Surface Finish in Machining of Dental Ceramics

H. Hocheng, S. Y. Lin and W. T. Lei

Department of Power Mechanical Engineering, National Tsing Hua University, Hsinchu, Taiwan

*hocheng@pme.nthu.edu.tw, b9g15708@oz.nthu.edu.tw, ctlei@pme.nthu.edu.tw

Keywords: Surface Roughness, Dental Ceramics, Diamond Abrasives, Machining.

Abstract. The five-axis machining of sculptured surface offers many advantages, including faster material removal rates, improved surface finish and elimination of hand finish. To implement a sophisticated five-axis computer-aided system for machining the dental ceramics, the required machining data for the numerical control of machining were investigated using special flat-end and sharp-end tools coated with diamond abrasives of different grit sizes. The major machining parameters include feed rate and depth of cut. The dental ceramics in this study was Vita Mark II commonly used for inlays, onlays and veneer restorations in the dental system. The surface quality of ceramics is examined and the relationship between surface roughness and machining parameters is revealed. The selection principles of tool and machining conditions were proposed based on the experimental results.

Introduction

Based on the outstanding mechanical properties, high alumina ceramics were commonly used for the dental applications. In use of the alumina, abrasive machining is employed in dentistry preparation of filling, crowns, and bridgework, and for making final fit adjustments on dental restorations. In the machining, a high-speed and air-driven dental handpiece with diamond abrasives are used [1]. In spite of the importance of diamond machining in dentistry, there have been limited published references on the subject [2-6]. Recent studies have provided data on the machining characteristics of tooth enamel [4], machinable glass-ceramics [5] and glass-infiltrated alumina [6] using a dental hand piece and diamond abrasives. In addition to hand piece machining performed by the dentist, abrasive machining is also used to prepare ceramic restorations in the dental laboratory using three-axis CAD/CAM systems [7]. The five-axis machining offers the advantages including faster material removal rates, improved surface finish and hence elimination of hand finish. As there is little published information available on the machining behavior of a commonly used dental ceramic(Vita Mark II) and none of the five-axis machining practice, the purpose of the present study is to investigate the surface roughness of this representative material under computer-aided machining parameters including the rotational rate, feed rate, cutting depth and abrasive mesh with special flat-end and sharp-end tools coated with diamond abrasives of different grit sizes.

Experimental setup

Material and Equipment. The dental ceramic in this study was Vita Mark II commonly used for inlay, onlay and veneer restorations in the CAD/CAM system. The microstructure shown in scanning electron micrograph of a polished cross-section has the glass matrix of approximately 30% (volume fraction) of irregularly-shaped crystalline particles from 1 to 7 µm in size. The mechanical properties were as follow: Vickers hardness = 6.3 ± 0.3GPa, Young’s modulus = 69.7GPa, and fracture toughness = 1.19±0.05 MPam^{1/2}. Specimens of 8mmx8 mmx15mm in dimension were fixed to a metal holder and all the surfaces were sand-blasted to achieve a uniform initial surface roughness.

Two kinds of cutting tools coated with diamond abrasives of different grit sizes were used in this study. The schematics of tool diameter and tool angle are shown in Fig. 1.
A machining center with high-speed spindle rotating from 30,000 rpm to 90,000 rpm, a numeral controller and cooling system providing the required precision and stability was used for experiment. **Procedure and Parameters.** The rotational rates were kept clockwise constant (70,000 rev/min for spindle and 60 degree/sec for specimen) during the tests. The specimens were pre-shaped from blocks into cylinders at feed rate of 0.6mm/rev and cutting depth of 1.2mm. The parameters design for the test can be divided into rough and fine machining as shown in Table 1.

<table>
<thead>
<tr>
<th>Flat-End Tool Diameter</th>
<th>Abrasive mesh</th>
<th>Feed rate</th>
<th>Depth of cut</th>
</tr>
</thead>
<tbody>
<tr>
<td>2mm</td>
<td>#170</td>
<td>0.2mm/rev</td>
<td>0.5mm</td>
</tr>
<tr>
<td>3mm</td>
<td>#230</td>
<td>0.4mm/rev</td>
<td>1.0mm</td>
</tr>
<tr>
<td>4mm</td>
<td>#325</td>
<td>0.6mm/rev</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sharp-End Tool (2mm diameter)</th>
<th>Abrasive mesh</th>
<th>Feed rate</th>
<th>Depth of cut</th>
</tr>
</thead>
<tbody>
<tr>
<td>45 degree</td>
<td>#170</td>
<td>0.05mm/rev</td>
<td>0.3mm</td>
</tr>
<tr>
<td>60 degree</td>
<td>#230</td>
<td>0.1mm/rev</td>
<td>0.6mm</td>
</tr>
<tr>
<td>75 degree</td>
<td>#325</td>
<td>0.15mm/rev</td>
<td></td>
</tr>
</tbody>
</table>

The surface roughness was measured by a stylus profilometer parallel to the machining direction with the length of 0.8mm and a cut off length of 0.25mm. Ten traces were taken at different locations along the cylinders. The arithmetic mean roughness (Ra) was used to characterize the machined surface. The mean value of ten measurements was used for discussions.

**Results and discussion**

**Effects of Feed Rate. Rough Machining.** Fig. 2(a) and (b) show the surface roughness increases with feed rate, grit size and depth of cut. The tool diameters and grit sizes change the machining performance of tools. Large tool diameter surpasses the effect of the feed rate of tool as shown in Fig. 2(b), while the grit size determines the produced surface roughness. In use of smaller tool diameter of 2mm, the slope of the roughness value decreases with the abrasive size. The result shows that surface roughness was primarily sensitive to the grit size. The effects of feed rate are clear when coarse grit and small tool diameter are used. When the feed rate drops to 0.2mm/rev, the effects of other parameters are nearly indistinguishable. On the other hand, when the mesh #325 of the diamond abrasives was used, the produced surface roughness is nearly constant. It indicates that the machining
results are steady and fine when tool diameter of 2mm with diamond abrasives of mesh #325 is used thus a good choice for rough machining.

**Fine Machining.** The sharp-end tools were used for fine machining and therefore not expected to afford the feed rate faster than 0.2mm/rev. 0.15mm/rev was set the maximum of feed rate for fine machining. As shown in Fig. 3(a) and (b), the surface becomes drastically rough when the feed rate reaches 0.15mm/rev and diamond abrasives of mesh #325 and mesh #230 are used. There exists a threshold value of feed rate between 0.1~0.15mm/rev, beyond that tool wear and rough surface will occur. Fine-grit tool is considered susceptible to fast wear-out of the abrasives, and the warn tool produces rough surface. At feed rate larger than 0.15mm/rev, the surface roughness remains low only when mesh#170 is used. This situation is also discussed in Sec. 3.5. Hence the diamond abrasive of grit size of mech#170 is suggested to be used for fine machining, which can sustain large feed rate and reduce the machining time and cost.

**Effects of Depth of Cut. Rough Machining.** The depth of cut is the major parameter affecting the material removal rate and the resulted machining time and cost. However, it can cause the tool wear and the rough surface if the depth of cut is too large. As shown in Fig. 4(a) and (b), the surface roughness slightly becomes rough as the depth of cut increases from 0.5mm to 1.0mm. When smaller diamond abrasives are used, the surface roughness is improved and the effect of depth of cut is reduced. Generally speaking, the surface roughness is mildly coarser when larger depth of cut is demanded.

![Graphs showing the correlation between roughness and feed rate in rough machining](image)

**Fine Machining.** As shown in Fig. 5(a) and (b), the surface roughness only increases noticeably with the depth of cut when mesh#325 diamond grit and large feed rate are used. In other cases, the increment is negligible at various levels of depth of cut and feed rate. It indicates when the tool remains sharp without wear-out of the grits, fine surface can be produced in wide range of cutting parameters.
Effects of Tool Diameter. The principle of machining tells the surface roughness is proportional to feed rate and inversely proportional to spindle speed. Because the higher the spindle speed or the slower the feed is, the more the specimen surface is covered by the cutting tool edge, by which lower surface roughness is achieved as shown in Fig. 6. Large tool diameter has similar effect for higher coverage in rough machining. Fig. 7 shows the surface roughness is significantly improved in use of tool diameter of 3mm, particularly when large feed rate is used.
**Effects of Tool Angle.** Sharp-end tools are used to machine the shapes that flat-end tools cannot. The tool angle affects the machining characteristics significantly. An efficient process, longer tool life and fine surface finish can be achieved by proper tool angle. Two tool angles were used for fine machining in this study. As Fig. 8 shows, the tool angle of 45° produces the finer surface roughness than 60° does. With the increase of abrasive mesh, such as #170, the effect of tool angle on surface roughness becomes milder. Larger grit size means rougher tool edge, thus the effect of tool angle will be reduced. The machining characteristics depend on the tool angle clearly when mesh #325 is used.

**Effects of Abrasive Mesh.** The surface roughness in abrasive machining of ceramics has been reported sensitive to the grit size. Larger diamond abrasives show lower tool wear and higher material removal capacity. However, they often cause rough surface. The tool diameter and tool angle used in this study affect the surface roughness parallel to the grit size. As shown in Fig. 9(a), the experiments of rough machining of cutting depth of 1mm using flat-end tool reveal the surface roughness decreases with the increase of abrasive mesh. These results are consistent with the surveyed references.

The tool wear increases with the increasing feed rate. Therefore the use of rough abrasive mesh will gain additional positive consideration. In use of the spear-head cutting tool, the fine abrasives show some negative effects, particularly at larger feed rates, as shown in Fig. 10. The feed mark left on the machined surface becomes the dominant feature of the surface roughness. The sharp-end tool with fine abrasives traveling at large feed rate will produce quite clear feed marks, namely rough finish. The use of large grits nevertheless reduces this effect by their rough cut along the tool path. Fig. 10 indeed shows the negative effects of fine abrasives when large feed rate is used. The effects are enhanced with the use of small tool angle.

**Selection Principles of Tool and Machining Conditions.** As mentioned in the previous sections, the machined surface of dental ceramics will be influenced by feed rate, depth of cut, diameter and angle of tool and the abrasive size. When the efficiency of machining process and quality of machined
surface are all taken into considerations, the selection principles of tool and machining conditions can be summarized as follows.

**Selection of Tool.** The tool diameter of 3mm is a better choice than 2mm for larger coverage hence less feed mark on the cut. In rough machining, fine abrasives are recommended for fine surface. In fine machining, the tool angle of 45 degree is better than 60 degree. When larger feed rate is used, one should then use the abrasives of appropriate mesh, such as #170 to avoid the formation of clear feed marks on the machined surface.

**Selection of Machining Parameter.** Large feed rate and depth of cut produce high material removal rate thus more efficient. However, the surface quality is affected proportionally. The feed rate shows much stronger influence on the depth of cut. The choice of these conditions is determined by the required level of the surface roughness quality of the product.

**Conclusions**

In this study, the surface quality in machining dental ceramics with special flat-end and sharp-end tools coated with diamond abrasives of various grit sizes are investigated. For rough machining, the surface roughness increases with the feed rate and the depth of cut but decreases with the increase of tool diameter. For fine machining, the experimental results show that the feed rate is very dominant. The choice of abrasive size is then dependent on feed rate and tool angle. There exists a limit of feed rate between 0.1 to 0.15 mm/rev for sharp-end tools coated with finer diamond abrasives, beyond that the surface roughness and tool life are threatened. In use of large feed rate and small tool angle, the coarse abrasives are recommended to avoid the negative effect of the feed mask on the machined surface during fine machining. Time saving can be achieved by increasing the feed rate. The choice of machining conditions in practice depends on the preset level of the desired surface finish.

**References**


Progress on Advanced Manufacture for Micro/Nano Technology 2005
doi:10.4028/0-87849-990-3

Surface Finish in Machining of Dental Ceramics
doi:10.4028/0-87849-990-3.1231