughness R_a

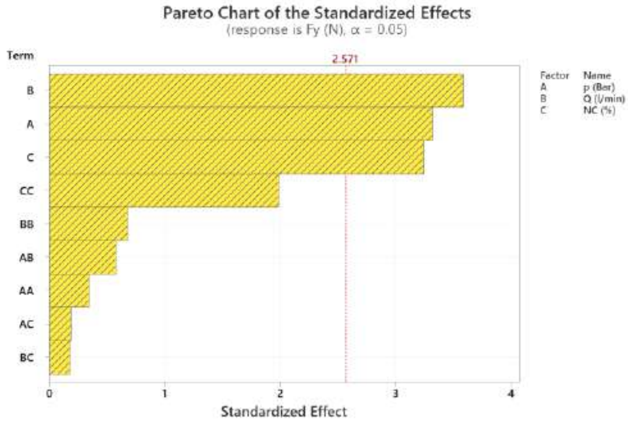

Figure 3. Pareto chart of air pressure, air flow rate, and nano concentration effects on cutting force F_y

The contour plot of the interaction effect of air flow rate and air pressure on the axial cutting force F_y when NC = 0.6% is fixed is shown in Figure 4. Based on the chart, Q = 170-200 l/min combined with p = 5.2-6.0 bar should be used to reduce the axial cutting force F_y. Moreover, Q = 170-200 l/min in combination with p = 4.2-6.0 bar will help to achieve the smaller surface roughness values (Figure 7).

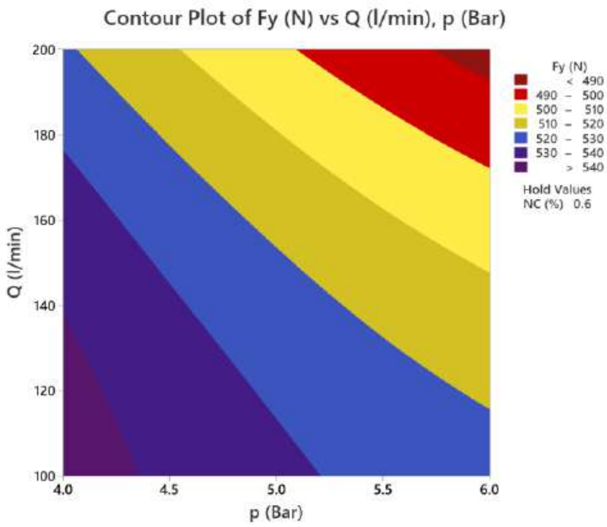

Figure4. The contour plot of the interaction influence of air flow rate and air pressure on cutting force F_y

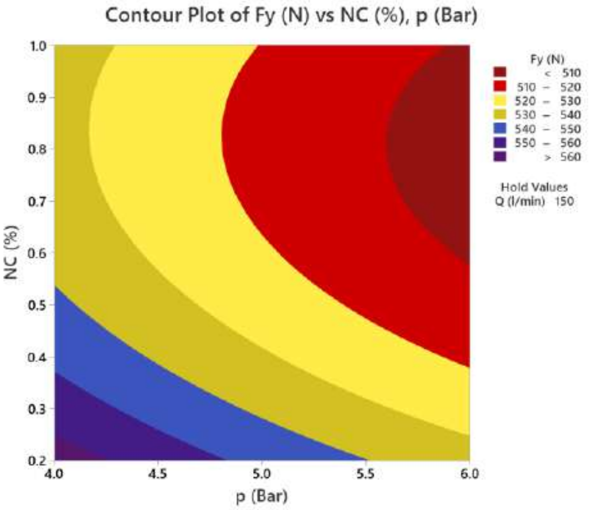

Figure 5. The contour plot of the interaction influence of nano concentration and air pressure on cutting force F_y

The contour plot of the interaction effect of nanoparticle concentration and air pressure on the axial cutting force F_y when Q = 150 l/min is fixed is shown in Figure 5. Based on the obtained results, NC = 0.4-1.0% combined with p = 4.8-6.0 bar should be chosen to achieve the smaller cutting force F_y. Besides, NC = 0.36-1.0% and p = 4.6-6.0 bar contribute to achieve the smaller surface roughness values (Figure 8).

The contour plot of the interaction effect of nanoparticle concentration and air flow rate on the axial cutting force F_y when p = 5 bar is fixed is shown in Figure 6. NC = 0.45-1.0% and Q = 170-200 l/min will contribute to reduce the axial cutting force F_y, and NC = 0.3-1.0% combined with Q = 190-200 l/min should be selected to achieve the smaller surface roughness values (Figure 9).

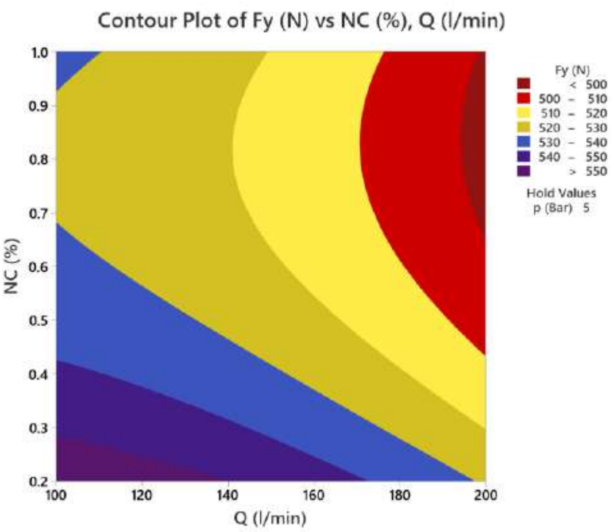

Figure 6. The contour plot of the interaction influence of nano concentration and air flow rate on cutting force F_y

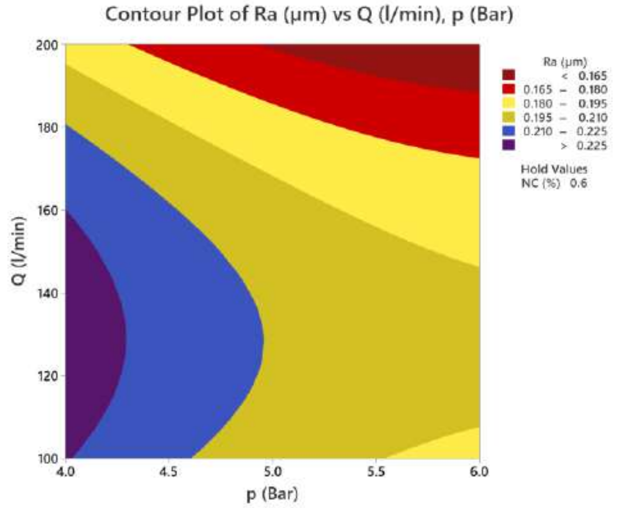

Figure 7. The contour plot of the interaction influence of air flow rate and air pressure on surface roughness R_a

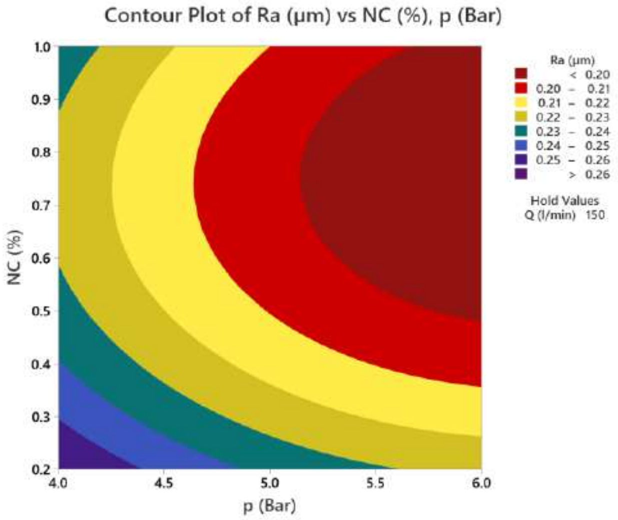

Figure 8. The contour plot of the interaction influence of nano concentration and air pressure on surface roughness R_a

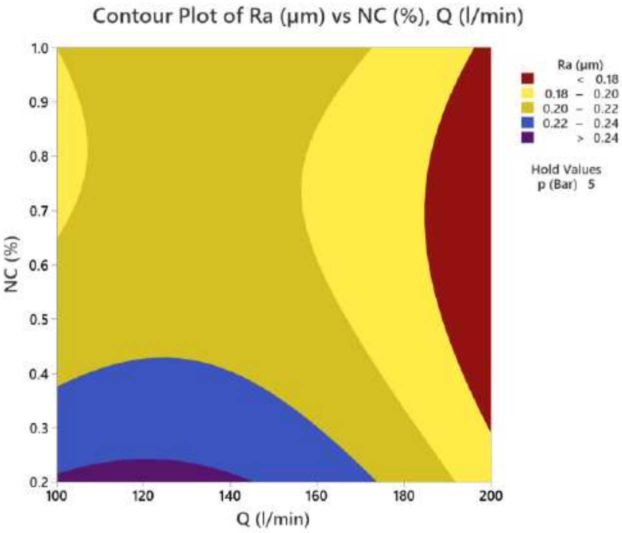

Figure 9. The contour plot of the interaction influence of nano concentration and air flow rate on surface roughness R_a

4. Conclusion

In this article, an experimental study was conducted to investigate the influence of the parameters of air pressure, air flow rate, and nanoparticle concentration on the drilling process of Hardox 500 steel with MQCL environment. Based on the obtained results, it can be seen that the survey variables have the great influences on the axial cutting force F_y and little influence on the surface roughness R_a. In addition, it was noticeable that the application of MQCL technology using Al_2O_3 nano cutting oil has improved the efficiency of the Hardox 500 drilling process, the machinability of carbide drills, and the machined surface quality, and the hole surface is quite good. Furthermore, the research results also provide technological guidelines for achieving small surface roughness values or smaller axial cutting force. Further research will focus on optimization to determine specific values for air pressure, air flow rate and nanoparticle concentration as well as the cutting condition.

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