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Optimize For 9XC Steel Hard Turning Process By CBN Inserts Using MQL Method With MoS_2 Nanofluids

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Abstract

*The 9XC alloy steel is among the most significant metals in industries. Turning of The 9XC alloy is important, especially to create product shape varieties for different applications. However, the demand for high quality draws attention to product quality, particularly machined surface roughness, as it directly affects the product's appearance, function, and reliability. Applying correct lubrication to the machining zone can enhance the tribological characteristics in the tool-workpiece interface. In this research work, a nanolubricant containing MoS2 nanoparticles is developed for hard turning of The 9XC alloy steel and the surface morphology of the machined workpiece is investigated as well. The level of influence of the factors and their interactions on the output factor is surface texture analyzed by the ANOVA analysis. The results of ANOVA analysis show that particle concentration (NĐ), second order interaction (NĐ*NĐ) and interaction between particle concentration and gas pressure (NĐ*p) have strong influence on surface roughness. The study also provides a regression model for surface texture, and at the same time proposes a set of parameters to ensure the minimum surface roughness value. The minimum surface roughness value is Ra = 0.239 µm when machining with a concentration of MoS2 nanoparticles of 0.42%, a gas flow pressure of p = 4.6 bar and a gas flow rate of 207 (l/min).*

Keywords: *Hard turning, 9XC, Nanofluids, MQL, CBN,* MoS_2

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I. INTRODUCTION

The 9XC steel is a low-alloy tool steel, often used in manufacturing hand tools, molds, and bearings ... with a hardness after tempering usually reaching 60-62 HRC. Normally, the grinding process is used to machine 9XC steel after heat treatment. In recent years, the hard turning process is being widely used to replace the grinding process in industrial production. However, the hard turning process still has many problems such as high cutting force and cutting heat, causing part deformation and reducing tool life. However, this occupation of cutting fluids by customary flood cooling can cause thermal shock, and damage the tool and workpieces. Moreover, this method has also adversely altered environmental integrity, human health, and the economy [1]. Therefore, in recent years, many new lubrication and cooling technologies have been researched and applied in hard machining processes such as minimum quantity lubrication (MQL), Nanofluid minimal quantity lubrication (NFMQL)...

MQL technology is a new cooling lubrication technology used in hard machining process to overcome the disadvantages of dry machining and flood cooling technology. In the MQL method, a small amount of lubricating fluid is introduced into the cutting zone in the form of oil droplets to improve frictional conditions [2]. Research on the application of MQL technology in hard turning has been studied by many authors. The studies mainly focus on investigating the influence of the cutting parameters and the MQL technology parameters on the efficiency of the cutting process. The results of the studies show that when using MQL technology, it is possible to improve the surface quality and increase tool life compared to dry machining and flood cooling technologies.

In addition, MQL has the disadvantage of limited cooling capacity [3]. To overcome this drawback, there are a number of solutions, in which the use of nano-cutting oil (Nanofluid - symbol NF) is an effective solution. [4]. NF cutting oil is essentially a mixture of one or several types of nanoparticles (aluminum oxide Al2O2, SiO2 Silicon oxide, CuO2 copper oxide, MoS2 black molybdenum sulfide, etc.) with cutting oils (collectively referred to as base oils). . Nanofluids are being studied for applications in machining because of their many advantages in terms of thermal properties and lubricating properties. The application of nano-cutting oil to lubricate and cool the cutting area has been studied by many authors. Sharma et al. have analyzed and evaluated the effectiveness of the application of MQL with nano-cutting oil in the cutting process [5]. The research results have shown that the minimum quantity lubrication (NFMQL) method with nanofluids shows promising results compared with the MQL using normal oil in terms of cutting zone temperature and surface roughness. Shen et al studied the effect of nanofluids mixed with nanodiamonds, and nanoparticles Al2O3 and water on the grinding process of cast iron [6]. Research has shown higher grinding efficiency, lower tangential cutting force, better surface structure, and lower grinding temperature when using nanofluids for grinding. Setti et al studied the effect of flow rate and concentration of Al2O3 nanofluid in the grinding process of Ti-6Al-4 V alloy. Research results show that using Al2O3 nanofluid reduces the cutting temperature in the grinding area, reducing friction and improving grinding ability [7]. Vasu and Reddy studied the performance of Al2O3 nanofluids in the machining process of Inconel 600 alloy [8]. Research results have shown that nanoparticle-enhanced MQCL can lead to significant reductions in cutting force, surface roughness, temperature, and tool wear.

In recent years, the application of nanofluids with MoS2 nanoparticles in the machining process has been studied by many authors. Studies on the application of MoS2 nanofluids in the grinding process show that it is possible to reduce the specific energy and reduce surface roughness when grinding [9]. Parash Kalita has studied and applied the MQL method with MoS2 nanofluids to the cast iron grinding process [10]. The study has shown that the MQL-NFMoS2¬ method has the ability to reduce the specific energy when grinding and improve the surface quality compared to the overflow machining method. ZHANG Dongkun et al (2014) analyzed the effect on surface texture and cutting force when machining with different nanofluids (MoS2, ZrO2, and Carbon nanotube) [11]. The analysis results show that the application of nanoparticles can reduce the unit cutting force and reduce the surface roughness of the machined surface. Yanbin Zhang et al analyzed the lubricating efficiency of MoS2/CNT nanofluid when grinding TiTan alloy [12]. Research results show that the nanofluid with two nanoparticles is more effective than using a type of nanoparticle. In 2015, Yanbin Zhang's studies show that MoS2 particles increase the lubricating efficiency of cutting oil, thereby contributing to reducing cutting heat and cutting force during grinding [13].

Thus, the study of the application of MQL using NF MoS2 in hard turning is also of interest to many researchers [14-15]. However, studies on the influence of the technological parameters of the MQL process using MoS2 nanoparticles on the efficiency of the 9XC steel hard turning process with CBN inserts are limited [10-15]. This study mainly focuses on analyzing the influence of MoS2 nanoparticle concentration, air pressure, and air flow on surface roughness when turning 90xc steel using CBN insert.

II. EXPERIMENT AND METHOD

In this study, the experiments were carried out on the experimental system arranged as shown in Figure 1. The experiments used 90CrSi alloy steel with a diameter of 40 mm and heat treatment to reach hardness HRC=60-62. The experimental process was carried out on a CS-460x1000 Chu Shing lathe (Pin Shin Machinery Co., LTD, Taichung City, Taiwan). The cutting tool used is CBN inserts with code CGW09T308S01020FWH7025 of Sanvik. This study used the MC 1700 nozzle of NOGA company (Noga Engineering & Technology (2008) ltd, Israel) and some accompanying equipment including an air compressor, rice oil, MoS2 nanoparticles. In this study, MoS2 nanoparticles with layered structures and the average size of 30 nm were produced by Luoyang Tongrun Info Technology Co., Ltd., China, figure 2. Based on previous studies, along with recommendations of cutting tool manufacturers, some technological parameters were fixed in the study and shown in Table 1.

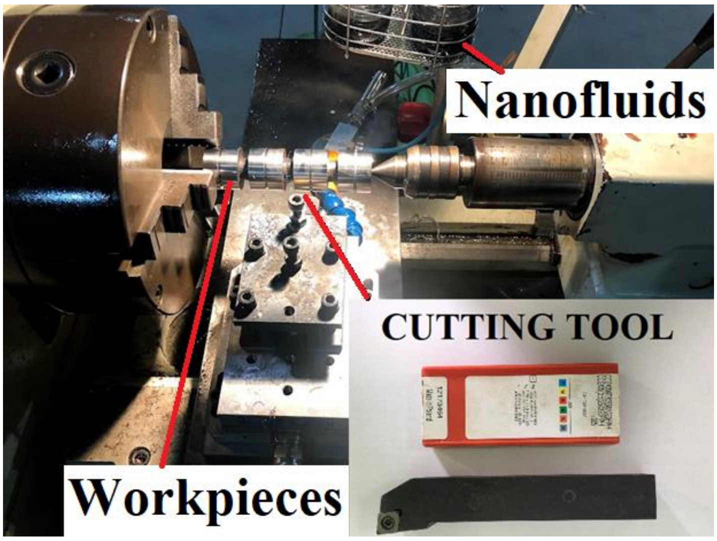

Figure 1. The experimental setup

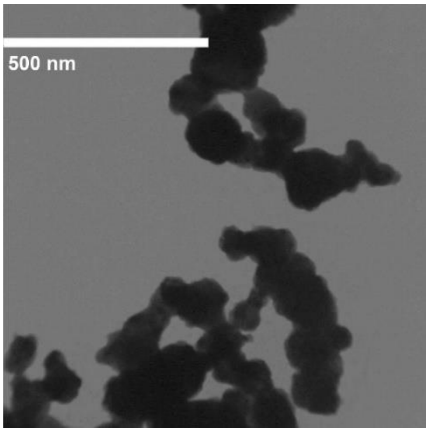

Figure 2. The nanoparticle MoS_2

Table 1. The fixed technology parameters in the research

Cutting speed (m/min)	Cutting depth (mm)	Feed rate (mm/rev)	Base oil	Nanoparticles
160	0.12	0.12	Rice oil	MoS_2

The Box-Behnken design is an independent quadratic design in that it does not contain an embedded factorial or fractional factorial design. In this design the treatment combinations are at the midpoints of edges of the process space and at the center (figure 3). An experimental matrix of 15 trials according to the Box - Behnken optimal planning model for 03 survey variables with two levels of values is designed in Minitab 19 software. Three survey parameters include nanoparticle concentration, air pressure, and flow of air. The value levels of the survey variable are shown in Table 2. the experimental implementation was accorded to RunOrder and, the value of Ra is measured after each machining turn by roughness meter SJ210. The results of the evaluation parameters according to the experimental planning scheme are shown in Table 3.

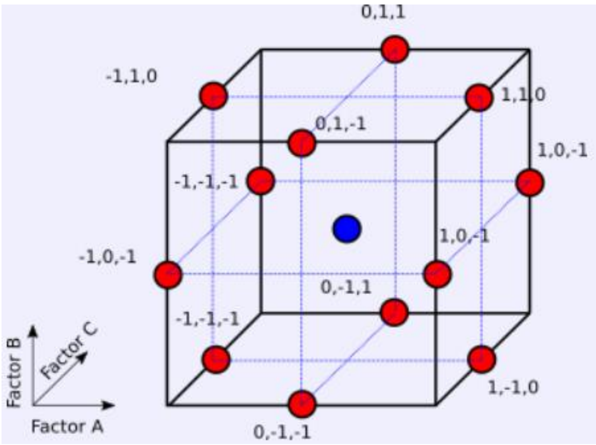

Figure 3. The Box-Behnken design

Table 2. Input parameter values and experimental variables in the Box – Behnken model

No.	Experimental factors	Symbols	Low level	High level
1	**Nanoparticle concentration (%)**	**NĐ**	0,2	0,8
2	**Air pressure (bar)**	**p**	4	6
3	**Air flow (L/min)**	**Q**	150	250

Table 3. Experimental matrix and results

RunOrder	PtType	Blocks	NĐ (%)	p (Bar)	Q (L/min)	Ra (µm)
1	0	1	0,5	5	200	0,250
2	2	1	0,5	4	150	0,354
3	0	1	0,5	5	200	0,238
4	2	1	0,8	5	250	0,378
5	2	1	0,8	4	200	0,455
6	2	1	0,8	5	150	0,442
7	2	1	0,5	6	150	0,280
8	2	1	0,2	4	200	0,249
9	2	1	0,5	6	250	0,274
10	2	1	0,2	5	250	0,395
11	2	1	0,2	6	200	0,356
12	2	1	0,8	6	200	0,385
13	2	1	0,2	5	150	0,345
14	2	1	0,5	4	250	0,276
15	0	1	0,5	5	200	0,244

III. RESULT AND DISCUSSION

Analysis of variance (ANOVA) with a significance level of 0.05 was performed on Minitab 19 software and the results are shown in Table 3. In this study, the model with quadratic interactions was selected to investigate the influence of the survey factors on the surface roughness objective function (Ra). The results of ANOVA analysis give us P values and F coefficients, thereby assessing the influence of factors and their interactions on the surface roughness objective function, as shown in Table 4. The nanoparticle concentration (NĐ), its second-order interaction (NĐ*NĐ), and the interaction between nanoparticle concentration and air pressure (NĐ*p) strongly affect the surface roughness. Other factors of air pressure, flow, and interaction have less influence on surface roughness.

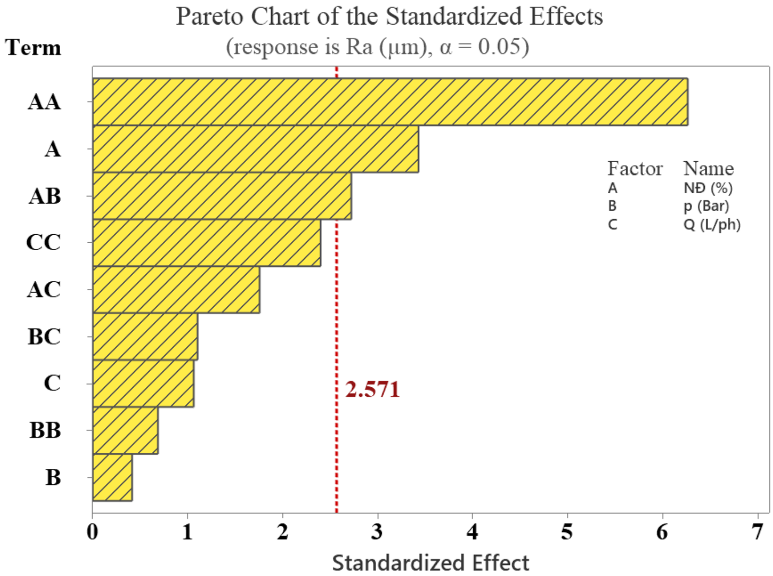

Figure 3. Pareto plot for the surface roughness

Table 4. Results of ANOVA . analysis

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	0.071193	0.007910	7.53	0.019
Linear	3	0.013733	0.004578	4.36	0.073
NĐ (%)	1	0.012364	0.012364	11.78	0.019
p (Bar)	1	0.000181	0.000181	0.17	0.696
Q (L/ph)	1	0.001188	0.001188	1.13	0.336
Square	3	0.045145	0.015048	14.33	0.007
NĐ (%)*NĐ (%)	1	0.041259	0.041259	39.30	0.002
p (Bar)*p (Bar)	1	0.000495	0.000495	0.47	0.523
Q (L/ph)*Q (L/ph)	1	0.006044	0.006044	5.76	0.062
2-Way Interaction	3	0.012315	0.004105	3.91	0.088
NĐ (%)*p (Bar)	1	0.007788	0.007788	7.42	0.042
NĐ (%)*Q (L/ph)	1	0.003249	0.003249	3.09	0.139
p (Bar)*Q (L/ph)	1	0.001278	0.001278	1.22	0.320
Error	5	0.005250	0.001050		
Lack-of-Fit	3	0.005184	0.001728	52.23	0.019
Pure Error	2	0.000066	0.000033		
Total	14	0.076443			

The influence of the survey factors and their interactions on the surface roughness is also clearly shown in the Pareto chart in Figure 3. The results show that the factors NĐ and the interaction of NĐ*NĐ, and NĐ*p have a great influence on the surface roughness Ra because it has a larger influence coefficient than the standard one (2,571). In which, the second order interaction NĐ*NĐ has the strongest influence on the surface roughness. In addition, Air pressure (p), air flow rate (Q), and other interactions have little influence on the value of the surface roughness.

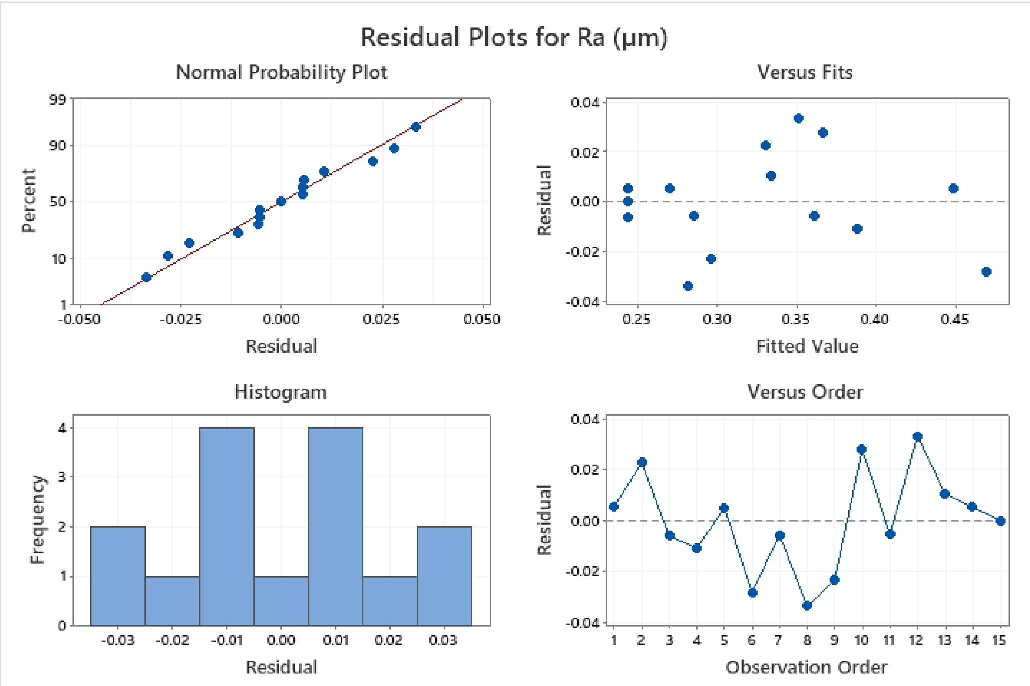

Figure 4. Residula plots for Ra

The results of the evaluation of the fit of the used model are shown on the graphs in Figure 4. Figure 4a depicts the normal plot, which shows that the residuals of the experimental points are all followed. along the red line, so the residuals follow a normal distribution. Figure 4c,d shows the estimated partial values for the surface roughness values randomly distributed around the mean. Figure 4c shows the frequency with which values closely follow the normal distribution. Thus, using a quadratic model with interactions between factors to evaluate the influence of input parameters on the surface roughness value is appropriate and statistically significant.

Figure 5 describes the main influence of the survey factors on the average surface roughness value in the 9XC steel hard turning process using the MQL method with MoS2 nanofluids. The results shown in Figure 4a show that the nanoparticle concentration (ND) has a significant influence on the surface roughness. The surface roughness approaches the smallest value with an average nanoparticle concentration of about 0.45%. The reason may be that MoS2 nanoparticles have a sheet structure that easily adheres to the tool surface, when using MoS2 particles with a reasonable nanoparticle concentration, it is able to reduce friction, resulting in a rough surface. However, when increasing the concentration of MoS2 nanoparticles, it is possible to make these nanoparticles stick together, causing the phenomenon of pinching and scratching the surface, reducing the surface roughness. As a result, Figure 4b shows that increasing the air pressure from 4 to 6 bars does not change the surface roughness much. Meanwhile, varying the air flow from 150 to 250 (l/min) also significantly affects the average surface roughness value. Surface roughness reaches its minimum when using an air flow of about 200 l/min.

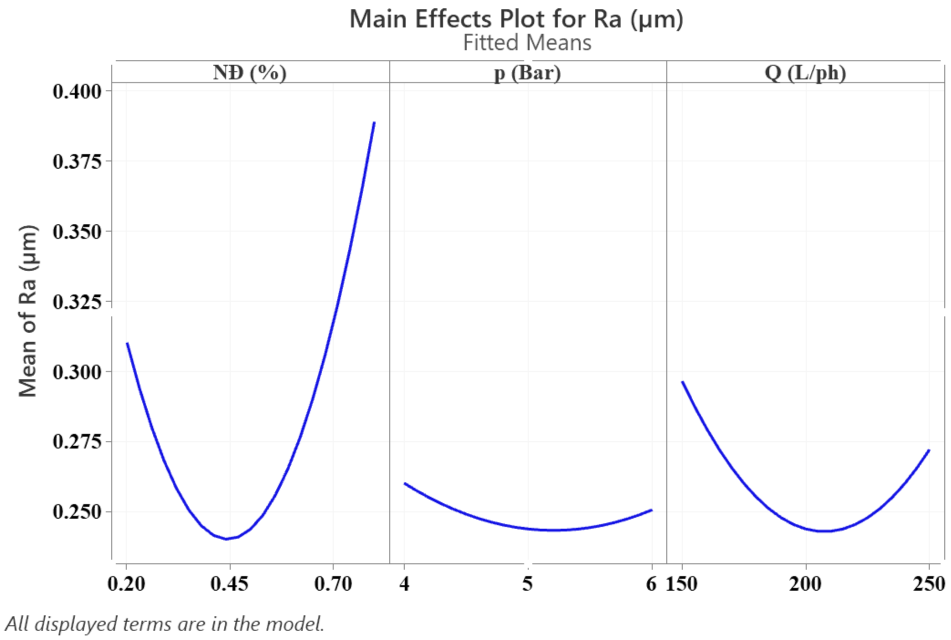

Figure 5. Main effects plot for Ra

The interaction effect between factors on surface roughness value when turning 9XC steel with CBN tool using MQL technology with MoS2 nanofluids is shown in Figure 6. The results show that the second-order interaction of the particle concentration has a great influence on the surface roughness. At the same time, the p*ND interaction also significantly affects the surface roughness value. When using medium concentrations, the surface roughness value is less affected by air pressure changes in the range of 4 to 6 bar. When using a small nanoparticle concentration (0.2%), the surface roughness decreases with decreasing air pressure. While with a large nanoparticle concentration (0.8%), the surface roughness decreases with increasing air pressure.

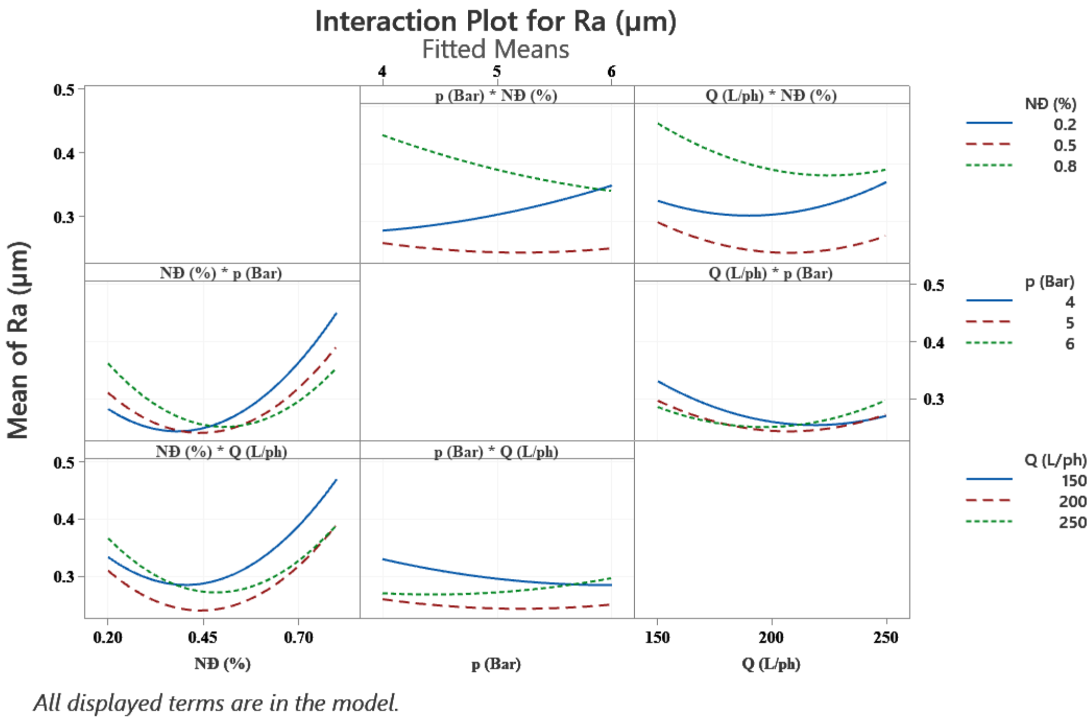

Figure 6. Interaction effects of factors on the surface roughness

With the Box-Behnken optimization planning method in the Minitab 19 software, solving the optimization problem is quite convenient. Based on the specific conditions and requirements of the machining process, it is possible to choose the appropriate objective function and optimal criteria.Using Minitab 19 software, the regression model for the surface texture objective function is built and shown in Equation 3.1. The coefficient of determination R2 (93.13% for Rq) and the adjusted coefficient of determination Adj R2 (80.77%) are much larger than 50%, proving that the model is suitable for prediction and evaluation. the influence of the survey factors on the objective function Ra.

Ra(µm)=1.281+0.072NĐ- 0.119 p - 0.00755 Q+ 1.175 NĐ *NĐ + 0.0116 p *p+ + 0.000016 Q *Q - 0.1471 NĐ *p - 0.00190 NĐ*Q + 0.000358 p *Q (3.1)

The optimal technological parameters for surface roughness when turning 9XC steel with CBN tools using MQL technology with MoS2 nanofluids were determined through the optimization module on Minitab 19 software. The minimization objective was selected for the surface roughness objective function with equal importance and weight equal to 1. The optimization results are shown in Figure 7. The results show that the surface roughness reaches the minimum value of Ra=0.239µm when machining with a concentration of MoS2 nanoparticles of 0.42%, an air flow pressure of p=4.6 bar and an air flow of 207 l/min.

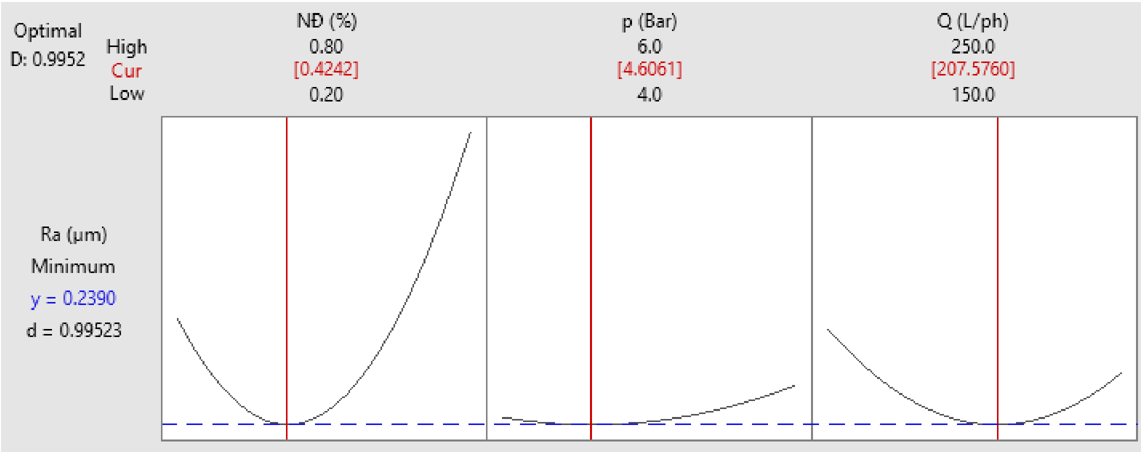

Figure 7. Optimization for the objective function Ra

IV. CONCLUSION

In this investigation, the effects of MoS2 nanolubricant on the machined surface morphology in the hard turning process were studied. The nanolubricants were prepared by suspending MoS2 nanoparticles (30 nm) in base oil (rice oil). The mixtures were stirred for 48h, followed by ultrasonication for 48 h. The cutting experiments were carried out on the hardened 9XC steel workpiece. To accelerate the lubricant into the tool-workpiece interface, pressurized air was used, which too, led to less nanolubricant consumption and optimal surface morphology. The presence of MoS2 nanoparticles in the tool-workpiece interfaces improved the quality of the machined surface.

Using nanolubricant in hardened 9XC steel turning produced fine machined surfaces owing to the function of the suspended nanoparticles. Having MoS2 nanoparticles in the tool-workpiece interface enhanced the machined surface due to the rolling, filling and polishing actions at the tool-workpiece interface. According to the experimental results, the surface roughness reaches the minimum value of Ra=0.239µm when machining with a concentration of MoS2 nanoparticles of 0.42%, an air flow pressure of p=4.6 bar and an air flow of 207 l/min. Finally, it can be concluded that MoS2 suspended in nanolubricant is an excellent alternative for achieving ideal surface quality. For future work, research to investigate the potential and feasibility of MoS2 application in the die and mould, as well as the automotive and aerospace industries, should be sustained.

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