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# Development of chemical vapor deposition diamond burrs using hot filament

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The fabrication of boring tools (burrs) for dentistry with the use of a hot-filament chemical vapor deposition (CVD) system, to form the diamond abrading structure, is reported here. The diamond was synthesized from a methane/freon gas mixture diluted in hydrogen. Comparative drilling tests with conventional diamond burrs and the CVD diamond burrs in borosilicate glasses demonstrated a lifetime more than 20 times larger for the CVD diamond burrs. Also, heat flow experiments in dentine showed that the CVD diamond burrs induce temperature gradients of the same order as the conventional ones. These characteristics of the CVD diamond burrs are highly desirable for odontological applications where the burrs' lifetime and the low temperature processing are essential to the quality and comfort of the treatment. © 1996 American Institute of Physics. [S0034-6748(96)02104-8]

## I. INTRODUCTION

The extensive work done in the last years to study the growth of diamond by chemical vapor deposition (CVD diamond) is still a very interesting subject for basic research on materials science. It is also opening a flourishing area of new technological applications of this material.<sup>1-5</sup> One of the attractive uses of CVD diamond is in the fabrication of small diameter dentistry's boring tools, usually named as "burrs." Conventional burrs are obtained by soldering small industrial diamond particles on stainless steel pins by galvanic processes. This old technology dates from the 1950s and has some inherent limitations due to the non uniformity of the diamond grain shapes and to the difficulty of automatization.<sup>6,7</sup> In this article, we will report our first results on the production of polycrystalline CVD diamond with convenient shapes for burrs. The characteristic parameters of these tools such as tool lifetime, cutting speed, abrading coefficient and induced temperature in the dentine pulp, compared with conventional burrs, are studied here.

## II. EXPERIMENT AND PROCEDURES

A schematic diagram of the hot-filament deposition system used in this work is presented in Fig. 1. The reactor is a vertical quartz tube 60 mm in diameter and 300 mm in length. Multiple molybdenum wires of 0.9 mm diameter were placed in vertical position at 3 mm from the hot filament, and used as substrates. Thus, diamond films were simultaneously deposited onto their tips. The temperatures of the hot filament and of the substrate holder were maintained at about 2500 and 1000 K, respectively. A diluted gas mixture of 2.0 vol. % CH<sub>4</sub> and 2.0% CF<sub>4</sub> in hydrogen was used

with a typical 50 Torr pressure in the reactor. The total time required for growth was about 30 h, with a growth rate of 10 to 12 μm/h. Diamond was deposited up to a burr top diameter of 1.6 mm. After growth, the diamond were laser cut to 2.5 mm height tips. The substrates were etched in 30 vol. % HNO<sub>3</sub> - 60 vol. % HCl solution, and the tips were welded to stainless steel pins in a high temperature vacuum oven.

To comparatively analyze the performance of CVD diamond burrs to the conventional diamond burrs' performance we have used drilling tests in borosilicate glasses. We have used the factor of merit  $F$  to quantify the drilling efficiency, as the ratio of the cutting speed  $V_c$  to the abrading area coefficient  $C_a$ . The heat flow generated by the drilling process was evaluated by measurement of the dental canal's

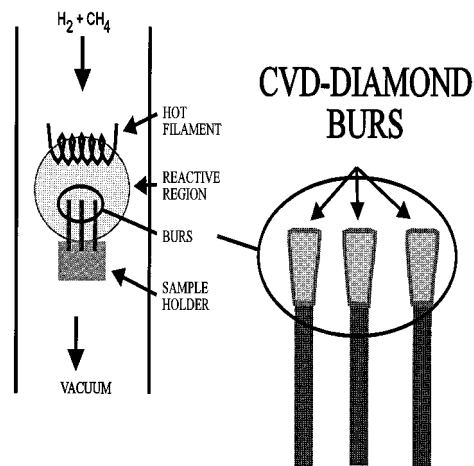


FIG. 1. Schematic of the hot-filament CVD system for burr fabrication. The molybdenum tips are from 0.9 mm diameter wire. CVD diamond is grown to a burr diameter of 1.6 mm.

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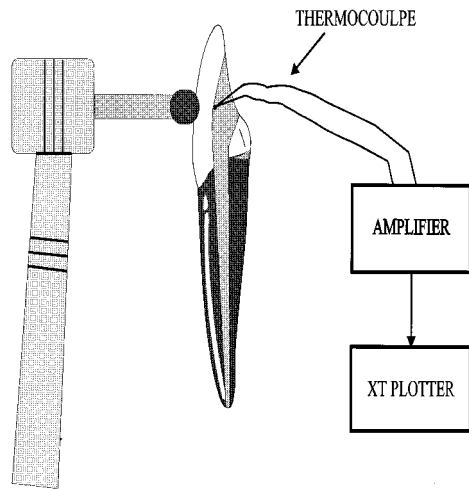


FIG. 2. Schematic of the heat flow tests in dentine.

infra-temperature in radial perforations. The thermal experiments were done *in vitro* using adult human tooth specimens, as shown schematically in Fig. 2.

### III. RESULTS AND DISCUSSION

Comparing the morphology of the typical CVD diamond burr, Fig. 3(a), with the morphology of a conventional diamond burr, Fig. 3(b), the complete coalescence of the diamond crystals on the CVD sample and a better grain uniformity are observed. Therefore, the diamond contact area of

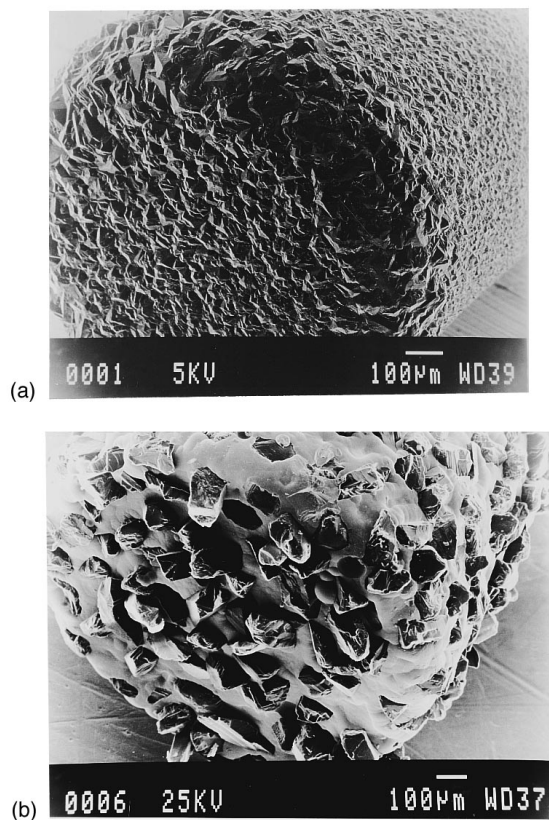


FIG. 3. SEM micrograph of (a) CVD diamond burr and (b) conventional burr.

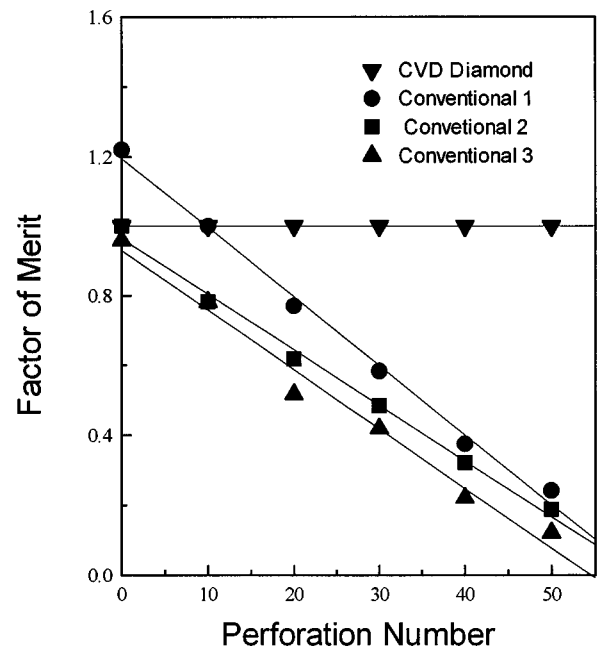


FIG. 4. Factor of merit  $F$  as function on number of drillings in borosilicate glasses.

the CVD sample is larger. We will recall these observations after the discussion of the abrading tests, in sequence.

A sequence of fifty drillings was employed in each test, using either the CVD burr or the conventional burr. The drillings were made with a conventional dentist's drill, with coolant water at 20 °C. The sharpness condition and the diameter of the burs were inspected by optical microscopy after every ten drillings.

In order to quantify the quality criteria we define the abrading coefficient of drilling  $C_a$  as the ratio between the burr's total abrading area ( $S$ ) and the effective diamond burr area (the area covered by diamond) used during the abrading process. The effective diamond burr area is given by the difference of the nominal diamond burr area ( $D_b$ ) and the area of diamond wasted during drilling ( $W_b$ ). We can write  $C_a$  as follows:

$$C_a = \frac{S}{(D_b - W_b)}. \quad (1)$$

A high quality tool is one that produces an accurate cutting, that has an area  $S$  close to  $D_b$  and that does not lose diamond material in the process, i.e.,  $W_b \approx 0$ . This tool will have an abrading coefficient close to 1. On the other hand, the drilling quality is also dependent on the cutting speed defined by the relation between the perforation depth and the perforation time. One may use the following equation as a first approximation for a comparative factor of merit  $F$  in the tool's testing:

$$F = \frac{V_c}{C_a}, \quad (2)$$

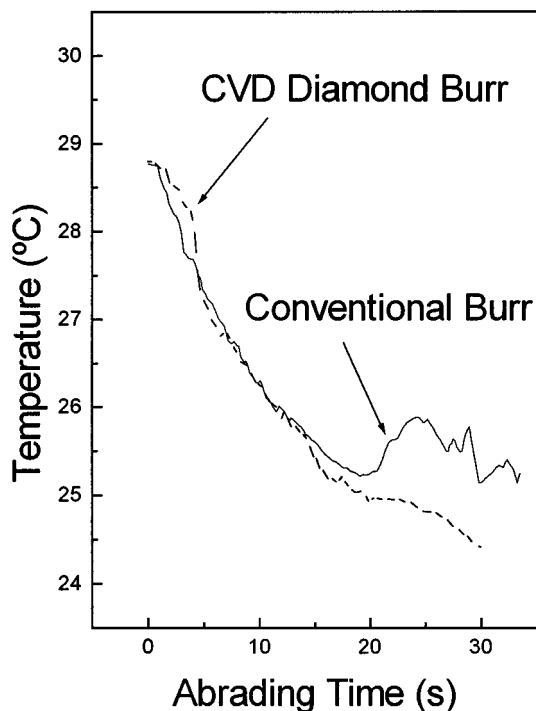


FIG. 5. Pulp temperature as function of time in radial drilling.

where  $V_c$  is the cutting speed of the burr being tested normalized to the cutting speed of the CVD diamond burr. More specifically,  $F$  is a parameter directly related to the lifetime of the tool in specific drilling process.

In Fig. 4 we give the experimental results of the factor of merit  $F$  versus the number of drillings in borosilicate glass for three different types of commercial burrs as compared to the CVD diamond burr drillings. One can observe in Fig. 4 clear evidence that the factor of merit decreases by a factor

of at least 10 after more than 50 drillings in conventional burrs. On the other hand, this detrimental performance is practically not observed in the CVD diamond burr.  $F$  is 1 even up to  $10^3$  drillings. After the abrading test, the conventional burrs have lost most of the grains at cutting edge. This is the main cause of the decrease in its efficiency. The CVD diamond burr remains unchanged. Therefore, this reflects the high quality of the CVD diamond tool.

Although the heat generated by the tooth drilling in the dentine is moderate, the tooth specific sense nerves connected to the central nervous system are extremely sensitive to temperature variations and this is the main cause of pain and discomfort during a tooth odontological repair. We experimentally measured the temperature in the tooth canal for controlled radial perforations as a function of time. The temperature decrease observed in Fig. 5 is due to the coolant water at 20 °C. We found that the temperature induced by the CVD diamond burr is of the same order of the temperature induced by the conventional diamond burr, with little advantage for the CVD diamond for long drilling time. This relatively smaller temperature indicates a higher cutting efficiency of the CVD diamond burr for long drilling time.

#### ACKNOWLEDGMENTS

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