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Diamond wheel grinding performance evaluation of yttria stabilized zirconia – cubic and tetragonal phases

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Abstract

The objective of this paper is to assess the material removal response using different cutting conditions in ultraprecision diamond grinding of Yttria stabilized Zirconia with two different phases, tetragonal and cubic. The machined surfaces were analyzed by means of non contact 3D surface profiler and Micro Raman Spectroscopy. Sub micrometer range average surface roughness Ra was obtained for both phases. It is proposed the concept of the volume analysis estimation for comparison of material removal rate and material removal mode during machining. It is shown that the material removal may well be evaluated by means of "total volume displaced" as well as the 3D (Areal) surface texture S parameter Height called Sz. Micro Raman spectroscopy was used to probe phase transformation after machining. Results showed that a very narrow outmost layer undergoes phase transformation from tetragonal phase to monoclinic phase after machining. In the case of cubic phase this was not probed and the material removal is predominantly more brittle.

Type the keywords here: Machining performance, Yttria stabilized Zirconia, grinding, diamond wheel, areal surface texture height Sz.

1. Introduction

Structural ceramic materials such as Yttria-Stabilized Zirconia (YSZ), alumina, silicon nitride, silicon carbide present high strength, wear resistance, heat resistance, chemical inertness and light weight, and are considered strong candidates for many applications ranging from solid electrolytes for fuel cells and oxygen gas sensors up to storage capacitors in dynamic random access memories [1]. In addition, structural ceramics have found applications where high temperature and high stress are present such as turbine blades, heat engine components, wear parts and cutting tools [2]. High wear resistance, strength and fracture toughness are inherent properties of Yttria partially stabilized tetragonal zirconia polycrystal (Y-TZP), which make them feasible as a structural engineering ceramic material and is well established as implant material [3]. The components made of YSZ generally demand high dimensional accuracy and surface finish. Based upon this, the application of shaping processes such as machining technologies has received more attention and contributions lately. Grinding with diamond wheels is the most considered material removal process to be applied to cut structural ceramics. Furthermore, performance decrease (strength degradation) and consequent reliability function deterioration of structural ceramic components may as well be seriously compromised by the typical damages induced by grinding. Ceramics normally present very high hardness and due to its policrystalline microstructure may respond in very different ways in terms of material removal mechanism. In this case, the brittle to ductile transition may also be dependent on its sintered phase. The objective of this paper is to assess the material removal response using different cutting conditions in diamond wheel grinding of Ytria stabilized Zirconia with two different phases, tetragonal and cubic.

2. Experimental Method and Materials

Grinding experiments were performed on a ultraprecision machine Rank Pneumo ASG 2500. A V-shaped 75mm diameter resin bond diamond-grinding wheel, with an average grit size 400 mesh was used in the present study. The grinding tests were conducted under the conditions of grinding speed (*vs*) of 19.63 m/s, depth of cut (ap) of 0.5 and 1.5 μm, the feed rate of 0.05 and 0.15 μm/rev, and the part moves against the wheel at a constant workspeed (v_w) 1000rpm. During grinding, a 16:1 mixture solution of a water-based coolant was applied from the nozzle to the grinding zone at a flow rate 2.0 l/min.

The study was conducted on yttria stabilized tetragonal and cubic zirconia polycrystal. The work materials were produced from TOSOH Corporation Zirconia Powder (TZ-3Y-E Lot No.: Z305181P and TZ-8YS Lot No.: S805603P) isostatically pressed (200 MPa) and sintered at 1400 °C for 2 h. The fabricated workpieces were in the form of discs with 20mm in diameter and 5 mm thickness. The average grain size for the 3Y-TZP was 0.35237 ± 0.07663 μm. The 8Y-CZP sample presented slightly large grain size; the average grain size for the 8Y-CZP was 0.44643 ± 0.07822 μm. The surface integrity of machined surface of 3Y-TZP and 8Y-CZP were assessed using a VEECO non-contact high-resolution profiler Wyko NT 1100. The scanning areas for all measurements were kept constant at 45 x 59 μm^2. Four measurements were obtained at each 90° around the machined surface disc and average and standard deviation were calculated. For surface finish evaluation, two parameters were obtained to know: *average roughness* Ra and 3D (Areal) surface texture S parameter Height called Sz. Sz stands for the *maximum height of the surface*, and is found from Sz = Sp – Sv. (Sp is the *maximum peak height*, is the height of the highest point, Sv, the *maximum valley depth*, is the depth of the lowest point - expressed as a negative number)[Note 1]. The latter parameter was used along with a "volume analysis" provided by the optical profiler software Vision 4.2. The volume analysis estimates the volume occupied by the space between a surface and a plane parallel to the reference plane of the surface that intersects the maximum height of the surface [4]. According to the user's guide [5] the definition of the Total Volume displace (Qw - given in μm^3) it the volume of "water" that the surface must hold in order to completely "submerge" it. The Raman measurements are performed using an T64000 Jobin-Yvon spectrometer to probe of disorder effects, the 514.5 nm line of an argon ion laser was used. The laser power was kept low at about 0.5 mW, in order to avoid heating effects.

3. Results and Discussion

Figures 1 and 2 show a sequence of Raman spectra for both yttria stabilized Zirconia cubic and tegragonal phase, before and after machining, respectively. Figs. 1a and 1b show that both Raman spectra present the same characteristic peaks (at *150, 250, 360, 480 and 600* cm^{-1} [5]) attributed for the cubic phase and no transformation took place after machining.

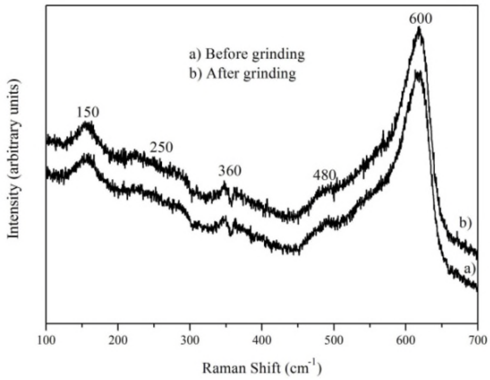

Figure 1. Raman spectra of yttria stabilized Zirconia cubic phase; a) before grinding, and; b) after grinding (f=0.05 µm/rev and 0.5 µm).

Figure 2 a) and 2b) show a sequence of Raman spectra for Yttria stabilized Zirconia tetragonal phase, before and after machining. Differently from the former spectra, the spectrum obtained after machining present, besides the characteristic peaks attributed for tetragonal phases (at 146, 270, 318, 458 and 648 cm^{-1} [5]) it also reveals the following peaks at 175, 190, 348, 381 534, and 619 cm^{-1}, which are assigned to monoclinic phase [5].

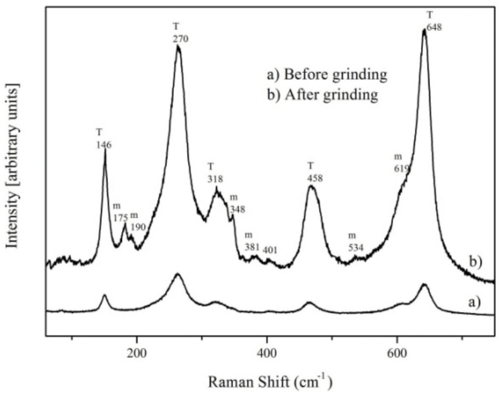

Figure 2. Raman spectra of yttria stabilized Zironia tetragonal phase; a) before grinding, and; b) after grinding (f=0.05 µm/rev and 0.5 µm).

Table 1 presents the results of surface finish for the 3YTZ and the total volume displacement values. The surface finish of the samples machined under the different cutting conditions presented a ductile material removal response and very low surface finish. The total volume displaced value increased with the increase of material removal. This was attributed to the depth of the grooves left in the surface after machining, once no sign of brittle damage was probed.

Table 2 presents the results of surface finish for the 8YCZ and the total volume displacement values. In this case, as the cutting conditions were increased, the presence of microcracks and pits in the surface increased. This contributed to the increase in surface finish values as well as in the total volume displacement. The values are in the order of 200 up to 300% larger in this case, which are attributed mainly to the brittle involved during material removal.

The results showed that it is possible to assert that the material removal mode is dependent of the crystalline structure of the yttria stabilized Zirconia. From a machining economic point of view it is possible to assert that the cubic structure present a more efficient material removal rate under the same cutting conditions aided by the brittle response involved during machining. This corroborates with the measured values of Sz and total volume displaced (Qw) increase with the increase in material removal rate for the 8YCZ sample. However, the results showed that it is possible to achieve a very low surface finish for the 8YCZ once very low depth of cut and feed are applied. This means that the material removal rate has to be very low in order to achieve a damage free surface finish. From a surface finish stand point, the 3YTZ sample presented much better results along with damage free machined surface. In the case of the 3YTZ any of the conditions used showed any sign of brittle response from the cut surface. The only change was the depth of the ductile machined grooves observed in the tetragonal phase sample, which increased with the increase of the cutting conditions.

Table 1. Surface finish values (Ra and RZ) and Total Volume displaced (Qw) for Ytria stabilize Zirconia - Tetragonal phase.

	3YTZ f = 0.05 µm/rev		***3YTZ f = 0.15 µm/rev***	
Depth cut	**0.5 µm**	**1.5 µm**	**0.5 µm**	**1.5 µm**
Ra **(nm)**	58.5±4.3	73.6±13.2	119.6±24.9	115±6.87
Sz **(µm)**	0.519±0.8	0.763±0.07	1.05 ±0.15	1.02±0.14
Qw **(µm³)**	152.6±11	191.5±34.3	313.3±65.5	300.7±18.3

Table 2. Surface finish values (Ra and RZ) and Total Volume displaced (Qw) for Ytria stabilize Zirconia - Cubic phase.

	8YCZ f = 0.05 µm/rev		***8YCZ f = 0.15 µm/rev***	
Depth cut	**0.5 µm**	**1.5 µm**	**0.5 µm**	**1.5 µm**
Ra **(nm)**	93.1±7	165±28	258±24	360±115
Sz **(µm)**	1.525±0.23	2.85±0.83	3.51 ±0.07	4.39±0.77
Qw **(µm³)**	241.12±18	429.04±73.5	655.7±60.72	938.47±299

4. Final considerations

In this study, we investigated the machining characteristics of cubic and tetragonal Yttria stabilized zirconia during ultraprecision grinding, using a resin bond diamond wheel, with different depths of cut and feedrates. Differently, the tetragonal phase presented ductile response at all cutting conditions applied. The 3D area surface texture Sz parameter height versus material removal rate (Qw) was used in order to assess effect of microcracks upon surface finish. The values of Sz vary significantly for the two samples. Therefore, the values were larger for the cubic phase zirconia ceramic. The cubic phase Yttria stabilized Zirconia presented a scale factor for the brittle -to- ductile transition. The lower the cutting condition (f x ap) the lower was the presence of damage in the surface such as pits and/or microcracks. In addition, the material removal mode contributes intrinsically to an increase in the material removal rate for the cubic. Micro Raman spectroscopy results showed no transformation for the cubic phase. However, the tetragonal phase presented some characteristic peaks for monoclinic (m-phase) Zirconia. More investigation has to be made in order to be more conclusive on this phase transformation. This will be object of future study.

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Note 1. Earlier standards referred to Rz as a average of the 10 highest to 10 Lowest Points and other variations. The ISO community agreed for the newer standard, ISO 25178-2 to establish Sz as strictly the peak to valley height over a areal measurement) – According to Michigan Metrology [13] – Glossary of Surface Texture Parameters, 2009.