Proceedings of COBEM 2009 20th International Congress of Mechanical Engineering
 November 15-20, 2009, Gramado, RS, Brazil

Performance of Different Coatings on High Speed Steel Broaches

Sergio Henrique Andrade, andrasrg@schaeffler.com
Anselmo Eduardo Diniz, anselmo@fem.unicamp.br
Department of Fabrication Engineering
The State University of Campinas (UNICAMP)
Rua Mendeleieve, s/n
Cidade Universitário "Zeferino Vaz" Barão Geraldo
13083-970 Campinas, SP, Brasil

Abstract. *High speed steel is a material with high wear resistance and high hot hardness, with a large application to make tools with complex shapes and dimensions. The present work evaluated the application of coatings of wear resistance materials on high speed steel broach in broaching of profile. The workpiece material was a clutch component denominated hub, made of DIN C45 steel. Different tests were carried out varying the coatings, TiN, TiCN and AlCrN and the tool substrate - the conventional high speed steel M2 and the powder metallurgy high speed steel. Tool wear, tool life, pressure in the broaching machine hydraulic system and the profile dimension were measured. The analysis of the results allowed us to conclude that the broaches with coating led to a longer tool life than the uncoated condition. The same happened when the broach was resharpened and didn't receive a new coating and, so, worked uncoated in the rake face. Among the coatings, the TiCN and AlCrN have shown the best performances. Although TiCN presented a little longer tool life than AlCrN, it wasn't possible to affirm statistically that there is a difference between them. The use of a coating, in the opposite of what has been expected, it caused the increase of pressure in the broaching machining hydraulic system for the three kinds of coatings. There was not a large difference of tool's life when comparing the conventional high speed steel and the powder metallurgy high speed steel substrate. We've come to the conclusion that the profile dimension doesn't suffer much variation during tool life.*
Key Words: *broaching, PVD coating, powder metallurgy high speed steel.*

1. Introduction

Broaching is an important production process and produces parts at a high rate. Broaching produces external and internal surfaces such as holes of different shapes like squares, irregular shapes, keyways and teeth of internal gears. One of the advantages of the broaching process is the ability to remove heavy amounts of stock and to carry out rough and finishing operation in just one pass with a short time process (Motter 2006). The process is stable and it's able to produce parts with high quality. Broached surfaces can reach surface quality within Ry 8 to 10 μm (Hori 2005). The tool has many teeth when you compare with mills, each tooth remove a little volume of material. Therefore a broach can produce a high number of parts before resharpening (HSS Forum, 2005) .

The broach is the most important item in broaching process. In this process it is not possible to modify cutting conditions, except cutting speed, during the process. Once the tool is manufactured, all parameters are built into the broaching tool.

Broaching competes favorably with other process such as boring, milling, shaping and reaming. Although broaches tend to be expensive, the cost is justified, because of their use for high production runs (Schneider, 2001).

Broaching process pass through an evolution, support to new machines and materials. New developments of powder HSS provide high productive and improvement of tool life. The use of coatings has further increased tool life and also made possible the increase of productivity with the use of higher cutting speed.

The main goal of this work is to evaluate the performance of broaches for machining DIN C45 steel with 2 kinds of substrate, powder HSS an M2, and 3 types of coating, TiN, TiCN and AlCrN.

2. Experimental Methods

For these experiments, the clutch disc component known as a clutch hub was used as workpiece. The clutch hub is manufactured with DIN C45 steel at 23 – 28 HRC hardness. Figure 1 shows the dimensions of the internal profile, used in the clutch hub.

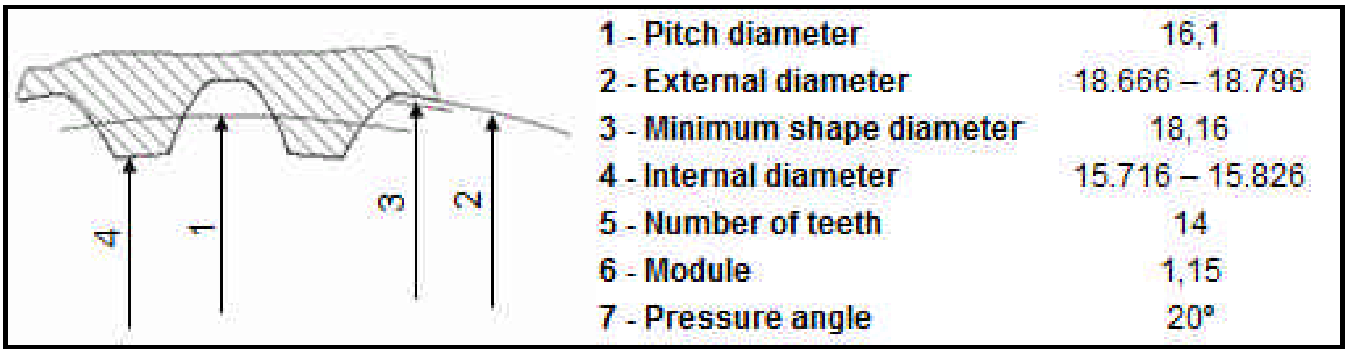


Figure 1: Internal profile construction dimensions

The tests were carried out with special broaches, which were manufactured according to a pre-defined profile. Broach length was 950 mm, with 617.5 mm used by the cutting teeth, that are formed by 77 rings. Figure 2 details some the dimensions of the broach's teeth.

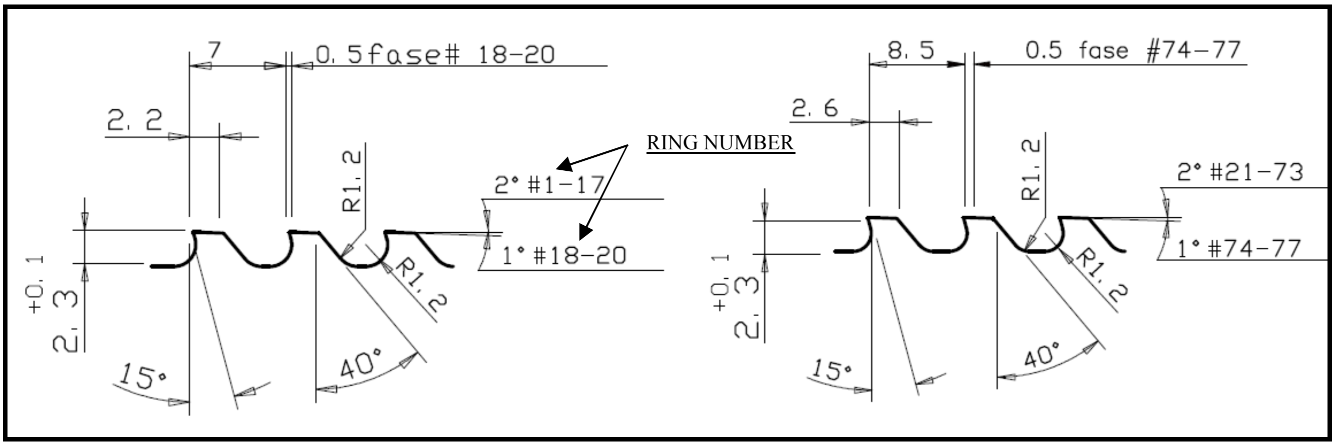


Figure 2: Details of the dimensions of the broach teeth.

The measurements of maximum flank wear on the clearance face of the broaches (V_{BMax}) and the figure of the wear were obtained with a three-dimensional optical machine with magnifying capacity of 202 times. At first, the wear was measured by the machine with a graduated loupe magnified to 8 times and a 0.01mm graduation scale. Once the end-of-tool-life criterion was reached, the broach was taken to the three-dimensional optical for final measurement.

The following procedures were followed during the tests:

- Broaching was conducted with external refrigeration by synthetic oil emulsion at 9 – 11% concentration.
- Cutting speed 8m/min.
- Six different broaches were used. Two broaches were manufactured with ASP® 2030 powder high-speed steel, one with TiCN coating and the other uncoated and four broaches were manufactured with M2 high-speed steel. One of the broaches was uncoated, and the three other had three different coatings applied: TiN, TiCN and AlCrN. The broaches had their rake face resharpened at the end of each test, and coated broaches were resharpened and re-coated. At each test replica, each broach always received the same type of coating.
- During the third tool life test of the M2 high-speed steel broach with TiCN coating, was measured the internal profile of the part. One out of every 1,000 broached parts was separated for the measurement of all the clearances of the profile.
- A test was regarded as concluded when 20% of the broach's rings, 11 teeth – which were responsible for the machining of the profile of the part – had at least one tooth showing a 0.15mm or above V_B wear.

3. Results

In Fig. 3, the dots represent the values obtained for each test, and the columns represent the average of values. Analyzing the results obtained for uncoated broaches, one can notice that the difference between the averages is rather low, below 3%. Therefore, it is not possible to assure that the sintered high-speed steel broach outperforms the M2 high-speed steel broach regarding the quantity of the broached parts.

The coated broaches significantly outperformed the uncoated broaches. Even the broach that received the TiN coating – which showed the poorest performance amongst the coated broaches – had an average result of 68% higher when compared with the M2 broaches, and 63% higher than the sintered broach, which were both uncoated. When this comparison is made between tools with AlCrN and TiCN coating, rather than TiN coating, the difference increases largely (to 130% and 123% for broaches with A1CrN, and 149% and 142% for broaches with TiCN coating). This is a result of the increased surface hardness of the tools provided by the use of these coatings.

The resharpened coated broaches (and so, uncoated on the rake face, which allowed the chippings to have direct contact with the broach substrate)— demonstrated a shorter tool life compared with the full coated tools, for all types of coatings. On average, the broach tool life decreased by 25%. However, when we compare with the broaches which did not receive coatings, the resharpened broaches which maintained their coating on the clearance face, showed an increase in the number of broached parts per tool life of approximately 30% for TiN broaches, 68% for A1CrN and 86% for TiCN broaches. The test showed that the coating improves the performance of a broach, not only during the first tool life when it has its surface fully coated, but also when the broach is re-sharpened and not recoated. A good reason for the outstanding performance of broaches uncoated on rake face, as shown later, is the absence of crater wear which could cause the embrittlement of the cutting edge, causing further wear, since the coating still remains on the clearance surface – the area of friction with the part during broaching.

The powder steel substrate broach with TiCN coating showed a poorer performance than the M2 high-speed steel substrate broach, when average values are compared. However, through a hypothesis test, it is not possible to confirm statistically that there is a difference between the two types of substrate. A possible explanation for the poorer performance of the sintered high-speed steel, it might be that machining occurs at low cutting speed (8m/min) generating temperatures below sintered steel temperature resistance limits, thus matching the M2 high-speed steel, under equaled conditions.

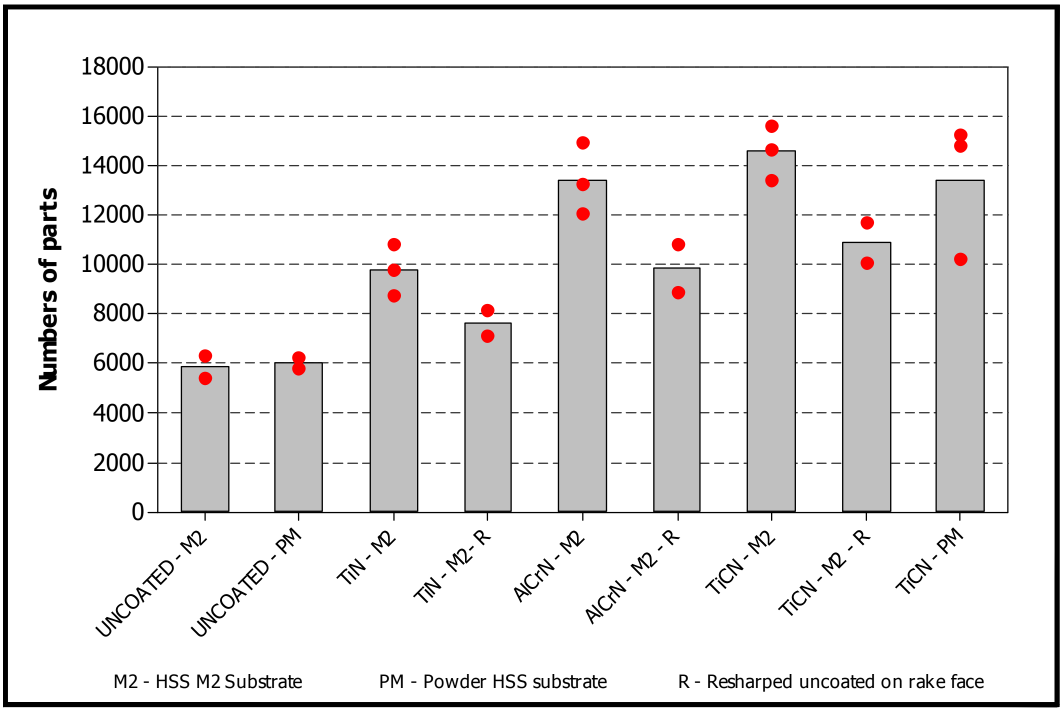


Figure 3: Coated and uncoated broches

3.1 Dimension of the internal profile

Trying to verify the behavior of the dimension of the internal profile during the life of the broaches, the internal profile has been measured during the third tool life test of TiCN coated, with M2 high-speed steel broaches. The specification of values between balls of the internal profile must range between 14.381 and 14.442mm. Figure 4 shows the values found in measurements throughout the test.

The measurement between balls is equivalent to the distance between two clearances of the internal profile which are positioned at a 180º angled distance. As the internal profile of the part contains 14 clearances, each measuring generated seven values for each part. Figure 4 shows the dimensional variation of the internal profile for each pair of clearances and in distinct parts during the life of the broach. The variation found in values of the internal profile in the same part is caused mainly by the dimensional variation of the broach. This dimension did not show significant variations during the tool life. The same occurred when the dimensional variation between parts was analyzed, which remained small. The likely reason for such small variations is the slight diameter reduction of the broach when the clearance surface wear reaches the end of the tool life criterion. A 0.15mm wear on the clearance surface of the broach causes a reduction of the broach tooth of only 0.005mm, consequently 0.01mm of the broach diameter.

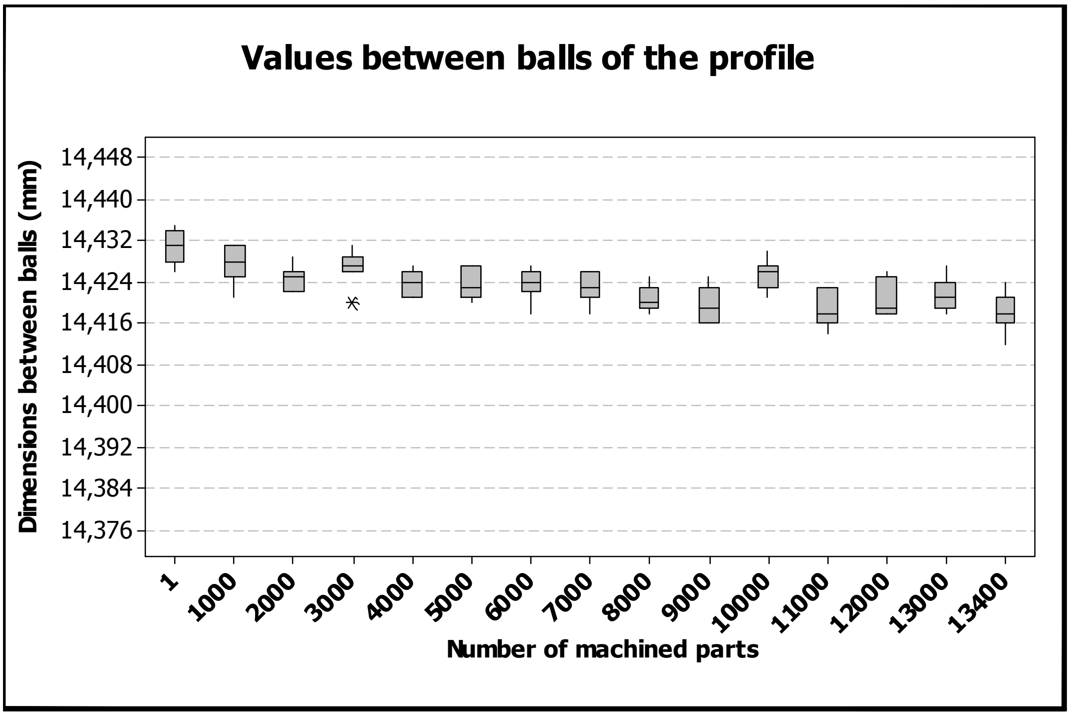


Figure 4: Values between balls of the profile

Another possible explanation is that during broaching each tooth machines at the height related to each tooth's course, without altering the height machined by the prior tooth. According to the scheme shown in Fig. 5, while a part is machined, broach tooth 2 does not remove material from the area previously machined by tooth 1, and tooth 3 behaves likewise

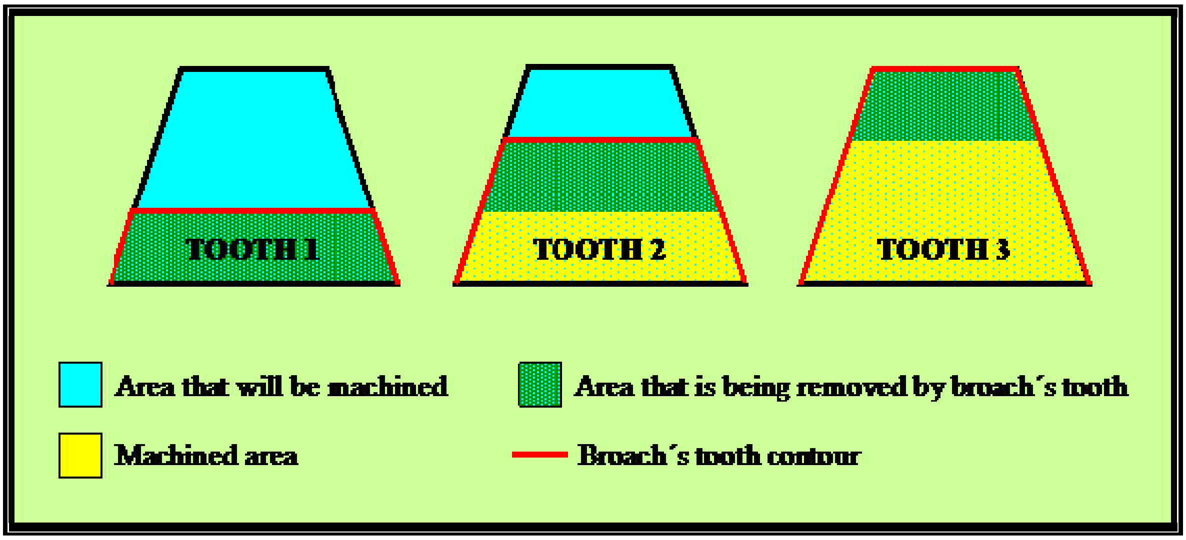


Figure 5: Machining of the teeth

As the cutting edge and, subsequently, the corner of the tooth wear, the width of the area machined in this region is reduced. Due to the wear, the area of the broach's tooth – which earlier simply drove past the clearance that had been previously machined by the prior tooth without removing further material – now it starts to remove material from the part's clearance which had not yet been removed by the prior tooth. This will continue to happen to the other teeth of the broach, contributing to a small dimensional variation of the profile. Figure 6 shows what happens in machining, in the presence of wear.

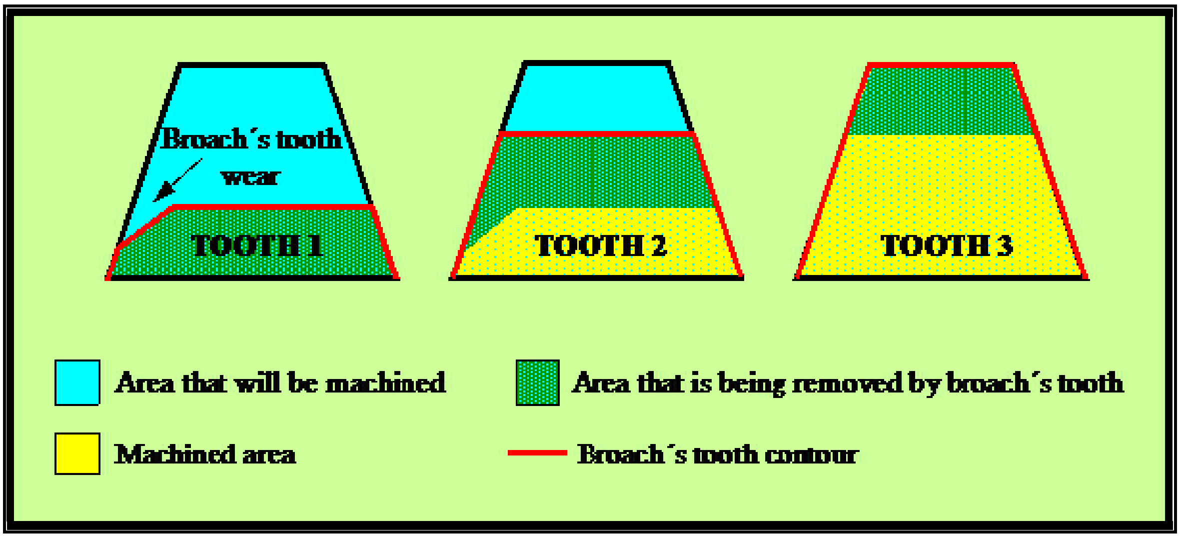
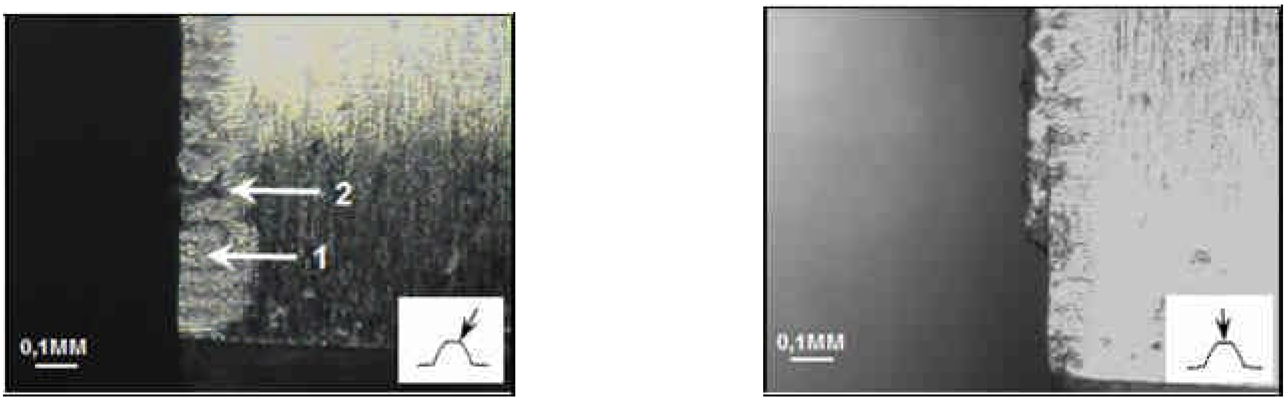


Figure 6: Machining of teeth with wear.

While machining the part, in order to stop the broach's tooth from suffering friction of its side edge against the area of the part that has already been machined by the previous tooth, there is a tooth width reduction of 0.036mm from the first to the last tooth that machines the internal profile.

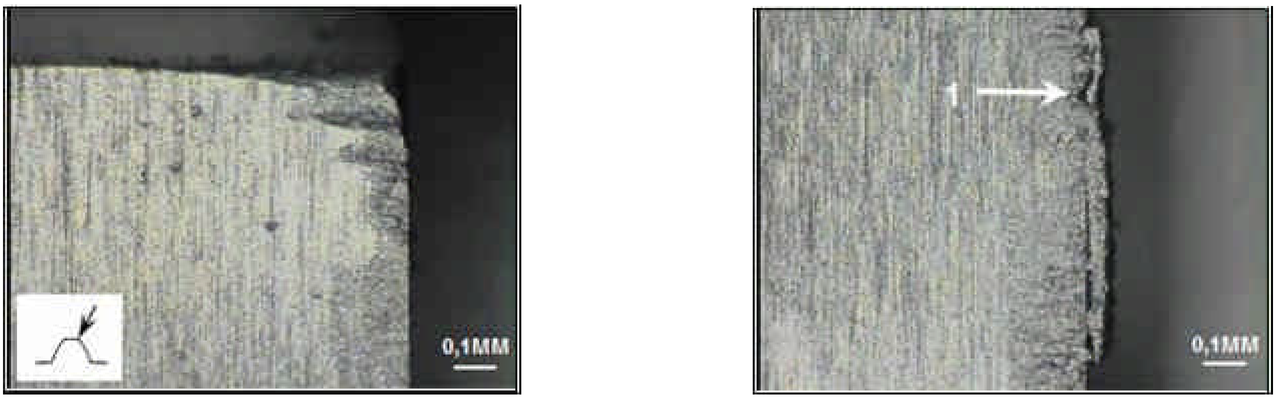
3.2 Tool wear

Figure 7a, magnified to 202 times, shows the most severely worn region of the cutting edge of a tooth of a M2 high-speed steel broach. The same figure shows point 1 identifying abrasive wear, generated by the contact of the clearance surface of the tool with the part. Point 2 identifies that material has been removed from the tool, most likely caused by adhesive wear. Figure 8a shows severe abrasive wear on the broach's tooth corner, at the intersection of the lateral surface and the top of the tooth. This is mainly due to the embrittlement of this area, given that these two surfaces meet at a sharp corner. When measuring the wear, it has become evident that the area of the corner of the tooth is the most severely affected. In Fig. 7b and 8b, a build up cutting edge appears and point 1 of Fig. 8b shows the removal of material from the cutting edge, most likely caused by the breaking of the build up cutting edge during broaching.



a) b)

Figure 7: M2 high-speed steel broaches.



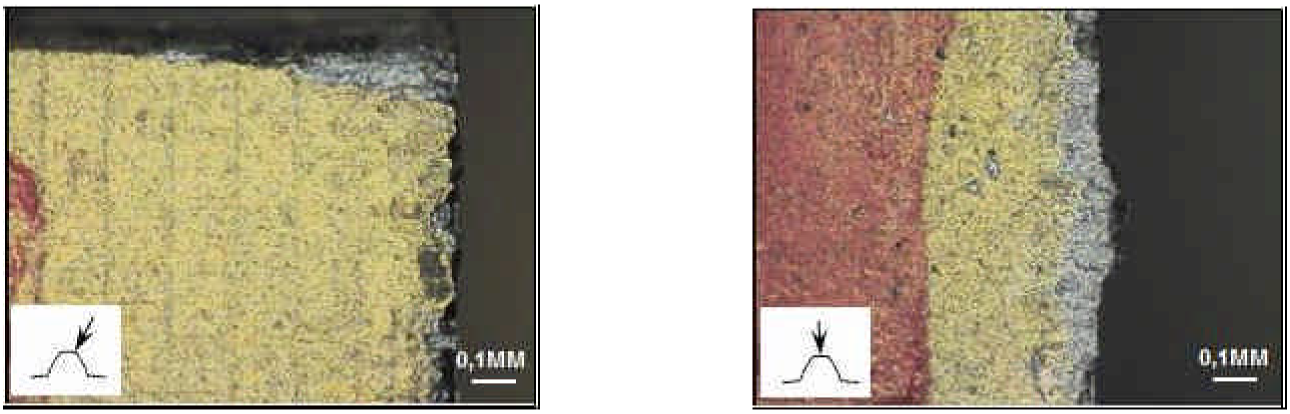
a) b)

Figure 8: Sintered high-speed steel broaches.

The types of wear found after experiments with M2 high-speed steel broaches coated with TiN, A1CrN and TiCN were nearly the same as those found in experiments with uncoated broaches. Figures 9a and 9b show the presence of part material adhered to the cutting edge. Points 1 and 2 of Fig. 9a show the removal of material from the tool, most likely caused by adherence wear processes. Figure 10b and 11b again show that there have been part material adherence to the tool, with the appearance of a build up cutting edge in 10b, and a severe wear on the corner of the broach's tooth in 11b. The same might have occurred to the tooth shown in Fig. 10a, where drawn out material from the cutting edge can be seen in various points, as well as a severe wear on the corner of the broach's tooth. In Fig. 11a, we can notice the occurrence of abrasive wear, and because the wear did not remove all the TiCN coating from the broach's tooth, we cannot see part material adhered to the tool.

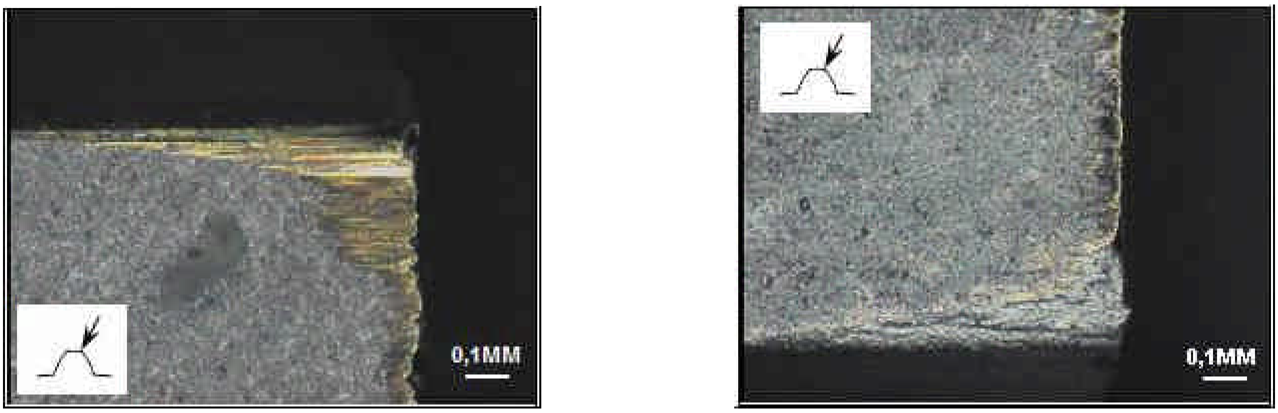
a) b)

Figure 9: Broaches with AlCrN coating



a) b)

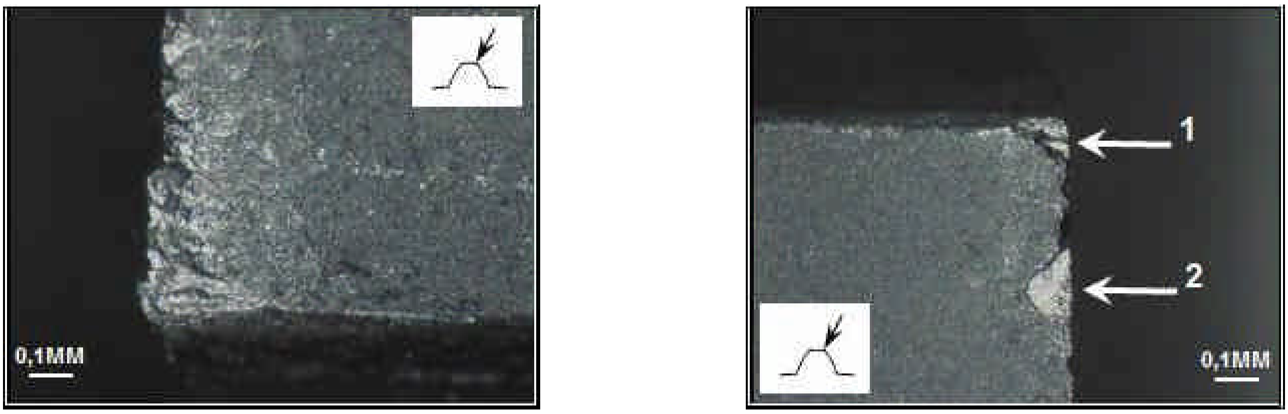
Figure 10: Broaches with TiN coating.



a) b)

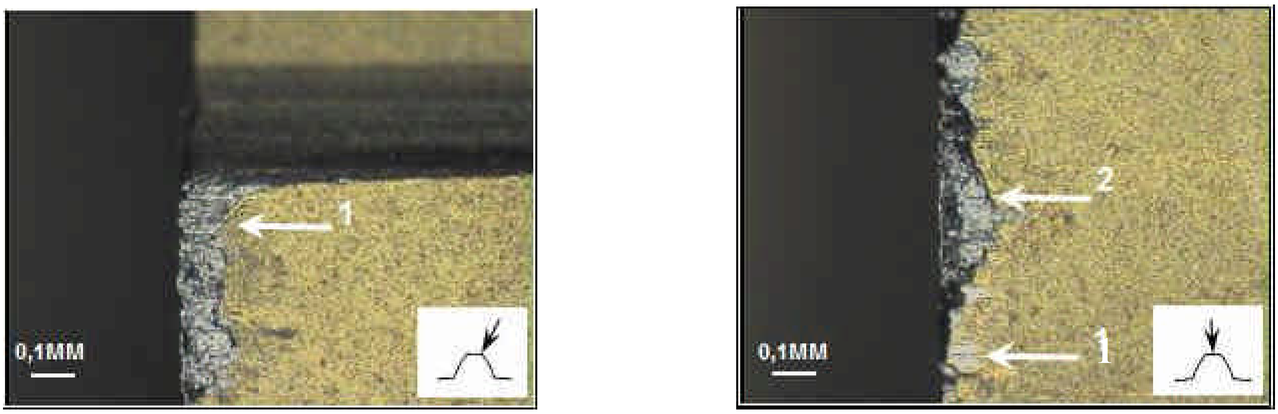
Figure 11: Broaches with TiCN coating.

Resharpened tools that had not been retreated with a new coating, as shown in Fig. 12a and 14a, show the adherence of part material on the tool, and the appearance of a build up cutting edge. However, in Fig. 13b, 14a and 14b, point 1 clearly identifies abrasive wear of the cutting edge. Figures 12b, 13b and 14b, show in point 2, the presence of various points of frittering/micro-chip, which probably happened because of the absence of coating on the rake face of the broach. This often leads to a greater incidence of adherence of part material on the cutting edge and the appearance of a build up cutting edge, resulting in the deterioration of the edge. Another possible reason is the displacement of the coating on the clearance surface of the tooth, as seen in point 1 of Fig. 12b and 13a, allowing direct contact of the part material with the broach's substrate on the tooth's clearance surface, rapidly increasing wear on these regions, since the substrate offers a significantly lower resistance than the coating.



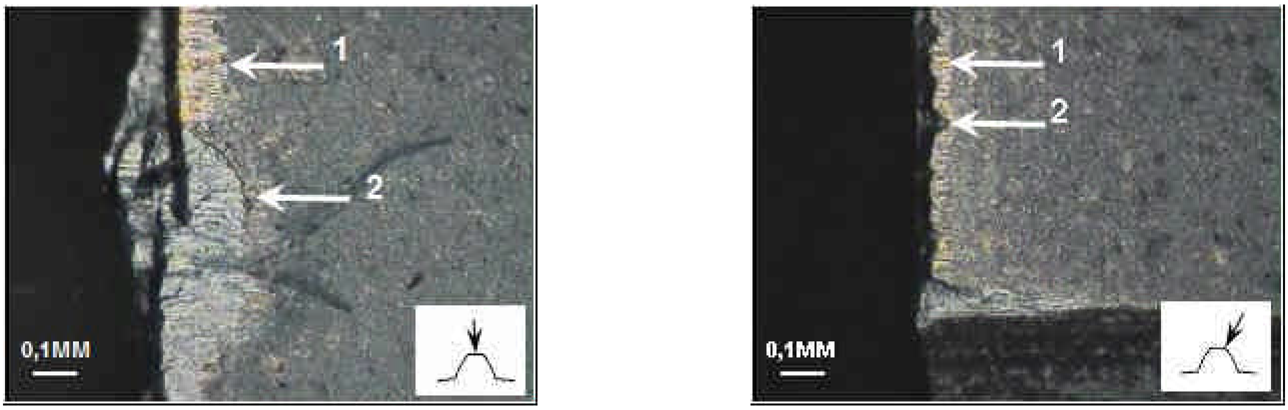
a) b)

Figure 12: Broaches with AlCrN uncoated on rake face.



a) b)

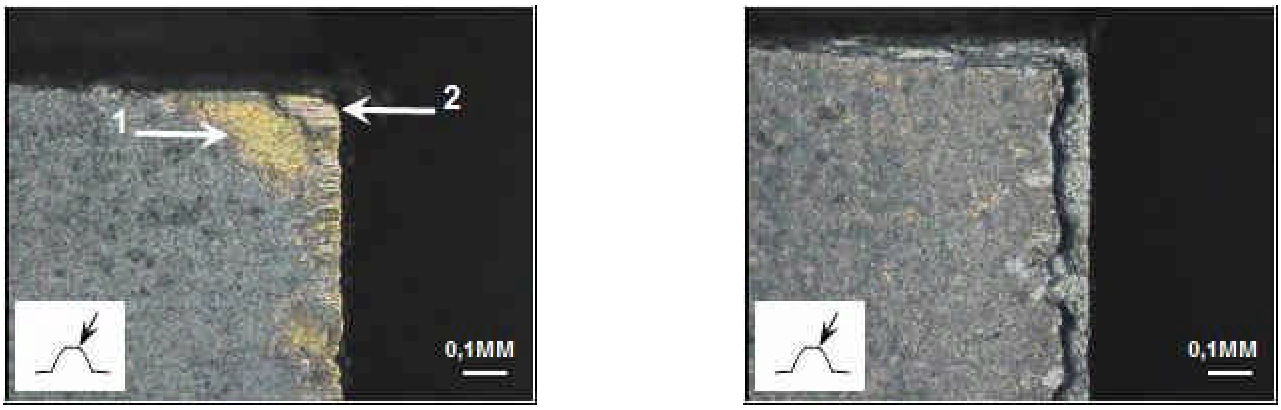
Figure 13: Broaches with TiN uncoated on rake face



a) b)

Figure 14: Broaches with TiCN uncoated on rake face

For TiCN coated, powder high-speed steel broaches, point 1 of Fig. 15a shows the displacement of the coating. In point 2, one can notice the occurrence of abrasive wear, characterized by scratches parallel to the cutting direction. In Fig. 15b one can see that the broach's material has been drawn out, probably due to adherence of part material. It is also possible to notice that the tooth's corner presented a more severe wear. Apparently, there have been both adherence and abrasive wear.



a) b)

Figure 15: Broach with TiCN coating.

4. Conclusions:

Based on the results obtained in this work, the following conclusion can be taken:

- Powder high-speed steel has not shown improvements to the broach's performance compared to the regular high speed steel tool regarding the number of parts produced per tool life, either with TiCN coating or uncoated.
- TiN, TiCN and AlCrN coated broaches have always shown superior performance than uncoated broaches.
- Statistically, TiCN and AlCrN coated broaches have equivalent performance levels, and they have always shown superior performance to broaches coated with TiN.
- Coating improves performance, not only during the first life, but also when the tool is resharpened and not recoated, operating uncoated on the rake face.
- The main wear mechanism identified in tools was the adherence between parts and tool material. This is the reason why the TiCN coated broach has shown superior performance. This coating has been capable of virtually stopping part material/chip adherence on the tool.

5. References

Hori, I.,High Performance Broaching. First International HSS FORUM Conference, Aachen, Germany, Febr. 2005, 7p.

Schneider, G. Cutting Tool Aplications. 2ed. Broaches and Broaching, 2001, Cap 14.

Motter, C. V., The Basics of Broaching. Gear product News, pp. 26-30. Febr. 2006.

HSS Smart Guide – Broaching. First International HSS FORUM Conference,Aachen, Germany, Febr. 2005, 21p.