Experimental Investigation of Turning Process Parameters of D3 Steel under nanofluid condition with CBN Insert

ISSN (e) 2520-7393
ISSN (p) 2521-5027
www.estirj.com

Naeem Ahmed[1*],Tanweer Hussain[2], Imtiaz Ali Soomro[3],Waseem Ahmed[4], Mansoor Ali[5]

[1,2,4]Department of Mechanical Engineering, Mehran University of Engineering and Technology, Jamshoro, Sindh, Pakistan
[3,5]Department of Metallurgy and Materials Engineering, Mehran University of Engineering and Technology, Jamshoro

Abstract: In recent years, nanofluids are widely used as coolant for machining of metals to enhance tool life and to impart good surface finish of workpiece. Turning D3 steel, a high carbon and high chromium steel commonly used for tool and die manufacturing, poses challenges such as elevated tool wear, low material removal rate (MRR) and difficulty achieving a smooth surface finish. This study investigates the turning process of D3 steel using Cubic Boron Nitride (CBN) insert with the assistance of nanofluid in a minimum quantity lubricant (NFMQL) setup. Nanofluid was developed by dispersing silver doped Al_2O_3 nanoparticles in different portions in the deionized (DI) water. Turning D3 steel involved adjusting key parameters (cutting speed, feed rate, and depth of cut) while maintaining a constant MQL flow rate of 240 ml/hr. The results show nanofluid based turning generated better surface finish on the D3 steel compared to dry turning and to analyze the impact of Ag Al_2O_3 based nanofluid on the surface finish of workpiece under both coolant and dry conditions. The percentage reduction between average surface roughness values under dry and nanofluid is approximately 29.17% and tool life is about 49.05% increased under nanofluid compared to dry conditions.

Keywords: *Machining, Hard-turning, AISI D3 Steel, CBN Inserts, Nanofluids*

1. Introduction

One of the major challenges facing for the manufacturers in today's technological era is providing hardened steel components with the proper quality characteristics in the required quantity as quickly and affordably as possible. Hardened steels, ranging from HRC 42 to 68, have been in high demand for over five decades due to their capacity to produce precise components with exceptional mechanical performance, widely utilized in various engineering applications. These materials find extensive use in the manufacturing of tools and dies, automotive parts, bearings, and molds. Their essential properties encompass superior abrasiveness, a high hardness-to-elastic modulus ratio, low ductility, and excellent indentation resistance, rendering them challenging to machine [1], [2]. In the industrial sector, hard turning is employed, utilizing low feed and smaller depth of cut to attain improved surface finish without the necessity for conventional turning. In the production of tools, dies, shafts, bearings, and other components, an important surface characteristic of hardened steels is surface roughness. Hard turning specifically designed for materials with a hardness of 45 HRC or higher, reduces machining time and improves surface roughness compared to traditional grinding, especially when using CBN cutting tool inserts [3]. Machining hard-to-cut materials, such as D series steel with high chromium and high carbon, super alloys, stainless steel, titanium alloys, and nickel-based alloys, presents numerous challenges [4]. Issues encompass high cutting force values, heightened vibration levels in machining systems, heat concentration, elevated cutting temperature, rapid tool wear, the potential for catastrophic tool failure, frequent stability losses, and noticeable deterioration in surface finish [5]. Lubricating the tool tip and workpiece is crucial for reducing the frictional heat generated between them [6].

Two crucial controlling variables in machining processes are surface roughness (Ra) and material removal rate (MRR). MRR serves as a measure of productivity, while Ra indicates surface excellence [7]. Optimal selection of cutting speed, feed rate, depth of cut, and insert nose radius contributes to decreased Ra and increased MRR [8], [9].

2. The Tribological Mechanisms of Nanoparticles on Surface Roughness of Hard Steel Under Nano-lubricant (NMQL)

Currently, the most commonly used nanoparticles consist of carbon family materials like graphene, carbon nanotube (CNT), and diamond as well as metallic and non-metallic compounds like Al_2O_3 [10], [11], SiO_2 [12], CuO [13], [14], [15] ZrO_2 [10] and MoS^2[10], [14], [16]. The process by which the lubrication film forms between the workpiece and abrasive grain can alter when solid nanoparticles are introduced into the surface and tool interface under nanofluid MQL. According to current research, there are four main tribological mechanisms for nanoparticles: (1) The rolling effect: Rolling friction can be created between the workpiece and the abrasive grain by using nanoparticles. (2) The filling effects: In order to repair the workpiece's

*Corresponding author Email address:*engrnaeemsheikh@gmail.com*

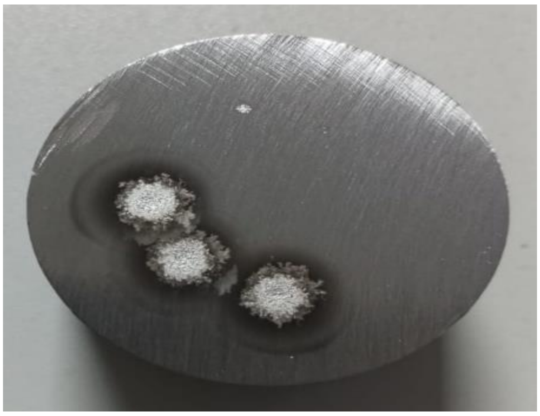
surface, nanoparticles can be used to fill in the groove-like fractures on it. (3) Polishing effect: In the space between the workpiece and the abrasive grain, nanoparticles can have a polishing effect. (4) The interplay among the nanofluid, abrasive grain, and workpiece may induce chemical reactions, resulting in the formation of a chemical reaction film at the abrasive grain/workpiece grinding interface. Concurrently, nanoparticles demonstrate diverse tribological behaviors on the grinding interface, encompassing adsorption, shear, extrusion, rolling, deformation, and sliding. [17]–[19].

3. Material and Methodology

In this experimental investigation, we explore the effects of different parameters on surface roughness, tool wear (tool life), and the physical characteristics of chips. The study is conducted under both nanofluid-assisted Minimum Quantity Lubrication (MQL) and dry turning conditions. Experiments are conducted on a high carbon and high chromium AISI D3 cylindrical steel bar, also known as 1.2080 (Werkstoff) or SKD1, utilizing a Cubic Boron Nitride (CBN) tool insert.

3.1 Testing Material—Workpiece

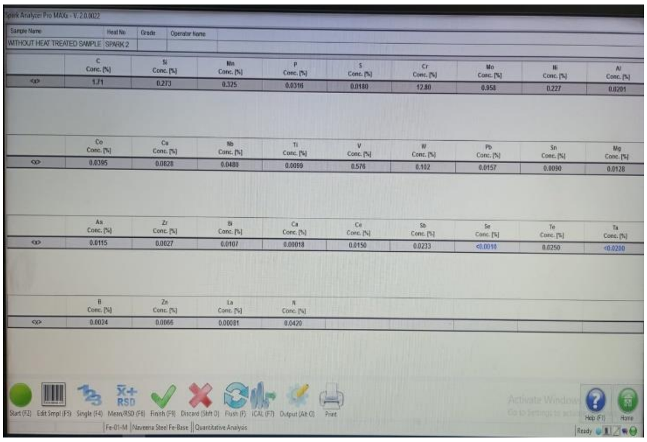
The workpiece employed in this turning experiment is a heat-treated D3 steel with dimensions measuring 40 mm in diameter and 101.6 mm in length. The chemical composition of AISI D3 steel, presented in Table 1 through spectroscopy using the Spark Analyzer Pro MaXx-V.2.0.0022 equipment, is provided for reference a image of spark can also seen in figure no. 1 as three spark test performed during chemical composition testing and a result of spart three is also mentioned in figure number 2 for reference. Prior to the experimental study, the workpiece undergoes heat treatment at approximately 900℃ for 40 minutes, reaching an austenizing temperature, and is subsequently oil quenched. Subsequently, it is subjected to a one-hour tempering process at 300℃, followed by cooling. This process is essential for relieving residual stresses in the workpiece, resulting in a homogeneous structure and achieving a hardness increase within the range of 62±1 HRC.



(Fig. 1: Spark impression on workpiece)

Table no. 1 Chemical Compositions of AISI D3 Steel

Elements	C	Si	Mn	Cr	Mo	Fe
Composition (%)	1.71	0.273	0.325	12.80	0.958	Balance



(Fig. 2: Composition of workpiece noted after spark test)

3.2 Testing Material—Cutting tool

For the experimental work, specified CBN (Cubic Boron Nitride) tools were used for the machining operations in this experiment because of their outstanding cutting abilities. The nose radius of the particular CBN tool insert that was used was 0.8 mm, a complete tool insert with holder is shown in figure number 3 and figure number 4 shows as upper part of insert is a shim and lower part shows a CBN nose radius indicates the insert and selected tool holder was identified as an *MCLNR2020K12ow* and was made in a right-handed fashion. In order to ensure precise and effective cutting performance on the heat-treated D3 steel workpiece during the machining process.

(Fig. 3: CBN insert with holder)

(Fig. 4: CBN inserts)

3.3 Nanofluid—cutting coolant

In present work the nanofluids of doped nano silver (Ag) particles Al_2O_3 were produced and their heat extraction efficiency was studied. Nanofluids possess notable superior qualities that account for their extensive applications in many fields of engineering like manufacturing, geothermal, aerospace, and energy generation. These fields generate larger amounts of heat that require rapid extraction; therefore, because of their increased thermal conductivity and thermophysical properties, the presence of these characteristics in mono or hybrid nanofluids enables the rapid extraction of heat. [20]. Clustering of nanoparticles causes settling and blockage, which reduces nanofluid thermal conductivity. Consequently, it is essential to research and evaluate the factors influencing the stability of nanoparticles during their dispersion [21].

Preparation of Ag doped Al_2O_3 based Nanofluid

The nanofluid of different composition were prepared. Table no. 2 provides the detail of the ingredients of the nanofluids. Before using the nanofluids the pH of the fluids was adjusted to 11.

Table no. 2 Nanofluid composition

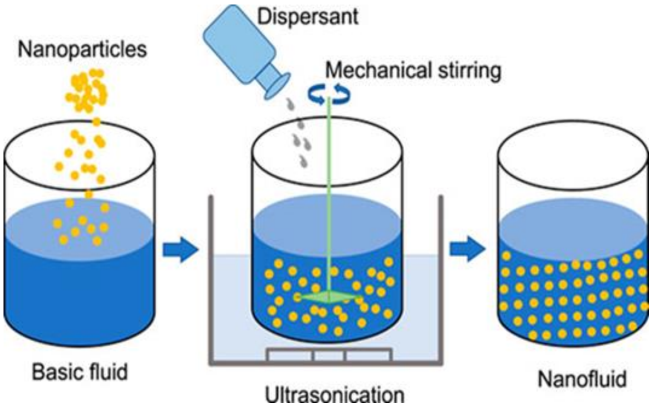
Sample ID	Nanoparticle type	Weight (mg)	DI Water volume (ml)
Al_2O_3	Aluminum Oxide	500	1000

The procedure of preparing the nanofluids is as following steps:

1) **Dispersal of Nanoparticles:** Nanoparticles were dispersed in DI water.

2) **Ultra-sonification:** The procedure was used to completely sonicate the dispersed particles for about 2 hours a graphical demonstration can be observed in figure number 5. This process indicates that the nanoparticles are distributed evenly throughout the cooling fluid.

3) **Readiness for use:** after ultrasonification nanofluid are ready to use for use in machining process, having ability of cutting-edge coolant for turning process.



(Fig. 5: Preparing step's graphical demonstration of NF)

3.4 Experimental Equipment

The experimentation was carried out utilizing a Computer Numerical Control (CNC) lathe machine, specifically the *LC6NO* model. Surface roughness measurements were conducted using the widely utilized Mitutoyo *SJ-210* Surface test model *No. UNI312-0913* surface roughness tester. Tool life and the average final surface roughness (Ra) of the workpiece were determined with the aid of a stopwatch.

3.5 Machining Optimization Considerations

Achieving an effective cutting combination is crucial for minimizing both production costs and time. Evaluating the machinability of heat-treated materials involves considering various factors such as cooling conditions, material hardness, insert type, cutting parameters, and nose radius. This study involved hard turning at three different speeds and three distinct levels of depth of cut and feeds.

The machining operations took place in two different environments, comparing dry machining to Nanofluid Minimum Quantity Lubrication (MQL), with the MQL flow rate set at 240 ml/hr. Utilizing Nanosilver (Ag) particle-doped Al_2O_3 nanofluid as the lubricant, based on literature recommendations, establishes the groundwork for investigating the impact of different factors on the turning process and achieving an optimal combination for improved efficiency. In conjunction with the experimental setup, Table no. 3 outlines the levels of cutting parameters consideration for the turning experiments.

Table no. 3: Experimental levels for cutting parameters

Cutting Parameters	*Run Levels*		
	1	2	3
Cutting Speed (V) (m/min)	130	130	150
Feed Rate (f) (mm/rev)	1.1	1.1	0.56
Depth of Cut (d) (mm)	0.05	1.0	0.1

These levels indicate alterations in cutting speed, feed rate, and depth of cut, establishing a comprehensive framework to investigate the impact of various cutting parameters on the turning process.

4. Results and Discussion

4.1 Surface Roughness (Ra) and Material Removal Rate (MRR)

The hard-turning procedure in this experimental investigation was carried out with Nanofluid Minimum Quantity Lubrication (NFMQL) and in dry conditions. A notable improvement in surface roughness was noted along with a notable change in tool life. The outcomes of the experiments are presented in Table 4. Noticeable, the implementation of NFMQL revealed nothing identifiable effect on the Material Removal Rate (MRR). The MRR achieved its peak values at the highest configurations of depth of cut, feed, and cutting velocity. These finding highlights how the parameters of feed rate, depth of cut, and cutting speed have a direct relationship with MRR. The calculation for MRR was performed using the formula: $MRR = d \times f\,Vc$. These findings show how MQL has a subtle effect on surface roughness and demonstrate how adding a nanofluid can produce results that are similar in terms of surface finish. It is observed a good reduction in surface roughness under nanofluid conditions shows the positive impact of nanofluid assisted MQL on achieving improved surface finish compared to dry conditions.

(Table no. 4: Surface Roughness and MMR Results)

No. of Run	Cutting Condition	Cutting Speed Vc (m/s)	Feed Rate f (mm/rev)	Depth of Cut d (mm)	Surface Roughness $Ra\ (\mu m)$	Materials Removal Rate MRR (mm/min)
1	Dry	130	1.1	0.05	1.10	7.15
2	Dry	130	1.1	1.0	1.3	143
3	Dry	150	0.56	0.1	1.14	8.4
4	NF	130	1.1	0.05	0.99	7.15
5	NF	130	1.1	1.0	0.77	143
6	NF	150	0.56	0.1	0.71	8.4

4.2 Impact on Tool Life:

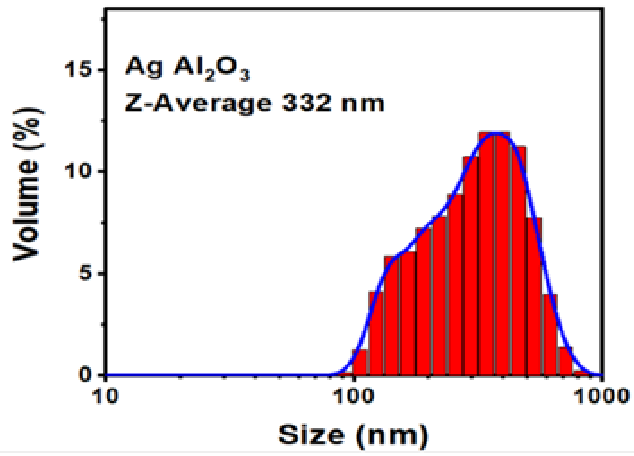
The study showed that the CBN tools' life (Table no. 5) is significantly influenced by cutting velocity, while the depth of cut and feed play minor roles. Faster cutting speeds generally mean shorter tool life, but introducing Nanofluid Minimum Quantity Lubrication (NFMQL) extended tool life across all cutting speeds compared to dry conditions. These factors provide a clear picture of how different factors impact tool durability, important for optimizing the machining process.

Table 5: Tool Life Analysis with respect to Time

Cutting condition	Cutting Velocity (m/mint)	Tool Life (mins)
Under Dry	130	38.1
Under Dry	130	26.4
Under Dry	150	17.1
NF—MQL	130	59.9
NF—MQL	130	37.1
NF—MQL	150	26.7

4.3 Dynamic light scattering analysis of Nanofluid

The particle size distribution of Ag-doped nanoparticles obtained from Dynamic Light Scattering (DLS) analysis reveals significantly wider spectrums. The average sizes for Ag-doped Al_2O_3 are recorded as 304 nm, 332 nm, and 368 nm, respectively, as illustrated in Figure 3. Moreover, Figure 4 displays a prepared and tested sample of Ag-doped Al_2O_3 nanofluid, totaling approximately 800 ml in quantity.



(Fig. 3 DLS result of Ag doped Al_2O_3)

5. Conclusion

An exploration of the turning lathe machining process for AISI D3 steel, utilizing CBN tools in both dry and Nanofluid Minimum Quantity Lubrication (NFMQL) conditions, reveals key findings. Optimal surface roughness is achieved at higher cutting speeds with a minimal feed rate. The depth of cut is pivotal, with an ideal range to minimize roughness, avoiding both excessively small and large depths, which increase roughness. The study highlights a direct relationship between feed rate and surface roughness, while cutting speed shows an inverse correlation. However, higher speeds reduce tool life, evident in decreased tool life at faster speeds. For the best surface roughness, the highest speed and minimum feed rate, 150 m/min and 0.56 mm/rev, prove effective in both dry and NFMQL conditions. NFMQL brings notable enhancements, achieving a 29.17% improvement in surface roughness and a significant 49.05% increase in tool life. This results in an average 9.72% percentage difference between Dry and NFMQL conditions across all parameters. Furthermore, Material Removal Rate (MRR) shows an upward trend with increasing cutting velocity, feed, and depth of cut. The study uncovers a consistent tool life ratio across all three cutting parameters. It's important to acknowledge that the research is confined to AISI D3 steel, CBN tool inserts, and the innovative use of Ag-doped Al_2O_3 nanofluids.

About Author:

Naeem Ahmed is currently enrolled in the Master's program in Manufacturing Engineering at the Department of Mechanical Engineering, Mehran University of Engineering and Technology (MUET), Jamshoro, Sindh, Pakistan. His research focuses on Coating Technology, Surface Roughness, and Advanced Materials.

References

[1] L. Dash, S. Padhan, A. Das, and S. R. Das, "Machinability investigation and sustainability assessment in hard turning of AISI D3 steel with coated carbide tool under nanofluid minimum quantity lubrication-cooling condition," *Proc Inst Mech Eng C J Mech Eng Sci*, vol. 235, no. 22, pp. 6496–6528, 2021, doi: 10.1177/0954406221993844.

[2] S. A. Khan, T. Hussain, I. A. Tunio, and M. Aleem, "Hard Turning of AISI D2 Steel Using CBN Tools under MQL : Assessment of MRR , Tool Life and Surface Integrity of the Workpiece," pp. 106–114, 2023.

[3] V. D. Patel and A. H. Gandhi, "Analysis and modeling of surface roughness based on cutting parameters and tool nose radius in turning of AISI D2 steel using CBN tool," *Measurement (Lond)*, vol. 138, pp. 34–38, 2019, doi: 10.1016/j.measurement.2019.01.077.

[4] A. M. M. Ibrahim, M. A. E. Omer, S. R. Das, W. Li, M. S. Alsoufi, and A. Elsheikh, "Evaluating the effect of minimum quantity lubrication during hard turning of AISI D3 steel using vegetable oil enriched with nano-additives," *Alexandria Engineering Journal*, vol. 61, no. 12, pp. 10925–10938, 2022, doi: 10.1016/j.aej.2022.04.029.

[5] S. Padhan *et al.*, "Investigation on Surface Integrity in Hard Turning of AISI 4140 Steel with SPPP-AlTiSiN Coated Carbide Insert under Nano-MQL," *Lubricants*, vol. 11, no. 2, 2023, doi: 10.3390/lubricants11020049.

[6] S. Integrity, "Advances in Hard – to – Cut Materials : Manufacturing , Properties , Process Mechanics and Evaluation of," 2020.

[7] N. Bhone, N. Diwakar, and S. S. Chinchanikar, "Multi-response optimization for AISI M7 Hard Turning Using the utility concept," *The Scientific Temper*, vol. 14, no. 01, pp. 142–149, 2023, doi: 10.58414/scientifictemper.2023.14.1.16.

[8] K. Mondal, S. Das, B. Mandal, and D. Sarkar, "An Investigation on Turning Hardened Steel Using Different Tool Inserts," *Materials and Manufacturing Processes*, vol. 31, no. 13, pp. 1770–1781, 2016, doi: 10.1080/10426914.2015.1117634.

[9] R. Mallick, R. Kumar, A. Panda, and A. K. Sahoo, "Current Status of Hard Turning in Manufacturing: Aspects of Cooling Strategy and Sustainability," *Lubricants*, vol. 11, no. 3, 2023, doi: 10.3390/lubricants11030108.

[10] Y. Wang *et al.*, "Experimental evaluation of the lubrication properties of the wheel/workpiece interface in MQL grinding with different nanofluids," *Tribol Int*, vol. 99, pp. 198–210, Jul. 2016, doi: 10.1016/j.triboint.2016.03.023.

[11] S. Ma, Y. Yin, B. Chao, K. Yan, B. Fang, and J. Hong, "A real-time coupling model of bearing-rotor system based on semi-flexible body element," *Int J Mech Sci*, vol. 245, p. 108098, May 2023, doi: 10.1016/J.IJMECSCI.2022.108098.

[12] Y. S. Dambatta, M. Sayuti, A. A. D. Sarhan, M. Hamdi, S. M. Manladan, and M. Reddy, "Tribological performance of SiO2-based nanofluids in minimum quantity lubrication grinding of Si3N4 ceramic," *J Manuf Process*, vol. 41, pp. 135–147, May 2019, doi: 10.1016/J.JMAPRO.2019.03.024.

[13] R. L. Virdi, S. S. Chatha, and H. Singh, "Performance evaluation of nanofluid-based minimum quantity lubrication grinding of Ni-Cr alloy under the influence of CuO nanoparticles," *Adv Manuf*, vol. 9, no. 4, pp. 580–591, 2021, doi: 10.1007/s40436-021-00362-1.

[14] A. Azami, Z. Salahshournejad, E. Shakouri, A. R. Sharifi, and P. Saraeian, "Influence of nano-minimum quantity lubrication with MoS2 and CuO nanoparticles on cutting forces and surface roughness during grinding of AISI D2 steel," *J*

Manuf Process, vol. 87, no. January, pp. 209–220, 2023, doi: 10.1016/j.jmapro.2023.01.029.

[15] M. Wang, K. Yan, Q. Tang, J. Guo, Y. Zhu, and J. Hong, "Dynamic modeling and properties analysis for ball bearing driven by structure flexible deformations," *Tribol Int*, vol. 179, p. 108163, Jan. 2023, doi: 10.1016/J.TRIBOINT.2022.108163.

[16] B. Shen, P. Kalita, A. P. Malshe, and A. J. Shih, "Performance of novel MoS2 nanoparticles based grinding fluids in minimum quantity lubrication grinding," *Transactions of the North American Manufacturing Research Institution of SME*, vol. 36, pp. 357–364, 2008.

[17] A. Singh, A. Kumar, V. Sharma, and P. Kala, "Sustainable techniques in grinding: State of the art review," *J Clean Prod*, vol. 269, p. 121876, May 2020, doi: 10.1016/j.jclepro.2020.121876.

[18] X. Wang *et al.*, *Nanofluids application in machining: a comprehensive review*. Springer London, 2023. doi: 10.1007/s00170-022-10767-2.

[19] X. CUI *et al.*, "Minimum quantity lubrication machining of aeronautical materials using carbon group nanolubricant: From mechanisms to application," *Chinese Journal of Aeronautics*, vol. 35, no. 11, pp. 85–112, 2022, doi: 10.1016/j.cja.2021.08.011.

[20] H. Mercan, A. Celen, and T. Taner, "Thermophysical and rheological properties of unitary and hybrid nanofluids," *Advances in Nanofluid Heat Transfer*, pp. 95–129, Jan. 2022, doi: 10.1016/B978-0-323-88656-7.00005-2.

[21] R. Surakasi *et al.*, "Synthesis and Characterization of TiO2-Water Nanofluids," *Adsorption Science and Technology*, vol. 2022, 2022, doi: 10.1155/2022/3286624.