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ASPECTS CONCERNING THE INFLUENCE EXERTED BY THE PROPERTIES OF CERAMIC MATERIALS ON THE CUTTING MECHANISM AND THE SURFACE QUALITY

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ABSTRACT
The grinding working is necessary when the requirements of dimensional accuracy and of quality of the surface are not satisfied after the compacting and sintering process. Depending on mechanisms of chip formation the quality of processed surface varies in relatively wide range. This paper will try to establish a dependency relation between the parameters of the grinding regime, the mechanism of chip formation and the quality of the processed surface.

KEYWORDS
grinding, ceramics, cutting mechanism, zirconium, alumina

INTRODUCTION

The rapid development of performance ceramics, whose excellent electrical, mechanical, chemical and thermal properties rate it in almost all top areas of industry, led to an exponential increase of volume in the global market. Statistics for 2000 revealed a market volume of about 50 billion USA dollars for technical ceramic materials in industrialized countries (1).
Research is performed on the production of ceramic pieces in order to optimize manufacturing operations and processing costs. Due to special properties (high density and hardness, lack of ductility, low resistance to thermal shock, special resistance to abrasion, fragility etc.), almost all ceramic products can be processed by grinding only with diamond tools. In this respect, the characteristics specific to this processing method can be taken as a basis to assess the workability of ceramics by other processes (cutting, honing, lapping, polishing).
Processing ceramic products by cutting is accompanied by phenomena which are completely different from those specific to metal cutting. One of the special problems of cutting ceramic materials is due to the stress appeared during processing which may favour the occurrence of some defects of ceramic products (cracks, tears, breakage), especially in the edges or transitions from one cross section to another. Research performed until now (2) point out that radial cracks located normally on the cut surface and longitudinal cracks oriented in directions tangential to the surface generated by cutting are formed in the chip formation and sampling areas with the increase of the cutting regime parameters and under the action of the abrasive particle. If the cutting process takes place with low specific loads, longitudinal cracks are no longer formed. In the case of ceramic products with higher toughness and fine-grain structure, the chips formed by grinding have the appearance of scales formed by exfoliation or by sliding in the plane of shear, like in the case of glass.
Therefore, the main phenomena of chip formation mechanism when processing ceramic materials by cutting are (2):
-chip formation by taking material particles in the form of scales (small pieces of irregular shapes), due to cracks caused by the cutting force (compression);

- material state changes in the chipped area due to the formation of a strong tamped layer, where a web of cracks is formed after elastic recovery;
-expulsion of particles of indefinite geometric shape after the elastic shocks generated by the tool entering or leaving the chipped layer at the end of the working stroke.
Depending on these mechanisms of chip formation the quality of processed surface varies in relatively wide range. This paper will try to establish a dependency relation between the parameters of the grinding regime, the mechanism of chip formation and the quality of the processed surface.

CHARACTERISTICS OF PROCESSED MATERIALS AND MEANS USED TO PERFORM THE PROCESSING

The processing specimens are obtained by using ceramic powders:
-zirconium oxide (ZrO_2) partially stabilized with 5 mole% yttrium oxide (Y_2O_3), powder produced by CéramiquesIndustrielles-Saint Gobain, France;
-alumina (Al_2O_3), purity 95%, produced by CéramiquesIndustrielles-Saint Gobain, France.
Powders are compacted by biaxial pressing at a pressure of 400 MPa in the form of rectangular plates with different dimensions L x L x h for the two materials analysed. Then, they are sintered at a temperature of 1600°C for 5 hours. Both the increase and decrease in temperature were made with low speed (25 °C/h) to avoid internal stress due to thermal shock. For plates made of zirconium oxide partially stabilized with yttrium oxide, the dimensions are 80x80x10, while for those made of alumina the dimensions are 55x55x10. The plates are fixed on the machine table through a support plate to which they are attached by thermoplastic putty.The mechanic characteristics of the two materials are presented in table 1.

Table 1.Physico-mechanical characteristics of processed materials

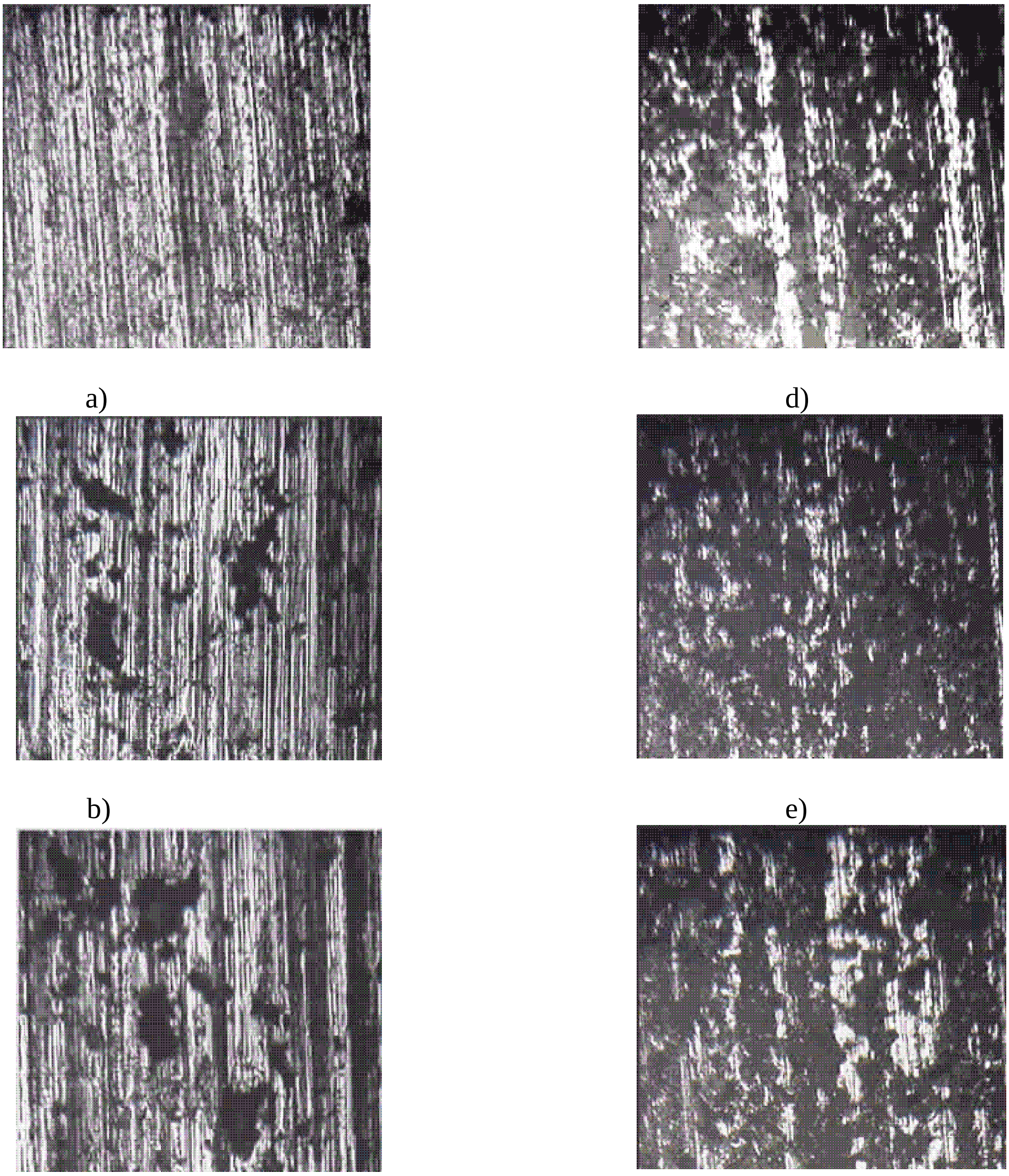
Characteristics	alumina (Al_2O_3)	zirconium oxide (ZrO_2)
Density ρ, [g/cm^3]	3.9 - 3.99	5.5 - 5.8
Modulus of elasticity E [GPa]	360 - 410	180 - 200
Breaking resistance to bending R_i[MPa]	280 - 500	450 - 800
Resistance to compression R_c[MPa]	2200 - 4000	1800 - 2500
Weibul modulus m, la T=20 °C	6 - 8	20
Critical intensity factor of stress K_{Ic}, in MPa m$^{1/2}$	4.2 - 5.9	10 - 15
Resistance to thermal shock $R_{ş\theta}$, [K]	80	260

Micro hardness measurements were also performed on the samples with the help of M-400-H1 micro hardness tester. The data related to the impression size were processed with the program Akashi At-201. A load of 500 g was used and the following values of micro hardness were obtained: 1238 HV in the case of ZrO_2samples and 1250 HV in the case of Al_2O_3samples.
Diamond tools of the type 1A1 175-10-3 were used for the processing and they were made with synthetic diamonds with different grains (D64, D107 and D181), friable medium type (DSD-M) and uncovered diamonds. The diamond concentration used was C75. The diamonds were embedded in a Bz 335 metallic binder (the metallic binder is indicated by literature for grinding oxide ceramic materials).
The main part of the installation used to study the grinding process of ceramic materials with the help of diamond blades isrepresented by a universal grinding machine, Tacchella Machine 6 AP.

For each type of processing (roughing, semi finishing and finishing) and cutting regime, samples of the processed ceramic plates were taken for microscopic observations meant to determine the type of micro cutting. Microscopic observations were made using different sizes.The roughness measurements were performed with the help of Taylor Hobson roughness tester.

INTERPRETING THE RESULTS

A series of conclusions on the mechanisms of cutting can be expressed after comparatively analysing the micrographs of the surfaces processed by grinding with the help of the diamond tools with grain D181 used for roughing processing, figure 2.



a) d)

b) e)

c) f)

Figure 2. Aspect of surfaces processed with diamond tools D181 to:
a), b), c) process ZrO_2 and d), e) f) process Al_2O_3, respectively

When processing alumina (images in the second column), it can be noted that regardless of the chip size taken by the diamond tools and of the grain of the diamond tools, the chip is removed in a fragile regime characterized by multiple breakage and fractures of the ceramic material. This cutting mechanism is due to high fragility of alumina (because of the mechanic stress which appear during the grinding process, the value of the critical stress intensity factor K_{IC} is exceeded, which results in the appearance of cracks) and to the use of some diamond tools with metallic binder characterized by low elasticity which will lead to achieving surfaces sparkled with small craters characterized by rather high roughness.Also, it can be noted that as the thickness of the chip increases, the size of these surface defects increases as well, which will lead to a deterioration of the processed surface aspect. These aspects of surface defects are doubled by other defects in the superficial layer which are due to the introduction of tension during grinding. Since the elasticity of the material is very low, the stress builds up in the superficial layer of ceramic parts having a negative effect on their operation. The relatively small variation of specific energy Espwith the size of chip taken, h_{eq}, (in the case of alumina), is due to the fact that it still remains in the range variation belonging to the grinding regime, the same fragile processing regime (figure 3).

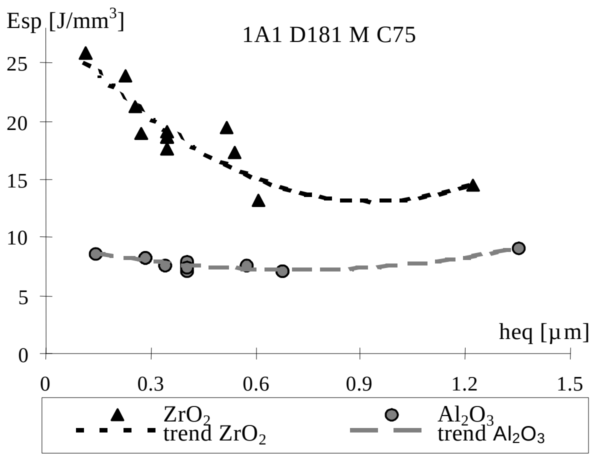


Figure 3. The energy specific to cutting Esp [J/mm^3] depending on the equivalent thickness of the chip h_{eq} [µm] when roughing processing ZrO_2 and Al_2O_3

In the case of zirconium oxide, the surfaces obtained by grinding with the help of diamond tools with grain D181 have different aspects depending on the size of the chip taken. When the grinding is performed with cutting regimes which determine smaller values of the chip sizes, the cut surface has a uniform appearance without excessive surface defects (figure 2.a). Considering the fact that the values of specific energies Esp, obtained when processing with larger regimes, and the fact that zirconium oxide is characterized by a much higher tenacity than alumina, we can assert that in these situations we deal with a mainly ductile cutting regime achieved through the classical process of shearing which leads to obtaining a surface with a better roughness and without too many other surface defects or in the superficial layer. However, in the micrographs presented it can be noted that even at smaller sizes of chips there are surface defects in the form of small craters on the surface of the processed ceramic material. These can be due to the initial porosity of the ceramic material or to the existence of micro cracks in the mass of material occurred during the process of sintering and which led to pulling out micro particles during processing under the influence of mechanic stress. As the cutting regime intensifies the mechanical stress leads to overcoming the critical stress intensity factor K_{IC} which will lead to passing from a predominantly ductile cutting regime to a mainly fragile regime (figures 2. b and c). Actually this shift from a predominantly ductile regime explains the decrease of specific energy values Esp because as it is known the values of specific energies corresponding to ductile regimes are higher than those corresponding to fragile regimes. Thereby, when processing zirconium oxide, the specific energy Esp evolves after a decreasing curve with the increase of the equivalent thickness of the chip to an optimal value (in terms of energy), after exceeding this optimal value, the specific energy remains almost constant with even small increases recorded. As it can be noted in the graph presented in figure 3, the energy minimum is located around the value h_{eq}=0.6 [μm]. Instead, when processing alumina, in the variation range of h_{eq}, the variations of specific energy Esp are almost insignificant. At the same time, roughness measurements were performed. The results are presented in figure 4.

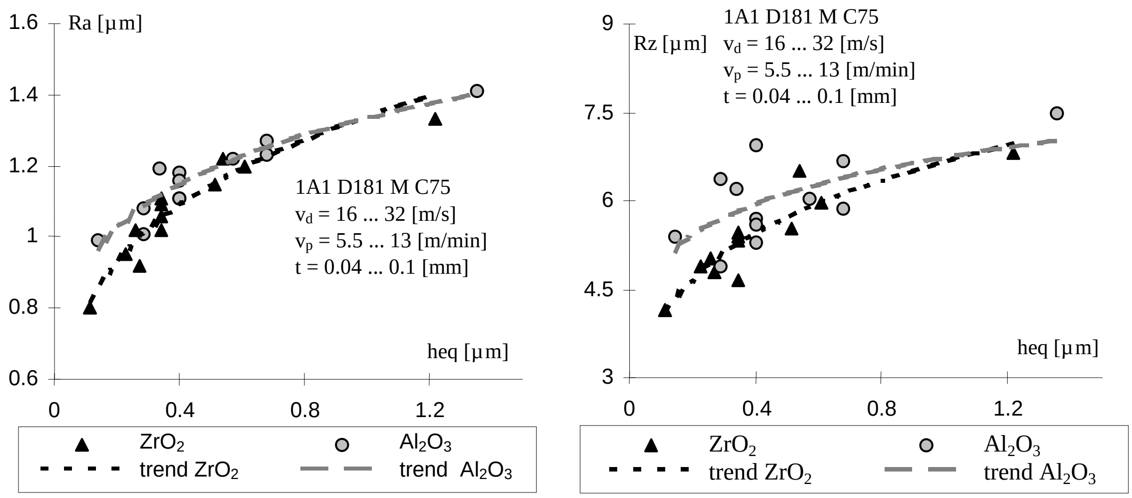


Figure 4. The dependence of roughness parameters Ra and Rz of surfaces processed by grinding with diamond tools with grain D181

As it can be noted in the graphs, the values of roughness obtained when processing the two materials are almost equal for values of the equivalent thickness of the chip of h_{eq}> 0.5 [μm], namely values of chip thickness when the micro cutting is preponderantly fragile for both materials studied. For values of h_{eq}< 0.5 [μm] it can be noted that the values of roughness parameters obtained when processing zirconium oxide are smaller than those obtained when processing alumina. This arrangement is explained by the existence of two different micro cutting mechanisms corresponding to two materials (in the case of zirconium oxide, for chip values smaller than (0.5 ... 0.6) [μm], the micro cutting is mainly ductile as compared to that corresponding to alumina which is predominantly fragile regardless of the chip size).

CONCLUSIONS

Peculiarities of the cutting processes differ depending on the processed material, namely on the material toughness.

-in the case of materials with high toughness (group of which zirconium oxide is part), processing is characterized by the existence of two different cutting mechanisms. For values of the grinding regime parameters (vd, vp and t) which determine the values of the equivalent thickness of the chip h_{eq}< 0.5...0.6 [μm], high values of specific energy and the micrographs of processed surfaces allow us assert that processing by cutting is performed in a mainly ductile regime by the classical process of shearing. This type of micro cutting will lead to obtaining a processed surface characterized by a better roughness and without too many