PERFORMANCE EVALUATION OF CUTTING TOOLS PRODUCED BY BRAZING OF A CVD DIAMOND FILM ON A WC-Co SUBSTRATE

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Abstract: *This work presents results obtained for the performance evaluation of cutting tools produced by brazing a thick diamond film on a tungsten carbide substrate. The evaluation was based on the machining of aluminum-silicon alloys. The diamond films, approximately 500 μm thick, were produced at LAPMA-IF-UFRGS in a microwave plasma CVD reactor (Astex A5000 – 5 kW). The brazing process was optimized in order to promote a strong adhesion between the diamond film and the substrate, using a CuAg(Ti) brazing filler in-between them. The performance of the cutting tools was evaluated through the wearing of the cutting edge, related to the quality of the machined surface (roughness). The results obtained for the produced cutting tools were also compared to the results obtained for the machining with a a commercial diamond tool, considered as a reference. These results show that the performance of the cutting tools produced by brazing a diamond film on a tungsten carbide substrate for machining non-ferrous materials is very good.*

Keywordss: *Cutting Tools; CVD Diamond Film; Brazing on Tungsten Carbide.*

1. Introduction

The use of cutting tools made of superhard materials has increased in the last decade, specially in the metal-mechanic industry. This class of materials includes the polycrystalline diamond compacts – PCD – and the cubic boron nitride compacts – PCBN (ASM, 1989). The inserts can be used alone or they can be brazed on a tungsten carbide substrate. In the present work, the cutting tools were produced with thick CVD diamond films brazed on tungsten carbide substrates. While the PCDs are produced by sintering of diamond grains under high pressure and high temperature, the self-standing diamond films are produced at high temperatures and low pressure (below atmospheric pressure), in a CVD (Chemical Vapor Deposition) reactor.

In the cutting tools produced with diamond films, it is required a strong adhesion between the film and the substrate. The substrate is reponsible for the toughness of the tool and WC-Co is the best candidate for this purpose. In this work, the brazing of the diamond film on the tungsten carbide substrate, with a brazing filler in-between them, was performed at high temperatures (920° C) under vacuum (1,3 x 10^{-2} Pa), in order to avoid de deterioration of the diamond film and of the brazing filler in an oxidant environment. The tools were shaped according to an adequate profile to be used in the machining of a cylinder of aluminum-silicon alloy. The evaluation of the performance of the tools was based on the wearing of the cutting edge at constant machining conditions, comparatively to the behavior of commercial diamond tools.

2. Methodology

The development of this work was based on the following procedures:

2.1 Production of the Cutting Tools

The cutting tools were produced at Advanced Materials and High Pressures Laboratory (LAPMA) of Instituto de Física of UFRGS-RS. The process involves three steps (Santos 2004, Santos et al., 2004): the deposition and cut of the self-standing CVD diamond film; the brazing of the diamond film on the WC-Co substrate, and the final lapping of the edges of the brazed set. Each one of these steps will now be briefly described.

2.1.1 Diamond Film

The diamond film was grown in a conventional CVD process over a silicon substrate of 5 cm diameter, involved in a plasma created by microwaves in an atmosphere of hydrogen, oxygen and methane at flux of 532:9:60 cm^3/min, respectively. The temperature of the silicon substrate during depositon is about 900° C and the growth rate is approximately 6-8 μm/h. After the required thickness is obtained (~ 500 μm), the deposition process is stopped and the silicon substrate is removed by chemical etching, remaining the self-standing diamond film.

This film is cut with a pulsed high power Nd-YAG laser, in order to obtain a diamond slab with the shape as close as possible to the shape of the WC-Co substrate where it will be brazed.

2.1.2 Brazing Process

A reactive brazing process was used to promote a strong adhesion between the diamond film and the WC-Co substrate because it enables the joining of different materials with a good mechanical strength at the interface. The same process is used for brazing single crystals of diamond and PCDs on substrates. It is accomplished at high temperature under controlled atmosphere to avoid the oxidation of the reactive element of the brazing filler, as well as of the diamond film itself. In this work, the sample consisted of a WC-Co substrate with a diamond slab over it, and a brazing filler in-between them. The brazing filler was a thin foil (127 μm thick) of Cerametil 721 (AgCu-Ti). The sample was placed in a holder inside a silica tube under vacuum of 1,3 x 10^{-2} Pa. This tube was then placed inside a furnace and heated with a heating rate of 15° C/min, up to 920° C, held for 20 min and coolled down.

2.1.3 Grinding

In the last step, the brazed set was ground in a grinding machine (APFU-400/H - Sulmecânica) adapted to produce the desired geometry and lapping at the cutting edge. Three abrasive wheels with different diamond grain sizes were used for this purpose.

2.2 Characterization of the Produced Cutting Tools

Before the machining test, the produced cutting tools were initially characterized by optical inspection concerning the geometry and features of the interface between diamond film and substrate. Figure 1 shows details about the diamond film (0,33 mm), the brazing filler (0,17 mm), and the WC-Co substrate for one of the samples produced at LAPMA-IF-UFRGS.

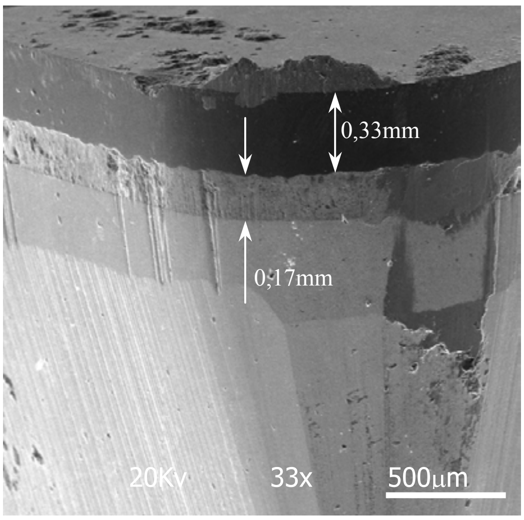

Figure 1- SEM micrograph of one of the cutting tools produced at LAPMA-IF-UFRGS, showing the diamond film, the brazing filler and the WC-Co substrate.

An important feature of a cutting tool is the curvature radius of the cutting edge (König, 1990). Table 1 shows the radius or curvature of the produced cutting tools.

Table 1. Radius of curvature of the cutting tools produced by brazing of a diamond film on a WC-Co substrate.

Cutting Tool	Radius of Curvature (mm)
Tool 01	0,8
Tool 02	1,4
Tool 03	1,4
Commercial Tool	0,4

2.3 Machining Test

The same machining conditions were applied in all cases in order to evaluate, on a qualitative basis, the performance of the produced cutting tools, compared to the performance of the commercial tool.

The commercial tool was a TPUN 16 03 04 FP CD10, where the insert is a PCD, since CVD diamond cutting tools are not yet easily available. The holder for the inserts was the CTGPR 25x25x16, with a position angle of 90º.

The performance of the tools was evaluated comparatively through the wear on the cutting edge induced by the machining process, and the quality of the machined surface. The wear was monitored by the characteristic marks on the cutting edge at determined time intervals during the machining cycle of each tool. The quality of the surface was monitored by the measurement of the surface roughness, R_a, perpendicularly to the tool path along the surface.

3. Experimental Procedure

The evaluation of the tools were performed by machining tests where the conditions were fixed along the cycle. In order to maintain the same working conditions, each tool machined its own workpiece. The standard workpieces, shown in Figure 2, were automotive pistons made of aluminum-silicon, with a final diameter of 106 mm and machining length of 50 mm. All of them were identified, related to a specific cutting tool.

Figure 2- Standard workpiece.

The standard workpiece presented a hardness HV 67, measured with a load of 2 kgf. The machining tests were accomplished in a CNC lathe (Centur – ROMI). The working conditions were set for lapping, with an feed rate of 0,1 mm/rev, cut depth of 0,3 mm and cutting speed of 780 m/min. The monitoring of the flank wear and the measurement of the surface roughness of the standard workpiece, were performed after 30 s, 100 s and 200 s of the tool lifetime. These time intervals were selected in order to monitor the increasing wear after keeping the cutting conditions at the same level of the one required for industrial applications. The surface roughness was measured in situ, with a portable surface roughness analyzer (SJ-201P - Mitutoyo, *cut-off* 0,8 mm), shown in Figure 03. The surface roughness was measured in four different points at the standard workpiece surface to improve the accuracy of the results. The quality of the surface was monitored through the parameter R_a of roughness, more appropriate in this case (Whitehouse, 1994).

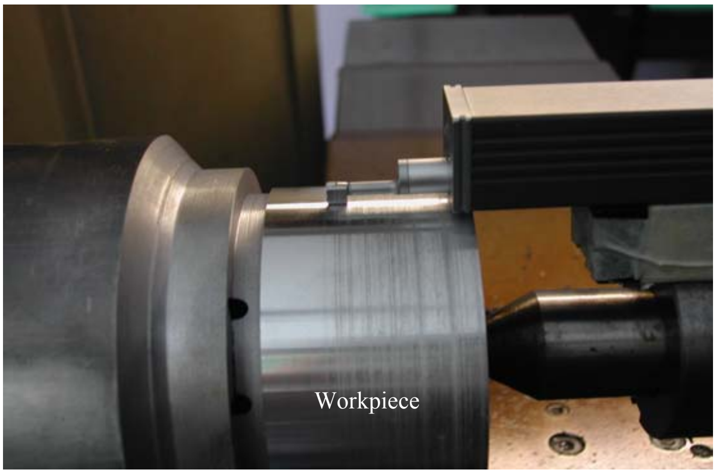

Figure 03 – Measurement of the surface roughness with a portable surface roughness analyzer.

The wear for each one of the cutting edges was recorded with a digital camera in a microscope for posterior analysis of the wearing marks (Teixeira, 2000) as shown in Figure 04.

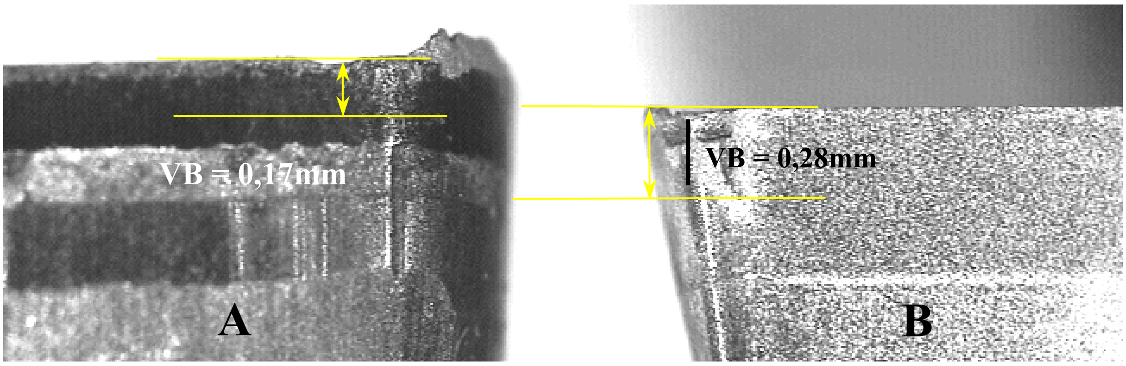

Figure 04 – Measurement of the wear mark VB_{max} on the cutting tool 01 (A) and on the commercial tool (B)

4. Results

The selected machining conditions were severe, with a cutting speed of 780 m/min and cutting time of 12 s in each step. After 30 s, 100 s and 200 s, the machining test was stopped for measuring the surface roughness and wearing of the cutting edge.

Table 2 shows the average results obtained for every cutting tool. It is possible to observe the influence of the cutting edge curvature on the roughness of the surface (R_a).

Table 2 – Average values of the surface roughness obtained for the machined standard workpieces after 30 s, 100 s and 200 s of the lifetime for each one of the cutting tools.

Machining Time (s)	**Tool 01** $r_{e = 0,8\ mm}$	**Tool 02** $r_{e = 1,4\ mm}$	**Tool 03** $r_{e = 1,4\ mm}$	**Commercial Tool** $r_{e = 0,4\ mm}$
30	0,74 μm	0,50 μm	0,52 μm	1,18 μm
100	0,81 μm	0,58 μm	0,79 μm	1,23 μm
200	0,82 μm	0,65 μm	0,74 μm	1,22 μm

OBS. : Average roughness calculated for four measurements; parameter R_a with *cut-off* 0,8 mm.

Table 3 shows the values obtained for the wearing of the cutting edges of the tools.

Table 3 – Wear VB_{max} measured after 200 s of the tool lifetime.

Tool	$VB_{max.}$	OBS.
Tool 01	0.17 mm	Localized mark on the cut edge
Tool 02	0.11 mm	Mark along the cut region
Tool 03	0.13 mm	Mark along the cut region
Commercial Tool	0.28 mm	Localized mark on the cut edge

5. Conclusions

Based on the results obtained in the present work, it is possible to conclude that:

1) The cutting tools produced by reactive brazing of a CVD diamond film on a WC-Co substrate showed a performance similar to the performance of a PCD commercial tool under severe machining conditions;
2) The difference in the contact area between the cutting tool and the machined material resulting from different curvatures, did not influence the wear rate of the cutting edges;
3) The radius of curvature of the cutting edge affected the machined surface roughness, as expected;
4) For all the cutting tools produced at LAPMA, the wear rate was smaller than the wear at the PCD tool;
5) The difference in the wear rate observed for the PCD (commercial tool) and CVD cutting tools is probably related to the presence of the metallic binder phase in PCDs. The CVD diamond film consists of diamond grains sintered together during the film growth processs, whereas in the PCD, the diamond grains are sintered by the addition of a metallic binder, usually cobalt. The wear rate in these two distint microstructures is certainly different.
6) The grinding step of the production of the cutting tools at LAPMA should be improved, according to the results of the characterization of the cutting edges and radius of curvature by optical microscopy.

6. Acknowledgements

The authors would like to thank the financial support of FAPERGS, CNPq, FINEP and CAPES.

7. References

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