TURNING SPECIALITIES OF ZrO_2 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 [6]. 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.) which are developing presently [2]. We would like extending our research work in this course, too.
To clarify the machinability – turning – of ZrO_2 ceramics we developed a cutting force measurements for the applied CBN and PCD cutting tools. The forces were studied in the function of cutting speed and feed, the surfaces were analized by SEM and the cutting process was controlled by thermo-camera. The failure of cutting edges were also studied. The summarized results suggest the possible turning possibilities of ZrO_2 ceramics.

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

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 [1] 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].

	Dimension	
Material		ZN 40
Main component		ZrO_2-MgO
Density	g/cm^3	5,74
Bending strength	MPa	500
Compression strength	MPa	1600
Young modulus	GPa	210
Poisson - ratio		0,3
Vickers hardness HV0,5		1240
Thermal convectivity	W/mK	3
Linear coefficient of thermal expansion	$10^{-6}K^{-1}$	10,2

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 [8] 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.

3 DISCUSSION

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.

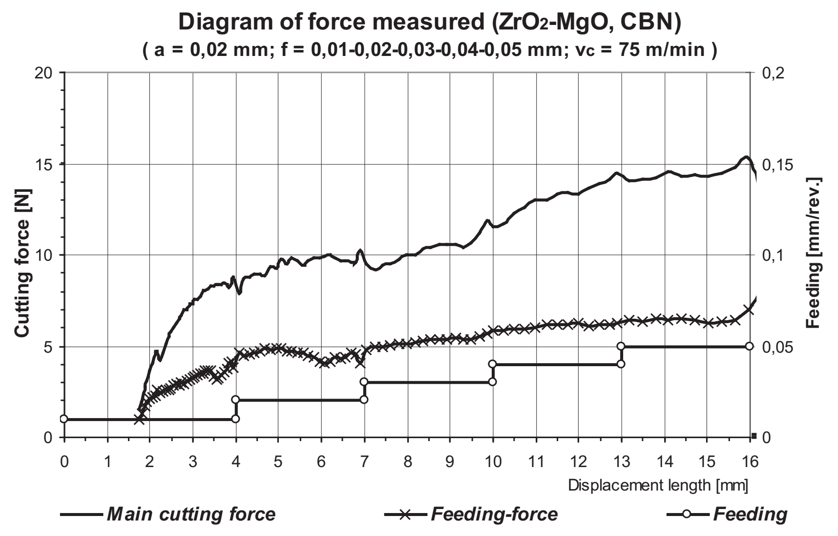

Figure 2. Diagrams of main cutting force and feeding force
(v_c= 75 m/min., a= 0,02 mm; f= 0,01-0,02-0,03-0,04-0,05 mm,
ceramic: zirconiumdioxide, tool: CBN)

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.

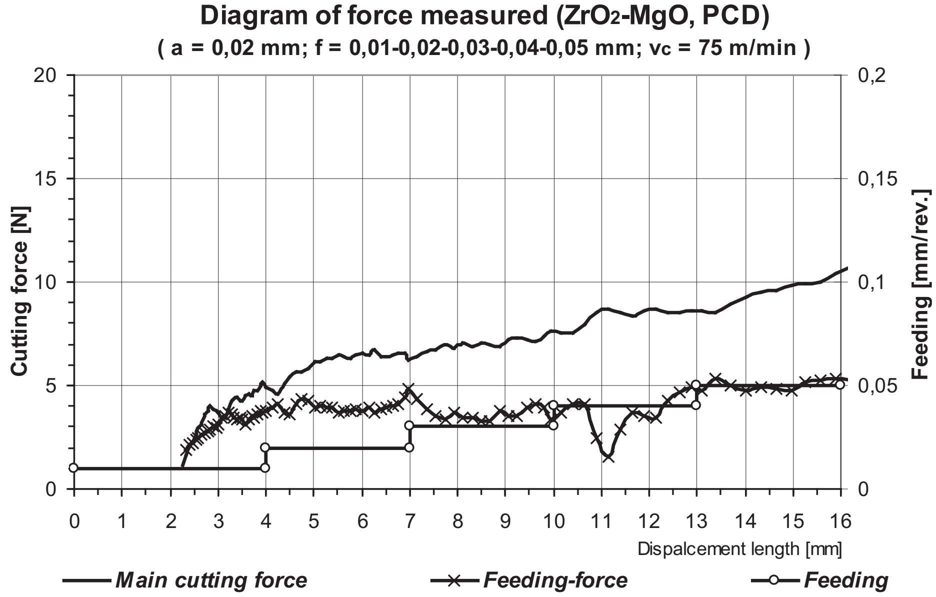

Figure 3. Diagrams of main cutting force and feeding force
(v_c= 75 m/min., a= 0,02 mm; f= 0,01-0,02-0,03-0,04-0,05 mm,
ceramic: zirconiumdioxide, tool: PCD)

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.

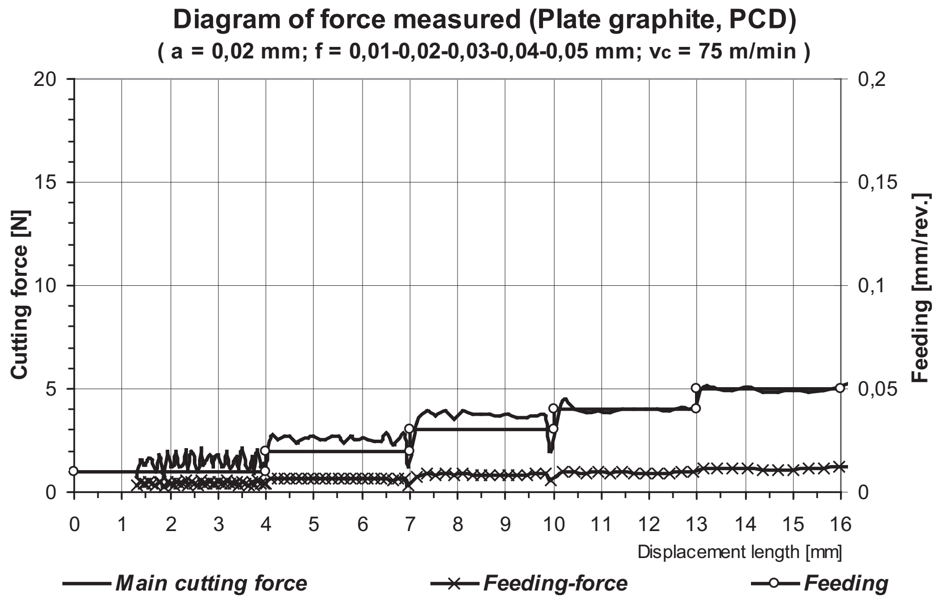

Figure 4. Diagrams of main cutting force and feeding force
(v_c= 75 m/min., a= 0,02 mm; f= 0,01-0,02-0,03-0,04-0,05 mm,
cast iron: plate graphite, tool: PCD)

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.

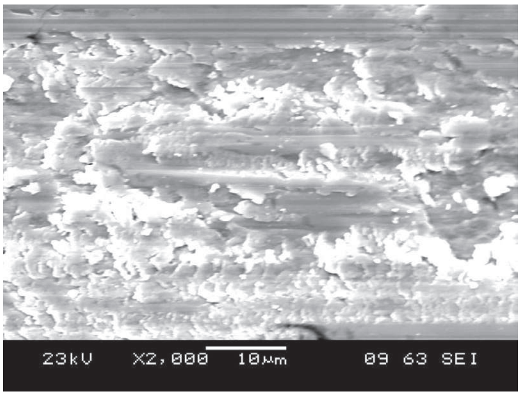

Fig. 5. Ceramic surface, machined with CBN. v_c=75 m/min., a = 0.02 mm, f = 0.04 mm/rev. magnification x2000

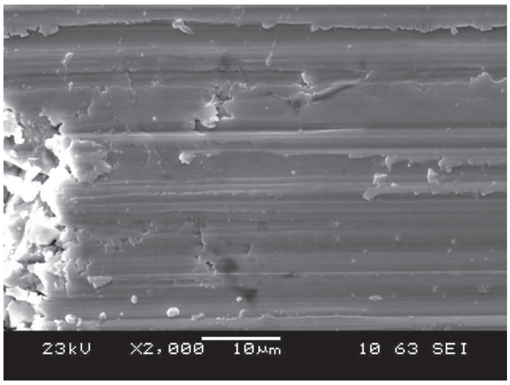

Fig. 6. Ceramic surface, machined with PCD. v_c=75 m/min., a = 0.02 mm, f = 0.04 mm/rev. magnification x2000

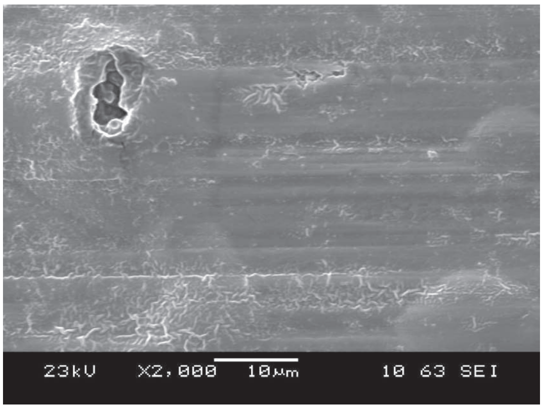

Figure 7. Grinded surface

The 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 8-10.

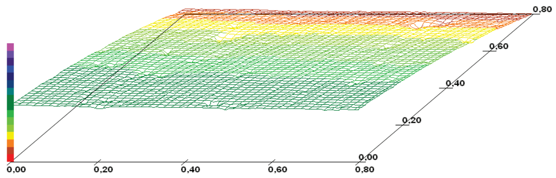

Figure 8. PCD tool turned
v_c =75 m/min., a = 0.02 mm, f = 0.05 mm/rev.

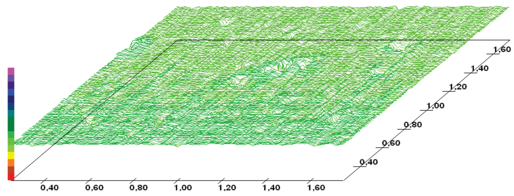

Figure 9. PCD tool turned
v_c =75 m/min., a = 0.02 mm, f = 0.02 mm/rev.

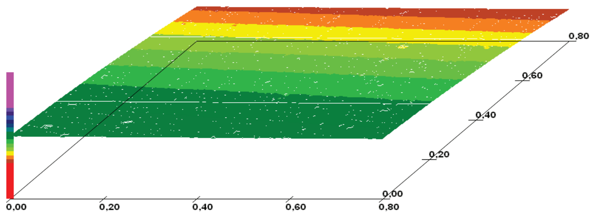

Figure 10. Grinded surface

In Figure 8-9. 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.).

From the point of applicability of cutting technology for ceramics, it is important to examine the friction behaviour of the different machined ceramic surfaces (grinded and machined surfaces with different cutting tools and technological settings) because the most common applications of such materials can be found among the slide bearing solutions.

In the dry friction tribological model system – steel pin on the machined ceramic ring surfaces - we have analyzed the friction force (coefficient) (Figure.11), and wear. Regarding the machining phenomena of the two tool materials, the PCD tool was selected to produce machined ceramic surfaces with different technological settings. In the tribological test system we have increased the normal load in three steps: starting with 50N ($\sigma_{Hertz\text{-}max}$ = 391 N, without wear) load the measurements were running for 5 minutes, then it was increased upto 100 N for 5 minutes and further 150N was applied to the seizure of samples.

Having S355 steel pin with grinded surface Ra 0,3 on the different machined ceramic ring surfaces, we have found that the applied higher cutting speed (v_c=75 m/min) and lower feed (f=0,01-0,02 mm/ford) resulted lower friction between the steel and ceramic surface than it was with the original grinded ceramic surface. The original grinded ceramic surface has more but smaller sized “pits”, which can stick the steel worn particles, thus the friction process turns quickly to a steel/steel like contact having relatively high adhesion.

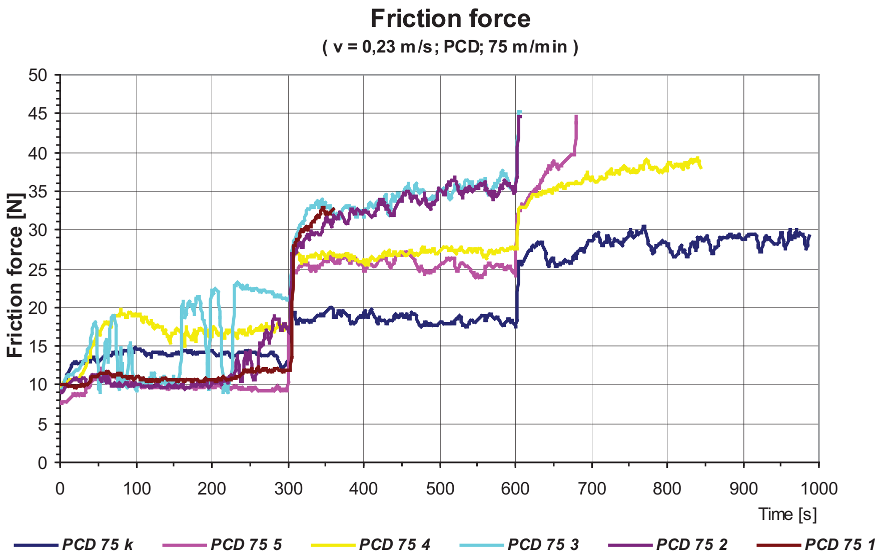

Figure 11. Friction force diagram
(steel/grinded and machined ceramic surfaces)

3 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.

We have found that it is possible to produce machined ceramic surface, which can offer better sliding properties against steel than the original grinded ceramic surface.

4 NOMENCLATURE

a	depth of cut	mm
CBN	cubic boron nitride	-
f	feed	mm/rev
F_c	cutting force	N
HV	Vickers hardness	-
PCD	polycrystal diamond	-
R_a	surface roughness	µm
S355	structural steel	-
SEM	scanning electron microscop	-
v_c	cutting speed	m/min
ZrO_2	zirconium – dioxide (ceramic)	-
ZrO_2-MgO	zirconium – dioxide with magnesiumoxide (ceramic)	-
σ_{Hertz}	Hertzian stress	MPa

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