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Optimization of finishing process during polishing of Zerodur

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Abstract

The abrasive machining processes applied to obtain surfaces with optical quality are based on the removal of the surface damage after the cutting process and the form generation. These damages are essentially a set of lateral, radial and median surface and subsurface microcracks. For the removal of such damages, a sequence of abrasive grains from the largest to the smallest size is employed. In this inverstigation, ZERODUR® samples were subjected to indentation and Scratching tests in order to study the brittle-ductile transition and material removal mechanisms. Indenter penetration depth 0.46 and 0.59 µm under test loads of 5g and 10g, respectively, were probed using an optical profiler. Scratching tests were then carried out and the results showed that the ductile to brittle transition took place in the range of 0.315 and 0.45 µm. These results were used to predict the performance of the subsequent grain size to remove the damage for each step. The influence of the grain size upon damage removal was evaluated by mean of two sets of samples lapped/polished using the same time period for both sets. Using an optical profiler, after each step, three different parameters were obtained: surface roughness, *total volume displace* (Qw - given in µm^3) and the surface index (i.e., the ratio between surface area to lateral area). These parameters were used to assess defect removal at each step. The results demonstrate a nonlinear relationship between the grain size used and the amount of damage removed at each step, decreasing the lapping time down to 40% which turns to be significative when large wopieces are processed, representing time reducing in the order of days.

Zerodur, lapping, polishing, surface damage removal, process performance

1. Introduction

In the lapping and polishing processes, as known, the surface of the material is ground by abrasive grains. The substantial difference between the two processes regards to the size of the grains and type of matrix used [1, 2, 3]. The material removal process can be done by an abrasive that is bonded by a binder, is kept loose or is suspended in liquid (water is usually used for this function). The process of abrasive machining is very complex because it is not deterministic and involves several processes of material removal until a surface of high quality and free of cracks is obtained [4]. This paper presents a study on the machining of ZERODUR® glass ceramic composite elements by means of conventional polishing and lapping. More specifically, we aim to verify the damage levels caused by different sizes of abrasive grains in the material removal process. For this purpose, the following variables were monitored during the tests: surface quality, machining time, water volume and surface index.

2. Experimental methodology

For the lapping and polishing tests, 6 samples with Ø25 mm and 4 mm of thickness were made in ZERODUR®. Samples were numbered and separated into two sets of three parts each. Samples from each set were glued with beeswax onto an aluminum support, as can be seen in Figure 1.

With the aid of indentation and scratching tests it was possible to determine features such as: hardness of the material, feed rate, critical depth of the britlle-ductile transition, etc. [5]. Indentation and scratching tests were carried out in order to define the depth of the britlle-ductile transition. Confronting the results obtained in the testsThe average values found in the indentations suggest that the transition is related to a depth of 0.59 µm or less, while the scratching tests pointed to a depth of less than 0.315 µm. If only the similarity between the scratching test and the material removal process were considered, this test would be enough to determine the depth of the transition. However, in the model described by Blake (1988), the contact surface of the tool in the scratching test is much larger than in the actual machining process, which results in a higher tension in the region of material removal. Thus, it is expected that a transition occurs at an intermediate depth between 0.315 µm and 0.59 µm.

Ater these tests, both sets of samples were machined by the conventional abrasive process (lapping and polishing).

Figure 1. Detail of the set with the three samples glued

To verify the action of the grain on the whole surface of the samples, two techniques were used: the technique of painting the surface to be machined, where it is observed if all the paint is removed during the machining process, and the subsequent visual inspection of the surface with the aid of light and lenses. If spots and scratches are found in the inspection performed with these techniques, this indicates insufficient machining.

2.1. Machining strategies

The first set was machined using a sequence of abrasives which is conventionally employed in machining processes of optical components with loose grains, i.e. # 400, 600, 800, 1500, 2000 and 3000 (22 µm, 16 µm, 12 µm , 5 µm, 4 µm and 1 µm respectively).

The second set received the same machining process, but started the process with abrasive # 600 and proceeded with the others.

The control of the thickness of material removed in each step was done with a submicrometric probe. The surface roughness, volumetric parameter and surface index were determined using an optical profilometer.

3. Results

The grains used for the normalization of the surfaces, that is, # 400 in set 1 and # 600 in set 2, caused peak-valley damages around 14 µm and 10.3 µm respectively. During the action of the subsequent (finer) grains, these damages are smoothed until an optical surface quality is reached. The Table 1 presents the results of surface roughness for the grain sizes used.

Table 1 – Roughness obtained x grain size

Grain size	Set 1		Set 2	
	Rt [µm]	Ra [µm]	Rt [µm]	Ra [µm]
#400	13.77	0.99	-	-
#600	11.55	0.95	10.28	0.76
#800	9.28	0.41	8.91	0.43
#1500	9.09	0.39	8.86	0.43
#2000	8.39	0.38	6.9	0.36
#3000	0.05	0.004	0.09	0.007

3.1. Volumetric Parameter Analysis

It was possible to observe a large variation in the volumetric parameter during the normalization of the surface with coarse grains, while with intermediate grain sizes there were no significant differences in this parameter. The same behaviour is observed for the roughness Ra and Rt, that is, they vary with coarse grains (# 400 and # 600) our with the finest grain (# 3000), but do not vary significantly with intermediate grain sizes. These results can be seen in Figure 2.

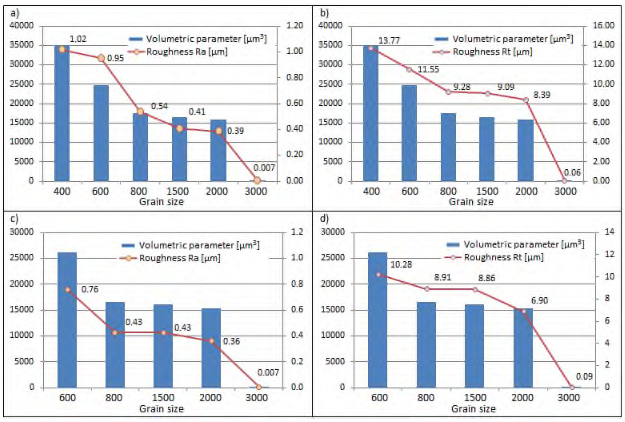

Figure 2. Graphs of the volumetric parameter [µm3] versus Ra and Rt. Details a) and b) set 1 and details c) and d) set 2.

3.2. Surface Index Analysis

As in the analysis of the volumetric parameter, it is possible to observe a great variation in the surface index during the action of the normalization grains, whereas for the intermediate grains there were no significant changes in this parameter. These results are presented in Figure 3.

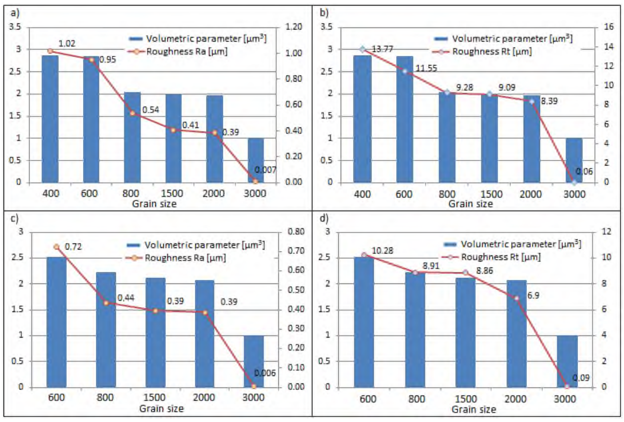

Figure 3. Graphs of surface index versus Ra and Rt. Details a) and b) set 1 and details c) and d) set 2.

4. Conclusions

This research investigated some parameters of the conventional abrasive machining processes applied to the ZERODUR® glass ceramic. Based on the observations of the measurements carried out, it was possible to verify that when the difference in grain size between the prior and the subsequent step is small, no significant improvement of the surface quality were probed. In this way, it is possible to infer that the process could be carried out in less manucaturing steps. A first step would involve to achieve dimension and form as well as elimination of surface damages, followed by a step of subsurface damages removal, finally, polishing. Thus, it was found that the time used for lapping could be reduced down to 40 % of the conventional time applied in this stage. This will impact positively when large workpieces ar to be manufactured by reducing the throughput time in order of days.

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