

HARD TURNING OF INTERRUPTED SURFACES USING PCBN AND CERAMIC TOOLS

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Abstract. *The flexibility and ability of machining complex geometries with a single machine setup are the main advantages of using hard turning instead of grinding process. Economically, the cost of turning process is generally lower than the cost of grinding process. Moreover, hardened steel turning is carried out dry, which eliminates probable workers health problems and the necessity of cutting fluid disposal. The major reseachers involving hard turning process are done by cutting continuous surfaces, but most of these real workpieces involve some kind of interruption. This fact can decrease the tool life. The objective of this work is to investigate certain conditions on hard turning of interrupted surfaces, in which PCBN (Polycrystalline Cubic Boron Nitride) and ceramic tools are used. It will be used PCBN and ceramic tools based on aluminum oxide reinforced with whiskers (SiC), in two different cutting types (continuous and interrupted) of ABNT 4340 steel with hardness of 56*HR_C*. Results show that the use PCBN tools in continuous cutting increases the tool life but the value is lower than in the interrupted surfaces case. The performance of the PCBN tools is nearly equal to the ceramic tools when cutting interrupted surfaces. But in terms of roughness, the PCBN tools shows best results when compared to the ceramic tools in the same cutting conditions.*

Keywords*: hard turning, PCBN tool, ceramic tool, interrupted cutting.*

1. INTRODUCTION

The high flexibility and the capacity of cutting complex geometries with a single machine setup represent the main technological advantages in the use of hard cutting substituting the grinding process. Regarding the economic aspect, the cost of turning is generally lower than the grinding operation, what reduces de machining costs. Notwithstanding the hard turning process is generally carried out without cutting fluid, which eliminates its storage, handling and disposal, and probable health workers problems (Klocke *et al*., 2005; Byrne and Scholta, 1993).

The hard turning process has the capacity of machining parts such as ball bearing tracks, gears, shafts, cams, concerning roughness, dimensional and form tolerances. Nevertheless, the cutting parameters must be carefully defined and tool life criteria considered with the objective of avoid damage in superficial part microstructure. Superficial modifications in part microstructure may occur due to the thermal quick variations and the heat flow. The presence of white layers, designation generally used to define the layers formed in ferrous materials in various conditions, which when analyzed in the microscope appear in white color, produce negative effects in the fatigue strength of machined parts, connected to superficial embrittlement and to the appearance of microcracks. (Bosched and Mativenga, 2006).

Zhou *et al*. (2003) studied the influence of microgeometry chamfer angle on tool wear using hard turning. Five values of chamfer angles (0º, 10º, 15º, 20º and 30º) were used for the cutting tests. The workpiece material used was a bearing steel 100Cr6 with hardness of 60-62 HR_C. The cutting parameters were v_c = 160 m/min, f = 0.05 mm/rev and a_p = 0.05 mm. The results suggest that chamfer angle has a great influence on the tool life. Considering the VB_B = 0,20 mm tool life criteria, the use of 15º chamfer tool caused the longest tool life (≈ 50 minutes). The results from finites elements indicate that the principal stresses acting on the cutting edge with 15º chamfer angle has the smallest value compared to the others cutting tools, which suggests there is an optimum chamfer angle around 15º where the tool has maximum tool life.

Regarding the turning of materials with hardness higher than 45 HR_C and with described cutting speeds, the thermal and mechanical loads in cutting tool become very higher. Consequently, high friction coefficients and compression loads occur in the cutting region, formed by the cutting tool and the machined workpiece. These loads cause different tool wear phenomenon and, normally the tool wear progression causes the reduction of the part superficial quality. The application high-speed steel, tungsten carbide and cermet tools do not produce satisfactory results in these conditions. Moreover, the use of PCBN tools promotes better results in terms of tool life than the ceramic tools (Yallese *et al*., 2005).

Diniz and Oliveira (2007) studied the influence of the two PCBN grades (PCBN 7020, with low PCBN concentration and with ceramic phase of TiC; and PCBN 7050, with high PCBN concentration without ceramic phase) and cutting type (continuous, semi-interrupted and interrupted) in the turning of the ABNT 4340 steel with hardness of 55 HR_C, using the following cutting parameters: v_c = 150 m/min, f = 0.08 mm/rev e a_p = 0.15 mm. The results show that the use of the tool with low PCBN concentration and with TiC phase gives the better results in the 3 cutting types.

This result is due to the ceramic phase present in the tool which reduces the thermal conductivity and increases the chemical stability taking into consideration the metallic elements presents in the chips. So, this tool material avoids the diffusion phenomenon, the main responsible for crater wear in the continuous cutting, present in the tool with high level of PCBN and without ceramic phase.

Nevertheless, PCBN tools are still relatively expensive when compared to ceramic tools (about eight times more expensive). Depending on the size of the production lot, ceramic tools may be an interesting alternative to the use of PCBN tools (Zhou *et al*., 2003; Yallese *et al*., 2005). Mainly with workpieces that promote interrupted cut, due to the grooves in the face or diameter, an air flux is generated and help it maintained the workpiece and tool temperature in lower levels (Diniz and Oliveira, 2007). If the cutting parameters and the workpiece and tool fixation systems are rigid so do not occur fracture in the ceramic tool, the application of tool of ceramic material in the hard turning may produce satisfactory results. The mixed ceramic is recommended for continuous hard steel cutting, due to its high hardness and chemical stability but it is not recommended for the interrupted cutting, because it does not have sufficient toughness for the operation. In the odder hand, the Al_2O_3 based ceramic reinforced with whiskers (SiC) tool does not have the same chemical stability than mixed ceramic tool, but it is more adequate to interrupted cut due to its higher toughness.

This work goal is to continue the work of Diniz and Oliveira (2007) concerning the comparisons in the PCBN tool application in the continuous and interrupted cutting. However, in this phase, ceramic tool reinforced with whiskers (SiC) will be test and workpieces with different numbers of interruptions will be use.

2. EXPERIMENTAL PROCEDURES

The workpiece material was ABNT 4340 with 56 HR_C of hardness. Three types of geometries were defined (Fig. 1, 2 and 3). These workpieces were built in order to obtain continuous, 4 and 8 interruptions cutting during their radial turning. The 4 interruptions workpiece has the grooves width twice greater than the grooves width of the 8 interruptions workpiece, in order to promote the same machining area both situations.

The tools used were Polycrystalline Cubic Boron Nitride (PCBN) and ceramic with whiskers. According to the tool manufacturer, the 7020 PCBN tool has a ceramic phase (TiC) and the CC670 ceramic tool is an Al_2O_3 based ceramic with whiskers reinforcement of SiC. These two tool materials are recommended to machining hardened steel and cast-iron in finishing operations with interrupted cutting (Sandvik, 2007).

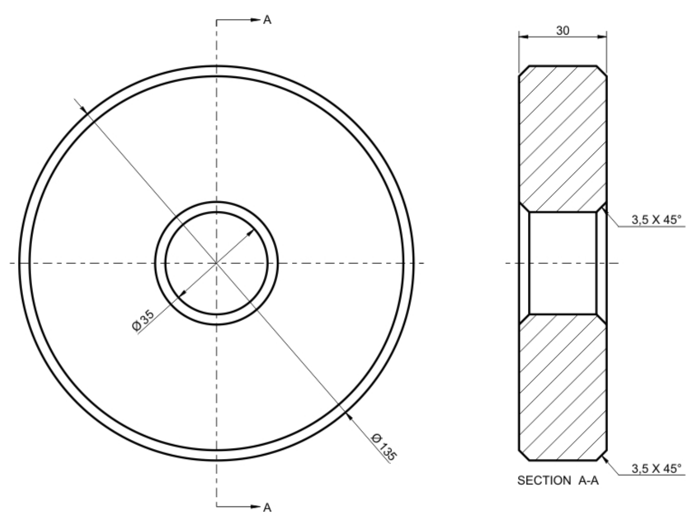

Figure 1. Workpiece for continuous cutting

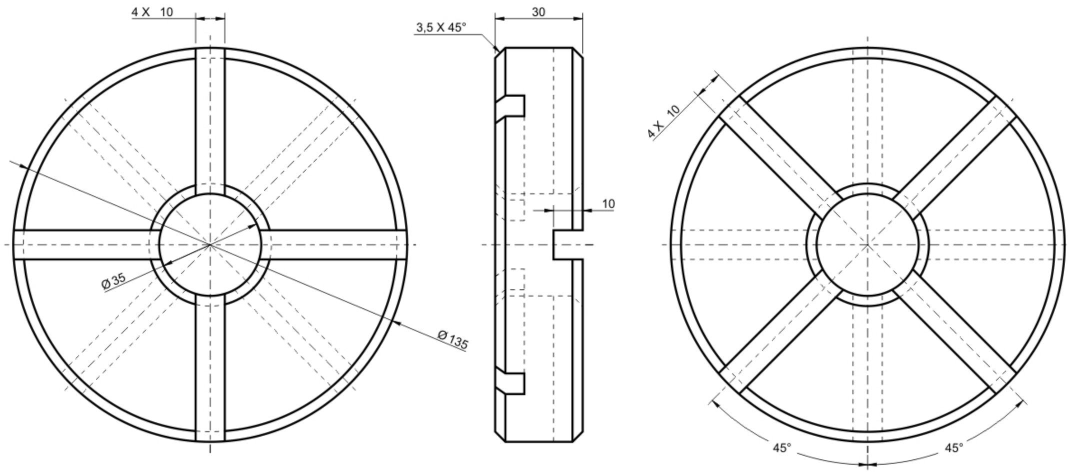

Figure 2. Workpiece with 4 grooves for interrupted cutting

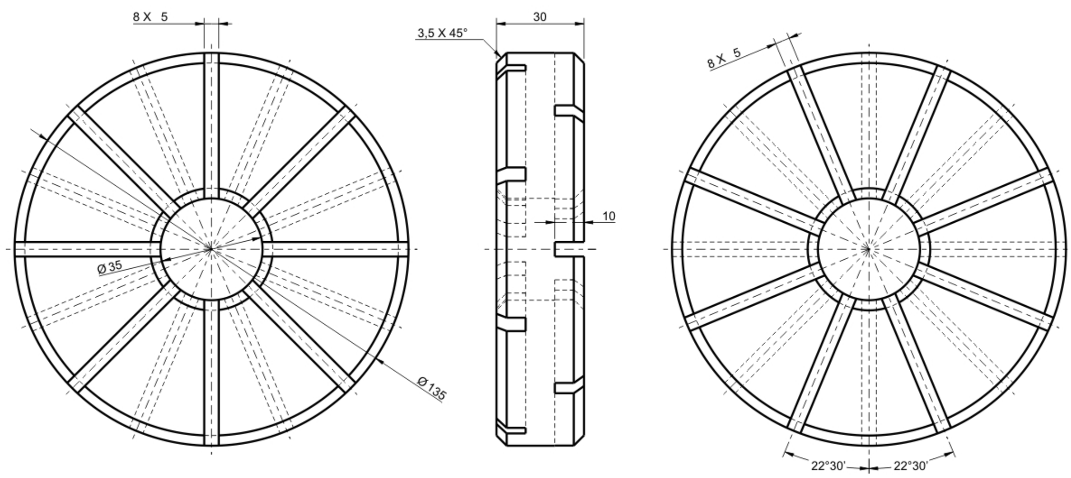

Figure 3. Workpiece with 8 grooves for interrupted cutting

The tools used in the experiments were square geometry. The ISO code of the PCBN insert was SNGA 120412 T01020A with TiN coating. The ISO code of the ceramic reinforced with whiskers was SNGN 120412 T01020 without coating. Both tools have the same microgeometry: a chamfered cutting edge with 0.10 mm×20º. Both tools were mounted in tool holder DSBNR 2525M 12-2. The cutting parameters recommended by the tool manufacturer were: v_c = 150 m/min, f = 0.08 mm/rev e a_p = 0.15 mm.

The experiments were carried out in a Romi CNC lathe, Galaxy 20 model, with 15 kW of power in the spindle motor and maximum revolution speed of 4500 rpm.

The measurement and analyses of the tool flank wear (VB_B) during tool life was inspected using an optical microscope. The tool end of life criteria used was the flank wear of VB_B = 0.20 mm.

The average and maximum surface roughness analyses (R_a e R_y) of the machined surfaces were done during the experiments, using a portable Mitutoyo roughness tester. This equipment was mounted in a magnetic base and fixed in the lathe turret, in order to measure the roughness without removing the workpiece from the jaws.

The experiments consisted of successive radial turning passes of the workpiece surface, starting from the larger diameter, until the end of life criteria would be reached. Each experiment was curried out at least twice.

In order to eliminate possible sources of variation some special procedures were taken. Before starting each experiment, chamfers were machined in both, external an internal diameter of the workpieces in order to avoid shocks in the tool entrance and exit and to reduce the radial runout. Moreover, the first pass in the workpiece surface was made by another tool (not the one used in the experiments) in order to correct any axial error. To avoid any deformation of the lathe jaws along successive fixtures of the workpieces, the fixation system used quenched and tempered jaws (40 HR_C). These special procedures were show in Fig. 4.

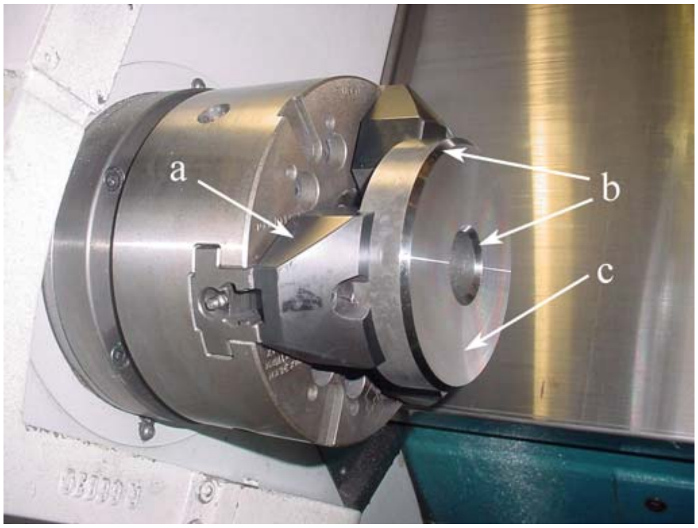

Figure 4. Initial preparations for the experiment: (a) quenched and tempered jaws with larger contact area; (b) workpiece chamfers and (c) face clean up

3. RESULTS AND DISCUSSIONS

Figure 5 shows the results of tool life using two types of tools (PCBN and ceramic with whiskers) in turning hardened steel with three different types of surfaces (continuous, with 4 and 8 grooves).

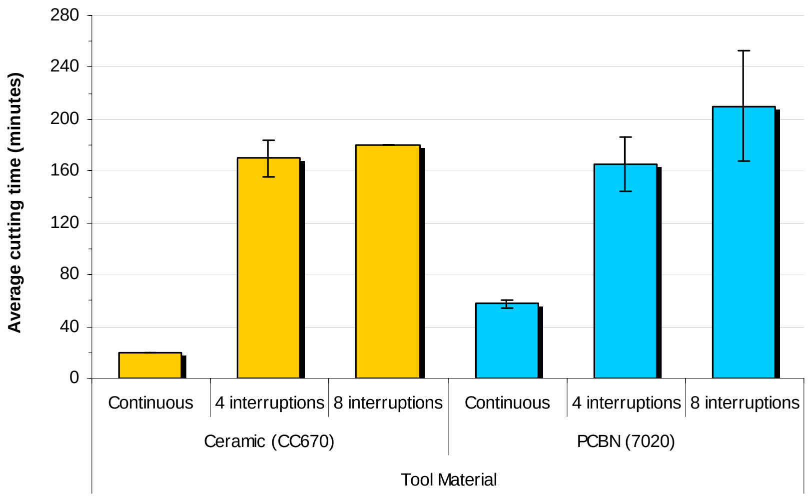

Figure 5. Tool life for each cutting condition

In the continuous cutting condition, the average tool life of the PCBN tool (60 minutes) was 3 times greater than ceramic tool life average (20 minutes). In this case, differently from interrupted cutting, the tool is all the time in contact with the workpiece surface, causing elevated temperatures in the cutting region. According to Trent and Wright (2000), for temperatures up to 700°C, the PCBN tools shows higher hardness than the Al_2O_3 based ceramic tool. The results show that this PCBN property has significance on the tool life.

The tool life, independently of the interruption numbers (between 4 and 8 grooves) and tool material, was greater in the interrupted cutting condition, when compared to the continuous cutting condition. The workpiece with interruptions not only reduce the tool contact time with the workpiece surface, but also produce a cooling effect due to the air flux produced by the rotation of the grooved workpiece. So, the tool temperature is smaller when compared to the tool used in the continuous cutting. With this, the tool hardness is higher when compared to the continuous cutting, causing better strength to the abrasion wear.

Moreover, in the interrupted cutting, there is not a significant difference on tool life using the both tool materials. With the reduction in the cutting area, due to the air flux, the reduction of ceramic material strength is less accentuated and it causes a higher tool life for this material when compared to continuous cutting.

However, the best tool choice does not depend on the useful cutting time. This choice must also lead in consideration the roughness values of the machined surface. The results related to the roughness (R_a e R_y) will be discussed afterwards.

3.1. Tool Wear

The main types of wear verified in the cutting edges were the flank and crater wear. The first type of wear occurs because of the abrasion mechanism in the workpiece-tool interface. The second type of wear occurs mainly because of the diffusion mechanism in the tool-chip interface, which facilitates the chemical exchange between tool and chip materials. The Fig. 6, 7 and 8 shows the VB_B wear curves for the first sample of the experiments. The behavior of the tool wear curves is similar in others replications.

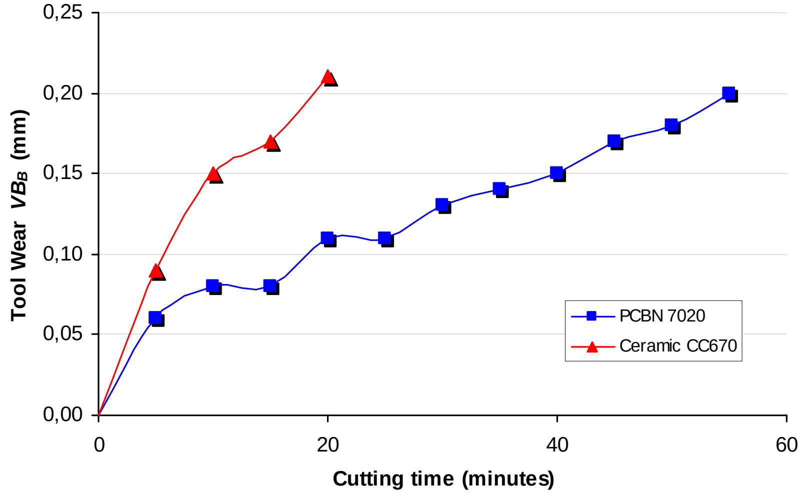

Figure 6. Tools flank wears VB_B versus cutting time for continuous cutting condition

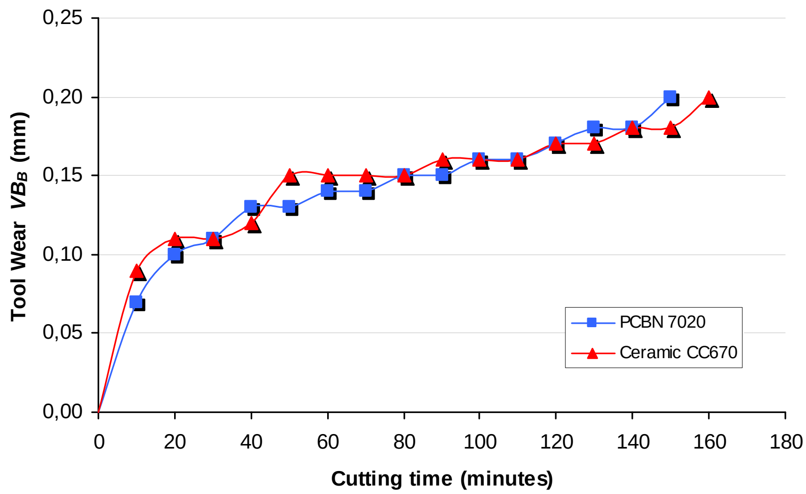

Figure 7. Tools flank wears VB_B versus cutting time for 4 interruptions cutting condition

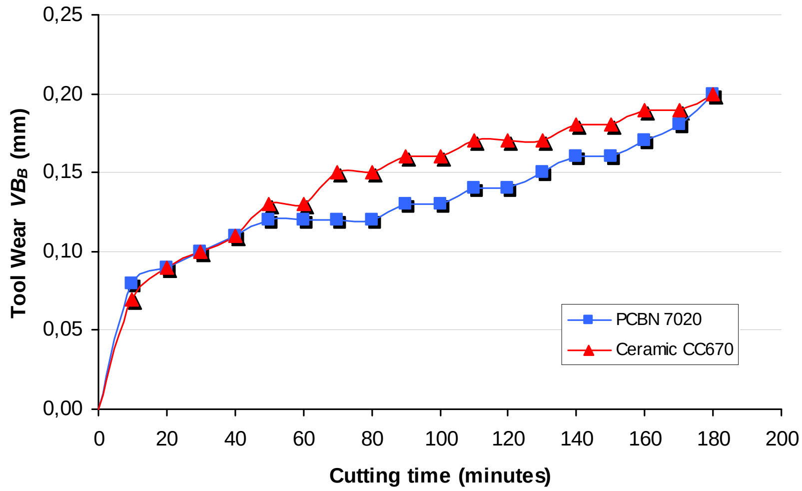

Figure 8. Tools flank wears VB_B versus cutting time for 8 interruptions cutting condition

According to the figures, the grown up of the flank wear in all cases, occur gradually and without abrupt variation. This shows the lack of chipping in the cutting edges and also shows that cutting parameters were chosen adequately, independently of the tool type and workpiece geometry used.

The analysis of the curves for the continuous cutting (Fig. 6), reveal that the PCBN tool wear rate is smaller than ceramic tool. As it was describe before, this mainly depends on the high temperature in the cutting region.

In the interrupted cutting (with 4 and 8 interruptions), showed in the Fig. 7 and 8, the wear rates of each tool are the same and smaller than the continuous cutting. Consequently, the end of tool life ($VB_B = 0.20$ mm) for both tools and for both cutting interruptions was obtained practically at the same cutting time ($\cong 160$ min).

In the continuous cutting, the mainly wear mechanisms identified in the cutting edges were the abrasion and diffusion. However, in the interrupted cutting, the cutting edges analysis show that only the abrasion works as a wear mechanism, independently of the number of interruptions. The lack of microchipping is the result of proper tool toughness for the operation and the high stiffness of the workpiece and tool fixation systems.

According to Diniz and Oliveira (2007), the tool cutting edge microgeometry has a strong influence in the tool wear rate for all cutting situations (continuous, semi-interrupted and with 4 interruptions). The use of tools with chamfer in cutting edge causes a small upsetting level to chips formations (when comparing chamfered and edge rounding tools) which causes lower tensions and temperatures levels in the tool, making a longer tool life possible for this tool cutting edge microgeometry.

3.2. Roughness

The substitution of grinding by the hard turning operations produces in the manufacturing process some advantages as described before, but three requirements must be analyzed with more attention: dimensional tolerances, form errors and roughness (Trent, 1991).

The dimensional tolerance and the form errors, depend on factors linked to the machine tool stiffness and fixation device stiffness, on the part geometry and on the process temperature. As the steel hard turning is generally done without cutting fluid, part thermal expansion must not be discarded. For this, small depth of cut is used to minimize the thermal loads. The roughness also depends on machine tool stiffness and of the fixation device stiffness, but is directly influenced by the feed rate and by the tool nose radius. Usually, small feed rates combined with a large tool nose radius are used to result in roughness values compatible with the grinding operations (Weck *et al*., 1995; Klocke and Eisennblätter, 1997).

The Fig. 9, 10 and 11 show the average roughness values (R_a), obtained in the first sample of the experiments, for the three cutting situations.

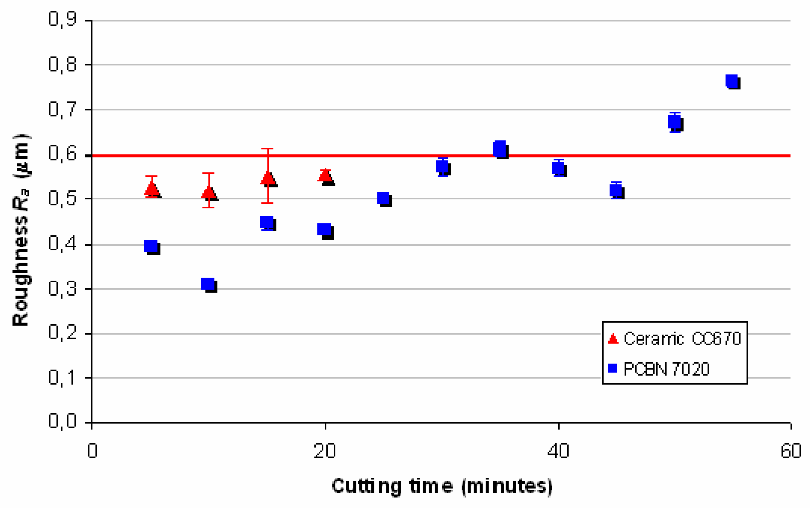

Figure 9. Surface roughness (R_a) versus cutting time for continuous cutting condition

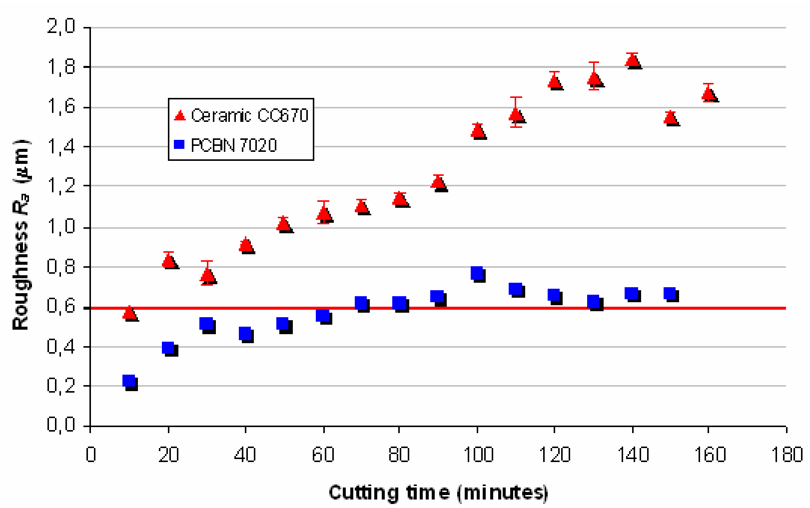

Figure 10. Surface roughness (R_a) versus cutting time for 4 interruptions cutting condition

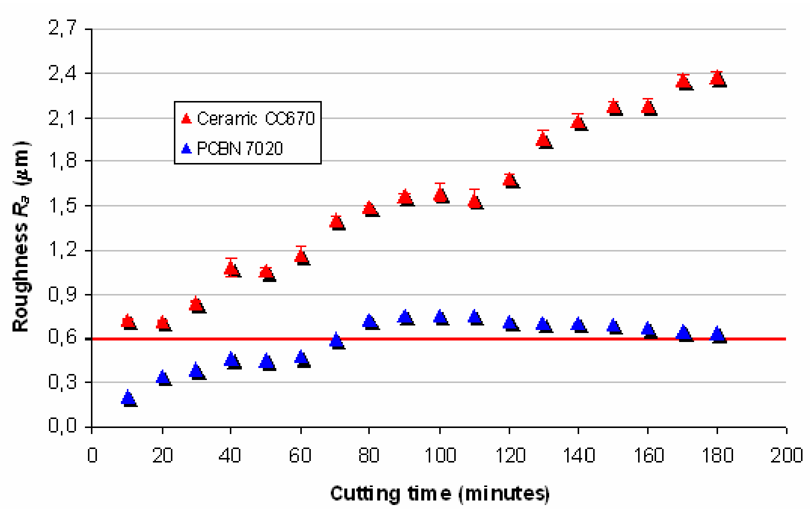

Figure 11. Surface roughness (R_a) versus cutting time for 8 interruptions cutting condition

Analyzing the roughness values for the continuous cutting condition (Fig. 9), it can be observed that both tools proportioned average roughness values typical of a surface produced by the grinding process, that is, approximately values of R_a = 0.6 µm (Klocke, Brinksmeier and Weinert, 2005). The R_a values obtained with ceramic tool to 0.6 µm up to 20 minutes of cutting time, when the tool reached the end of life criteria. PCBN tool had a tool life 3 times greater than ceramic tool, but only obtained roughness values lower than R_a = 0.6 µm up to 30 minutes of cutting time.

Figures 10 and 11 show the roughness curves for the 4 and 8 interrupted cutting conditions, respectively. It can been verify that in the majority of these cutting situations, the machined surfaces with ceramic tool reinforced with whiskers, showed roughness values superior to R_a = 0.6 µm. The roughness curve growth rates remained constantly stable along the time until they reached the maximum values of 1.8 and 2.4 µm for the 4 and 8 interrupted cutting conditions, respectively.

However, the PCBN tool in both cutting conditions, proportioned R_a values lower than R_a = 0.6 µm to 60 minutes of cutting time and from this time ahead, the values were practically stable, around R_a = 0.7 µm, inferior to these values obtained by the ceramic tool.

The Fig. 12, 13 and 14 show the maximum roughness values (R_y), obtained in the first sample of the experiments, for the three cutting situations.

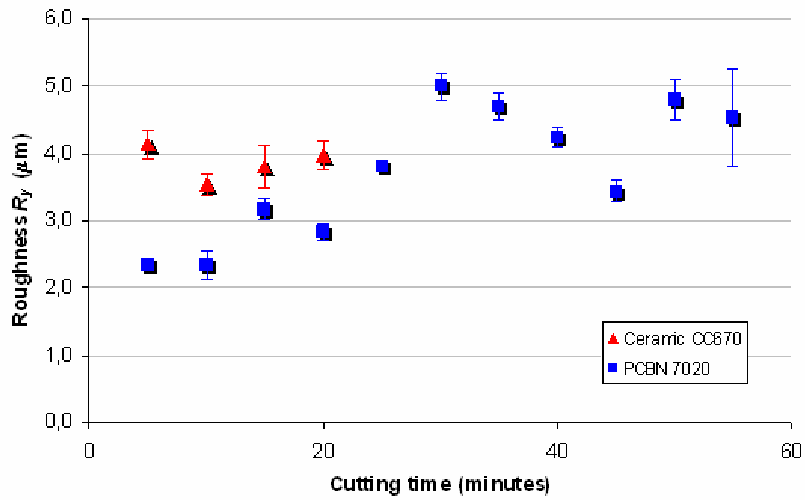

Figure 12. Surface maximum roughness (R_y) versus cutting time for continuous cutting condition

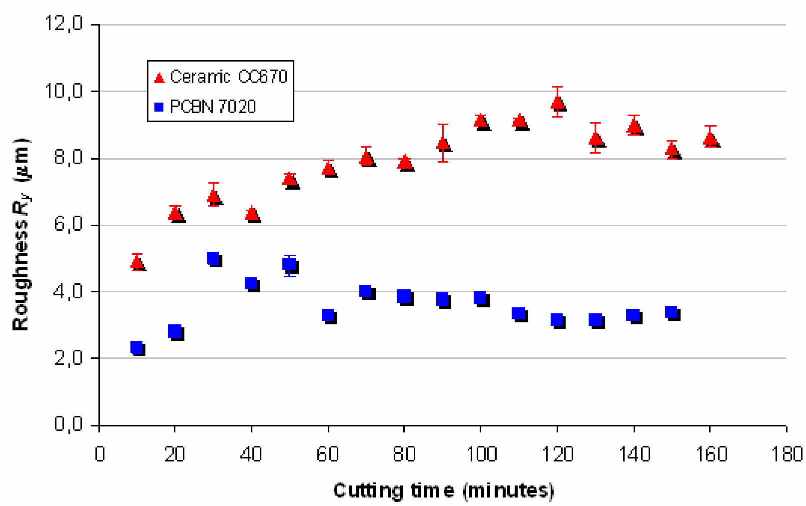

Figure 13. Surface maximum roughness (R_y) versus cutting time for 4 interruptions cutting condition

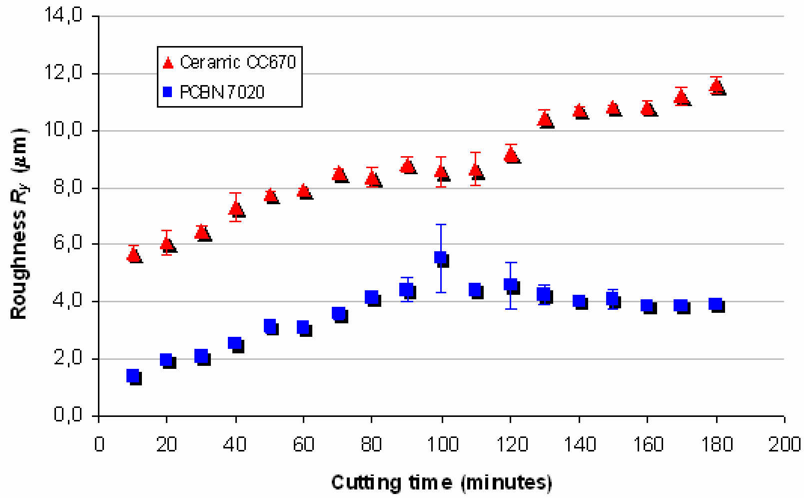

Figure 14. Surface maximum roughness (R_y) versus cutting time for 8 interruptions cutting condition

The theoretical maximum roughness value, considering the cutting parameters used, is 0.66 μm. There is a great difference between the theoretical roughness value and the experimental values obtained with the R_y values. The roughness parameter R_y considers the maximum difference between peak and valley (in cut-off length) such as the maximum theoretical roughness. The difference between these two parameters shows the difficulty to obtain real roughness values approximate to the theoretical values. This is due to influence of the wear mechanism and the process vibrations.

A hypothesis to explain the difference in the R_y roughness values using PCBN and ceramic reinforced with whiskers tools along the tool life (Fig. 12, 13 e 14) is associated to the wear characteristic of the cutting edge. According to Trent and Wright (2000), even in high temperatures the PCBN hardness stands in higher levels than the Al_2O_3 based ceramic material. Consequently, the tool nose radius modification, which has a greater influence in the roughness, occur in the Al_2O_3 based ceramic material. However, when it used PCBN tools, the modification of tool nose radius is more difficult. So, the PCBN tool is capable of maintaining roughness values inferior to the ones obtained with the Al_2O_3 based ceramic tool reinforced by whiskers.

4. CONCLUSIONS

Based on the results obtained in this work, its possible to concluded that in the radial turning of ABNT 4340 steel with hardness of $56HR_C$ in finishing operation that:

a) in continuous cutting, the PCBN tool shows greater tool life than the ceramic tool reinforced with whiskers;

b) in both interrupted cutting (with 4 and 8 grooves), the tools life using PCBN and ceramic reinforced with whiskers tools were practically the same.

c) in roughness terms, PCBN tool caused a lower values than the ceramic reinforced with whiskers tool in all cutting situations (continuous, with 4 and 8 interruptions).

5. ACKNOWLEDGEMENTS

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