International Journal of Engineering Inventions
e-ISSN: 2278-7461, p-ISSN: 2319-6491
Volume 15, Issue 5 [May 2026] PP: 163-167

Investigating the effect of MQL using MoS_2 nano-cutting oil on surface roughness when turning hardened 90CrSi steel

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Abstract
Minimum quantity lubrication using nano cutting fluids (NFMQL) supports hard turning processes by improving cutting conditions, enhancing the economic and technical efficiency of hard turning, and aligning with the trend toward sustainable and environmentally friendly manufacturing. This research presented the results of a study on the influence of NFMQL using MoS_2 nano-cutting oil on the surface roughness R_a during the hard turning of 90CrSi steel (60 - 62 HRC). Analysis of variance (ANOVA) was used to evaluate the influence of nanoparticle concentration (NC), air flow pressure (p), and air flow rate (Q) on surface roughness (R_a). The research showed that NC had the greatest influence (57.42%), followed by Q (27.10%), and p (15.48%)
Keywords: *Hard turning; cutting parameter; cutting speed; feed rate; depth of cut; surface roughness.*

Date of Submission: 17-05-2026 Date of acceptance: 31-05-2026

I. Introduction

Hard turning is a commonly used term for the machining process in which the cylindrical surface of hardened steel (45 – 68 HRC) is machined using a cutting tool with a defined cutting edge.

The hard turning process was developed and has been widely applied in industries such as automotive manufacturing, mold making, aerospace, and other industrial sectors. Applications of hard turning have shown that it can partially replace the traditional grinding process, and it is widely used for both rough and finish machining.

Hard turning can achieve a surface roughness value of $R_a = 0.4 – 0.8\ \mu m$, a circular tolerance of $2 – 5\ \mu m$, and a dimension error of $\pm(3-7)\ \mu m$. When finishing with CBN tools, dimension accuracy up to IT3 can be achieved, with a surface roughness value of Ra = 0.1 μm. Research results showed that CBN tools can provide better surface quality than ceramic tools, however, since ceramic inserts are more cost effective, so they are still widely used [1-2].

To improve the economic and technical efficiency of hard turning, many solutions have been proposed, among which lubrication and cooling using nano cutting fluids under minimum quantity lubrication and (NFMQL) had emerged as a new trend. The recent studies showed that the numbers of researches on NF MQL for hard machining had increased significantly each year, demonstrating the growing interest in the application of NF MQL in manufacturing [3].

Many groups have conducted experiments using NF MQL. By using MQL, the results showed that cutting performances are improved, cutting forces are reduced, and consequently, power consumption decreased while tool life increased compared with dry machining and traditional flood cooling methods [5-11]. Duc et al. [12] performed hard turning using NF MQL with MoS_2 and Al_2O_3 nano cutting oils. The results showed that the cutting force F_z (tangential force), as well as the normal cutting force F_y were lower when using MoS_2 nano cutting oil than Al_2O_3 nano cutting oil. However, when using a soybean oil-based Al_2O_3 cutting fluid, a better quality surface was obtained due to the lower normal cutting force generated during the cutting process.

Duc et al. [13] further developed the MQL technique by adding Al_2O_3 and MoS_2 nanoparticles to two types of base oils: soybean oil and a water-based emulsion, for turning hardened 90CrSi steel (60–62 HRC). A factorial experimental design was used to evaluate the effects of nanoparticle type, cutting fluid type, nanoparticle concentration, and cutting speed on the cutting force components and surface roughness R_a. The results showed that MoS_2 nano-cutting fluid was highly effective in reducing cutting force components F_x and F_z but increased the thrust force F_y, whereas the Al_2O_3 nano-fluid showed the opposite effect. Furthermore, to achieve the lowest surface roughness value R_a, the soybean oil-based Al_2O_3 nano-fluid demonstrated better performance than the other fluids investigated.

To maximize the advantages of NF MQL using soybean oil-based MoS_2 nano-cutting fluid, which significantly reduces the cutting force components F_x and F_z, it is necessary to determine the optimal NF MQL conditions for minimizing surface roughness. Therefore, this paper aims to investigate the optimal nano-particle concentration (NC), air flow pressure (p), and air flow rate (Q) when using NF MQL with MoS_2 nano-cutting fluid for turning hardened 90CrSi steel.

II. Materials and methods

The experiment was conducted by using a system of machines and equipment for hard turning, as shown in Figure 1. The machine used was a Chu Shin CS-460x1000 lathe (Shin Pin Machinery Co., Ltd., Taichung City, Taiwan). The cutting insert was a Sandvik CBN insert, model HW 7025 (Figure 2), with the following basic geometric parameters: Tip angle 800; nose radius RE = 0.8; rake angle GB = -200; rear angle = 70; edge width BN = 0.1 mm (Figure 2). The workpiece material was 90CrSi steel (ISO DIN 4957), chemical composition (Table 1), dimensions ϕ45 (mm) x 45 (mm) x 4 pieces, hardness HRC = 60±1. The MQL nozzle, designated NOGA MiniCool MC1700 (Noga Engineering & Technology (2008) ltd, Shlomi, Israel), was mounted to spray directly onto the back of the cutter. A Mitutoyo SJ-210 surface roughness meter was used to measure the surface roughness value Ra with a standard length of 0.08 mm. After each cut, the surface roughness was measured three times and the average value was taken.

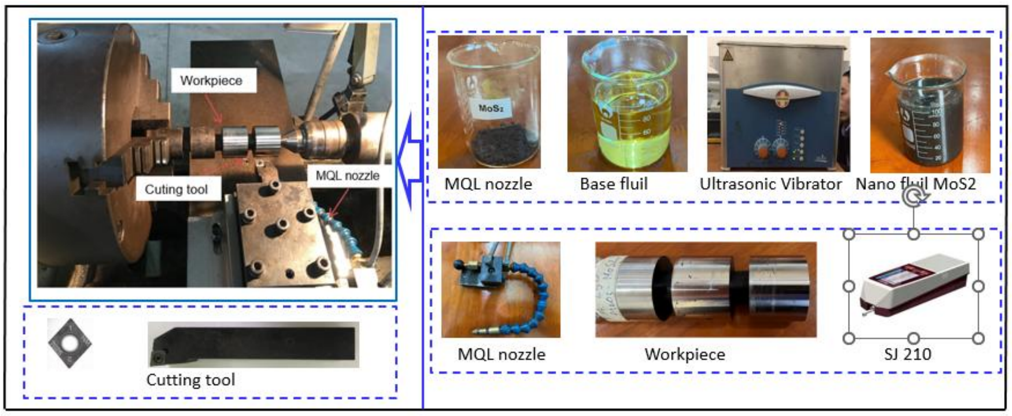
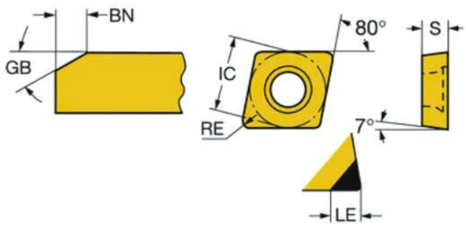


Figure n. Experiment set up



Face land width (BN) 0.1 mm
Face land angle (GB 20^0
Hand (HAND) Neutral
GRade (GRADE) 7025

Figure 1. Cutting insert geometric parameter

MoS_2 nanoparticles with a particle size of 30 nm were dispersed in soybean oil to form NF MoS_2 nano-cutting oil. NF MoS_2 nano-cutting oil was prepared through the following basic steps: direct mixing of MoS_2 nanoparticles into a base oil (soybean oil); mechanical stirring; and ultra-sonication by using an Ultrasons-HD ultrasonic vibrator (JP Selecta, Abrera - Barcelona) for 1 hour at a frequency of 40 kHz.

Table 1. Chemical composition of 90CrSi Steel

Element	C	Si	Mn	P	S	Cr	Ni	Mo	W	V	Ti	Cu
Percentage (%)	0.85-0.95	1.20-1.60	0.30-0.60	Max 0.03	Max 0.03	0.95-1,25	Max 0.40	Max 0.20	Max 0.20	Max 0.20	Max 0.03	Max 0.03

Minitab 21 software was used for the Box-Behnken experimental design with three input variables (nanoparticle concentration, air pressure and gas flow rate) and their levels are given in Table 2. A total of 15 experiments were conducted independently, each replicated three times. Cutting parameters were fixed at cutting speed V_c = 160 m/min, feed rate f = 0.12 mm/rev. and cutting depth a_p = 0.12 mm. Summary of experimental results is given in Table 3.

Table 2. Box-Behnken experiment design with three survey variables

No.	*Variable*	*Symbol*	*Low level*	*High level*
1	Particle concentration *(%)*	NC	0.2	0.8
2	Air pressure *(Bar)*	p	4.0	6.0
3	Air flow rate *(l/min)*	Q	150	250

Table 3. Summary of surface roughness R_a measurement at 15 experimental points.

StdOrder	*RunOrder*	*PtType*	*Blocks*	*NC (wt%)*	*P (bar)*	*Q (l/min)*	*R_a (µm)*
6	1	2	1	0.8	5	150	0.442
11	2	2	1	0.5	4	250	0.276
5	3	2	1	0.2	5	150	0.345
15	4	0	1	0.5	5	200	0.250
14	5	0	1	0.5	5	200	0.238
8	6	2	1	0.8	5	250	0.318
7	7	2	1	0.2	5	250	0.240
10	8	2	1	0.5	6	150	0.280
12	9	2	1	0.5	6	250	0.274
2	10	2	1	0.8	4	200	0.355
13	11	0	1	0.5	5	200	0.244
9	12	2	1	0.5	4	150	0.254
4	13	2	1	0.8	6	200	0.385
1	14	2	1	0.2	4	200	0.249
3	15	2	1	0.2	6	200	0.356

III. Results and discussion

Preliminary survey results show that only the independent variables (NC, p, and Q) and the second-order terms (NC^2, p^2, and Q^2) have a significant influence on the objective function Ra. The interaction terms, including NC**p, NC**Q, and p*Q, have an insignificant effect on the objective function and were therefore neglected in this study. With the support of Minitab 21 software, the experimental data were processed, yielding the following results.

The experimental regression function describing the dependence of R_a on the investigated variables is presented in Equation (1). The independent effects of the investigated variables on the objective function R_a are illustrated in Figure 3. The goodness of fit of the experimental model to the experimental data was evaluated using the coefficient of determination R^2, as presented in Table 4. The results show that the coefficient of determination R^2 is 79.87%, indicating that the experimental model fits the experimental data very well.

$$R_a = 0.958 - 0.746\,NC - 0.115\,p - 0.00269\,Q + 0.875\,NC*NC + 0.0135\,p*p + 0.000005\,Q*Q \quad (1)$$

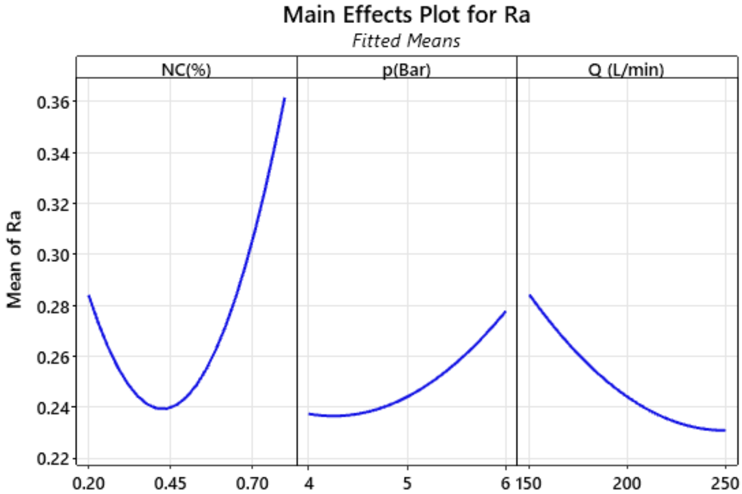


Figure 2. The independent effect of the survey variables on the objective function R_a

Table 4. Summary model of surface roughness evaluation parameters R_a

S	R-sq	R-sq(adj)	R-sq(pred)
0.0373158	79.87%	64.78%	19.72%

The independent effects of the investigated variables on the objective function R_a, as shown in Figure 3, indicated that all three variables (NC, p, and Q) influence the surface roughness value R_a. Among them, the nanoparticle concentration (NC) had the greatest influence, followed by the gas flow rate (Q), while the gas pressure (p) had the least influence.

At low MoS_2 nano-particle concentrations (NC ≈ 0.2%), the surface roughness value Ra was relatively high. As the concentration increases, the Ra value decreased and reached its minimum at approximately NC ≈ 0.4%. However, with a further increase in concentration, the surface roughness R_a rises rapidly. This can be explained by the fact that, at a medium concentration (NC ≈ 0.4%), the number of nano-particles was sufficient to form a lubricating friction film, thereby improving the cutting conditions and reducing R_a. At low concentrations, the number of MoS_2 nano-particles was insufficient to form this friction film, limiting the effectiveness of the nano-cutting fluid. In contrast, at high concentrations, the excessive number of nanoparticles in the cutting zone tends to adhere to the cutting edge, reducing cutting performance and causing the surface roughness to increase rapidly [13]. These results demonstrated that the concentration of MoS_2 nano-particles has a significant and highly sensitive effect on the surface roughness value R_a; therefore, determining the optimal nano-particle concentration was essential.

The ANOVA results (Table 5) showed the contribution levels of the investigated factors, with the overall model accounting for 79.87% of the variation. Within the model, the first-order terms (linear effects) contribute 47.33%, while the second-order terms (quadratic effects) contribute 52.67%. Among the first-order terms, nanoparticle concentration (NC) had the greatest contribution (57.42%), followed by air flow rate Q (27.10%), and finally air pressure p (15.48%).

Table 5. Results of Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Contribution	
Model	6	0.044206	0.007368	5.29	0.017		***79.87%***
Linear	3	0.020924	0.006975	5.01	0.030	47.33%	
NC	1	0.012013	0.012013	8.63	0.019		57,42%
p	1	0.003240	0.003240	2.33	0.166		15.48%
Q	1	0.005671	0.005671	4.07	0.078		27.10%
Square	3	0.023282	0.007761	5.57	0.023	52.67%	
NC*NC	1	0.022898	0.022898	16.44	0.004		98.35%
p*p	1	0.000673	0.000673	0.48	0.507		2.89%

Q*Q	1	0.000673	0.000673	0.48	0.507	2.89%
Error	8	0.011140	0.001392			***20.13%***
Lack-of-Fit	6	0.011068	0.001845	51.24	0.019	
Pure Error	2	0.000072	0.000036			
Total	14	0.055346				

V. Conclusion

In this paper, the minimum quantity lubrication (MQL) method using MoS_2 nano-cutting oil was successfully applied to the turning process of hardened 90CrSi steel (60-22 HRC) using a CBN turning tool. The influences of nano-particle concentration (NC), air flow pressure (p), and air flow rate (Q) on surface roughness R_a were studied and evaluated. A Box-Behnken design was used for the three variables investigated with the support of Minitab 21 software. ANOVA analysis showed that all three variables influenced the surface roughness Ra. The NC nano-particle concentration had the greatest influence (57.42%), followed by air flow rate Q (27.10%) and finally air pressure p (15.48%). The results also showed that the roughness value R_a reached its lowest value in the medium concentration range (NC ≈ 0.4%), and R_a was highly sensitive to changes in MoS_2 nanoparticle concentration. This result indicates that further research is needed to determine the optimal nanoparticle concentration was necessary.

Acknowledgments

The work presented in this paper is supported by Thai Nguyen University of Technology, Thai Nguyen University, Vietnam.

Reference

[1]. Manjunath Patel G. C, Ganesh R. Chate, Mahesh B. PaRappagoudar, Kapil Gupta (2020); *Machining of Hard Materials, A Comprehensive Approach to Experimentation, Modeling and Optimization;* Springer; https://doi.org/10.1007/978-3-030-40102-3

[2]. Rahul G. Chaudhari, Fukuo Hashmoto (2016) *"Process controls for surface integrity geneRated by hard turning"*; Available online at www.sciencedirect.com; http://creativecommons.org/licenses/by-nc-nd/4.0/

[3]. Anxue Chu, Changhe Li, Zongming Zhou; *Nanofluids Minimal Quantity Lubrication Machining: From Mechanisms to Application*; *Lubricants 2023, 11, 422.https://doi.org/10.3390/lubricants11100422.*

[4]. Yihan Liu, Shutao Huang, Ruyu Li, Zhonghan Cui, Yupu Zhang and Chengwei Liu 2; *Study on D6AC Steel PCBN Hard Turning and Optimization;* Materials 2026, 19, 1850; https://doi.org/10.3390/ma19091850

[5]. Avinash Kumar, Anuj Kumar Sharma and JitendRa Kumar Katiyar; *State-of-the-Art in Sustainable Machining of Different Materials Using Nano Minimum Quality Lubrication (NMQL);* Lubricants 2023, 11, 64.

[6]. https://doi.org/10.3390/lubricants11020064

[7]. Khalil, A.N.M.; Ali, M.A.M.; Azmi, A.I; *Effect of Al2O3 nanolubricant with SDBS on tool wear during turning process of AISI 1050 with minimal quantity lubricant;* Procedia Manuf. 2015, 2, 130–134.

[8]. Khajehzadeh, M.; MoRadpour, J.; *Razfar, M.R. Influence of nanolubricant particles' size on flank wear in hard turning*; Mater. Manuf. Process. 2019, 34, 494–501.

[9]. Khalil, A.N.M.; Ali, M.A.M.; Azmi, A.I; *Effect of Al2O3 nanolubricant with SDBS on tool wear during turning process of AISI 1050 with minimal quantity lubricant;* Procedia Manuf. 2015, 2, 130–134.

[10]. Khajehzadeh, M.; MoRadpour, J.; *Razfar, M.R. Influence of nanolubricant particles' size on flank wear in hard turning*; Mater. Manuf. Process. 2019, 34, 494–501.

[11]. Das, A.; Patel, S.K.; Biswal, B.B.; *Sahoo, N.; PRadhan, A. Performance evaluation of various cutting fluids using MQL technique in hard turning of AISI 4340 alloy steel*; Measurement 2020, 150, 107079.

[12]. Das, A.; Patel, S.K.; Das, S.R; *Performance comparison of vegetable oil based nanofluids towards machinability improvement in hard turning of HSLA steel using minimum quantity lubrication;* Mech. Ind. 2019, 20, 506.

[13]. Duc, T.M.; Long, T.T; Chien, T.Q; *Performance evaluation of MQL paRameters using Al_2O_3 and MoS_2 nanofluids in hard turning 90CrSi steel;* Lubricants 2019, 7, 40.

[14]. TRan Minh Duc, TRan The Long, TRan Quyết Chiến; *Performance Evaluation of MQL PaRameters Using Al_2O_3 and MoS_2 Nanofluids in Hard Turning 90CrSi Steel;* Lubricants 2019, 7(5), 40. https://doi.org/10.3390/lubricants7050040