COMPARING CERAMIC AND CBN TOOL IN THE TURNING OF INTERRUPTED SURFACES OF HARDENED STEEL

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Abstract. *In the machining of hardened steel surfaces, turning instead of grinding has been employed increasingly due to several advantages it offers, such as flexibility and the possibility of dry cutting. The main tool materials used for this purpose are CBN and ceramic due to their high hardness even at high temperatures and, in the case of some grades of these materials, high chemical stability with iron. However, many workpieces used in industrial environments present interruptions. When interrupted surfaces are turned, the tool requires not only these properties but also sufficient toughness to resist impacts against workpiece interruptions. Therefore, the main goal of this work is to compare CBN and ceramic tools in interrupted cutting. To this end, several turning experiments were carried out on interrupted surfaces comparing the performance of a high CBN content and a SiC-reinforced tool. The high CBN content tool does not present such high chemical stability as the low CBN content tool (CBN plus a ceramic phase added), but it is recommended for interrupted turning of hardened steel due to its higher toughness and, therefore, its good ability to withstand impacts. Also the Si-C reinforced alumina based ceramic presents lower chemical stability than the mixed and pure alumina based ceramic but its superior toughness makes it suitable to be used in the turning of interrupted and hardened surfaces. The experiments were carried out in two different cutting speeds, turning a 56 HRc quenched and tempered AISI 4340 steel. The surfaces turned in the experiments were designed in such a way that the turning tool impacted against an interruption four times in each workpiece revolution. The main conclusions of this work were that the CBN tool exhibited a much better performance with respect to both tool life and workpiece surface roughness than the ceramic tool.*

Keywords*: Hard turning; CBN tools; ceramic tools; wear; roughness* (Times New Roman, italic, size 10)

1. INTRODUCTION (Times New Roman, bold, size 10)

Hardened steel turning has been more and more used to replace grinding operations due to the development of very hard tool materials (ceramics and CBN) and very rigid machine tools, which can ensure, for the turning operation, geometrical and dimensional tolerances close to those obtained in grinding.

High hot hardness and chemical stability are the most important properties for a tool material used in turning of hardened steel. The hardened workpiece surface has an abrasive effect on the tool, and the high cutting edge temperature causes diffusion between tool and chip. Moreover, if the surface has any kind of interruption, toughness is also necessary for the tool material to prolong tool life (Wellein and Fabry, 1998).

Ceramics and CBNs are the best and most used tool materials for this type of operation, due to their high hot hardness and wear resistance. Their hardness and chemical stability make them able to withstand the high thermal and mechanical loads of such machining operations. CBN has a higher hardness than ceramic tools at both low and high temperatures. Other CBN properties such as high thermal conductivity and low thermal expansion coefficient are also important when using such tools in hardened steel turning (Abrão, 1995).

Ceramic also has good properties for use in hardened steel turning, such as hot hardness, wear resistance and excellent chemical stability. In terms of chemical stability, mixed ceramic is better than SiC whisker reinforced ceramic which is better than PCBN (Childs et al., 2000). Pure ceramic tools have found limited success in hard turning due to their poor thermal shock resistance and fracture strength. Such characteristics make them unsuitable as tool materials in hardened steel turning of interrupted surfaces (Luo et al., 1999). Microchipping and fracturing, which are common occurrences when using this tool material, are caused by hard inclusions in work material, high cutting forces, vibrations, thermal shock and improper entry or exit of the tool in the cutting operation. However, the fracture and thermal shock resistance of alumina tools can be increased by adding ZrO_2, TiC, TiN or SiC whiskers. Under these conditions, SiC whisker-reinforced tools are recommended for interrupted cutting operations.

CBN tools are usually classified in two grades: high CBN content (around 90% of CBN), called CBN-H and low CBN content (around 60% of CBN), called CBN-L, with a ceramic phase added to the material, usually titanium nitride. CBN-H tools exhibit higher toughness than tools with an added ceramic phase (CBN-L). Therefore, CBN-H tools are recommended for turning interrupted surfaces of hardened steels. Moreover, the high CBN content of these tools makes them harder than those with a lower amount of CBN. The CBN grade that has a ceramic phase added loses in hardness and toughness, but gains in chemical stability. This is important for the finish turning of continuous surfaces, in which high temperature is reached and diffusive wear must be avoided (Sandvik Coromant, 1994).

2. EXPERIMENTAL PROCEDURE

The experiments were carried out on a CNC lathe with 15kW of power in the spindle motor. The workpiece material was made of tempered and quenched AISI 4340 steel with hardness of 56 HRC. Figure 1 shows a scheme of the workpiece used in order to obtain interrupted cutting during radial turning. The tool materials used in the experiments were a high CBN content (CBN-H – 7025 grade) and a SiC whisker reinforced ceramic (CC670 grade) materials. According to the tool supplier (Sandvik Coromant, 2006), both materials are recommended for the machining of hardened steel and cast iron in finishing operations of interrupted surfaces.

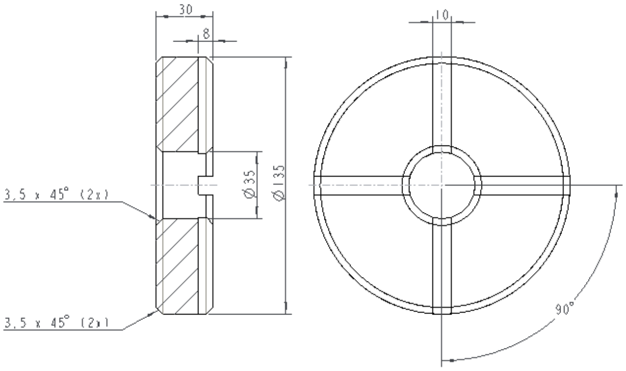


Figure 1 – Scheme of the workpiece used in the turning experiments

The ISO code of the tool holder and inserts were, respectively, DSBNR2525M12 and SNGN120412S01030A (CBN-H) and SNGN120412T01020 (SiC whisker-reinforced ceramic). The tools were geometrically identical except for the tool chamfer. The CBN tools had a 0.3 mm x 20° chamfer slightly rounded at the tip, while the ceramic tools had a 0.2 mm x 20° chamfer without rounding.

The cutting conditions used were: depth of cut $a_p = 0.15$ mm and feed f = 0.08 mm/revolution. Two cutting speeds were used: $v_c = 150$ and 195 m/min. These cutting speeds were chosen because the first one is recommended by the tool supplier for CC670 tool and the second for the CBN-H tool for turning of hardened steel.

Throughout the tool life, flank wear was inspected with an optical microscope. One experiment consisted of successive radial turning passes of one of the surfaces shown in Fig. 1 with the same cutting edge until the moment that either flank wear reached $VB_B = 0.20$mm or cutting time reached 100min, if this flank wear value had not been reached. At the end of the experiment, the worn inserts were examined under a scanning electronic microscope coupled to an EDS system.

Each experiment was carried out three times. During each experiment, ten measurements of the workpiece surface roughness were taken at different moments of tool life. Roughness was measured at three points of each surface.

3. RESULTS AND DISCUSSIONS

3.1. Tool wear

Figure 2 shows the results of flank wear against volume of material removed for all experiments. As can be seen, the CBN-H tool presented a much slower growth of flank wear when compared to the whisker-reinforced ceramic tool (CC670) at both, the speed recommended for the ceramic (150 m/min) and for the CBN-H (195 m/min) tools.

The decisive factor for this difference in the flank wear growth was the sudden chipping of the whisker-reinforced ceramic tool, as will be discussed later. In interrupted cutting, the tool's fracture strength, which is lower in the ceramic tools, is more important than its chemical stability and thermal conductivity, since the working temperature is lower than in continuous cutting. The fracture toughness of the high CBN content material is 10 MPa.$m^{1/2}$, while this value for the whisker reinforced ceramic is 8 MPa.$m^{1/2}$ (Abrão, 1995).

Figure 3 shows SEM images of the edges used in the interrupted cutting experiments. As mentioned previously, the whisker-reinforced ceramic tool showed edge chipping in all the experiments. In addition to chipping, abrasive scratches were visible on the worn lands used.

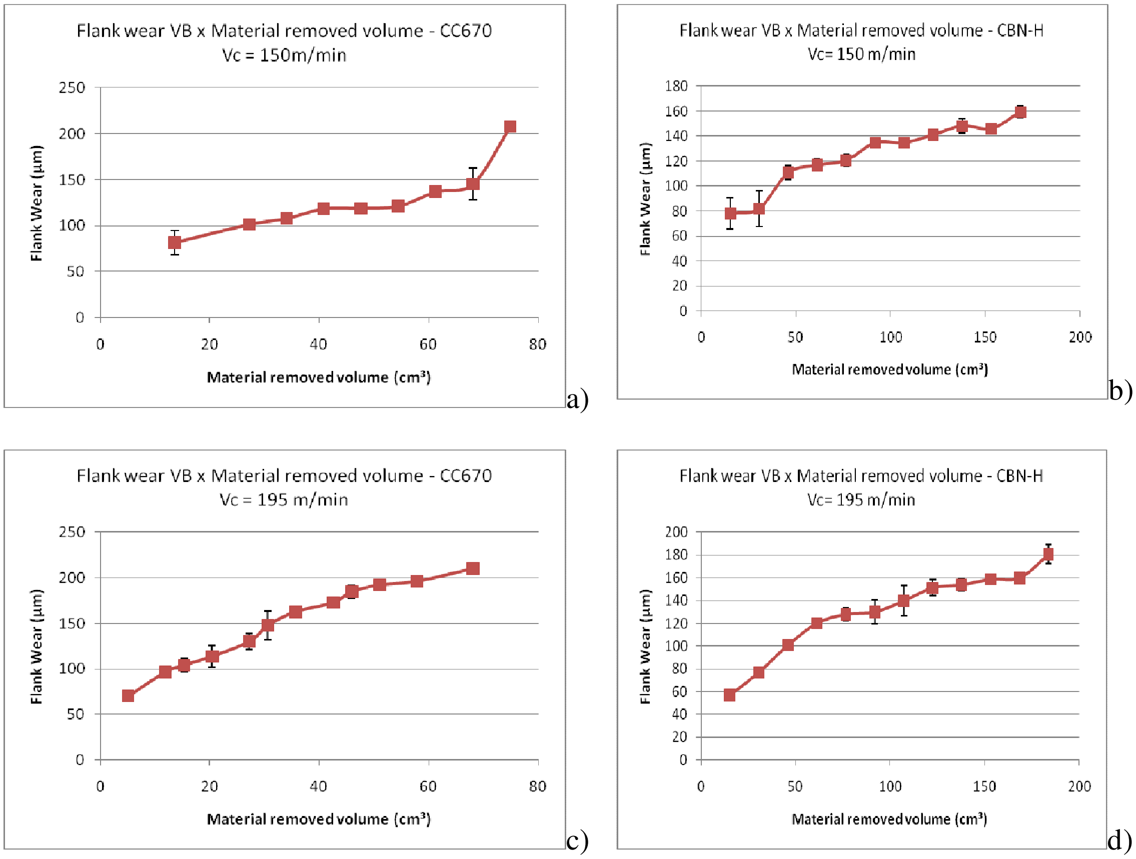


Figure 2 – Flank wear against material removed volume for all experiments

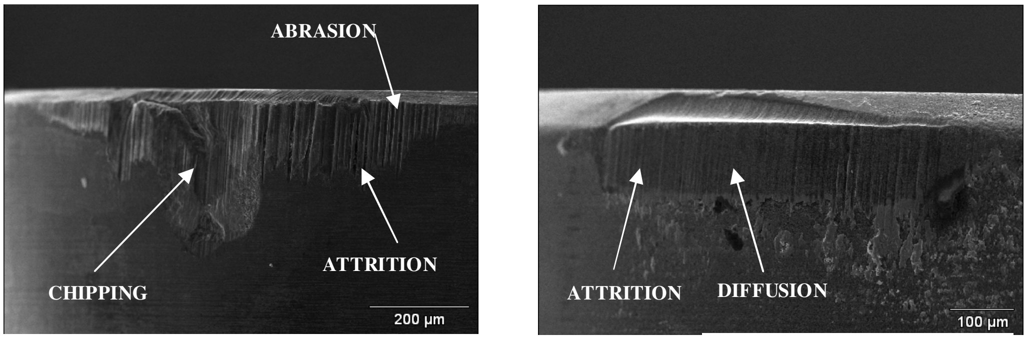
At v_c = 195 m/min, traces of Fe from the workpiece were not found outside the chipped region in the EDS analysis of the CC670 tool (see Fig. 4b). This indicates that attrition did not occur and was therefore not the cause of chipping. Figures 3a and 3c also indicate that the source of chipping was not thermal, in view of the absence of cracks which are typical in this type of failure. As this occurred in the region of the tool which faced the largest chip thickness (h – all the cutting occurred in the round part of the edge, inside the nose radius, and, so, chip thickness was the largest in the external point of the edge-workpiece contact), the reason for chipping was the mechanical shocks against the workpiece interruptions.

Abrasion may be caused either directly by friction with hard particles from the workpiece or by removal of binder caused by workpiece friction with the tool, and consequently, pullout of hard particles from the tool. These particles rub against the tool, causing wear. The first hypothesis is more likely, since the tool temperature was low due to the interruptions, preventing the binder from losing resistance and releasing hard particles from the tool.

At the lowest speed, Fe was found inside the abrasive scratches of the ceramic tool (Fig. 4d). Therefore, this abrasion was caused by attrition (cyclical adhesion and removal of workpiece/chip material from the tool). The tool particles removed by attrition rubbed against the tool as they were dragged by the movement between workpiece and tool, unlike what occurred at higher cutting speeds. Trent & Wright (2000) state that attrition occurs more easily at moderate cutting speeds. The cause of chipping was the same as the previous one (mechanical), but was less intense due to lower impact energy (lower cutting speed).

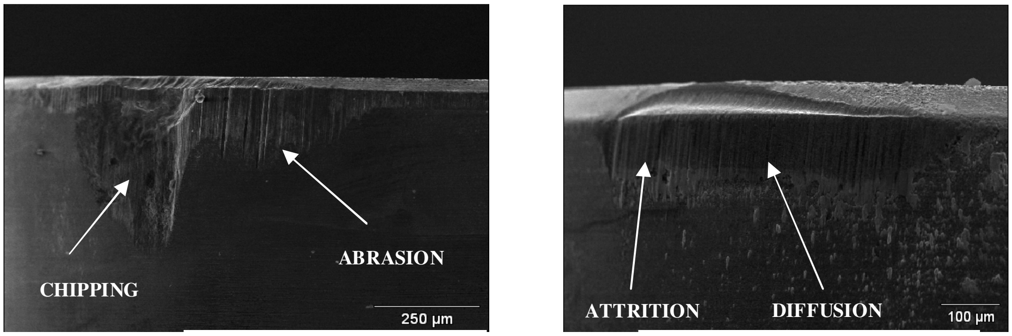
For the CBN-H tools, the smooth aspect on the tool rake face suggests diffusive crater wear at both cutting speeds, since CBN does not have the same high chemical stability as that of the whisker-reinforced ceramic tool. The ceramic tool presented shallower crater wear than the CBN tool (visual inspection). On the CBN-H flank face, iron was found in the lower periphery of the wear land at both cutting speeds (see Figures 4f and 4h), suggesting that attrition with pulled out particles was the main wear mechanism. When removed from the tool, these particles probably caused abrasion (abrasive scratches shown in figures 3e and 3g) mainly in the region where chip thickness was small and the cutting pressure was higher. This attrition may have been favored by the presumably low cohesion between CBN and the binder material. The smooth aspect in the region where the chip thickness was larger (low cutting pressure) suggests that diffusion was the main wear mechanism in this region.

It is important to point out that no chipping occurred on the CBN-H cutting edge, even after 100 min of cutting (a lot of impacts against the surface interruptions), proving that its toughness is sufficient to a tool designed to be used in this kind of cut.



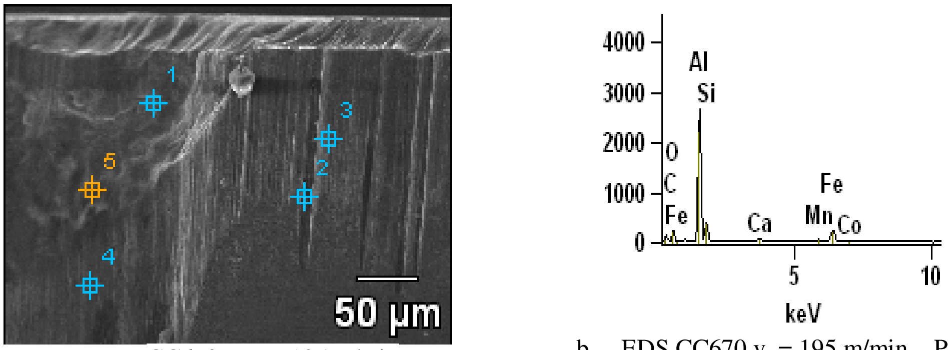
b. CBN-H – v_c = 150 m/min

a. CC670 – v_c = 150 m/min



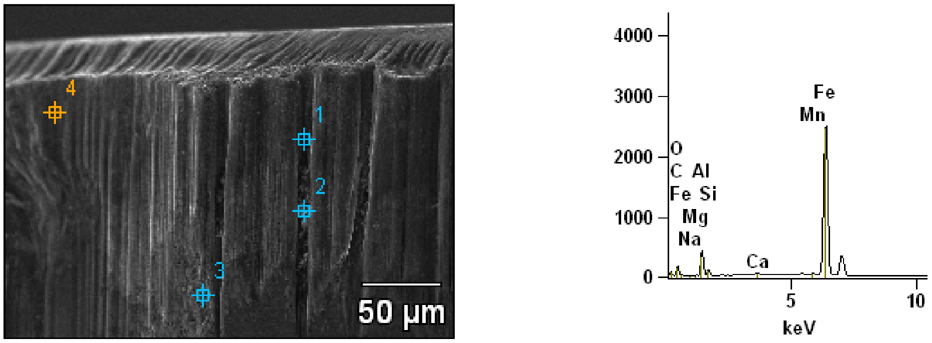
c. CC670 – v_c = 195 m/min d. CBN-H – v_c = 195 m/min

Figure 3 – SEM images of the cutting edges used in interrupted cutting



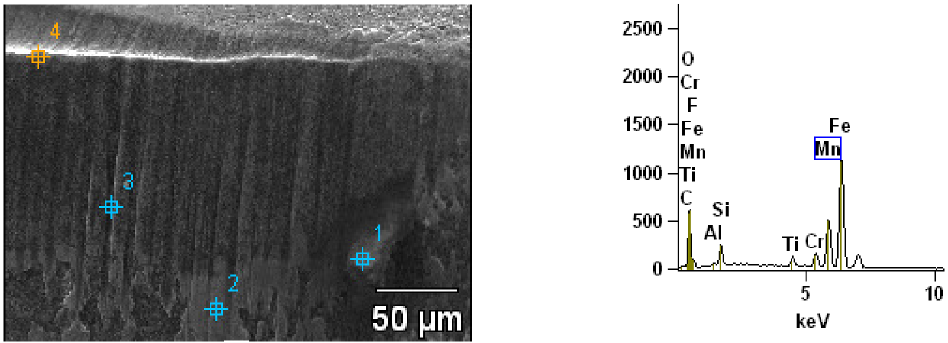
a. CC670 – v_c = 195 m/min

b. EDS CC670 v_c = 195 m/min – Point 2



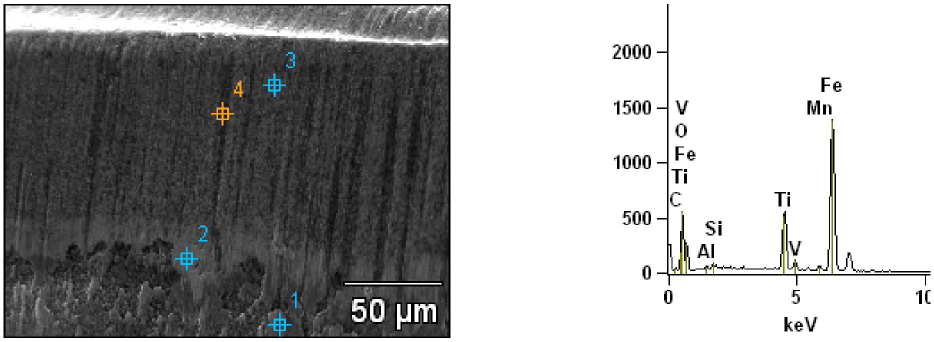
c. CC670 – v_c = 150 m/min

d. EDS CC670 v_c = 150 m/min – Point 2



e. CBN-H – v_c = 150 m/min

f. EDS CBN-H v_c = 150 m/min – Point 2



g. CBN-H – v_c = 195 m/min

h. EDS CBN-H v_c = 195 m/min – Point 2

Figure 4 – EDS of whisker-reinforced ceramic tool (CC670) and CBN-H tool

3.2. Workpiece Surface Roughness

Figure 5 shows workpiece roughness in the interrupted cutting experiments. This figure indicates that workpiece roughness remained virtually constant during the life of the CBN tool, regardless of cutting speed, with values of 0.4 µm at the lowest speed and 0.6 µm at the highest speed, while the roughness obtained with the ceramic tool increased rapidly, exceeding 2.00 µm at 150 m/min. The same kind of roughness behavior was obtained by Diniz at al. (2009) in the interrupted hardened steel turning using whisker reinforced ceramic.

These values can be related to the shape of the worn tool nose (Fig. 6). The increase in abrasive scratches caused a significant change in the ceramic tool nose shape (Fig. 6a), thus contributing to the increase in roughness values along the tool's life. However, the chipping that occurred at the ceramic tool's cutting edges did not contribute to the increase in roughness, as indicated by a comparison of Figs. 2a and 5. Chipping (which occurred when 70 cm^3 of chip material had been removed at v_c = 150 m/min) did not lead to a sudden increase in roughness values because it occurred on the main cutting edge, while it is the secondary cutting edge that is responsible for workpiece roughness. In the other hand, the CBN-H tool maintained a uniform nose shape (Fig. 6b) and, consequently, was able to keep the surface roughness values fairly stable. These results indicate that turning with the CBN-H tool can replace grinding operations on such surfaces because the Ra values obtained with this tool were always lower than 0.8 µm and mixed ceramic tools are not suitable to replace grinding in such operations.

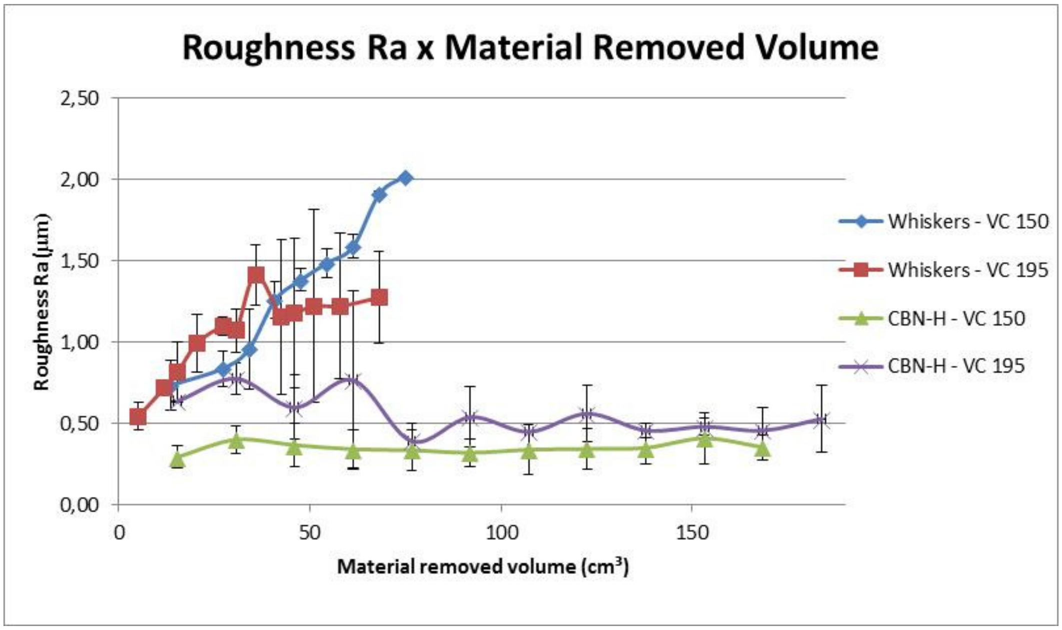
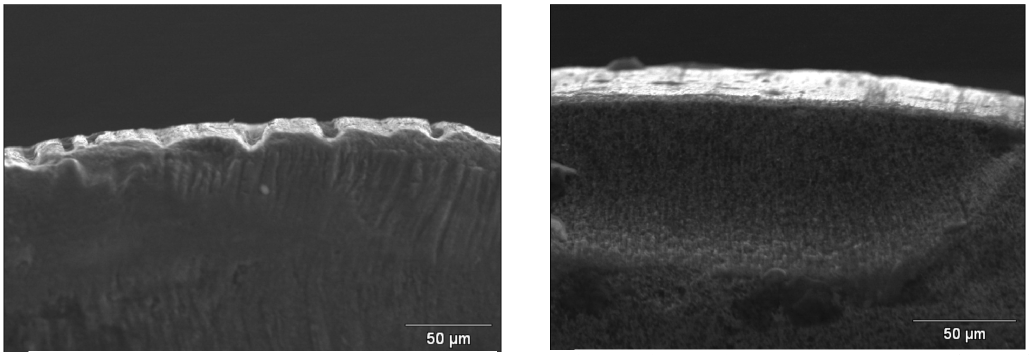


Figure 5 – Roughness Ra versus removed material volume in interrupted cutting



a - Tool nose shape CC670 – Vc = 150 m/min
b - Tool nose shape CBN-H – Vc = 150 m/min

Figure 6 – CBN-H and CC670 tool nose shape in interrupted cutting

4. CONCLUSIONS

Based on the results of this work in the radial turning of interrupted surfaces made of AISI 4340 steel with 56 HRC with high CBN content and and with SiC whisker-reinforced ceramic tools, and in conditions similar to those used in this work, it can be concluded that:

- the CBN tool flank wear growth was much lower than the ceramic wear rate at all cutting speeds used;
- the main wear mechanism of the ceramic tool was abrasion at high cutting speeds. At low cutting speeds, abrasion was stimulated by attrition. In both cases, sudden chipping of the cutting edge occurred in response to mechanical shocks;
- The wear mechanisms of the CBN tool were diffusion and attrition. Chipping of the edge did not occur on the CBN tool, proving that it is a suitable tool to be used in interrupted cutting;
- The workpiece roughness values obtained with the ceramic tools during their lives were considered high for an operation intended to replace grinding, because the type of wear these tools underwent caused considerable variations in the tool nose shape;
- The wear of the CBN tool did not cause major variations in the shape of the nose, mainly in its secondary cutting edge, enabling the roughness values to remain consistently low throughout the tool's life.

5. ACKNOWLEDGEMENTS

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