HITTITE JOURNAL OF SCIENCE AND ENGINEERING

e-ISSN: 2148-4171
Volume: 12 • Number: 1
March 2025

Assessment of the Altering of Tool Wear and Surface Finish in X2CrNiMoN2253 Stainless Steel Under Dry Machining Conditions

Fikret Sönmez
Manisa Celal Bayar University, Hasan Ferdi Turgutlu Faculty of Technology, Department of Mechanical Engineering, Manisa, Türkiye.

Corresponding Author

Fikret Sönmez
E-mail: sonmezfikret@gmail.com Phone: +90 236 314 1010 Fax: +90 236 314 2020
RORID: https://ror.org/053f2w588

Article Information

Article Type: Research Article
Doi: https://doi.org/10.17350/HJSE19030000349
Received: 07.12.2024
Accepted: 10.02.2025
Published: 25.03.2025

Cite As

Sönmez F. Assessment of the Altering of Tool Wear and Surface Finish in X2CrNiMoN2253 Stainless Steel Under Dry Machining Conditions. Hittite J Sci Eng. 2025;12(1):35-41.

Peer Review: Evaluated by independent reviewers working in at least two different institutions appointed by the field editor.
Ethical Statement: Not available.
Plagiarism Checks: Yes - iThenticate
Conflict of Interest: Authors declare no conflict of interest.

CRediT AUTHOR STATEMENT
Fikret Sönmez: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Resources, Supervision, Writing – review and editing.

Assessment of the Altering of Tool Wear and Surface Finish in X2CrNiMoN2253 Stainless Steel Under Dry Machining Conditions

Fikret Sönmez

Manisa Celal Bayar University, Hasan Ferdi Turgutlu Faculty of Technology, Department of Mechanical Engineering, Manisa, Türkiye.

Abstract

Machining is a challenging manufacturing method used for precision parts. In this method, tool wear is inevitable and increases constantly. Surface roughness values change caused by tool wear until the tool life is assumed to be complete. In this investigation, tool wear and the effect of tool wear on surface roughness were analyzed. For this purpose, the cutting experiments were performed on stainless steel material under dry machining circumstances at 1 mm depth of cut, 120 m/min cutting speed, and 0.1 mm/rev feed. The tool wear and surface roughness values were inspected at the finish of each operation on the CNC turning center without removing the workpiece. As a consequence of the measurements, it was concluded that the surface roughness values generally deteriorated, and the tool wear increased regularly. Flank wear was found to be the primary type of wear in the experiments, and interestingly, the surface roughness decreased at the end of tool wear. In addition, it was determined that the tool wear reached the limit at the completion of the machining time of 14.4 minutes.

Keywords: Tool wear, Surface roughness, Machining, Hard-to-cut materials

INTRODUCTION

Machining is a method used to fabricate machine components with superior dimensional consistency, tight geometric tolerance, and desired surface roughness [1]. For this reason, machining continues to be used in the production of precision machined parts. Numerous factors influence machining. These factors are typically cutting conditions, cutting tool material, and the material subjected to machining [2]. Although this method has many advantages, it also has unavoidable phenomena such as tool wear. Tool wear is a phenomenon that proceeds according to the cutting circumstances, and increased tool wear affects the workpiece properties, such as surface roughness and geometric tolerance [1, 3]. In addition, tool wear negatively affects machine vibrations and cutting forces [4, 5]. As a result, increased tool wear may lead to tool breakage, resulting in a completely unusable workpiece [6]. Although numerous types of materials can be manufactured through machining, certain materials are somewhat or entirely unsuitable for cutting due to their specific properties. An example of a difficult-to-machine ma terial is stainless steel. Stainless steel is a poor machining material due to its limited thermal conductivity [7] and vulnerability to strain hardening [1].

Del Risco-Alfonso et al. [8] in studies on AISI 316L stainless steel (austenitic) suggested that cutting speed (200-300-400 m/min) had a direct effect on tool life. Although the feed had a negative effect on tool wear, the main contributor to tool wear was dependent on the cutting speed. In their research, the researchers also pointed out that the differences between Minimum Quantity Lubrication (MQL) and dry cooling conditions were not significant in the experiments. Chen et al. [9] researched the cutting performance of stainless steel (AISI 304) under dry machining conditions using various cutting parameters. The surface finish and tool wear data were examined at certain minutes (6th, 12th, and 18th) throughout the experiments. The cutting tool showed insignificant wear initially, but the amount of wear accelerated later, and excessive tool wear was detected at the 18th minute. The scientists found that this wear caused the surface finish quality values to decrease by almost 14 times. He et al. [10] researched AISI 304 and demonstrated that the rate of rise in cutting tool wear changed from being initially rapid, then increasing steadily, and eventually rapidly increasing. The third zone, where the tool wear values increase rapidly, depends on the cutting circumstance, and can fluctuate up to fivefold. In addition, it has been revealed that wet cutting conditions delay tool wear and reduce cutting forces. Ebrahimi et al. [11] assessed cutting tests on AISI 360 stainless steel material. The researchers analyzed tool life and surface finish values during cutting. Cutting speed and feed were found to have a direct manipulation on the tool wear. The researchers also encountered that, using properly selected parameters, the flank wear and surface roughness values lessened by 33 percent and 23 percent, respectively. Szczotkarz et al. [12] employed turning experiments with AISI 316L steel under a variety of cutting parameters to investigate flank and crater wear values. The researchers benchmarked dry cutting with two cooling conditions (MQL and Minimum Quantity Cooling Lubrication (MQCL) with the addition of extreme pressure and anti-wear (EP/AW) method), and as a result, the researchers obtained up to 21% better tool wear values assessed to dry machining. The researchers emphasized that the cutting insert wear patterns were changed depending on the cooling conditions, especially the notch wear. Zawada-Michałowska et al. [13] performed tool wear tests on X20Cr13 and X8CrNiS18-9 stainless steels. The researchers also used three different cutting inserts in these experiments and achieved up to 75% worse tool life depending on the cutting insert used. In addition, the researchers unveiled that the surface finish values changed dramatically depending on the type of cutting insert.

In the literature review, it was comprehended that the machining of various types of stainless steel was discussed. However, limited research [14] was found in the literature on X2CrNiMoN2253, even though X2CrNiMoN2253 duplex stainless steel is a prominent material used across various industries (chemical, marine, oil, and gas) and applications due to its outstanding combination of high strength, remarkable toughness, and superior corrosion resistance. In addition, a comprehensive examination of the variation in tool wear over time and the variation of the workpiece surface roughness associated with the alteration of tool wear has not been found.

In this study, turning experiments and tool wear analysis were applied under dry machining conditions on X2CrNiMoN2253, a duplex, hard-to-cut stainless steel used for manufacturing many turning applications parts such as fittings, containers, storage tanks, pipelines, press rolls, and rotary shafts. Besides, the role of tool life in altering the surface finish of the workpiece was extensively investigated.

MATERIAL AND METHODS

In the present investigation, tool wear and surface roughness studies were completed on Ø61 mm x 110 mm duplex stainless steel (X2CrNiMoN2253). Table 1 lists the elemental content of the material employed in this study.

Table 1. The chemical composition of X2CrNiMoN2253 materials.

Element	Cr	Ni	Mo	Mn	C	Si	P	S	Fe
wt.%	22.69	4.84	3.11	1.40	0.015	max 1	max 0.035	max 0.015	Balance

The turning experiments were conducted using a universal-grade (TP2500) cutting insert (TNMG 160404-M3) suitable for P, M, and K-grade materials manufactured by SECO Company. The geometric information of the tungsten carbide (WC) based cutting insert is as follows: cutting edge length 16.50 mm, effective cutting edge length 14.50 mm, corner radius 0.80 mm, and insert thickness 4.76 mm. The cutting insert is suitable for light to medium impact cutting conditions (P25-Grade) and CVD (chemical vapor deposition) coated with (C, N) + Al_2O_3. Cutting tools with an approach angle of 90° are generally used due to their ability to perform both longitudinal turning and face turning. In addition, a tool holder with a 90° approach angle (PTGNR 2020K16) was chosen (Figure 1). ISO 3685 standard [15] was used to determine the turning parameters. The selected values are presented in Table 2.

Table 2. The cutting conditions.

Parameter	Value
Cutting speed	120 m/min
Depth of cut	1 mm
Feed	0.1 mm/rev
Cutting insert nose radius	0.4 mm

It is a well-known fact that the cooling environment, such as cutting fluids, greatly reduces tool wear. Therefore, all experiments were executed under dry-cutting conditions to better observe tool wear. The workpiece was turned in 13 passes, starting from Ø61 mm down to Ø35 mm. The cutting length was determined as 90 mm in each pass. Depending on the changing workpiece diameter, various cutting times were obtained in each pass (Table 3).

The turning experiments were continued for 14.4 minutes until the tool life was finalized (Table 3), and the output quantities (surface roughness and tool wear) were measured after the completion of all passes. The tool wear examinations were carried out by measuring both flank wear and notch wear values in a toolmaker's microscope (Mahr MM200). In addition to the toolmaker's microscope examination, the cutting tools were inspected by SEM-EDX after the termination of all experiments (Zeiss GeminiSEM 500). The surface roughness records were assessed in compliance with the ISO 21920-3:2021 (previously ISO-4288) standard [15]. The surface roughness measurements (Ra, Rz, and Rt) were repeated over five runs around the workpiece (Figure 1).

Table 3. The total cutting length and cutting time for the cutting insert.

Pass	Total cutting length (mm)	Total cutting time (min)	Pass	Total cutting length (mm)	Total cutting time (min)
1	90	1.39	8	720	9.8
2	180	2.73	9	810	10.82
3	270	4.03	10	900	11.78
4	360	5.28	11	990	12.7
5	450	6.48	12	1080	13.57
6	540	7.64	13	1170	14.4
7	630	8.74	Total	1170	14.4

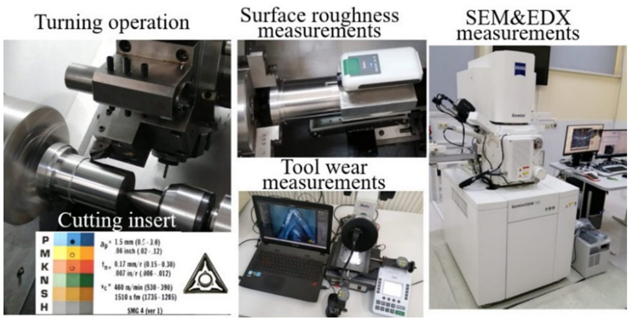

Figure 1. The experimental order.

RESULTS AND DISCUSSION

Tool Wear

During machining, cutting tools are affected by numerous factors and wear over time. As a result, various wear mechanisms appear on the cutting tool, and different wear types develop as a result of these wear mechanisms. Ultimately, the cutting tool becomes unusable after a certain period. In the research, the wear of the tool over time was studied. The measurements for the different passes (1st, 5th, 10th, and 13th) are given in Figure 2.

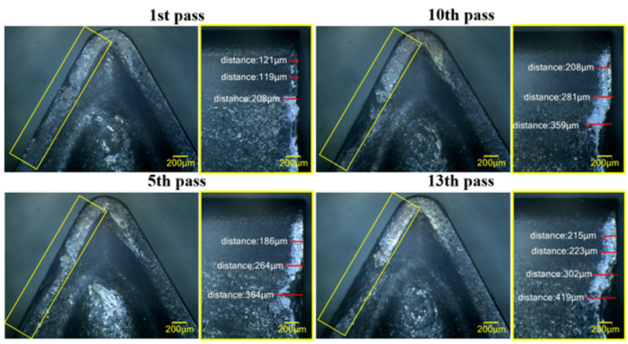

Figure 2. The tool wear examinations with the toolmaker's microscope.

Instead of a single wear mechanism, tool wear frequently consists of multiple wear mechanisms [16]. However, in this study, it is understood that abrasion wear (three-element abrasion wear) is dominant on the cutting tool, and abrasion marks are obvious (Figure 2). Over time, abrasion has caused flank wear and notch wear. Therefore, tool life analyses have been studied based on these two types of wear. CNC turning centers were frequently employed with single-point cutting tools, and ISO 3685 was applied to control the tool life [17]. In the current examination, the cutting tool wear was found to be regular, as shown in Figure 2. Consequently, a value of 300 µm was used to determine the flank wear limit value according to ISO 3685. The limit value was reached on the 13th pass (14.4 min cutting tool life); hence, the tool was considered worn, and the experiments were terminated. In their study, Letot et al. [18] detected 300 µm flank wear approximately after 10-14 minutes of cutting time. In addition, tool wear was monitored until the end of the time when the tool was considered worn (until the end of the 13th operation), and the tool wear was monitored by performing measurements after each operation (Figure 3).

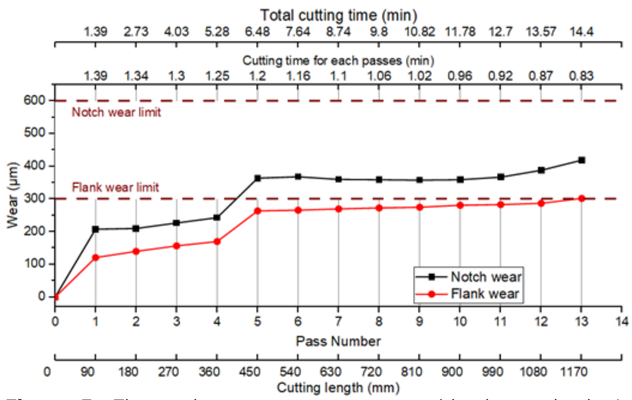

Figure 3. The tool wear measurements with the toolmaker's microscope.

The time-dependent tool wear shown in Figure 3 was examined. In the first pass, where the experiments started, there was a rapid increase in the notch wear and flank wear values. In all subsequent passes, the notch wear value was found to be higher than the flank wear value throughout all the tests. It is known that the notch wear moves faster when it is related to the flank wear [19]. Tool wear increased with time, as expected. It was known that cutting tools wear rapidly at the beginning, then continue to wear at a steady rate, and in the final stage, wear accelerates again; this was relatively ordinary in tool life curves in general [18, 19]. However, as the diameter of the material decreased with each pass, the cutting time decreased with each pass. The cutting time in the first pass was 1.39 minutes, while the cutting time in the last pass was 0.83 minutes. Therefore, the acceleration of tool wear was not developed as fast as expected. It was understood that the tool wear was slowed down considerably, especially in the last few passes. The machining operations were performed with a total length of 1170 mm within 14.4 minutes when the tool life was finalized, and the investigations were terminated due to tool wear. Finally, the worn cutting tools were monitored by SEM and EDX investigations (Figure 4).

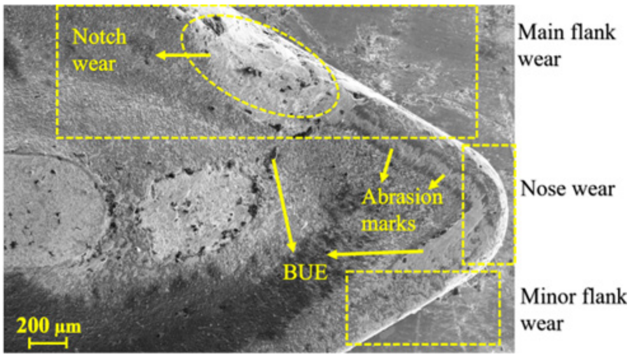

Figure 4. The tool wear measurements with the SEM.

The SEM examination was performed on the insert (Figure 4). Although flank wear and notch wear were detected in the microscopic examination, Built-up edge (BUE) formation and nose wear were also observed in the SEM analysis. However, since the surface examination did not provide sufficient information on insert wear, the insert was examined from an oblique view (Figure 5).

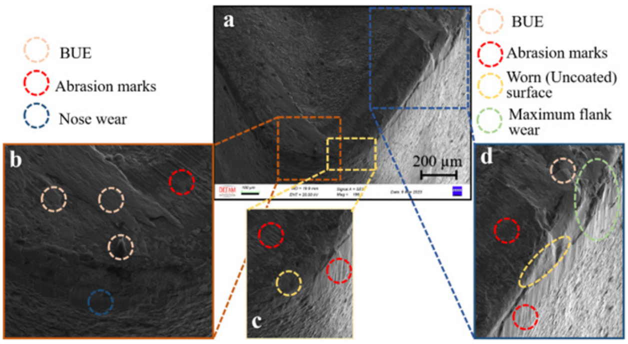

Figure 5. The SEM analysis according to the types of wear.

The SEM image (Figure 5) of the cutting tool was examined. The abrasive wear mechanism was apparent on all surfaces of the cutting tool that encountered the workpiece (Figures 5-b, 5-c, and 5-d). Both BUE formation and nose wear were evident in Figure 5-b, which shows the nose area of the cutting tool was presented. BUE formation is frequently observed in the literature [20]. Figure 5-d shows the surface where the cutting tool first encounters the workpiece. Since thermal cracks and crater wear are not observed, it can be argued that the wear is only due to mechanical effects. This surface showed significant wear due to three-element abrasion wear. The cutting tool was coated with Ti (C, N) and Al_2O_3 coating layers employing the Chemical Vapor Deposition (CVD) method. Coatings have many advantages in cutting tools, especially in extending tool life. However, as can be clearly detected in Figure 5-d, the coating on the cutting tool is largely removed as expected due to tool-workpiece interaction. Notch wear, which is frequently encountered in cutting tools, was partially visible in the tool. A SEM&EDX analysis was performed to obtain more information about the cutting tool surface (Figure 6).

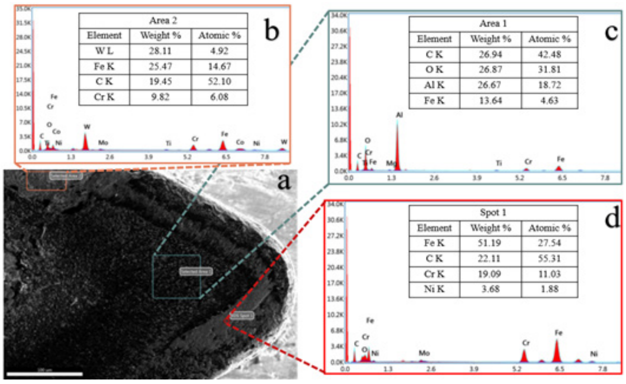

Figure 6. The EDX analysis of the top surface of the cutting insert.

The EDX investigations were operated on three different regions of the cutting insert (Figure 6-a). In Figure 6-b, where notch wear was observed, the presence of W and C atoms in the chemical composition showed that the cutting tool coating was completely worn, and the WC (tungsten carbide) substrate, which was expected to be seen in the substrate, became visible. Figure 6-c shows the chemical composition analysis taken from the area where there was no direct interaction between the workpiece and the cutting insert. Ti (C, N) and Al_2O_3, which were used in the cutting insert coatings, were expected to be seen in this area. The existence of Al, O, and C elements, as expected, indicated an unworn cutting tool coating. The presence of Cr and N elements, mostly related to the content of the workpiece material (stainless steel), in the last examination area (Figure 6-d), proves the formation of BUE in this examination.

Surface Roughness

Machine parts coming out of the machining process are expected to have certain qualities. One of these qualities is surface finish. In the present study, surface finish investigations were performed after each pass, and the average surface roughness (Ra) values presented in Figure 7 were obtained.

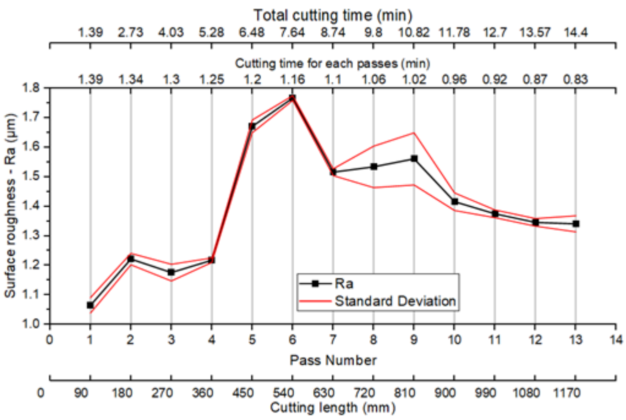

Figure 7. The surface roughness (Ra) results of the machined workpiece.

The surface roughness results were calculated by averaging a total of five measurements without dismounting the workpiece from the CNC lathe. Therefore, it is intended to increase the reliability of the measurement. In addition, the surface roughness measurement area is kept constant for each pass by using the C-axis capability of the turning center. It was reported in the literature that the surface roughness values deteriorate because of tool wear [2, 9, 21]. In the surface roughness measurements, a rapid increase in surface roughness as a factor of tool wear was monitored. Furthermore, it was also found that the standard deviation of these measurements was also low. However, after 7.64 minutes of tool life (after the 6th pass), the surface roughness measurements decreased interestingly until the end of the experiments. Some literature sources also highlighted this intriguing circumstance, and the researchers showed that the surface finish of the machined surface could increase as the tool life was near its end [19, 22]. The geometric shape of the cutting inserts transforms under the influence of tool wear. It was recognized that the two dominating influences on surface roughness were feed and tool geometry [23, 24]. It is also known that wiper cutting inserts are employed in some cutting tools to provide a smoother surface finish [3, 25]. The decrease in surface roughness can be explained in several ways. The tool nose radius directly affected the surface roughness; increased tool wear increased the tool nose radius, and increased tool nose radius decreased the surface roughness. Moreover, the geometrical change of the cutting insert could make a wiper tool effect to decrease the surface roughness. The coated layer of the tool is significantly harder than the substrate; therefore, a burnishing effect rather than a cutting effect could affect the surface roughness. Moreover, there were meaningful standard deviation differences in tool wear on the 8th and 9th passes. Since the feed was kept constant in all experiments, the change in surface roughness can only be explained by tool wear. Tool wear is affected by many factors; however, machining time or machining length can be defined as the main reason for the increasing tool wear [26,27]. In this case, while the increase in surface roughness due to tool wear was expected, the enhancement in surface roughness at the end of 7.64 minutes of tool life could be explained by the transformation of the worn tool surface into a geometry similar to wiper cutting inserts. In the evaluation of surface roughness, in addition to the average surface roughness parameter, the Rz and Rt parameters were also measured to better express the surface roughness (Figure 8).

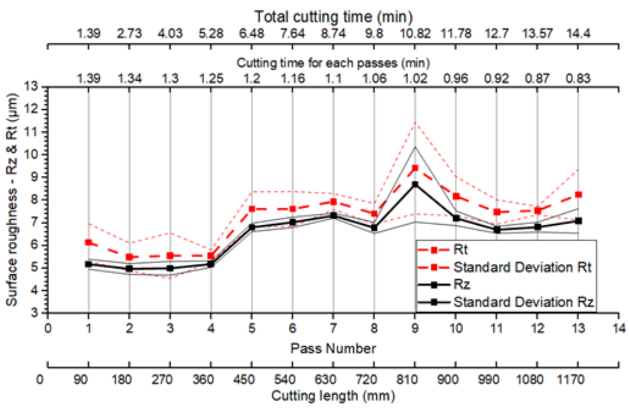

Figure 8. The surface roughness (Rz and Rt) results of the machined workpiece.

Similar to the Ra parameter, both the Rz and Rt parameters deteriorated due to tool wear (Figure 8). However, the enhancement in surface roughness seen in the Ra parameter after 7.64 minutes of tool life (at the end of the 6th pass) was interestingly not observed in the Rz and Rt measurements. In addition, as expected, the Rt parameter was higher than the Rz parameter in all experiments. Elba et al. [3] emphasized in their study that Rz and Rt were almost 5-6 times higher than Ra. Similarly, in this study, the Rz value was 4.67 times the Ra, and the Rt value was 5.2 times the Ra. After the tool life of 10.82 minutes (9th pass), it was discovered that there was a very significant standard deviation, similar to the Ra measurement. The entire surface roughness investigation examined and understood that both surface roughness values (Rz and Rt) deteriorate extensively with time.

CONCLUSION

In the current study, the tool wear and surface roughness changes in the turning of stainless steel were analyzed under dry machining conditions. For this purpose, the constant length of the workpiece (90 mm) was machined each time, and surface roughness and tool wear measurements were studied at the end of each cutting operation. The primary outcomes of these analyses were as follows:

Distinct types of wear, particularly notch and flank w ear, were monitored. The wear values increased with time and the tool life ended at the end of 14.4 minutes of machining time (1170 mm) when the flank wear value reached 300 µm. It was observed that both the flank wear and notch wear values intensified swiftly and then intensified at a steady rate. However, the third stage of tool wear, which was frequently seen in cutting tools and in which the cutting tool wears rapidly, has not been determined. In addition, significant BUE formation was revealed by SEM and EDX analysis.

To analyze the surface roughness values, in particular, the Ra parameter, the Rz and Rt parameters were also examined. It was observed that the Ra parameter first deteriorated due to tool wear, but after 7.64 minutes of cutting time, it interestingly improved until the end of 14.4 minutes when the experiments were completed. However, interestingly, this improvement was not observed for the Rz and Rt parameters.

Considerable detailed studies were conducted within the scope of this study. However, towards the end of the experiments, it was not entirely clear why the Rz and Rt parameters did not increase while the Ra parameter increased. An investigation of this situation may be interesting for future studies. In addition, conducting current experiments with wiper inserts and comparing the results can contribute to the literature.

Acknowledgement

The author received no financial support for the research, authorship, and/or publication of this article.

References

1. Stephenson DA, Agapiou JS. Metal cutting theory and practice. 3rd Ed. Boca Raton FL, USA, CRC Press, 2018.
2. Pinar AM, Fırat K. Machinability evaluation of multi-directional turning tools. Materials Testing. 2020 Feb 25;62(3):311-316.
3. Elbah M, Yallese MA, Aouici, H., Mabrouki, T., Rigal, J.-F. Comparative assessment of wiper and conventional ceramic tools on surface roughness in hard turning AISI 4140 steel. Measurement. 2013 Jun 26;46(9):3041-3056.
4. Huang YW, Yeh SS. Development of insert condition classification system for CNC lathes using power spectral density distribution of accelerometer vibration signals. Sensors (Basel). 2020 Oct 19;20(5907):1-20.
5. Tzotzis A, García-Hernández C, Huertas-Talón J-L, Kyratsis P. 3D Fe modelling of machining forces during AISI 4140 hard turning. Strojniški vestnik – Journal of Mechanical Engineering. 2020;66(7-8):467-478.
6. Sousa VFC, Silva FJG. Recent advances in turning processes using coated tools—a comprehensive review. Metals. 2020 Jan 23;10(170):1-28.
7. Callister Jr, WD, Rethwisch DG. Callister's materials science and engineering. 10th ed, New York, USA, John Wiley & Sons, 2020.
8. Del Risco-Alfonso R, Pérez-Rodríguez R, Zambrano Robledo, PdC, Rivas Santana M, Quiza R. Optimization of the cutting regime in the turning of the AISI 316L steel for biomedical purposes based on the initial progression of tool wear. Metals. 2021 Oct 25;11(1698):1-15.
9. Chen J, Wang Y, Zhang Y, Yang S, Zhang X. Investigation on tool wear mechanism during dry cutting 304 stainless steel. Manufacturing Technology. 2020 Jul 31;20(1):36-44.
10. He Q, DePaiva JM, Kohlscheen J, Veldhuis SC. Analysis of the performance of pvd altin coating with five different Al/Ti ratios during the high-speed turning of stainless steel 304 under dry and wet cooling conditions. Wear. 2022 Dec 8;492-493:204-213.
11. Ebrahimi SM, Hadad M, Araee A. Sustainable machining of hardened AISI630 stainless steel using thermally enhanced turning technique. Mach. Sci. Technol. 2021 May 14;25(4):608-636.
12. Szczotkarz N, Mrugalski R, Maruda RW, Królczyk GM, Legutko S, Leksycki K, Dębowski D, Pruncu CI. Cutting tool wear in turning 316L stainless steel in the conditions of minimized lubrication. Tribol Int. 2021 Dec 5;156(106813):1-11.
13. Zawada-Michalowska M, Piesko P, Jozwik J. Tribological aspects of cutting tool wear during the turning of stainless steels. Materials (Basel). 2019 Dec 26;13(123):1-12.
14. Sönmez F. The effect of feed and depth of cut parameters on surface roughness and chip morphology in stainless steel materials. European Journal of Technique (EJT). 2024 Jun 30;14(1), 69-75.
15. ISO 21920-3:2021. Geometrical product specifications (GPS) - Surface texture: Profile — Part 3: Specification operators, International Organization for Standardization. Geneva, 2021.
16. Singh Bedi S, Prasad Sahoo S, Vikas B, Datta S. Influence of cutting speed on dry machinability of AISI 304 stainless steel. Mater Today Proc. 2021 Jun 27;38: 2174-2180.
17. ISO 3685:1993. Tool-life testing with single-point turning tools, International Organization for Standardization. Geneva, 1993.
18. Letot C, Serra R, Dossevi M, Dehombreux P. Cutting tools reliability and residual life prediction from degradation indicators in turning process. Int J Adv Manuf Technol. 2015 Dec 16;86(1-4):495-506.
19. Derani MN, Ratnam MM, Nasir RM. Improved measure of workpiece surface deterioration during turning using non-contact vision method. Precis Eng. 2021 Dec 23;68:273-284.
20. Pekşen H, Kalyon A. Optimization and measurement of flank wear and surface roughness via Taguchi based grey relational

analysis. Materials and Manufacturing Processes, 2021 May 14;36(16):1865-1874.
21. Parsi PK, Kotha, RS, Routhu T, Pandey S, Dwivedy M. Machinability evaluation of coated carbide inserts in turning of super-duplex stainless steel. SN Appl Sci. 2020 Oct 31;2(1933):1-19.
22. Akhavan Niaki F, Mears L. A comprehensive study on the effects of tool wear on surface roughness, dimensional integrity and residual stress in turning IN718 hard-to-machine alloy. J Manuf Process. 2017 Oct 2;30:268-280.
23. Baday Ş, Ersöz O. Comparative investigations of cryo-treated and untreated inserts on machinability of AISI 1050 by using response surface methodology, Anova and Taguchi design. Proc. Inst. Mech. Eng., Part C. 2021 Agu 28;236(3):1751-1765.
24. Rashid WB, Goel S, Davim JP, Joshi SN. Parametric design optimization of hard turning of AISI 4340 steel (69 Hrc). Int J Adv Manuf Technol. 2015 Jun 13;82(1-4):451-462.
25. Subbaiah KV, Raju C, S Pawade R, Suresh C. Machinability investigation with wiper ceramic insert and optimization during the hard turning of AISI 4340 steel. Mater Today Proc. 2019 Oct 28;18:445-454.
26. De Oliveira PA, de Menezes Pereira LMP, Monção RM, *et al.* Tool wear, surface roughness, electric current, and chip morphology in the turning of AISI 1045 steel with minimum quantity lubrication (MQL) technique. Int J Adv Manuf Technol. 2024 Jul 08;133;5743–5759.
27. Bouchama R, Bouhalais ML, & Cherfia A. Surface roughness and tool wear monitoring in turning processes through vibration analysis using PSD and GRMS. Int J Adv Manuf Technol. 2024 Jan 05;130;3537–3552.