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STUDIES OF CVD DIAMOND APPLICATIONS AS ULTRASOUND ABRADING DEVICES IN ODONTOLOGY AND RELATED USES

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ABSTRACT

Very accurate, durable and noiseless tools for many applications have been of great interest. Diamond-coated ultrasonic tools are excellent alternatives in this perspective, mainly for cutting hard materials. However, the conventional technology for diamond powder aggregation with nickel metallic binders could not withstand ultrasonic power. The diamond grains easily peel off and the tools were not durable enough while in contact with hard surfaces. This work presents studies concerning the deposition of CVD diamond coatings on different forms of metallic substrates, with very good adherence, to obtain abrading devices for an ultrasonic scaler used in odontology. This kind of technique is powerful for hard material cutting and polishing with very good accuracy and less noise. Concerning teeth cavity preparation it presents the additional advantages of less pain and no bleeding. Diamond coating has been obtained by using an Enhanced Hot Filament Assisted Technique, with high growth rate, using conventional hydrogen and methane gas mixtures. Small and special metallic rods machined in the form of odontological burs, with a pre-prepared surface, were coated with thick CVD diamond film. These CVD diamond tips were tested for their life time and cutting accuracy by an abrading enamel of tooth and glass surfaces with the use of ultrasonic scaler, showing very good performance. Ultrasonic CVD diamond tips are around 30 times more durable than conventional ones. In all tests, the cutting regions present no damaged edges and the bore diameter maintains accurate values while the tips lasts. The morphology and roughness analyses of the abraded surface have been evaluated by SEM and AFM techniques. An important application of this device in dentistry, presented for the first time, is also discussed.

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1. INTRODUCTION

The growth in the application of CVD diamond with innovative characteristics shows the main effort in terms of studies and investment and how different kinds of new devices can be developed for industrial processes [1-3]. High-quality diamond coating on pre-shaped parts and synthesis of free-standing shapes of diamond are a reality. Polycrystalline diamond films have been deposited on a variety of substrates, including metals, refractory metals, semiconductors and ceramics [4,5]. Applications of CVD diamond are far beyond the traditional technology, and in terms of industrialization, the novelty products are the ones which are possible due to the advent of CVD diamond technology. CVD diamond as coated cutting tools, abrading devices, heat sinks, optical coatings, substrates for multichip module technology (MCM), electron field emitters, electrochemical electrodes and others [3-5], promise an important economical impact of this technology in terms of a profitable market. Even though, CVD diamond production cost is still high, it is already quite competitive in several areas. For example, a high rotary speed CVD diamond burr for odontological and related use is a new device with the emerging technology, which has been widely studied. The deposition process has been scaled up for [6].

Besides the rotary CVD diamond burr, this work presents CVD diamond tips for ultrasound cutting and abrading as a radical technology application, representing an innovative device with impact on odontological and medical applications. CVD diamond was deposited on small molybdenum rods. Ultrasonic equipment is used instead of a high rotary speed handpiece, for cutting tooth enamel, dentine and bone [6-8]. Even though the production cost for a CVD diamond burr is much higher than for a conventional tool, its performance is much superior and needs to be evaluated in terms of cost/benefit ratio.

In fact, ultrasonic equipment has been used in odontology for the last 50 years [9, 10], mainly in tartar removal and periodontal treatment. Owing to the absence of adequate tool tips its use for cutting tooth enamel and dentine was superseded by the high speed rotary system in the 1960's. At that time ultrasound cutting was performed with tools of conventional materials using an aluminum oxide abrasive slurry. Some alternative diamond tips had been developed using conventional and special processes to aggregate diamond powder with metallic binders. However, these alternatives had only very limited use because such diamond tips could not withstand efficiently the ultrasound power while cutting hard materials.

CVD Diamond tips as burrs for ultrasound handpieces, presented here for the first time, specially in dentistry may represent a revolutionary tool because of its durability, absence of noise, the reduction of pain implying less use of anesthesia, no bleeding, higher cutting precision, more comfort for the dentist and patient, better refrigeration, no water spray.

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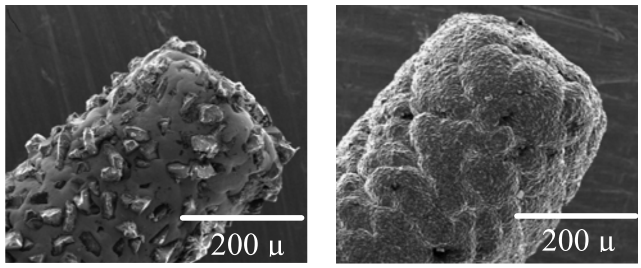
Other advantages dentists are finding every day. Besides this, its production is free of hazardous industrial waste.
CVD diamond burrs for ultrasound system became viable because of the high diamond growth rate in industrial scale production and the high adherence obtained between the thick diamond coating and the metal substrate, with very low mechanical stresses [11]. Some comparative results between CVD diamond and the conventional burrs for ultrasound handpiece in terms of cutting speed and life time are discussed in this work.

2. EXPERIMENTAL PROCEDURE

An enhanced “Hot Filament Assisted Reactor” (HFCVD) used for obtaining the CVD diamond burr for an ultrasound handpiece has been described elsewhere [3]. The scaling up was obtained by using a new concept of substrate holder and convenient parameters of diamond growth. Temperature, grain size, gas concentration, thickness, stress, and diamond quality have been studied as a function of the substrate diameter and length [12].
In this work, 25 mm long and 1.2 mm diameter molybdenum rods have been used, and only one model of diamond burr, with conical shape, has been considered for comparative testing. Two groups of 4 (four) diamond tips were chosen. One group of tips was made from diamond powder aggregated by a nickel metallic binder, called conventional burr, while the other was coated with a thick coalesced CVD diamond film. Also, other CVD diamond burr group, with the same model, has been obtained to measure the effect of tip roughness on the cutting time. The thickness of the CVD diamond film was around 100 micrometers. The ends of both burr groups had diameters of approximately 0.3 mm. The conventional diamond burrs were high quality commercial products. The CVD diamond burrs were obtained as described above.
A conventional ultrasonic scaller operating at 28 KHz and at 60% of its maximum (10 W) ultrasonic power was used for testing both groups of tips. An adaptor was developed to couple the CVD burr to the ultrasound handpiece with efficient transmission of the ultrasound power to the burr tip. The ultrasound power at both burrs tips was very similar.
These two groups of tips were submitted to tests of perforation and cutting on 1.2 mm thick glass plate and on enamel surfaces of human teeth. Wear measurements of enamel surfaces were carried out to measure the quality of the teeth surfaces after cutting. The tips surfaces were evaluated to verify the life time. Perforation was performed with the tip end forced by a low pressure against the material and making a gentle oscillatory movement, while ultrasound power was on. Cutting tests on glass plate were made by placing the tip side on the edge of the glass plate and gently moving it around 3 mm forward and backward with ultrasonic power. The same procedure was carried out to wear the enamel of the tooth surface.
The burr surface roughness is an important parameter to get a control in terms of cutting time when ultrasonic equipment is used. Six CVD diamond coated burr tips were prepared with different surface roughness, to observe their cutting efficiency. These tips were tested by measuring the time necessary to cut along 20 mm wide glass plates with thickness of 1.2 mm.
Scanning electron microscopy (SEM) was used to observe the burr tips and evaluate their wear. The roughness of the abraded surface was evaluated by mechanical perfilometry. Also, the variation of the tips diameter was measured during cutting tests.

3. RESULTS AND DISCUSSIONS

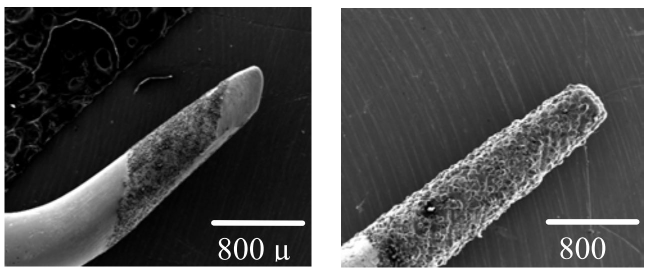
Fig. 1 shows typical brand new tips of both technologies. Fig.1a reveals the contours of diamond grains aggregated by a nickel metallic binder. The diamond grains emerge from the metallic surface (tip end). In Fig.1b, one can see the CVD diamond coating at the tip end, without salient grain, corresponding to a completely coalesced CVD diamond film.



a) b)

Figure 1 - Diamond tips for ultrasound handpiece, a) conventional burr with diamond powder, and b) coalescent CVD diamond coated tip. Magnification: 100X.

Fig. 2 shows the typical image of used conventional and CVD diamond tips. Fig 2a shows SEM image from the conventional tips after only 5 holes through 1.2 mm thick glass plate. The tip end is damaged. Obviously, the nickel metallic binder of diamond powder didn’t withstand the ultrasonic action against hard surface. Fig. 2b shows the tips with CVD diamond coating after 200 holes through the 1.2 mm thick glass plate. In this case no wear and no tip damage were observed, even after making 200 holes.



a) b)

Figure 2 - Diamond tips after perforation of 1.2 mm thick glass plate, a) conventional burr after 5 holes, and b) CVD diamond coated burr after 200 holes.

To measure the enamel surface quality after abrading, its roughness was measured as a function of the time of wear for the two different groups of tips, as shown in Fig. 3 and Fig. 4 for conventional burr tips and for CVD diamond coated tips, respectively.

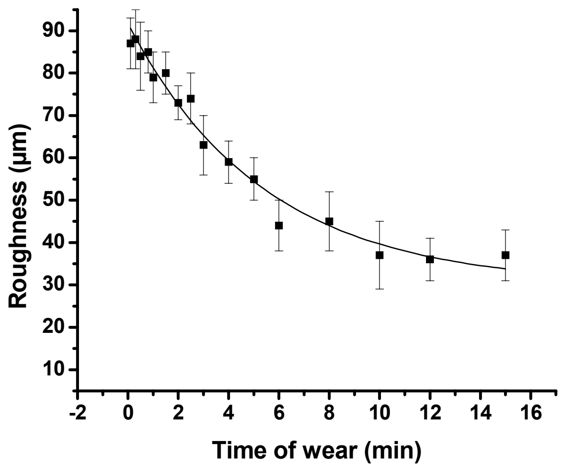


Figure 3 - Roughness of enamel of tooth surfaces after abrasion with conventional burr tips coated with diamond powder aggregated with a nickel metallic binder.

From Fig. 3, one can observe that the roughness of the enamel of tooth grinded by conventional burrs is very high at the beginning of the tests. It decreases drastically with time. This means that this kind of burr tips release diamond grains during cutting. Simultaneously, the grinded surface becomes smooth and the cutting performance of the burrs drops.

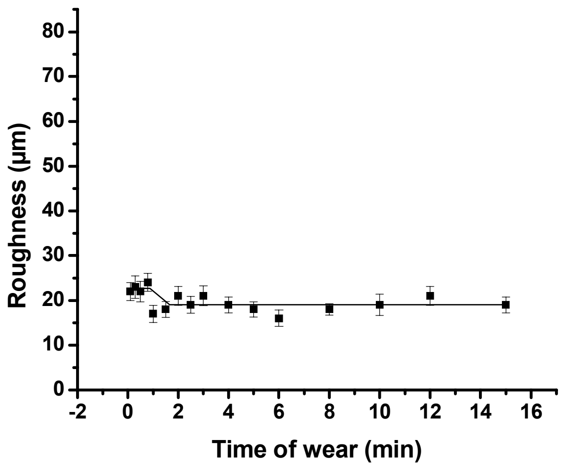


Figure 4. Roughness of enamel of tooth surfaces after abrasion with CVD diamond burr coated tips.

On the other side, in Fig. 4 it is observed that the enamel of tooth surface roughness is always low and doesn't change during cutting with the CVD diamond burr, meaning that the CVD diamond surface gives a better finish and doesn't wear. Its cutting performance is maintained during the entire test.

Fig. 5 shows the conventional burr tip diameter variation as a function of time for cutting a 1.2 mm thick glass plate. After 15 minutes of cutting, the tips were completely worn down.

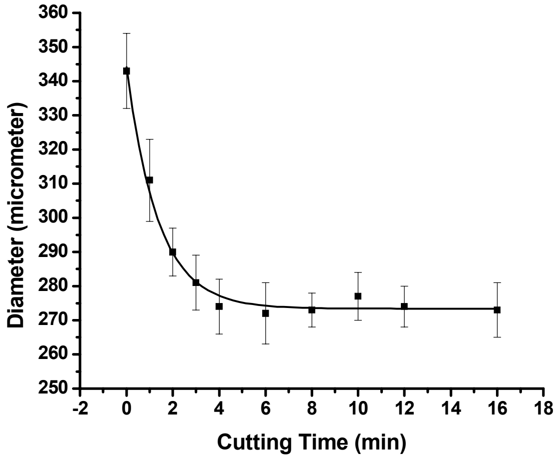


Figure 5 - Diameter of the conventional burr tips with diamond powder aggregated with a nickel metallic binder as a function of cutting time.

Fig. 6 shows the same tests for two different diameters of CVD diamond coated tips, 300 μm and 345 μm.

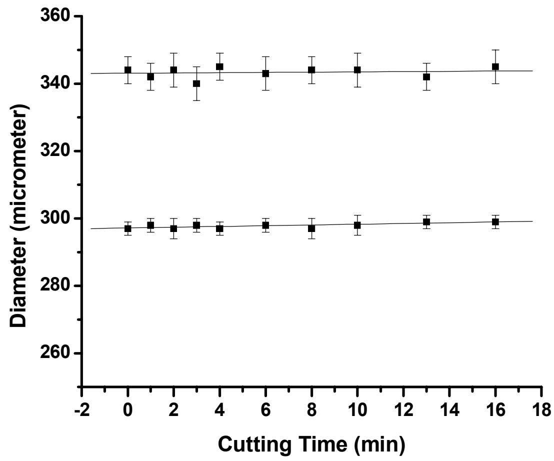


Figure 6 - Diameter of the CVD diamond coated burr tips as function of cutting time, a) 300 μm, b) 345 μm.

It is observed that while the conventional burr tip diameter decreases as a function of cutting time. The CVD diamond coated tip diameter doesn't change.

Figure 7 shows the cutting time of a 20 mm wide glass plates with the six tips of CVD diamond deposited with different surface roughness.

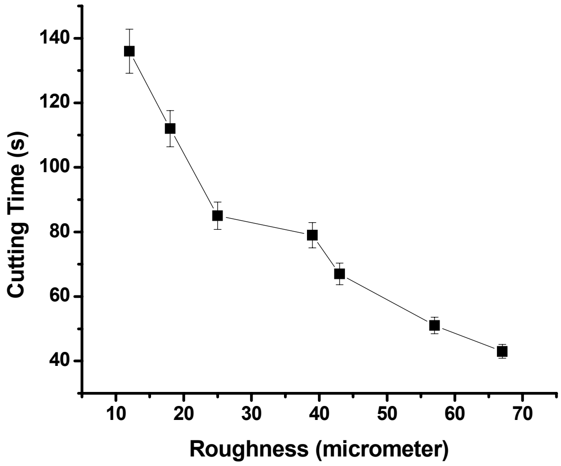


Figure 7 - Cutting time of the glass plate as function of the CVD diamond coated tips surface roughness.

The correlation of cutting time with roughness is very clear. More specifically, the cutting time decreases with increasing roughness.

4. CONCLUSION

CVD diamond has been shown to provide a new opportunity for application as devices for odontological, or even, medical applications. The advantage of CVD diamond coated devices in comparison with conventional technology has been clearly demonstrated. The low and constant roughness of the trimmed enamel of tooth surface shows the applicability for CVD diamond coated tips. The wear tests demonstrated that the performance of the CVD diamond coated tips is much better than the conventional burr with aggregated diamond powder. The growth of CVD diamond enables control of burr surface roughness, which is very important to determine the burr cutting efficiency. This allows for different tips with variable finishing quality and cutting efficiency for many applications in dentistry and others areas.

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