Advanced ceramics: evaluation of the ground surface
(Cerâmicas avançadas: avaliação da superfície polida)

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Abstract

The aim of this research is to evaluate the influence of grinding and cutting conditions on surfaces of advanced ceramics ground with diamond grinding wheels containing a binding resin bond. The quality surface was analyzed by Scanning Electron Microscopy (SEM).
Keywords: grinding of advanced ceramics, diamond grinding wheels, G ratio.

Resumo

O objetivo desta pesquisa é a avaliação da influência das condições de usinagem na superfície gerada de cerâmicas avançadas retificadas com rebolo diamantado com ligante resinóide. A qualidade superficial foi analisada utilizando-se a Microscopia Eletrônica de Varredura (MEV)
Palavras-chave: *moagem, rebolos adiamantados, razão G.*

INTRODUCTION

Advanced ceramics have been applied in the manufacturing of workpieces under great and complex demands, in which materials of high performance are required due to the unique combination of properties. It is a matter of especial situations, since the use on a large scale comes up against some restrictions with regard to the economic and technical justification.Among other applications such as in the nuclear industry and satellites, ceramic workpieces are also applied. Besides others, applications in bearings for nuclear use of ultra-accuracy mechanic and satellites should be noted; the same applies automotive pieces (sensors, insulators, catalyzers, pistons, jackets, inserts, valves, linings); biocompatible implants (coxofemoral and dental prosthesis, bone replacement, cardiac valves); parts that can wear out (valve seat, mechanical seals, guides); refractories (insulators, rocket lining plates, military linings, furnace components), substrates, bases and insulators in electric components.

The manufacturing process of these workpieces involves powder compaction, followed by machining, sintering and final machining using abrasive processes [1]. The abrasive machining involves grinding, polishing and lapping with abrasive diamond.

The high cost of machining is the main obstacle to large-scale ceramic industrial manufacturing [2]; thus, we expect to increase the machining rates without damaging the mechanical properties of the product. However, to achieve this, it is necessary to understand the material removal mechanism on a microstructural scale and the relation between the microstructure and the formation of a damaged layer by the machining process.

The grinding process, the most important step of the advanced ceramic machining process, is highly complex and involves the contact between a large number of abrasive particles with the surface of the workpiece. The grinding process allows a precise dimensional control, and a good superficial finishing, but requires ability from the machine operator, and the decision making concerning the final quality. Furthermore, the grinding characteristics of advanced ceramics are very different from the ones for metals [3], and it is still necessary to perform further studies to achieve a more comprehensive understanding and a better control of their parameters;. studies in this regard have already been made.

The understanding of the material removal mechanisms and its consequences in the mechanical properties, cost and surface quality is extremely important for the advanced ceramic manufacturing, in which failures like superficial and internal cracks, non-uniform voids, shapes and sizes of grains, act as tension amplifiers, making ceramic products fracture at tensions below the acceptable level.

This paper presents a study revealing the influence of the conditions on the ground surface of advanced ceramics, according to the variations in the equivalent cutting thickness $\mathbf{h_{eq}}$, analyzed by Scanning Electron Microscopy (SEM).

METHODOLOGY

To evaluate the behavior of the ground surface of one type of advanced ceramics (alumina 96%), when using a diamond grinding wheel containing a binding bond, a trial banktest setup was made up through the instrumentation of a plunge-grinding machine, model Ret-line.

At the trials, different test conditions were applied, in which cutting parameters were modified and the integrity of the ground ceramics was evaluated, by analyzing the surface using SEM. The relation between the surface damage and the cutting condition was analyzed by the measurement of some cutting variables: tangential cutting force during grinding $\mathbf{F_{tc}}$ [N], acoustic emission **EA** (V) and **G ratio** (relation between the total volume of ground material and the volumetric wear of the cutting tool). These

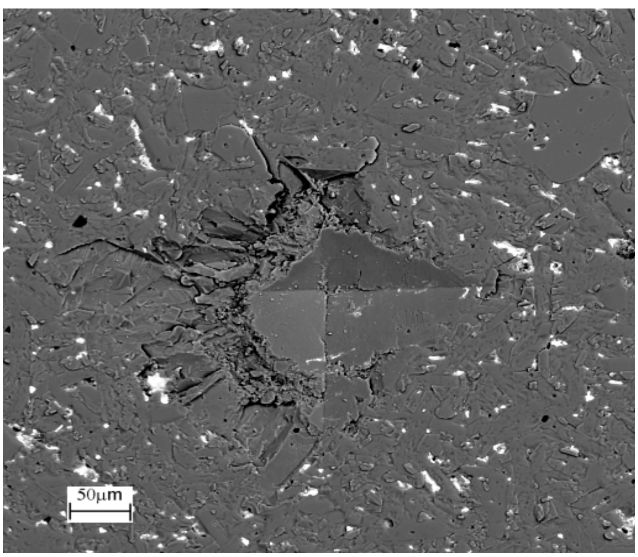

Figure 1: Vickers´s identation at alumina 96%, P, 98 N [4].
[Figura 1: Impressão do penetrador Vickers em alumina 96%, P, 98 N [4]]

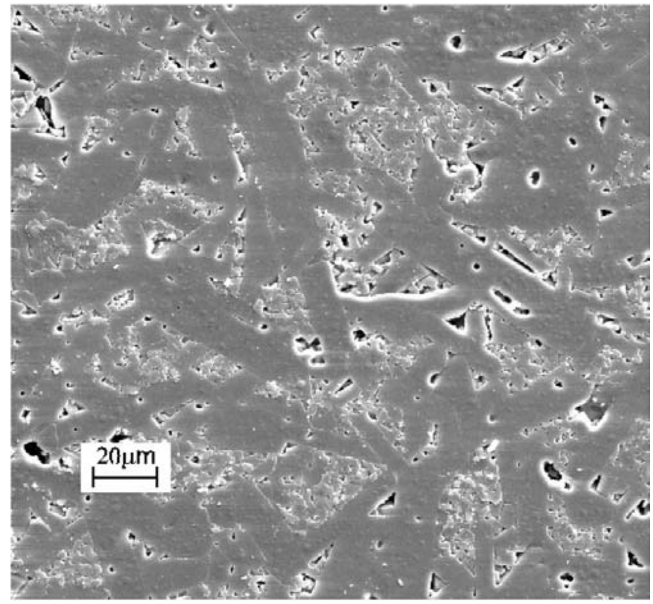

Figure 2: Surface of the alumina 96% before grinding (500x) [4].
[Figura 2: Superfície da alumina 96%, antes da usinagem (zoom 500X) [4]]

cutting variables were determined by using the developed trial bank test setup.

In order to characterize the surface's damage of the ground alumina, preliminary trials tests were done. At these trialtests, the cutting conditions used at the final trials tests were determined. These ones are shown in Table I, where **a** is the depth of cut (µm), $\mathbf{V_S}$ the grinding wheel cutting speed (m/s), $\mathbf{V_W}$ the workpiece speed (mm/s).

The diamond grinding wheel used is specified by D 107 N115 C50. The letter D indicates the type of grain being utilized

Table I - Cutting conditions.
[Tabela I - Condições de corte.]

Trial	h_{eq} (µm)	a (µm)	V_S (m/s)	V_W (mm/s)
1	0.15	80	35	65.63
2	0.20	80	35	87.50
3	0.25	80	35	10.40

***a:** depth of cut (µm); $\mathbf{V_S}$**:** grinding wheel cutting speed (m/s); $\mathbf{V_W}$**:** workpiece speed (mm/s)*

Table II - Cutting variable results.
[Tabela II - Resultados das variáveis de corte.]

Trial	h_{eq} (µm)	F_{tc} (N)	EA (V)	G
1	0.15	1.67	1.72	236.8
2	0.20	1.53	1.64	509.7
3	0.25	1.48	1.45	767.7

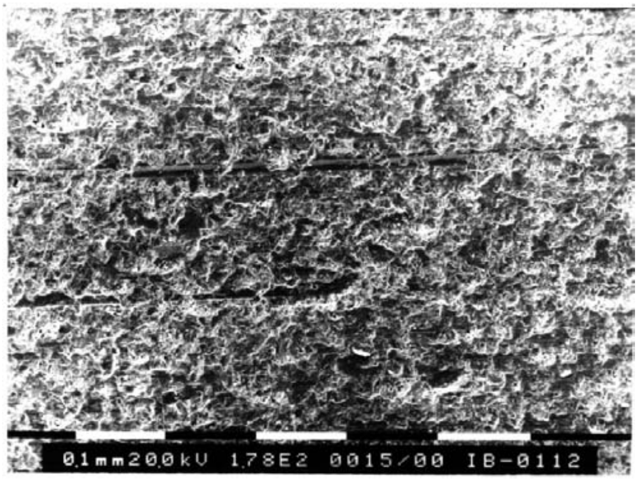

Figure 3: Ground surface $\mathbf{h}_{eq}$ = 0.15 μm.
[Figura 3: Superfície retificada $\mathbf{h}_{eq}$ *= 0,15 μm.]*

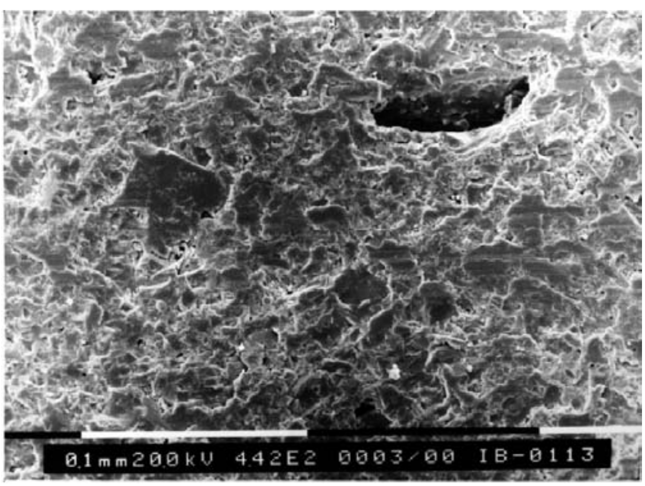

Figure 4: Ground surface $\mathbf{h}_{eq}$ = 0.20 μm.
[Figura 4: Superfície retificada $\mathbf{h}_{eq}$ *= 0,20 μm.]*

(diamond), the number 107 refers to the grain-size being used (107 μm), the letter N the hardness of the grinding wheel (average hardness), the value 115 indicates the type of diamond, and C50 refers to the concentration of grains.

The trial body test specimen was made in the rectangular shape, in standard dimensions for this study, 120 mm long x 5 mm thick x 50 mm high, from alumina 96%. It means that 96% corresponds to α-alumina (α-Al_2O_3) and the remaining 4% are made of fluxes, such as SiO_2, K_2O, Na_2O, MgO and CaO. These fluxes are additives, which shall reduce the sintering temperature, increase the densification and limit the grain size growing. The apparent average density (D_{ap}) was 3.73 g/cm^3 or 95.1% of the theoretical density (D_{th}), which is equal to 3.92 g/cm^3. Its Vickers' hardness was 3.8 Hv (98N) (GPa), or 380 Hv in kg/mm^2. The indentation obtained by Vickers' macro-hardening is shown in Fig. 1.

In Fig. 2, it's possible to observe the alumina surface before grinding. It was observed that a fraction of the grains presented

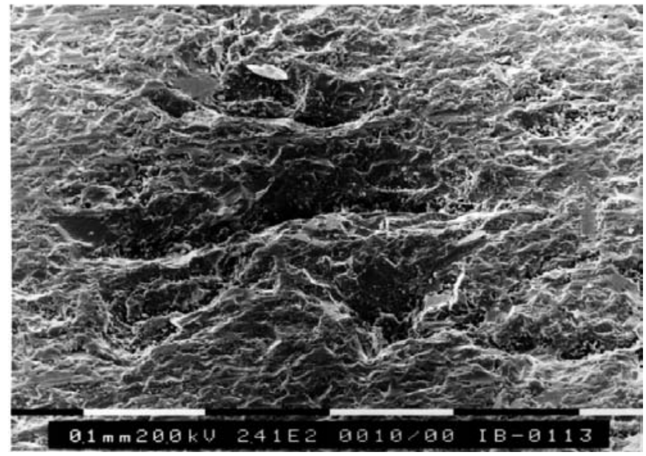

Figure 5: Ground surface $\mathbf{h}_{eq}$ = 0.25 μm.
[Figura 5: Superfície retificada $\mathbf{h}_{eq}$ *= 0,25 μm.]*

a preferential growth in specific directions. The average grain size was about 10 μm.

RESULTS AND DISCUSSION

Table II presents results related to the cutting variables measured using the trial bank developed.

Samples of each trial were analyzed using a Philips SEM microscope, model 515. The samples were covered with gold, 10 nm thick.

Figs. 3, 4, and 5 present the ground surface of trials using $\mathbf{h}_{eq}$ equal to 0.15, 0.20 and e 0.25 μm, respectively.

Fig. 5 presents the most fragmented surface, with the highest numbers of cracks when compared to Figs. 4 and 3. At this test, the lowest values of $\mathbf{F}_{tc}$ and **EA** and the highest value of **G ratio** (see Table II) were attained. It confirms the prevailing of the fragile mechanism of material removal, which causes an increase in the **G ratio** (by decreasing the abrasive wear of the disc), but it causes a decrease in the final quality of the ground surface and in its surface integrity

CONCLUSIONS

Analyzing the results, the cutting conditions had a significant influence on the final quality of the ground surface and on its surface integrity. As the rate of material removal is increased (with the increase of the parameter $\mathbf{h}_{eq}$) there is a decrease in the quality of the ground surface, increasing the number of cracks and the surface roughness. In this case, during grinding, the surface becomes more fragmented, resulting in lower cutting forces (less energy is necessary to remove the material already fragmented), keeping the grains fixed to the wheel for longer periods, decreasing the abrasive wear of the disc's wear (increasing the **G ratio**).

The SEM micrographs of the ground surface E confirmed the results of $\mathbf{F}_{tc}$, **EA** and **G ratio** obtained using the trial bank developed. The SEM analysis was extremely important to qualify the surface damage as a function of the cutting condition adopted. This qualification is extremely necessary, because the quality of the advanced ceramics can be improved if the right cutting conditions are chosen. Decreasing the surface damage, the flexural strength of the advanced ceramics can be improved, increasing its quality and life in service.

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REFERENCES

[1] M. Inoue, Y. Kihara, Y. Arakida, "Injection moulding machine for high performance ceramics", Interceram 2`89, J. Ceram. Rev. **2** (1989) 53-57.
[2] H. H. K. Xu, S. Jahanmir, "Simple technique for observing subsurface damage in machining of ceramics", J. Am. Ceram. Soc. **77** (1994) 1388-1390.
[3] J. E. Mayer Jr., G. P. Fang, "Diamond grinding of silicon nitride", NIST SP 847 (1993) 205-222.
[4] C. Fortulan, "A Influência dos métodos de injeção de prensagem isostática no desempenho de cerâmicas estruturais", Tese de Doutorado em Engenharia Mecânica, S. Carlos, EESC-USP (1997) in Portuguese.
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