CERAMICS TURNING
(Turning ZrO₂ ceramics)

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Abstract: In place of brittle ceramics used so far have appeared up-to-date so called tough ceramic materials resisting better against mechanical effects [1]. Such material is the zirconium-dioxide, too. The important advantage of hard-turning is the applicability of universal tool. Various outlines can be formed by a tool given. Machining ceramics in case of using traditional machining (turning, milling, drilling) requires special technological conditions (tools, machine-tools, technological parameters, etc.) [2] which are developing presently. We would like extending our research work in this course, too.

Keywords: polycrystal diamond, cubic boron nitride, 3D-topography, heat ring, surface roughness

1. Introduction

By industry development the demand is increasing for such materials to be applied at higher temperature beside at heavy physical and chemical load. The structural ceramics can have an important role exactly in this segment. The zirconium–dioxide is also such material [3]. The role of ceramics hard-machining is increasing presently [4]. The zirconium-dioxide deriving from its lower hardness and from other characteristics is suitable to machine by tool having regular edge can become a potential material at piece or small- and medium series production. To ensure this it has to be known its cutting characteristics [5]. Our research work focusing a part of this in keeping with the recommendation of the company producing and developing zirconium-dioxide semi-finished products.

2. Materials tested and their forms.

The common properties of engineering ceramics are that they have outstanding physical and chemical characteristics in very high temperature range [7]. The ceramics tested by us have got high hardness (1250-1800 HV), because of this it can be cut by polycrystal diamond and cubic boron nitride tools. The material tested is zirconium-dioxide ceramics. The specimens used at turning tests were cylindrical, their diameters were 16 and 20 mm (Figure 1.)

Figure 1. The zirconium-dioxide (Zn40) ceramics used at tests.
The ceramic properties tested [6].

<table>
<thead>
<tr>
<th>Material</th>
<th>Dimension</th>
<th>ZN 40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main component</td>
<td>ZrO&lt;sub&gt;2&lt;/sub&gt;-MgO</td>
<td></td>
</tr>
<tr>
<td>Density</td>
<td>g/cm³</td>
<td>5.74</td>
</tr>
<tr>
<td>Bending strength</td>
<td>MPa</td>
<td>500</td>
</tr>
<tr>
<td>Compression strength</td>
<td>MPa</td>
<td>1600</td>
</tr>
<tr>
<td>Young modulus</td>
<td>GPa</td>
<td>210</td>
</tr>
<tr>
<td>Poisson - ratio</td>
<td></td>
<td>0.3</td>
</tr>
<tr>
<td>Vickers hardness</td>
<td></td>
<td>1240</td>
</tr>
<tr>
<td>Thermal convectivity</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Linear coefficient of thermal expansion</td>
<td>10⁻⁶K⁻¹</td>
<td>10.2</td>
</tr>
</tbody>
</table>

Cutting tests

During turning the work-piece rotating movement is the main movement, the auxiliary movements are the turning tool movement in feeding and depth of cut directions. We have set the cutting speed by the work-piece revolution number.

To measure the axial and tangential components of the cutting force we have used a measuring tool-head with strain gauge. We have used the Spider 8 measuring amplifier for the tests. We have connected four channels. We have coupled to the O-channel the revolution marker, we have measured the tangential and feeding forces on the 1 and 2 channels. The 3. channel served to measure the tool displacement, here we have connected an inductive displacement tele-transmitter restored by spring.

Heat affected zone tests.

The heat arising during cutting influences considerably the removal of stock process as well as influences very much the tool durability. We have also made shots with thermo-camera during cutting to study the heat affected zone formed.

During cutting we have measured the main and feeding forces affecting the tool. With the measuring-system capable to measure active forces-developed by us in the institute – we show some diagrams (Figure 2 and 3) in the followings. We present the main cutting force with thin line the feeding force with crossed line. We show the change of feed-rate with sections having circle end point.

![Diagram of force measured (ZrO<sub>2</sub>-MgO, CBN)](image)

Figure 2 Diagrams of main cutting force and feeding force

(\( v_c = 75 \text{ m/min.}, a = 0.02 \text{ mm; } f = 0.01-0.02-0.03-0.04-0.05 \text{ mm; } v_c = 75 \text{ m/min.} \))
The zirconium-dioxide was cut with cubic boron nitride tool in the above. Figure 2. It can be seen that main cutting force and feeding force show increasing tendency with the increasing feed-rate.

![Diagram of force measured (ZrO₂-MgO, PCD)](image)

Figure 3 Diagrams of main cutting force and feeding force 
($v_c = 75$ m/min., $a=0.02$ mm; $f=0.01-0.02-0.03-0.04-0.05$ mm, ceramic: zirconium-dioxide, tool: PCD)

In Figure 3 at the same conditions but cutting with polycrystal diamond resulted some different curves. The main cutting force increase is less rising in this case but it has got similar tendency, the feeding force following a short rising shows rather smaller increasing angular curve.

![Diagram of force measured (Plate graphite, PCD)](image)

Figure 4 Diagrams of main cutting force and feeding force 
($v_c = 75$ m/min., $a=0.02$ mm; $f=0.01-0.02-0.03-0.04-0.05$ mm, cast iron: plate graphite, tool: PCD)

We have cut plate graphite cast iron with PCD-tool similar with previous cutting data in case of Figure 4. We compared the known cast iron with zirconium-oxide unknown from
turning standpoint is such way. The diagrams got are similar though with lower values. Difference can be experienced in the initial increasing section. The change of forces are directly proportional. In case of ceramic the initial increase is steeper at both tool materials. SEM photos of the cut surfaces can be seen in figure 5-7 in 2000 x magnification. The different surface effects of the CBN and PCD tools can be realized.

Fig. 5. Ceramic surface, machined with CBN. \(v_c=75\) m/min., \(a = 0.02\) mm, \(f = 0.04\) mm/rev. magnification x2000

Fig. 6. Ceramic surface, machined with PCD. \(v_c=75\) m/min., \(a = 0.02\) mm, \(f = 0.04\) mm/rev. magnification x2000

Fig. 7. Grinded surface

The \(\text{ZrO}_2\) phase transformation tracks caused by mechanical effect can be seen in 2000x-magnification of the original surface grinded (Figure 7.). In case of PCD-tool the rate of greater shell-like tears is similar to grinding. The amount of micro-cracks can be reduced based on the Figures. Less micro-cracks can be seen on surfaces turned compared to grinded in the Figures.

3D-topography pictures can be seen in Figure 8-12.
In Figure 8-11, can be seen that the higher cutting speed ($v_c = 75$ m/min.) resulted more favourable surface roughness than at lower cutting speed ($v_c = 25$ m/min.).

4. **Conclusions**

Trend characterizing steel turning appears at using CBN turning tool, local cutting force maximum can be identified. In case of PCD-tool at higher cutting speed more favourable surface roughness can be got, comparing to CBN-tool.

It is possible turning zirconium-dioxide semi-finished product. The condition of the starting surface has got definite importance how is possible to turn the surface point of view.
The raw-product surface grinded has damaged the PCD-tools in case of all cutting parameters tested.

The hardness recommendation accepted for tools in technical literature (3-4 times higher hardness difference in favour for the tool) can not be used at raw-products grinded in case of zirconium-dioxide ceramics, Softer, 2 times higher hardness can be used.

Based on the tests can be established that given cutting speeds in case of increasing feedings at different tool-materials and workpiece materials show similar tendency, only in steepness is change. The phenomenon validity can be extended from the steel/carbide connection to the zirconium-dioxide/CBN friction, chip removal connection, too. The CBN and PCD-tools have resulted significantly different cutting forces. It can be stated that the cutting speed increase has resulted well measured increase in cutting force in case of diamond turning tool which has called forth significant heat evolution. This is significantly unfavourable tribological connection.

The standard PCD–tool used did not result different surfaces regarding the surface roughness. It can be stated on the basis of SEM photos that on the surfaces grinded phase transformations take plate at microcracks. This results the higher cutting forces at turning in case of grinded surfaces. At surfaces turned phase transformation can not be seen. The surface cut by PCD–tool results favourable surface roughness.

References:

[7]. CeramTec AG Innovative Ceramic Engineering Medical Products Division: Broschüre 2008