Digital Manufacturing Technology
https://ojs.wiserpub.com/index.php/DMT/

UNIVERSAL WISER PUBLISHER

Conference Proceeding

Paper presented at the 1st International Conference on Modern Technologies in Mechanical & Material Engineering [MTME 2023]

Hard Turning of AISI D2 Steel Using CBN Tools under MQL: Assessment of MRR, Tool Life and Surface Integrity of the Workpiece

Sheheryar Ahmed Khan*, Tanweer Hussain, Intizar Ali Tunio, Muhib Aleem

Mehran UET, Jamshoro, Sindh, Pakistan.
E-mail: sheheryarkaimkhani@gmail.com

Received: 25 May 2023; **Revised:** 23 June 2023; **Accepted:** 18 July 2023

Abstract: Hard turning (HT) is a machining method which is widely adopted nowadays to produce an improved surface finish without the application of a grinding process. The available literature conveys to us that studies have been done to improve surface finish by using small feeds and high speed. This study is an effort to enhance the tool life, material removal rate (MRR) and surface roughness of the workpiece by using different combinations of cutting factors and a lubricating technique called minimum quantity lubrication (MQL). The workpiece used for this experiment is AISI D2 steel and the used tool inserts are cubic boron nitride (CBN) tools. The HT of the workpiece is done under 3 different cutting velocities, feeds and depths of cuts. The flow rate for the MQL process is kept at 240 ml/hr. We observed that at the highest speed and lowest feed, the achieved surface roughness was the best. Furthermore, the MQL showed some great results in the context of tool life as it was improved by approximately 48% as compared to that of dry machining. Also, there was an improvement of up to 12% in the context of surface finish. However, there was not any effect of MQL on MRR as it purely relies on cutting velocity, depth of cut and feed. Also, it did not have any effect on the workpiece and tool insert material used.

***Keywords*:** surface integrity, MRR, tool life, MQL, HT

1. Introduction

A lathe machine is one of the most important machines used in a mechanical workshop, which offers numerous machining operations. The operation performed by us in this research is a turning operation. Turning is a process whose sole purpose is to reduce the diameter of a cylindrical surface or likewise. In this process, a cutting tool insert is positioned along the axis of the rotation of the workpiece. When the hardness of the workpiece material is greater than 45 HRC, then the turning of that material is referred to as hard turning (HT) [1, 2], it is typically in the range of 58 HRC to 68 HRC. The primary purpose of HT is to eliminate the conventional grinding process. HT is now been used in the industrial sector as with low feeds and small depth of cut it provides a better surface finish without the application of a grinding process [2, 3]. The advantages that HT provide over conventional grinding are decreased manufacturing costs, less cutting time and increased material removal rate (MRR) with more flexibility. It is quite obvious that to turn hard materials one would need hard tools, that's why mostly the tools used in HT are cubic boron nitride (CBN) tools, polycrystalline diamond (PCD) tools, polycrystalline cubic boron nitride (PCBN) tools, cemented carbides, etc.

Copyright ©2023 Sheheryar Ahmed Khan, et al.
DOI: https://doi.org/10.37256/dmt.3220233087
This is an open-access article distributed under a CC BY license
(Creative Commons Attribution 4.0 International License)
https://creativecommons.org/licenses/by/4.0/

Moreover, to improve the tool life and workpiece surface finish sometimes machining is done in a wet environment. A technique is used nowadays for wet machining known as minimum quantity lubrication (MQL). MQL is a technique in which a small amount of liquid is sprayed on the workpiece at regular intervals for lubrication and/or as a cooling agent.

In a literature review of work on turning of AISI 4340 and D2 steel with chemical vapor deposition (CVD) coated carbide and TiN-coated alumina tools, respectively, researchers found that feed rate was the highly effective factor in the context of tool life, MRR and surface roughness. Cutting velocity too had a significant impact on the flank wear and surface integrity. While working on AISI 52100 steel, the type of tool insert was found to be the most effective factor, with wiper inserts offering a better surface finish than conventional inserts. Tool nose radius and depth of cut were also found to affect the result [1-3].

In a literature review of studies on cutting factors and environments, researchers found that supercooled carbon dioxide+MQL (scCO_2+MQL) is directed towards an enhancement in surface integrity and tool life compared to that of flood coolant. Another study found that a dry environment was more significant in the context of power consumption, surface integrity and micro-hardness for 303 stainless steel. The authors also noted that an optimal combination of cutting factors can provide better results in the context of power consumption and surface roughness. Another study on AISI D2 steel with coated carbides found that cutting velocity had an inverse relation with surface roughness and also that feed was a highly effective factor to control surface integrity [4-6].

In a literature review of studies on coated carbide tools under MQL, researchers found that using a small amount of lubricant during machining provides high strength to the tools to perform at a high range of cutting velocities and feed rates. Another review of HT of steel observed that a required finishing can be achieved without conventional grinding and that lubricant is not necessary to achieve a better surface finish. Dry and cryogenic machining was also found to be eco-friendly. In another review of MQL with nano-fluids, it was found that MQL is better than dry and flood machining in the context of providing a better surface finish, better tool life and increasing lubricity at a low cost and quantity of coolant. Another study also directed the fact that MQL machining is superior to wet and dry machining in the context of surface roughness and tool life [7-10].

In a literature review of studies on HT, researchers found that the surface roughness of AISI H13 die tool steel decreased as the hardness of the workpiece increased, and that feed rate had a direct relation with surface roughness. CBN tools were also found to be suitable for HT. Another study on HT of titanium alloy with PCD tool inserts found that cutting temperature had a direct relation with cutting velocity and an inverse relation with feed rate and that higher depth of cut produced improved surface finish in high-speed machining (HSM) than in conventional machining [11]. Finally, in another study, the impact of carbon nanotubes while turning AISI D2 steel under MQL with tungsten carbide (TC) tools was examined, it was found that the cutting zone temperature reduced which improved the surface quality and led to reduced tool wear [12, 13].

In a literature review of studies on HT, researchers found that cutting factors had a major impact on surface roughness. Srithar et al. [14] established that cutting velocity and surface roughness had an inverse relation and that feed rate was the highly effective factor that impacted surface integrity. Karthik et al. [15] also found that feed rate was the most effective factor and directly proportional to surface integrity in HT of EN31 steel while machining it with the CBN tool. Subbaiah et al. [16] observed the impact of the hardness of the workpiece on surface roughness, cutting force and tool wear while working on AISI 4340 steel with wiper ceramic cutting inserts. They found that the hardness of the workpiece had an impact of 30.27% and 29.4% on tool wear and cutting forces respectively. Furthermore, they achieved a surface roughness of 0.23 and 0.25 microns at low feeds and greatest cutting velocities.

Rafighi et al. [17] compared CBN tools with ceramic inserts in HT of AISI D2 steel and found that the feed rate was the highly effective factor on surface integrity followed by tool nose radius. They concluded that CBN tools executed better in the context of surface roughness than ceramic inserts. Senevirathne et al. [18] did HT of AISI D2 steel under MQL using various lubricants and compared the results of dry, flood and MQL machining under sunflower oil, waste cooking oil and coconut oil. They found out that out of all lubricants, sunflower oil gave the best results, followed by coconut oil. However, the results obtained while working with waste cooking oil were abysmal.

The gathered literature conveys that properties like MRR, tool life and surface integrity are affected by factors like feed rate, cutting velocity, depth of cut and tool nose radius. The literature shows that a rise in depth of cut and feed improves the MRR but at a cost of poor surface quality. Moreover, cutting velocity shows direct relation with MRR and an inverse relation with surface roughness and tool life. Furthermore, some attempts are made to improve tool life and surface quality through MQL.

HT is a process which nowadays is widely contributing to eliminating conventional grinding processes. The grinding process is generally used to provide a better surface finish but since the rise of HT, it has been excluded largely as a whole process is removed from machining and saves us the time, power consumption and machining cost spent on the grinding process. Studies have been done to improve tool life by reducing the depth of cut but it affected the MRR negatively. Moreover, the use of high feed rates helped in MRR but showed a negative impact on tool life and surface integrity. This research is an attempt to improve tool life and surface roughness simultaneously. We have tried to do so through a process called MQL. In this research we are focusing on:

- to perform HT at different feeds, cutting velocities and depth of cuts,
- to perform HT under MQL,
- to investigate the effects of the aforementioned factors as well as the lubricant on the tool and workpiece.

2. Materials and methods

2.1 *Workpiece and cutting tool*

The workpiece used in this research is AISI D2 steel, which is often used to make forming dies, machining tools, punches and cutting dies because of its properties such as toughness, good abrasion, wear resistance, etc. A cylindrical bar was used as the workpiece material, whose diameter was 61 mm and length was 60 mm. The chemical composition of the workpiece is mentioned in Table 1. Furthermore, the tool inserts used in the machining were CBN tools due to their excellent cutting tool properties. The nose radius used for the research was 0.8 mm. Moreover, the used tool holder was a right-handed style tool holder designated as MCLNR2020K12.

Table 1. Chemical composition of the workpiece

Material	Cu	Ni	Mo	S	P	C	Mn	Si	Cr	Fe
Quantity in the workpiece (%)	0.01	0.2	1.2	0.03	0.06	1.5	0.3	0.4	14.6	81.7

2.2 *Heat treatment*

The materials were heat treated to improve their mechanical properties such as strength, toughness, hardness and impact resistance. Initially, the workpiece was slowly preheated to 800 °C. Then, the temperature was raised to 1020 °C more rapidly and the material was held at that temperature for several minutes. Moreover, the material cooled down slowly. Then, at a temperature of 250 °C, tempering was applied to eliminate residual stresses in the workpiece. Lastly, a hardness of 60±1 HRC was achieved by cooling it in the air.

2.3 *Lathe machine and measuring apparatus*

The lathe machine used for the experiment was a CNC Lathe Machine LC6 NO1, whose specifications are as given below:

MAX: SPEED: 3000 RPM

MAX: POWER: 15 kW

MAX: TURNING DIAMETER: 75 mm

MAX: TURNING LENGTH: 550 mm

Furthermore, the measuring apparatus used for determining surface roughness was a portable surface roughness tester (i.e. Surtronic S25). The measurements were taken at three different points of the workpiece and the average of those values was taken as the final surface roughness (R_a) of the workpiece. Furthermore, the tool life was simply determined using a stopwatch.

2.4 *Cutting conditions*

Acquiring an optimum cutting combination is a very main issue to decrease the cost and time of production. Factors such as cooling conditions, material hardness, type of insert, cutting factors and nose radius are essential to assess the material's machinability in the HT process. In this research, the HT was done under 3 different speeds, at 3 different levels of depth of cut and feeds. The machining was done under 2 different environments (i.e. dry vs. MQL). The flow rate for MQL was kept at 240 ml/hr and the lubricant used for the study was sunflower oil. The selection of the lubricant was done according to the literature. The cutting factors used for the study are given in Table 2.

Table 2. Cutting factors used in the study

Cutting velocity (m/min)	Feed rate (mm/rev)	Depth of cut (mm)
90	0.05	0.15
130	0.15	0.3
170	0.25	0.45

(a) (b)

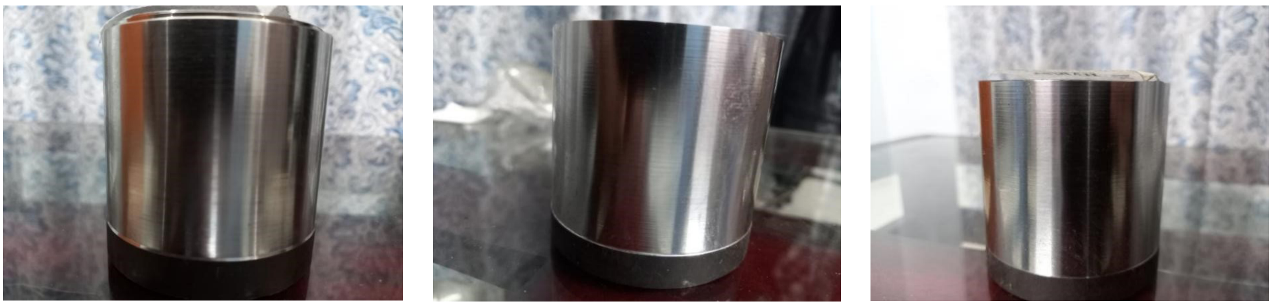
Figure 1. (a) CBN tool insert attached to MCLNR2020K12 tool holder, (b) hardened AISI D2 steel with hardness 60±1 HRC

3. Results

In this research, the HT was done under dry conditions as well as under MQL. However, there wasn't any appealing change in surface roughness but the tool life showed an interesting change. The achievements of the experiments are given below in Table 3. According to the results of the performed experiments, the achieved surface roughness lies in the range of 0.212-1.975 µm under the dry conditions, whereas, the surface roughness achieved in MQL conditions was in the range of 0.193-1.797 µm. Also, there was no effect of MQL on MRR and it was greatest at the greatest values of depth of cut, feed and cutting velocity. This shows that MRR has a direct relation with feed, depth of cut and cutting velocity. MRR was achieved using the following formula: MRR = V_c.f.d.

Table 3. Results of the experiments

No. of experiments	Cutting condition	V_c (m/min)	f (mm/rev)	d (mm)	R_a (μm)	MRR (mm^3/min)
1	Dry	90	0.05	0.15	0.577	675
2	Dry	130	0.15	0.3	0.482	5850
3	Dry	170	0.25	0.45	1.975	18360
4	Dry	90	0.05	0.3	0.328	1350
5	Dry	130	0.15	0.45	0.562	8775
6	Dry	170	0.25	0.15	1.817	6375
7	Dry	90	0.05	0.45	0.282	2025
8	Dry	130	0.15	0.15	0.402	2925
9	Dry	170	0.25	0.3	1.896	1275
10	Dry	90	0.15	0.45	0.610	6075
11	Dry	130	0.25	0.15	1.670	4875
12	Dry	170	0.05	0.3	0.212	2550
13	MQL	90	0.05	0.15	0.531	675
14	MQL	130	0.15	0.3	0.434	5850
15	MQL	170	0.25	0.45	1.797	18360
16	MQL	90	0.05	0.3	0.289	1350
17	MQL	130	0.15	0.45	0.511	8775
18	MQL	170	0.25	0.15	1.635	6375
19	MQL	90	0.05	0.45	0.259	2025
20	MQL	130	0.15	0.15	0.358	2925
21	MQL	170	0.25	0.3	1.668	1275
22	MQL	90	0.15	0.45	0.561	6075
23	MQL	130	0.25	0.15	1.520	4875
24	MQL	170	0.05	0.3	0.193	2550



(a) (b) (c)

Figure 2. (a) Workpiece turned at 130 m/min, 0.15 mm/rev and 0.3 mm, (b) workpiece turned at 90 m/min, 0.05 mm/rev and 0.15 mm, (c) workpiece turned at 170 m/min, 0.25 mm/rev and 0.45 mm

According to Figure 3, we can analyze that the surface roughness of the workpiece increases with the rise in feed. The graph shows that the surface roughness first surges gradually and after a certain point it increases at a quick pace.

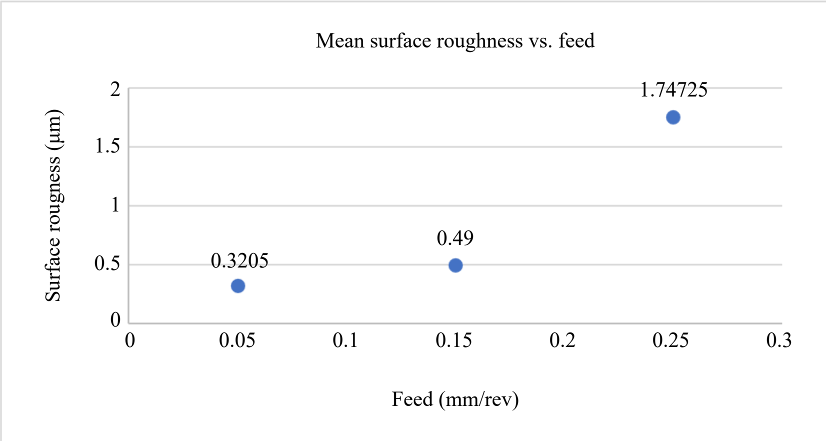


Figure 3. Mean surface roughness vs. feed

Moreover, Figure 4 conveys that there is a certain point of depth of cut to which the surface roughness achieved would be ideal after that it starts to increase again. According to this research depth of cut of 0.3 mm is the finest in the context of surface finish.

The tool life of CBN tools used in the study is given in Table 4. As from the previous studies we got the idea that tool life was mainly dependent on cutting velocity while the depth of cut and feed showed the minimum impact on tool life so those were neglected.

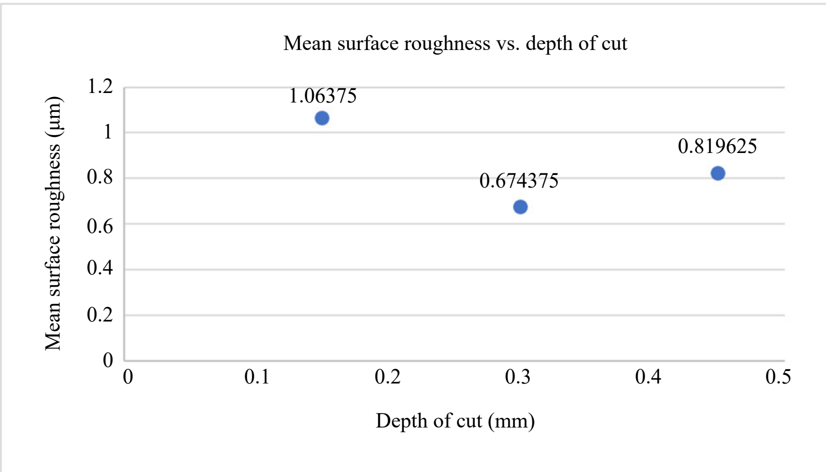


Figure 4. Mean surface roughness (R_a) vs. depth of cut (d)

Table 4. Tool life of CBN tool inserts

Cutting condition	V_c	Tool life (mins)
Dry	90	40.7
Dry	130	24.5
Dry	170	16.9
MQL	90	60.3
MQL	130	36.3
MQL	170	25.1

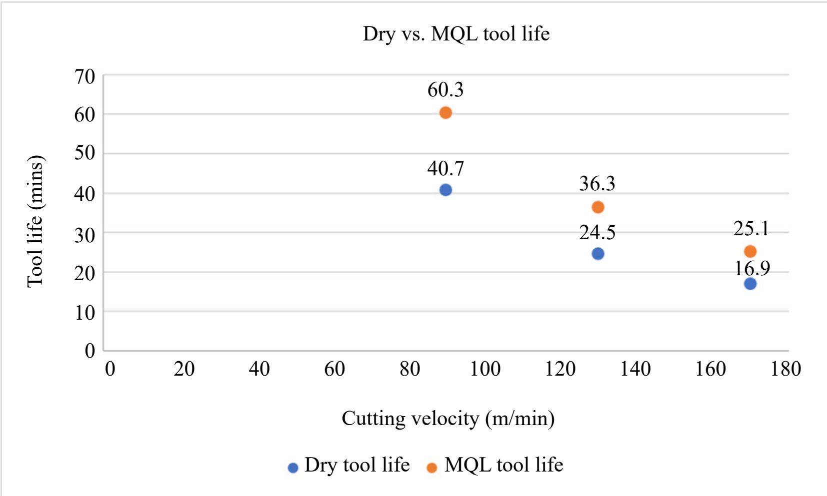


Figure 5. Analysis of tool life between MQL and dry environment

According to my analysis (see Figure 5), it is quite clear that the tool life drops with the rise in the cutting velocity. Moreover, while machining in the MQL environment we saw an increase of around 48% in the tool life of the material. An optimum tool life was achieved at the lowest speed.

4. Conclusion and future work

According to the achieved results, we have analyzed that while HT of AISI D2 steel with CBN tools, the best surface roughness was achieved when the machining was done at a higher velocity and the minimum feed rate. According to the analysis from the given results, we may conclude that there is a certain value of depth of cut to which we get an ideal value of surface roughness, too small as well as too large depth of cut can result in increased surface roughness. Moreover, we got the idea that feed rate is directly proportional to surface roughness while cutting velocity showed an inverse relation with surface roughness. Furthermore, at higher speeds, the achieved tool life was compromised and we got a low tool life compared to that achieved at low speeds. The best results in the context of surface roughness under both environments of machining were achieved at the highest speed and lowest feed (i.e., 170 m/min and 0.05 mm/rev). Also, MQL showed an improvement of up to 12% in the context of surface roughness and also improved the tool life of the material by around 48%. Also, the MRR shows a rise with the rise in cutting velocity, feed and depth of cut. We also saw that the ratio of tool life is almost the same at all 3 speeds.

This study was restricted to AISI D2 steel, CBN tool inserts and sunflower oil. Further studies can be done using different tool inserts such as diamond inserts, TC, etc. Also, a different lubricant might provide different results in the context of surface finish and tool life. Moreover, the properties like tool life, MRR and surface roughness can be tested at different speeds, feeds and depths of cuts.

Conflict of interest

There is no conflict of interest for this study.

References

[1] Das SR, Panda A, Dhupal D. Hard turning of AISI 4340 steel using coated carbide insert: Surface roughness, tool wear, chip morphology and cost estimation. *Materials Today: Proceedings*. 2018; 5(2): 6560-6569. https://doi.org/10.1016/j.matpr.2017.11.311

[2] Khan SA, Ahmad MA, Saleem MQ, Ghulam Z, Qureshi MA. High-feed turning of AISI D2 tool steel using multi-radii tool inserts: Tool life, the material removed, and workpiece surface integrity evaluation. *Materials and Manufacturing Processes*. 2017; 32(6): 670-677. https://doi.org/10.1080/10426914.2016.1232815

[3] Allu VP, Raju DL, Ramakrishna S. Performance investigation of surface roughness in hard turning of AISI 52100 steel - RSM approach. *Materials Today: Proceedings*. 2019; 18: 261-269. https://doi.org/10.1016/j.matpr.2019.06.299

[4] Wika KK, Litwa P, Hitchens C. Impact of supercritical carbon dioxide cooling with Minimum Quantity Lubrication on tool wear and surface integrity in the milling of AISI 304L stainless steel. *Wear*. 2019; 426-427: 1691-1701. https://doi.org/10.1016/j.wear.2019.01.103

[5] Muñoz-Escalona P, Shokrani A, Newman S. Influence of cutting environments on surface integrity and power consumption of austenitic stainless steel. *Robotics and Computer-Integrated Manufacturing*. 2015; 36: 60-69. https://doi.org/10.1016/j.rcim.2014.12.013

[6] Srithar A, Palanikumar K, Durgaprasad B. Experimental investigation and surface roughness analysis on HT of AISI D2 steel using coated carbide insert. *Procedia Engineering*. 2014; 97: 72-77. https://doi.org/10.1016/j.proeng.2014.12.226

[7] Elmunafi MHS, Noordin M, Kurniawan D. Tool life of coated carbide cutting tool when turning hardened stainless steel under minimum quantity lubricant using castor oil. *Procedia Manufacturing*. 2015; 2: 563-567. https://doi.org/10.1016/j.promfg.2015.07.097

[8] Sivaraman V, Prakash S. Recent developments in turning hardened steels–A review. In: *IOP Conference Series: Materials Science and Engineering*. Chennai, India: IOP Publishing; 2017. https://doi.org/10.1088/1757-899X/197/1/012009

[9] Patole PB, Kulkarni VV, Bhatwadekar SG. MQL machining with nano fluid: a review. *Manufacturing Review*. 2021; 8: 13. https://doi.org/10.1051/mfreview/2021011

[10] Dhar N, Kamruzzaman M, Ahmed M. Effect of minimum quantity lubrication (MQL) on tool wear and surface roughness in turning AISI-4340 steel. *Journal of Materials Processing Technology*. 2006; 172(2): 299-304. https://doi.org/10.1016/j.jmatprotec.2005.09.022

[11] Kumar P, Chauhan SR, Pruncu CI, Gupta MK, Pimenov DY, Mia M, et al. Influence of different grades of CBN inserts on cutting force and surface roughness of AISI H13 die tool steel during HT operation. *Materials*. 2019; 12(1): 177. https://doi.org/10.3390/ma12010177

[12] Abdelnasser E, Barakat A, Elsanabary S, Nassef A, Elkaseer A. Precision hard turning of Ti6Al4V using polycrystalline diamond inserts: Surface quality, cutting temperature and productivity in conventional and high-speed machining. *Materials*. 2020; 13(24): 5677. https://doi.org/10.3390/ma13245677

[13] Sharma P, Sidhu BS, Sharma J. Investigation of effects of nanofluids on turning of AISI D2 steel using minimum quantity lubrication. *Journal of Cleaner Production*. 2015; 108: 72-79. https://doi.org/10.1016/j.jclepro.2015.07.122

[14] Srithar A, Palanikumar K, Durgaprasad B. Experimental investigation and surface roughness analysis on hard turning of AISI D2 steel using polycrystalline cubic boron nitride (PCBN). *Materials Today: Proceedings*. 2019; 16: 1061-1066. https://doi.org/10.1016/j.matpr.2019.05.196

[15] Karthik MS, Raju VR, Reddy KN, Balashanmugam N, Sankar MR. Cutting parameters optimization for surface roughness during dry hard turning of EN 31 bearing steel using CBN insert. *Materials Today: Proceedings*. 2020; 26: 1119-1125. https://doi.org/10.1016/j.matpr.2020.02.224

[16] Subbaiah KV, Raju C, Pawade RS, Suresh C. Machinability investigation with wiper ceramic insert and optimization during the hard turning of AISI 4340 steel. *Materials Today: Proceedings*. 2019; 18: 445-454. https://doi.org/10.1016/j.matpr.2019.06.300
[17] Rafighi M, Özdemir M, Al Shehabi S, Kaya MT. Sustainable hard turning of high chromium AISI D2 tool steel using CBN and ceramic inserts. *Transactions of the Indian Institute of Metals*. 2021; 74(7): 1639-1653. https://doi.org/10.1007/s12666-021-02245-2
[18] Senevirathne SWMAI, Punchihewa HKG, Kosgahakumbura KNMDSK, Dissanayake DMP, Sahathevan T. Tool wear in machining AISI D2 steel with minimum quantity lubrication using alternative cutting fluids. In: *2016 Manufacturing & Industrial Engineering Symposium (MIES), October 2016*. Colombo, Sri Lanka: IEEE; 2016. p.1-6. https://doi.org/10.1109/MIES.2016.7780253