Nano World Journal

https://doi.org/10.17756/nwj.2023-s3-178

Research Article

Open Access

Comparing CNC Turning of S32750 Super Duplex Stainless Steel under nMQL Machining Condition by Novel Dual Textured Tool with Untextured Tool for Improving Tool Flank Wear

Bakthavachalam P, Thiyagu M*

Department of Mechanical Engineering, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, Tamil Nadu, India

***Correspondence to:**
Thiyagu M
Department of Mechanical Engineering, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, Tamil Nadu, India.
E-mail: thiyagum.sse@saveetha.com

Received: July 31, 2023
Accepted: November 01, 2023
Published: November 03, 2023

Citation: Bakthavachalam P, Thiyagu M. 2023. Comparing CNC Turning of S32750 Super Duplex Stainless Steel under nMQL Machining Condition by Novel Dual Textured Tool with Untextured Tool for Improving Tool Flank Wear. *NanoWorld J* 9(S3): S1012-S1017.

Published by United Scientific Group

Abstract

To compare innovative dual-textured and untextured carbide tool inserts in the context of CNC turning operations using S32750 super duplex stainless steel (SDSS) under nano-minimum amount lubrication to decrease flank wear. A modern, contemporary green manufacturing technique called surface texturing is utilised to alter the surface topography of the cutting tool at the rake face, improving the wettability of cutting fluid at the cutting edge. The tool surface is textured with square and linear groove patterns using a femtosecond laser technique. Addressing flank wear, a Jobber XL CNC turner used to turn S32750 SDSS employed dual-textured tool inserts compared with untextured tool inserts. The investigation was carried out with the division of participants into two distinct groups, namely the control group, comprising samples subjected to machining with untextured tool inserts, and the experimental group, encompassing samples subjected to machining with novel dual-textured inserts. Each group consisted of 20 samples, resulting in a cumulative sample size of 40. The determination of the sample size was based on a statistical power of 80% and a significance level (alpha) of 0.05, employing G Power analysis. The experimental results show a mean flank wear of 0.298 mm for the experimental group samples and 0.239 mm for the control group samples in turning S32750 SDSS rod. The obtained p value (2-tailed) of 0.001 ($p < 0.05$) from the independent sample t-test results in the CNC turning process with nano MQL machining conditions is statistically significant. Within the limitations of the investigation, the suggested dual-textured tool insert turned samples exhibit less flank wear than the untextured tool insert turned samples (18.26%). The process is statistically significant, as evidenced by the obtained p value of 0.001

Keywords

Flank wear, nMQL, Novel dual textured insert, Sustainable production

Introduction

The primary objective of this experimental study is to conduct a comparative analysis between dual-textured tools and untextured tools about their performance metrics, specifically material removal rate and average surface roughness. This evaluation is conducted within the context of CNC turning operations applied to duplex stainless steel, and it is performed under nano-minimum quantity lubrication (nMQL) [1]. Products with excellent surface finishes, precise geometrical forms, and accuracy are in increased demand. However, due to significant tool wear [2] it can be challenging to obtain a good surface quality when CNC turning S32750 super duplex stainless rod with nMQL since the feature's extreme hardness causes edge deterioration. Due to the high cutting zone temperature, one machining technique for hard materials results in severe tool wear and poor surface quality. Because the flood cooling approach has a detrimental impact on the environment and the health of the CNC lathe operations [3] it cannot be utilised to processS32750 super duplex stainless rod. Turning is the most common machining method used in the manufacturing sector. To fulfil its environmental obligations, industry has focused on low-volume lubrication machining methods [4].

This type of research has been the subject of around 532 publications, with 206 of those articles appearing in ScienceDirect. The term "machinability" refers to a material's ease of machining. However, it is impossible to put a number on machinability [5]. It is defined across the following estimators rather than directly: Cutting force, tool life and wear, chip form, and surface quality are listed in that order. A rise in these estimators' performance and productivity translates into an increase in the material's ability to be machined. The best machining lubrication is neat lubricating oil since the surface roughness values decrease because of the minimum quantity lubrication (MQL) being greater in this instance than in conventional cooling [6]. One outcome of this tool damage is cost-effective losses due to workpiece blemishing or poor surface quality. Because of their high rates of material removal and superior product quality, manufacturing industries are appealing [7]. The objective of this experiment is to augment the systematic assessment of the influence of process parameters on both surface roughness and material removal rate for workpieces constructed from LDX S32750 SDSS [8]. This experiment uses CNC lathe operations in tool inserts with and without texturing.

Although there is extensive ongoing study into the machinability of materials and alloys, few study that are like this work have been found. In the present study, the performance of the CNMG 120408 grade dual-textured tool insert is compared with the untextured CNMG 120408 insert in turning S32750 SDSS in terms of insert flank wear and wear analysis done using scanning electron microscope images [9, 10].

Materials and Methods

This experimental study was conducted at the Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Chennai, utilizing an on-site CNC turning machine. The work material employed for this study was the S32750 SDSS rod. Cylindrical rods, measuring 25 mm in diameter and 126 mm in length, were purchased for use in the turning experiments. The chemical composition analysis of the S32750 SDSS was performed and validated by MET Mech LAB, located at Chennai, 602105. The resulting chemical composition data is detailed in table 1. The research aims to assess the performance of a novel linear groove and square textured CNGA 120408 inserts in comparison to an untextured CNGA 120408 carbide tool insert during CNC turning of S32750 SDSS. The evaluation primarily focuses on output response and insert flank wear. This project is being carried out by two separate groups, where the experimental group utilizes the new CNGA 120804 insert with a surface texture featuring linear grooves, while the control group employs the same insert without any texture.

Table 1: Chemical properties of experimental work material SDSS.

Grade		C	Mn	Si	P	S	Cr	Mo	Ni	N
S32750	Min	-	-	-	-	-	21.9	2	4	0.181
	Max	0.03	1.2	0.81	0.03	0.02	24	3	6	0.24

Table 2: S32750 SDSS round bar physical properties.

Physical properties	Value
Density	0.278 lb/in^3
Melting range	2525 - 2630 °F
Specific heat capacity at 212 °F	0.119 Btu/lb/ °F
Thermal conductivity at 212 °F	8.4 Btu/hr-ft- °F
Poisson's ratio	0.3
Elastic modulus at 72 °F	29 x 10 psi

The turning trials are carried out in experimental group samples utilising a box-Behnken design and response surface approach, as shown in table 2. A unique linear groove texture and square texture were done on the rake face of the CNGA 120804 insert using the pulse laser engraving method. A linear groove and square texture tool insert of width 150 microns and depth 100 microns were made on the rake face perpendicular to the cutting edge. After acetone cleaning, the fabricated novel dual textured inserts were used to conduct turning experiments on a CNC lathe. In the control group samples, 20 turning experiments were run using an untextured CNGA 120804 tool insert in a CNC lathe. Graphene based nanolubricants in nMQL conditions used for cooling and lubrication promote sustainable production.

Laser surface texturing (LST) represents an advanced manufacturing method that has garnered substantial interest and adoption within diverse industrial sectors. This technique entails the meticulous alteration of material surfaces through the focused application of high-intensity laser beams, resulting in the deliberate formation of controlled patterns, structures, or textures. These surface features span a scale spectrum, ranging from microscale to nanoscale, and are intentionally designed to optimize the performance, functionality, and longevity of engineered components and products. According to published research, LST has several benefits over other techniques, including optimum surface topography and minimizing substrate surface contamination [11].

Tool wear arises due to multifaceted interactions occurring between the tool material and the workpiece, encompassing chemical, thermal, and mechanical processes. The predominant manifestations of tool wear, namely flank wear and crater wear, primarily stem from these intricate interactions and often serve as determinants of a tool's operational lifespan. The extent of flank wear is frequently related to the efficiency of the procedure. Numerous studies have demonstrated that rising cutting pressures due to growing flank wear result in higher machine tool power consumption [12]. The following steps make up the proposed methodology for calculating the wear on the microscope: When determining the features of the worn-out cutting insert, particularly the nose radius, when positioning the machine tool, consider the features of the cutting tool holder, starting with the front clearance angle [13]. Place the insert such that the wear on the flank is perpendicular to the microscope image, and the SEM image is being used to measure the tool wear [14]. Align the unworn edge with the horizontal reticle of the microscope, Place the vertical reticle of the microscope at the end of wear to direct measurements toward the cutting tool's tip (avoiding the nose radius of the insert), measure at each of the insert's five points, and then calculate the maximum flank wear. The tool insert flank wear was studied using scanning electron microscope images taken near the tool cutting edges. SPSS v.26 statistical software was used to calculate the mean value, standard deviation, and standard error.

Results

The proposed surface dual texturing strategy of CNGA 120804 tool inserts produces an average flank wear of 0.250 mm on a CNC turning of S32750 SDSS, whereas untextured CNGA 120804 tool inserts provide an average flank wear of 0.312 mm. Table 2 Physical properties of S32750 SDSS round bar. Table 3 Combinations of the input parameters for comparing the flank wear of a novel linear groove and square textured carbide tool insert (CNGA 120804) with an untextured carbide tool insert (CNGA 120804). The output parameter, flank wear, is measured and tabulated. Table 4 The group statistics of flank wear data obtained from the independent sample t-test. Figure 1 depicts the dual textured tool inserts preparation. Figure 2 shows the CNC lathe along with the MQL setup used for turning experiments. The carbide tool insert CNGA 120408 with an included angle of 80°, insert thickness of 4.8 mm, corner radius of 0.8 mm, and fixing hole diameter of 3.81 mm used for experimental trials is shown in figure 3. Figure 4 Dual textured CNGA 120408 inserts used for experimentation. Figure 5 displays an optical microscope with 10x magnification for flank wear measurement. Figure 6

Table 4: The group statistics for flank wear data derived through an independent sample t-test analysis.

Group statistics					
	Group	**N**	**Mean**	**Std. deviation**	**Std. error mean**
Flank wear (mm)	Control group	20	0.2983	0.05096	0.01139
	Experimental group	20	0.2392	0.03548	0.00793

Table 3: Box–Behnken design input parameter combinations to compare the flank wear of a novel dual-textured carbide tool insert (CNMG120804) with an untextured carbide tool insert (CNMG 120804).

S.no	**Cutting speed, Vc (m/min)**	**Feed rate, f (mm/rev)**	**DoC, d (mm)**	**Flank wear (mm)**	**Flank wear (mm)**
				Untextured tool	**Dual textured tool**
1	55	0.12	1.0	0.29512	0.248
2	113	0.12	1.0	0.24864	0.222
3	55	0.22	1.0	0.36058	0.298
4	113	0.22	1.0	0.25125	0.201
5	55	0.12	2.0	0.3162	0.255
6	113	0.12	2.0	0.22064	0.197
7	55	0.22	2.0	0.28438	0.241
8	113	0.22	2.0	0.25422	0.223
9	35	0.17	1.6	0.25724	0.218
10	133	0.17	1.6	0.2065	0.175
11	84	0.09	1.6	0.28438	0.241
12	84	0.25	1.6	0.22302	0.189
13	84	0.17	1.6	0.24128	0.208
14	84	0.17	2.0	0.25724	0.218
15	84	0.17	1.6	0.32332	0.274
16	84	0.17	1.6	0.26537	0.223
17	84	0.17	1.6	0.33579	0.287
18	84	0.17	1.6	0.3835	0.325
19	84	0.17	1.6	0.25645	0.223
20	84	0.17	1.6	0.26078	0.221

Figure 1: Dual textured tool inserts preparation.

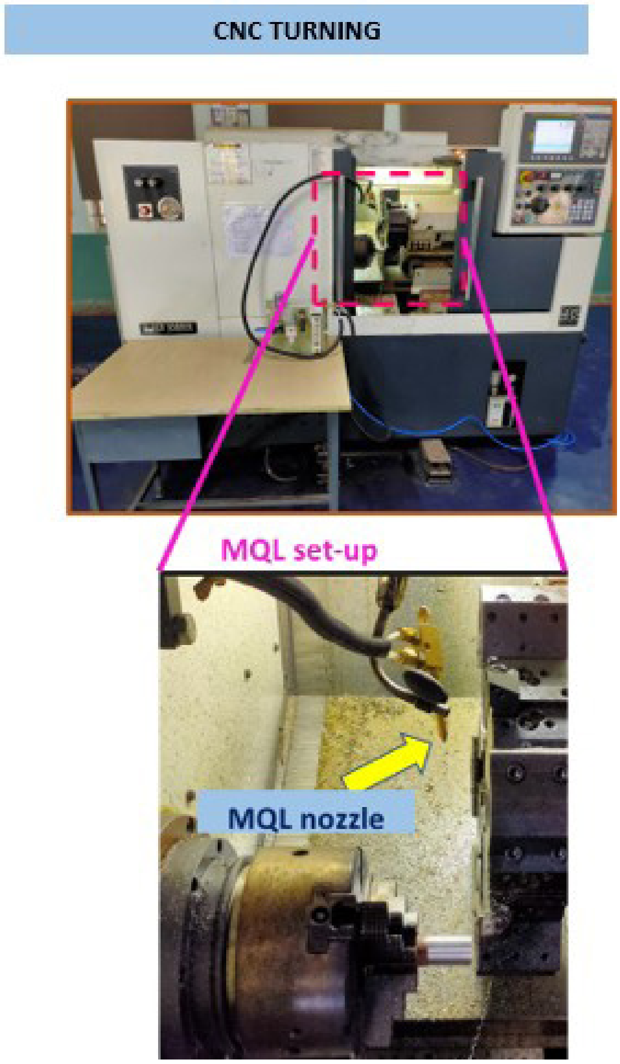

Figure 2: CNC turning machine with MQL set-up.

shows the SEM images captured near the tool insert cutting edge shows the tool flank wear land. Figure 7 shows the optical microscope images at 45X magnification showing flank wear of untextured and textured tool inserts. Figure 8 shows the SPSS bar graphs generated from the sample means of flank wear.

Discussion

In the CNC turning process of S32750 SDSS, the utilization of linear groove and square texture CNGA 120804 tool inserts yields an average flank wear measurement of 0.250 mm. In contrast, untextured CNGA 120804 tool inserts result in an average flank wear of 0.312 mm. Consequently, an evident reduction in wear rate is observed when employing the CNGA 120804 tool inserts in the present study, as reported by Nikam et al. [15]. These findings align with prior research conducted by other scholars. Taken together, these outcomes underscore the notable enhancement in tool insert flank wear achieved through the adoption of novel linear groove and square-textured tool inserts during CNC turning of S32750 SDSS, particularly when applying nMQL with graphene-based nano lubricants [16]. It was discovered that the nano-sized materials might perform as nano-sized ball bearings to convert sliding into rolling, reducing friction at the tool chip interference zone. This resulted in the nano-sized materials having outstanding tribological performance to make the surface hydrophobic, micro-texturing is applied [17]. To investigate the tribological characteristics occurring at the interfaces of chip-tool and work-tool, a micro-texturing approach, as detailed by Palanisamy et al. [18], has been

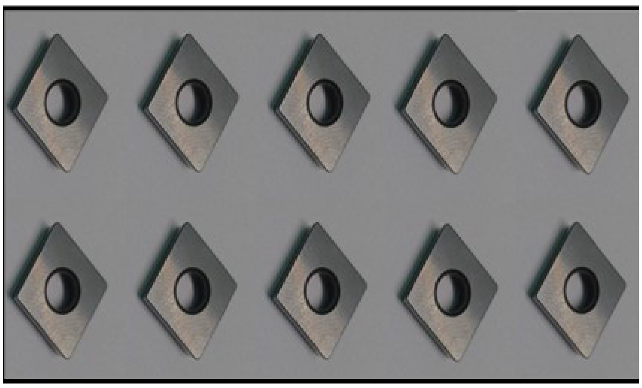

Figure 3: Carbide tool inserts with ISO specification CNMG120408.

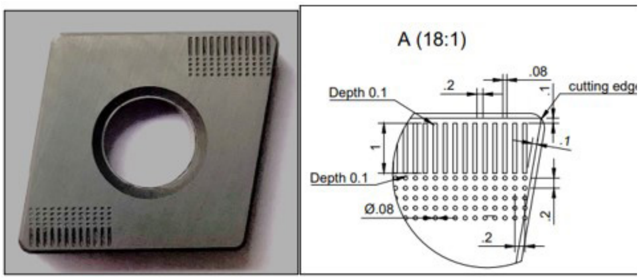

Figure 4: Dual textured CNMG 120408 inserts with include angle 80°, insert thickness 4.8 mm.

Figure 5: An optical microscope with 10x magnification for flank wear measurement.

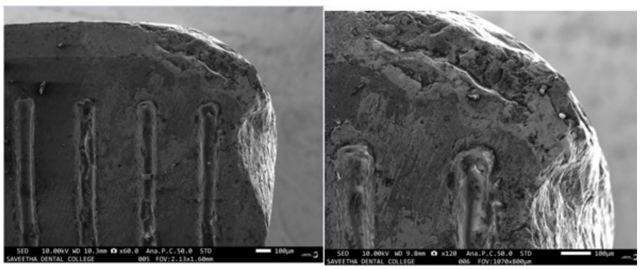

Figure 6: SEM images of dual textured inserts showing flank wear.

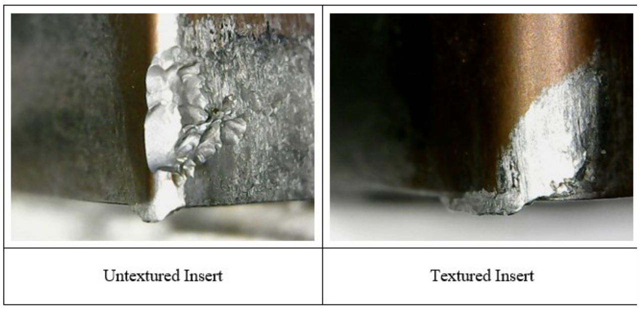

Figure 7: Optical microscope images showing flank wear of untextured insert and dual textured tool insert at 45X magnification.

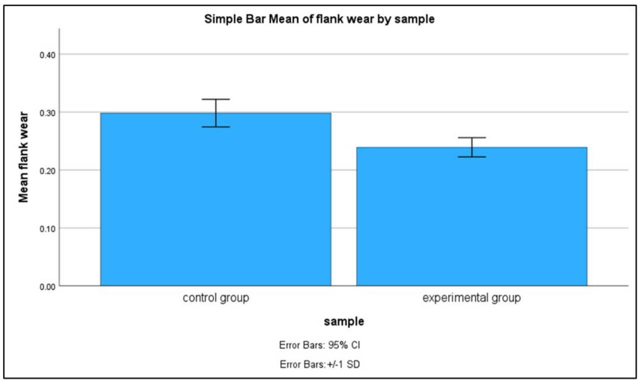

Figure 8: Comparison of control group and experimental group in terms of tool insert flank wear. The mean flank wear value using untextured carbide insert (control group) is high compared to the novel dual textured carbide tool insert (experimental group) and the standard deviation of experimental group samples is better than that of control group samples. X-axis: sample groups, Y-axis: mean flank wear with error ± 1 SD.

employed on the rake surface of the cutting insert. Microtexturing primarily offers the advantage of reducing the coefficient of friction at the chip-tool interface. Furthermore, as the chip flows over the rake face, it encounters obstructions within the textured grooves, resulting in the formation of short, irregular chips that facilitate machining processes. The adoption of novel dual-textured tools leads to reduced actual contact between the chip and the rake face of the tool. Consequently, the chips traverse a shorter segment of the rake surface, thereby mitigating tool wear [19].

The analysis of tool flank wear trends was conducted by considering 20 distinct combinations of cutting speeds, feed rates, and depth of cut. The outcomes of this investigation aligned with the discoveries made by previous authors. Notably, the presence of geometric texture on the rake surface facilitates the breakage and redirection of chips, thus extending the operational life of the tool, as elucidated by Liu et al. [20]. Moreover, the micro-texture on the rake surface can be conceptualized as an extended fin with a consistent cross-sectional profile, promoting enhanced heat dissipation to the surrounding environment. The results of this study have exhibited a reduction in tool flank wear, along with the potential functionality of the micro-texture as a reservoir for the intake and containment of cutting fluid, in accordance with the research conducted by Pivotto, et al. [21]. Future machining studies will involve nano-dual textured tool inserts, as well as assess different cryogenic lubrication conditions [18].

Our university is dedicated to conducting high-quality, fact-based research. In this study, we continue this tradition by addressing the machining challenges associated with the use of S32750 SDSS, necessitating nMQL for CNC machining. The observed drop in performance is likely due to increased cutting zone temperatures affecting the workpiece surface. Overcoming these challenges, as indicated by Makhesana and Patel [22] and Singh et al. [23], involves the application of nMQL and graphene nanoparticles. Future machining tests will explore ceramic inserts and assess different cryogenic settings.

Conclusions

Within the study's limitations, the proposed novel dual-textured CNGA120408 tool insert flank wear was 0.3120 mm compared to the untextured CNGA120408 tool insert flank wear of 0.2502 mm in turning S32750 SDSS under nMQL conditions using graphene-based nanofluids. The statistical significance is evident from the p value of (2-tailed) 0.0024. The application of novel dual-textured CNGA120408 tool inserts resulted in an 18.26% reduction in flank wear as compared to their untextured inserts during CNC turning of SDSS under nMQL machining conditions.

Acknowledgements

None.

Conflict of Interest

None.

References

1. Yağmur S. 2021. The effects of cooling applications on tool life, surface quality, cutting forces, and cutting zone temperature in turning of Ni-based Inconel 625. *Int J Adv Manuf Technol* 116(3): 821-833. https://doi.org/10.1007/s00170-021-07489-2
2. Vignesh S, Devi GR. 2023. Performance analysis of novel TiN coated and uncoated carbide tool in CNC wet turning of super duplex stainless steel to minimize tool wear. *Mater Today Proc* 79: 155-158. https://doi.org/10.1016/j.matpr.2022.11.420
3. Thiyagu M, Karunamoorthy L, Arun Kumar N. 2017. Magnetorheological fluid-based nanotexturing of tool inserts for turning of duplex stainless steel. *Mater Manuf Proc* 32(9): 1019-1025. https://doi.org/10.1080/10426914.2016.1257136
4. Kazeem RA, Fadare DA, Ikumapayi OM, Adediran AA, Aliyu SJ, et al. 2022. Advances in the application of vegetable-oil-based cutting fluids to sustainable machining operations-a review. *Lubricants* 10(4): 69. https://doi.org/10.3390/lubricants10040069
5. Korkmaz ME, Gupta MK, Boy M, Yaşar N, Krolczyk GM, et al. 2021. Influence of duplex jets MQL and nano-MQL cooling system on machining performance of Nimonic 80A. *J Manuf Proc* 69: 112-124. https://doi.org/10.1016/j.jmapro.2021.07.039
6. Tiwari PK, Raj S, Kumar R, Panda A, Sahoo AK. 2022. Machinability improvement investigation in face milling of Ti–3Al–2.5 V alloys using TiAlN coated carbide insert under dual nozzle minimum quantity lubrication cooling environment. Proceedings of the Institution of Mechanical Engineers, Part E.
7. Gupta MK, Niesłony P, Sarikaya M, Korkmaz ME, Kuntoğlu M, et al. 2022. Tool wear patterns and their promoting mechanisms in hybrid cooling assisted machining of titanium Ti-3Al-2.5 V/grade 9 alloy. *Tribol Int* 174: 107773. https://doi.org/10.1016/j.triboint.2022.107773
8. Chekuri V, Thiagarajan C. 2022. Innovative comparison on the performance of TiCN coated drill bit and uncoated drill bit in the novel CNC drilling of LDX 2205 duplex stainless steel for minimizing roundness error. *J Pharm Negat Results* 488-496. https://doi.org/10.47750/pnr.2022.13.S04.054
9. Hoghoughi MH, Farahnakian M, Elhami S. 2022. Environmental, economical, and machinability based sustainability assessment in hybrid machining process employing tool textures and solid lubricant. *Sustain Mater Technol* 34: e00511. https://doi.org/10.1016/j.susmat.2022.e00511
10. Thiyagu M, Karunamoorthy L, Arunkumar N. 2019. Thermal, and tool wear characterization of graphene oxide coated through magnetorheological fluids on cemented carbide tool inserts. Arch *Civil Mech Eng* 19: 1043-1055. https://doi.org/10.1016/j.acme.2019.05.005
11. Ranjan P, Hiremath SS. 2019. Role of textured tool in improving machining performance: A review. *J Manuf Process* 43: 47-73. https://doi.org/10.1016/j.jmapro.2019.04.011
12. Ferrando Chacón JL, Fernández de Barrena T, García A, Sáez de Buruaga M, Badiola X, et al. 2021. A novel machine learning-based methodology for tool wear prediction using acoustic emission signals. *Sensors* 21(17): 5984. https://doi.org/10.3390/s21175984
13. Bagga PJ, Makhesana MA, Bhavsar DL, Joshi J, Jain K, et al. 2023. Experimental investigation of different NN approaches for tool wear prediction based on vision system in turning of AISI 1045 steel. *Int J Interact Des Manuf* 17(5): 2565-2582. https://doi.org/10.1007/s12008-022-01072-z
14. Swain S, Kumar R, Panigrahi I, Sahoo AK, Panda A. 2022. Machinability performance investigation in CNC turning of Ti–6Al–4V alloy: dry versus iron-aluminium oil coupled MQL machining comparison. *Int J Lightweight Mater Manuf* 5(4): 496-509. https://doi.org/10.1016/j.ijlmm.2022.06.002
15. Nikam M, Karulkar A, Chowdhury A, Khalfay H, Rathod D. 2022. Performance of a Single Point Cutting Tool with Textured Surfaces: A Comparative Study of Different Textured Patterns. In Recent Advances in Manufacturing Processes and Systems: Select Proceedings of RAM. Singapore: Springer Nature, pp 777-790.
16. Arun K, Devi GR. 2022. Comparison of novel TiN coated and uncoated carbide tool in CNC green machining of AISI H13 to minimize tool wear. *Mater Today Proc* 69: 827-831. https://doi.org/10.1016/j.matpr.2022.07.269
17. Diaz-Saldaña G, Osornio-Rios RA, Cruz-Albarran IA, Trejo-Hernandez M, Antonino-Daviu JA. 2022. CNC Lathe Tool Wear Analysis Using Image Processing and Stray Flux. In IECON 2022–48th Annual Conference of the IEEE Industrial Electronics Society. pp 1-6.
18. Palanisamy D, Devaraju A, Narasimhamu KL, Manikandan N, Raju R, et al. 2022. Performance of Textured Tool with MQL in Machining Of Precipitation Hardened Stainless Steel. In Recent Advances in Materials and Modern Manufacturing: Select Proceedings of ICAMMM. Singapore: Springer Nature, pp 39-50.
19. Sawangsri W, Wattanasinbumrung P. 2022. A model approach for in-process tool condition monitoring in CNC turning using machine vision. *Int J Interactive Des Manuf* 16(4): 1439-1456. https://doi.org/10.1007/s12008-022-01010-z
20. Liu H, Ayed Y, Birembaux H, Rossi F, Poulachon G. 2022. Impacts of flank wear and cooling strategies on evolutions of built-up edges, diffusion wear and cutting forces in Ti6Al4V machining. *Tribol Int* 171: 107537. https://doi.org/10.1016/j.triboint.2022.107537
21. Pivotto LB, Antonialli AÍ, Ventura CE. 2023. Tribological Aspects of Tool Wear During Turning Ti-15Mo Alloy with Cemented Tungsten Carbide Cutting Inserts Prepared with Different Surface Finishes. Proceedings of the Institution of Mechanical Engineers 237(1): 190-198.
22. Makhesana MA, Patel KM. 2021. Optimization of parameters and sustainability assessment under minimum quantity solid lubrication-assisted machining of Inconel 718. Process Integration and Optimization for Sustainability 5(3): 625-644.
23. Singh V, Sharma AK, Sahu RK, Katiyar JK. 2022. State of the art on sustainable manufacturing using mono/hybrid nano-cutting fluids with minimum quantity lubrication. *Mater Manuf Proc* 37(6): 603-639. https://doi.org/10.1080/10426914.2022.2032147