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STUDY OF SURFACE FINISH AS A FUNCTION OF CERAMIC TOOL WEAR WHEN TURNING HARDENED AISI 52100 STEEL

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ABSTRACT

The turning process in hard materials has been way more used in the last few years because of the demand to reduce the manufacturing cost. This research analyzes the superficial roughness evolution in mixed ceramic tool`s wear used to turn ABNT 52100 hardened steel. This study has the objective to find the major reasons that influence the flank wear in ceramic insert and analyze how this wear influences the samples superficial roughness. In the turning process the variables cutting speed (Vc), feed (f) and machining depth (ap) were changed during the tests and analyzed their influences in superficial roughness. The experiments show that the greatest tool wear, for the variables used, was because of the forward speed. In the superficial finish study the only thing which has a great impact in average roughness (Ra) was the forward speed that when elevated has increased the average roughness. Meanwhile the vibration excess, caused by the machine`s low hardness, mainly for the several cutting properties, caused damage to the cutting tool that helped to increase the roughness rate while the flank wear also advanced.

Keywords: Turning Process, Ceramic Tools, Flank Wear, Roughness

1. INTRODUCTION

Usually, the process of chip removing materials that are between 45 to 68 HRC is called a hard turning process Bartarya and Choudhury (2012). A few years ago, the hardened materials which the turning process needed to be worked by the retification process. According to Diniz et al. (2014), the retification operations and the turning process of the hardened materials could be compared in technical terms and also in the actual manufacturing scenery therefore the turning process gains are significant in both situations. In contrast to the retification the costs of the turning process in hardened materials can be reduced by over 60% because of the low machine-tool cost, as well the reduced time and more flexibility of the process. Changing the retification process to the hardened turning process brings many advantages, among the possibilities is to work without cutting fluid, the possibility to skip some steps, higher production, low uses of energy for processed material volume, low costs machine-tools and also the possibility to do many operations in the same setup, which guarantees the geometrics characteristics and reduces the operation time.

Among the different types of tools that are used in hardened turning, this work choosed to use the ceramic tools because of its high hardness properties when working with high temperatures and high strength to natural wear and also for the low cost when compared to CBN or PCBN. The choice for the wet turning was because of the fact that in this condition the cutting in high temperatures increases the chip deformation and shear, reducing the cutting strengths. Wet conditions also avoid handling problems, maintenance and disposal problems which pollute the environment and human health too Wins and Varadarajan (2011).

About hardened materials tooling, it is possible to realize the cutting strength isn't necessarily high. It is because of the chip´s plastic deformation which is relatively small and also because of the small area of contact between the tool and the piece, which reduces the friction strength Nakayama and Kanda (1988). According to Abrão et al. (1995), tolling the ABNT 52100 steel (62 HRC) with PCBN and mixed ceramic, was possible to realize that during the superficial finish process, the passive strength (radial) was bigger than others strength's components, the reason is related to smaller position angle (χr) caused by the small deep tooling value in relation to the to the tool nose radius. Nakayama and Kanda (1988) says: turning a steel for bearing in two different types of heat treatment annealed 23 HRC and hardened 62 HRC), it was possible to observe that the value of the forward strength was bigger than the strength in both cases for an angle from 0 to 60 degrees. In the turning process, the superficial finish has great importance because it is directly related to the piece's functioness because it is also related to the wear resistance and fatigue, friction coefficient, corrosion resistance and lubrication Singh and Rao (2007). According to the He et al. (2018) it is possible to have in CNC turning machines a roughness from a that is what is generally expected.

A fact that has big influence on roughness and so in superficial finish of the pieces is the tool's corner geometry Thiele and Melkote (1999) and Özel et al. (2005), which suffers with big varieties as long as the tool's flank wear increases Zhou et al. (2004) and Binder et al. (2017). About the superficial finish in the turning process, Sata (1985) verified that not always the gain achieved is increased by the tool's tool nose radius (geometric influence) which is translated to a better superficial finish for the piece because will increase the tool nose radius and also the strengths involved in the process and consequently in the vibrations of the system. As König and Wand (1988) says that the increase of the cutting and the forward strengths demand a lot from the machine-tool to provides high power, meanwhile the passive strength's increases causing ELASTIC deformations of the system machine-tool-piece and also local ELASTIC deformations near to the point of cutting, so it can cause to the piece wrongs geometrics dimensions and even broking the tool. In the study of tool's life and average superficial roughness using the turning process, there are many factors that influence, for example the cutting speed, the feed rate and the deep cutting.

2. MATERIALS AND METHODS

The turning tests were dimensioned to proportionate a clear and accurate way to study speed cut, feed and machining depth influence in mixed ceramics tool`s wear and surface finish as well. To determine the tool`s end life was admitted flank wear Vbmax=0,3 mm. This criterion was admitted because above this value starts the risk of breaking the tool`s ceramic insert, besides that it represents a big value, when it happened the cutting edge became really damaged.

The experiments were done in a Turning CNC Nardini Logic 175 center. Mixed changing ceramics inserts (Al2O3 + TiC), Sandvik GC 6050 class roofed with Titanium Nitride (TiN) with ISO CNGA 120408 S01525 geometry chamfered. The test pieces used in the analysis were fabricated with AISI 52100 steel (Villares) and then heat treated to increase the hardness. It is shown in Table 1 the AISI 52100 steel chemical composition.

Table 1

Table 1 AISI 52100 Chemical Composition								
Chemical Composition (% weight)								
Element	**C**	**Si**	**Mn**	**Cr**	**Mo**	**Ni**	**S**	**P**
Concentration	1,03	0,23	0,35	1,40	0,04	0,11	0,001	0,01

After heat treatment the testing pieces showed 55 HRC average hardness until a deep 3,0 mm. The pieces were Ø49 x 104 mm of dimension and split in 2 parts of 50 mm length each.

The takes of average roughness (R_a) were done using a Taylor Hobson rugosimeter, model Surtronic 3+, calibrated before the takes. The flank wear (V_{bmax}) over the tool`s surface gap was monitored using microscopic optical photographs. The flank wear photos on the gaps surface were done with an image analyzer, which has an optic microscope that can zoom from 25 to 50 times linked to a camera plugged to a microcomputer.

During the tests two levels of variety were admitted for each parameter of tooling. It is shown in Table 2 three variables: cutting speed, feed and machining depth, and also shows the levels of variation for each parameter. The range of variations was changed respecting the manufacturer’s recommendations.

Table 2

Table 2 Machining Parameters Used				
Machining Parameters				
Parameter	**Simbol**	**Unit**	**Lower Level**	**Higher Level**
Cutting speed	V_c	m/min	200	240
Feed	f	mm/rotação	0,05	0,10
	a_p	mm	0,15	0,30
Machining depth				

3. RESULTS AND DISCUSSIONS

In the Figure 1 is shown the machining length (L_c) done by the mixed ceramic’s edge for each condition utilized and the respective value of average roughness (R_a) when achieved the full lifetime of tool use, the value stipulated was V_{bmax}=0,3 mm for flank wear. At the experiments the parameters speed cutting (V_c) was varied from 200 m/min to 240 m/min, feed (f) from 0.05 mm/v to 0,10 mm/v and machining depth (a_p) between 0,15 mm and 0,30 mm, which the tests utilized mixed ceramic covered with Titanium Nitride.

Figure 1

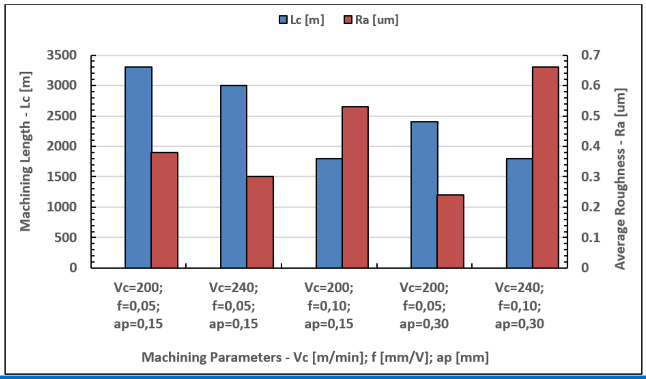

Figure 1 Cutting Edge Machining Lengths and Respective Average Roughness Values When Reaching the End of Tool Life Criterion.

The cutting conditions where the machining parameters are in the lowest level (Vc=200 m/min; f=0,05 mm/rotation; ap=0,15 mm) shows the longest machining length done by the cutting edge until achieving the lifetime end parameter. For the harshest cutting situation where all the parameters are in the highest level (Vc=240 m/min; f=0,10 mm/rotation; ap=0,30 mm), the cutting edge did the shortest length until achieving 0,3 mm flank wear.

For the parameters that have the most influence in tool's lifetime, it is possible to realize that increasing the feed levels provokes bigger wear and reduces tool's lifetime, represented by the shortest machining length done by the cutting edge. In sequence, in descending order of influence, appears machining depth and cutting speed, besides the condition that all the other parameters are in their highest levels. It is crucial to observe, though, for the fact that these results are relevant only for tooling tempered AISI 52100, machined with mixed ceramic tools (Al2O3 + TiC), covered with TiN (geometry: ISO CNGA 120108 S01525) and also with the cutting parameters variating in the level ranges already mentioned in this work.

In the Figure 2 is shown the average roughness behavior (R_a) related to the evolution of the flank wear (V_{bmax}) of the tool's cutting edge for the test using the parameters in the lowest levels.

Figure 2

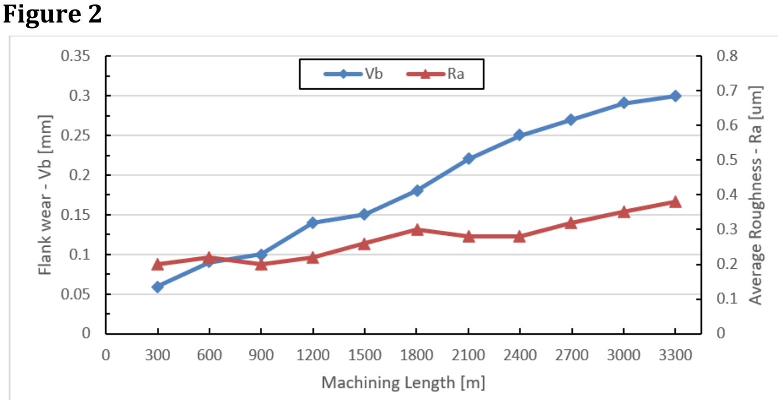

Figure 2 Roughness Behavior in Relation to the Progression of Flank Wear for the Condition Vc=200 m/min, fz=0,05 mm/V e ap=0,15 mm.

Is possible to realize that for this machining condition the roughness maintains between 0,2 to 0,38 μm, increasing as far as the flank wear increases. For gentle conditions of tooling the cutting edge achieves the longest length for the tests, validating the results found in literature. This happens because of the low heat generation and also of the system's low levels of vibration due to lower cutting effort.

Grzesik (2008) analyzed the effects of the tool's wear in surface roughness during the tooling process of hardened steel using ceramic tools. The results show an increase in average roughness as far as the flank wear increased. Raising the cutting speed to Vc=240 m/min and keeping the other parameters in the lowest levels was possible to see a small reduction in machining length as shown in Figure 3. The roughness continues inside a good range of values, varying between 0,15 to 0,30 μm and progresses slowly as far as the flank wear increases. The reduction in length machining happens because of the high temperatures at the cutting area due to a bigger cutting speed which favors a bigger level of wear at the cutting edge.

Figure 3

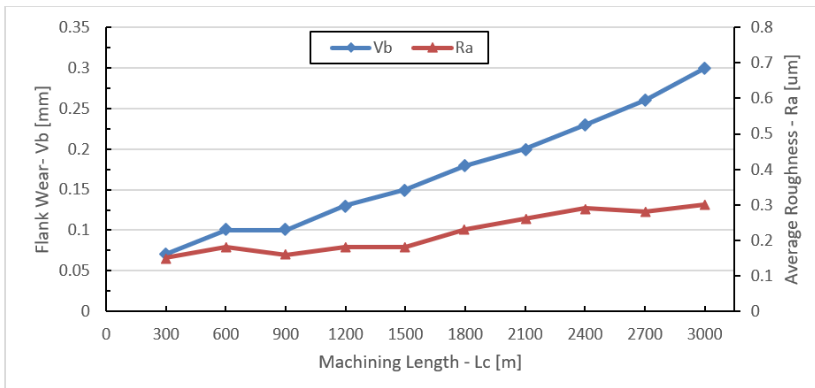

Figure 3 Roughness Behavior in Relation to the Progression of Flank Wear for the Condition Vc=240 m/min, fz=0,05 mm/V e ap=0,15 mm.

The increase of the cutting speed provided a small improvement in roughness behavior because of a more dynamic cutting due to a higher speed.

In Figure 5 it is shown the behavior of the flank wear and average roughness to increase in the machining feed from a 0,05 mm/rotation to 0,10 mm/rotation. It was expected that increasing the feed would also increase the average roughness during all the machining length due to a bigger cutting tool displacement between subsequent rotations. However, increasing the feed caused a great decrease of the machining length, decreasing to 50% of the value achieved with its lowest feed level. For this cutting parameter the tool's cutting edge broke when achieved the flank wear V_{bmax}=0,25 mm, so the lifetime ended before the expected.

Figure 4

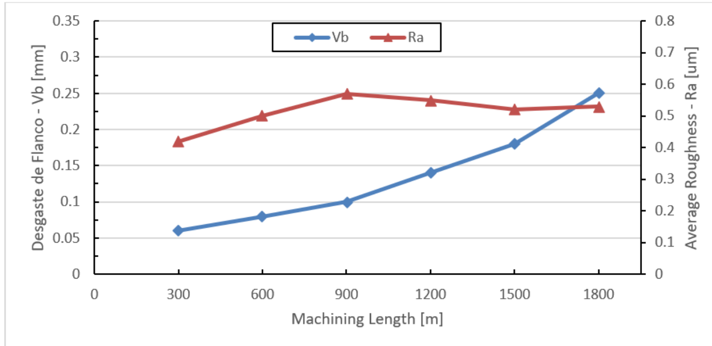

Figure 4 Roughness Behavior in Relation to the Progression of Flank Wear for the Condition Vc=200 m/min, fz=0,10 mm/V e ap=0,15 mm.

This cutting edge broke probably due to a bigger vibration of the system machine/tool/piece because of the highest cutting strengths happened by the feed increase. The turning CNC used for this work has low stiffness and this also relates to the fact that the ceramic tool has low tenacity. This combination makes the tool suffer with little chips due to bigger vibration and cutting strengths, breaking the tool.

In Figure 5 it is possible to see that increasing the machining depth has a small influence in machining length, providing a smaller decrease compared to what the cutting speed increase provided. The roughness showed lower values of all tests done keeping its value around 0,20 µm during all the machining length. A small reduction in machining length relative to a condition with all the parameters in the lowest level, the significant wear increase from 1800 m machining length as well. probably happens due to bigger cutting strengths consequently bigger system's vibrations. Otherwise, the increase of the machining depth provided low roughness values. This shows that the biggest tool's penetration contributed to a better surface finish bringing better results like the results by increasing the tool nose radius.

Figure 5

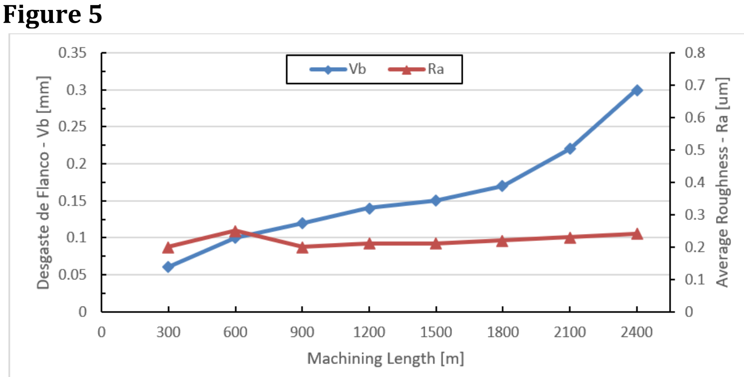

Figure 5 Roughness Behavior in Relation to the Progression of Flank Wear for the Condition Vc=200 m/min, fz=0,05 mm/V e ap=0,30 mm.

For the condition with all the machining parameters in the highest values, it is possible to observe a new reduction in machining length, as shown in Figure 6. This behavior is similar to what happened in the test of increasing the feed. This fact confirms the thesis that the machining feed provides biggest cutting strengths and consequently increases the system's vibration damaging faster the ceramic tool's cutting edge causing small chips deformation. It is also possible to observe an increase of the average roughness, that has direct relation to the flank wear increase and the feed in its highest value as well.

Figure 6

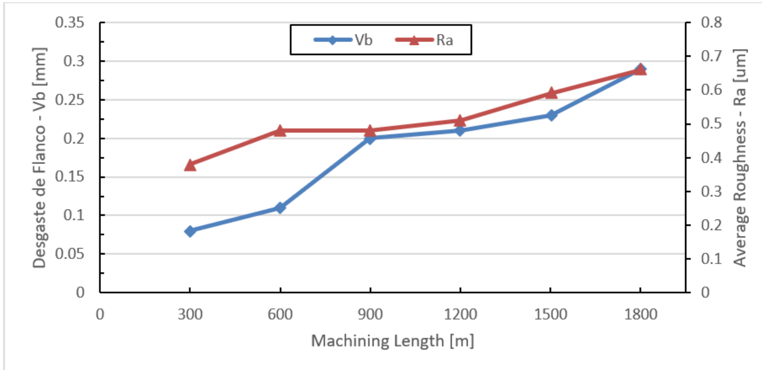

Figure 6 Roughness Behavior in Relation to the Progression of Flank Wear for the Condition Vc=240 m/min, fz=0,10 mm/V e ap=0,30 mm.

In his study about the influence of the tool's wear in the surface roughness tooled, Pavel et al. (2005) reported that with the progression of wear, all the roughness parameters studied increased.

For all the conditions, were verified mostly the flank and the crater wear, with some chip's occurrence. As shown in Figure 7 where the parameters Vc, f and ap were in their lowest values, the tool's wear was uniform, observing a crater wear and an increasing flank wear that progressed until achieving the lifetime Vbmax=0,3 mm.

Figure 7

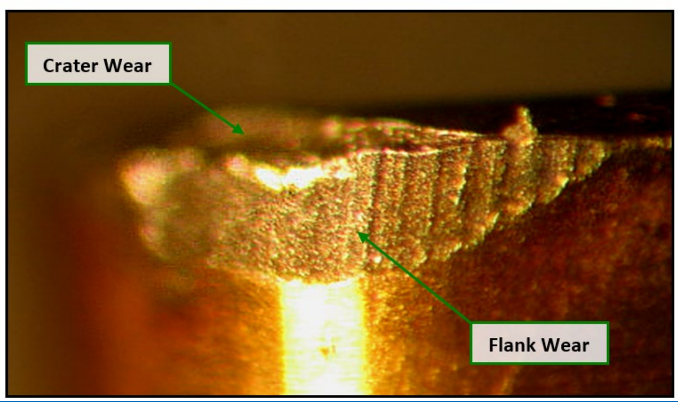

Figure 7 Tool Wear After Reaching End-of-Life Criteria for Vc=200 m/min, f=0,05 mm/v e ap=0,15 mm.

In Figure 7 is shown vertical wear marks that evidence the occurrence of wear of mechanical abrasion. As much the frontal wear as the crater wear can be caused by abrasion, but the abrasion stands out on frontal wear due to friction of surface gap with a hard element, that is the piece, while the exit surface is in touch to the flexible element, which is the chip. This type of wear is caused by the hard particles of the piece's materials and by the cutting temperature that reduces the tool's hardness.

An example of tool breaking is in Figure 8. This breaking occurred for Vc=200 m/min; f=0,10 mm/v; ap=0,15 mm, where is visible the most important factor in reducing the lifetime of the tool, the feed, in its highest level. In Figure 8 observe a high crater wear that occurred at the exit surface of the tool, caused by the friction between the tool and the chip. This break happens when the crater wear progresses until reaching the flank wear, in this case the situation was amplified by the turning machine's lack of hardness.

Figure 8

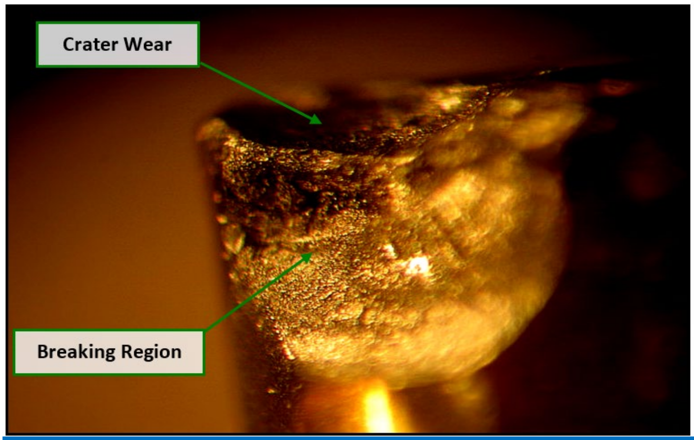

Figure 8 Tool Breakage for the Condition Vc=200 m/min, f=0,10 mm/v e ap=0,15 mm.

In the experiments were observed occurrences of chip and break at the cutting edge, mainly for the several conditions of machining. In these conditions became more pointed the cutting strengths and system's vibration, caused as much by the high machining speed as by the lack of turning machine's hardness. Another reason that can contribute to the chip occurrence and breaks is the fact that the turning process was done with ceramic tools, which, due to its low tenacity and high hardness, became extremely sensitive to vibrations from a system with lower hardness.

4. CONCLUSIONS AND RECOMMENDATIONS

Tests of turning process were carried under various conditions using AISI 52100 hardened steel. The purpose of these tests was to determine tooling's parameters influences over the behavior of the roughness and also over the machining length, and the behavior of the roughness in relation to the progression of the flank wear as well. The following conclusions can be drawn:

- The factors cutting speed (Vc), feed (f) and machining depth (a_p) wield significantly influence over the machining length traveled by the tool until reaching the lifetime criterion, which each one contributes to the reduction of cutting tool's lifetime.
- Among the factors analyzed, the greatest influence wielded over the machining length traveled by the tool was because of the feed, following by the machining depth and finally by the cutting speed.
- In the studies of surface finish, the unique factor that wielded great influence on the average roughness (Ra) was the feed, which when always increased provided an increase in average roughness.
- For feed f= 0,05mm/rotation, it is possible to achieve average roughness values equals to values of conventional ratification process, but with a feed f=0,10 mm/rotation this value (Ra ≤ 0,40 μm) was sometimes exceeded.

- The excess of vibration caused by the machine's lack of hardness, mainly for the most severe cutting conditions, provoked damages to the cutting tools, like small and big chipping and even breaking the cutting edge, being responsible to the lifetime end.

CONFLICT OF INTERESTS

None.

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REFERENCES

Abrão, A. M., Aspinwall, D. K., & Wise, M. L. H. (1995). Tool Wear, Cutting Forces and Temperature Evaluation When Turning Hardened Bearing Steel Using PCBN and Ceramic Materials. In Proceedings of the Thirty-First International Matador Conference (pp. 209–216). Manchester. https://doi.org/10.1007/978-1-349-13796-1_33

Bartarya, G., & Choudhury, S. K. (2012). State of the Art in Turning. International Journal of Machine Tools and Manufacture, 53(1), 1–14. https://doi.org/10.1016/j.ijmachtools.2011.08.019

Binder, M., Klocke, F., & Doebbeler, B. (2017). An Advanced Numerical Approach on Tool Wear Simulation for Tool and Process Design in Metal Cutting. Simulation Modelling Practice and Theory, 70, 65–82. https://doi.org/10.1016/j.simpat.2016.09.001

Diniz, A. E., Marcondes, F. C., & Coppini, N. L. (2014). Material Machining Technology (6th ed.). São Paulo: Artliber Publisher.

Grzesik, W. (2008). Influence of Tool Wear on Surface Roughness in Hard Turning Using Differently Shaped Ceramic Tools. Wear, 265(3–4), 327–335. https://doi.org/10.1016/j.wear.2007.11.001

He, C. L., Zong, W. J., & Zhang, J. J. (2018). Influencing Factors and Methods of Theoretical Modeling of Surface Roughness in the Turning Process: State of the Art. International Journal of Machine Tools and Manufacture, 129, 15–26. https://doi.org/10.1016/j.ijmachtools.2018.02.001

König, W., & Wand, T. H. (1988). Turning Bearing Steel with Amborite & Ceramic. Industrial Diamond Review, 47(3), 117–120.

Nakayama, K., Arai, M., & Kanda, T. (1988). Machining Characteristics of Hard Materials. Annals of the CIRP, 37(1), 89–92. https://doi.org/10.1016/S0007-8506(07)61592-3

Özel, T., Hsu, T., & Zeren, E. (2005). Effects of Cutting Edge Geometry, Workpiece Hardness, Feed Rate and Cutting Speed on Surface Roughness and Forces in Finish Turning of Hardened AISI H13 Steel. International Journal of Advanced Manufacturing Technology, 25(3–4), 262–269. https://doi.org/10.1007/s00170-003-1878-5

Pavel, R., Marinescu, I., Deis, M., & Pillar, J. (2005). Effect of Tool Wear on Surface Finish for a Continuous and Interrupted Hard Turning Case. Journal of Materials Processing Technology, 170(1–2), 341–349. https://doi.org/10.1016/j.jmatprotec.2005.04.119

Sata, T. (1985). Analysis of Surface Roughness Generation in Turning Operation and its Applications. Annals of the CIRP, 34, 473–476. https://doi.org/10.1016/S0007-8506(07)61814-9

Singh, D., & Rao, P. V. (2007). A Surface Roughness Prediction Model for Hard Turning Process. International Journal of Advanced Manufacturing Technology, 32(11–12), 1115–1124. https://doi.org/10.1007/s00170-006-0429-2

Thiele, J. D., & Melkote, S. N. (1999). Effect of Cutting Edge Geometry and Workpiece Hardness on Surface Generation in the Finish hard Turning of AISI 52100 Steel. Journal of Materials Processing Technology, 94(2–3), 216–226. https://doi.org/10.1016/S0924-0136(99)00111-9

Wins, K. L. D., & Varadarajan, A. S. (2011). An Environment Friendly twin-jet Minimal Fluid Application Scheme for Surface Milling of Hardened AISI 4340 Steel. International Journal of Manufacturing Systems, 30–45. https://doi.org/10.3923/ijmsaj.2011.30.45

Zhou, J. M., Andersson, M., & Ståhl, J. E. (2004). Identification of Cutting Errors in Precision Hard Turning Process. Journal of Materials Processing Technology, 153–154, 746–750. https://doi.org/10.1016/j.jmatprotec.2004.04.331