Ground Surface of Y-TZP

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Y-TZP の研削加工面

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A monoclinic phase is frequently seen on fractured surfaces of yttria stabilized tetragonal ZrO_2 polycrystals (Y-TZP). In this study, Y-TZP materials were ground by diamond grinding wheels of different grain sizes and the effects of grinding on the structure in the surface layers was examined from the viewpoint of the grinding mechanism. It was found that a compressive layer was formed on the ground surface and bending strength was increased by grinding under specific conditions.

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1. Introduction

Y-TZP is characterized by increased toughness induced by tetragonal to monoclinic (T-M) transformation and recently it has attracted special interest as a structural material. Grinding by diamond grinding wheel is an essential process for Y-TZP to give it both required shape and good finish.

It has been established that the monoclinic phase is formed on the fractured surface of Y-TZP by T-M transformation. Since the ground surface consists of microfractures formed by the action of abrasive cutting edges, it can be expected that the monoclinic phase exists in it. It was pointed out by Gupta¹⁾ that the strength of Y-TZP was improved when its surface was ground using SiC abrasive paper. Walls et al.²⁾ reported that compression stresses existed in the ground surfaces of various kinds of ceramic materials. Hasegawa³⁾ found that the rhombohedral phase developed on the surfaces of TZP when it was polished by SiC abrasive paper. However, the effects of grinding conditions on the properties of ground surfaces have not yet been fully examined. In this study, grinding conditions affecting on the strength of TZP were studied and the mechanism is discussed based on microstructural data of the ground surfaces.

2. Experimental procedure

2.1 Preparation of Y-TZP specimens

For raw material for the specimens, zirconia powder with Y_2O_3 content of 3 mol% and particle

size of 270 Å (Tōyō Sōda Co., TZ-3 Y) was adopted. After this powder was mixed with 3 wt% binder (Chukyo Yushi Co., D-830) in an alumina ball mill, the mix was granulated to 80 μm particle size using a spray-dryer, then pressed into 60×25×4.5 mm bars with 800 kgf/cm². The pressed green specimens were heated at a rate of 300°C/h up to 1500°C, then kept at this temperature for 3h.

These specimens consisted of fine particles of the tetragonal phase and the content was estimated to be 91% by X-ray method.⁴⁾

2.2 Grinding conditions

Resin-bonded diamond grinding wheels were used for the surface grinding tests. Four kinds of wheels with different grain sizes, 270/325, 170/200, 80/100 and 30/40, and fixed concentration of 75% were prepared. All diamond grinding wheels were rotated at a peripheral wheel speed of 250 m/min, and were dressed with a vitrified # 120 silicon carbide rotary wheel at 500 m/min peripheral speed, then supplied for the grinding tests.

Both sides of test pieces were ground using the diamond grinding wheels under the following grinding conditions :

(a) Grinding machine : horizontal spindle reciprocating table surface grinding machine, Type Okamoto PSG-52 A, 2.2 kW,

(b) Type of grinding : surface grinding of plunge cut type without sparking-out process,

(c) Wheel size and shape : straight wheel, 180 mm outside diameter × 10 mm thick × 31.75

mm hole diameter,

(d) Peripheral speed : 1600 m/min,

(e) Table speed : 10 m/min,

(f) Down feed rate : 10 $\mu\text{m/pass}$,

(g) Coolant : water soluble type W-2, 10 liter/min.

Because a value of grinding force, which is composed of normal force F_n and tangential force F_t , is the most appropriate value to evaluate grindability, the components of the grinding force were measured during grinding down to 3 mm ground depth.

2.3 Test procedure

The test pieces, of which both sides were ground so as to be 3 mm thick, were cut off by a diamond cutting wheel to 40 mm long by 4 mm wide. Altogether 10 bending test pieces for each grinding condition were subjected to a three-point bending test, with the load applied to the ground surface.

To evaluate compression stresses in the surface layers of the specimens, the X-ray diffraction method was used. In this method, changes in (113) lattice spacing caused by residual stresses were measured using $\text{CrK}\alpha$ radiation. Residual stress was calculated with Young's modulus $E = 2.10 \times 10^4 \text{ kgf/mm}^2$ and Poisson's ratio $\nu = 0.28$, using the following equation⁵⁾ :

$$\sigma = -\frac{E}{2(1+\nu)} \cot \theta \frac{\partial 2\theta}{\partial \sin^2 \psi}$$

Surface roughness was measured and X-ray patterns were recorded of scanning the ground surface in the range $2\theta = 37.5\text{--}32^\circ$.

3. Results and discussion

Grinding force during grinding is shown in

Fig. 1. Change in grinding force with grinding depth.

Fig. 1. Both grinding forces, F_n and F_t , remained unchanged with grinding time. No significant change in tangential force was observed although grinding wheels were changed. This can be taken that the amount of material removed and heat generated were almost the same throughout the experiment. Normal force for the grinding wheel of finer grain size showed a lower value except in the case of 270/325 wheel, where very high normal force was observed.

Bending strength, residual stress and surface roughness of Y-TZP test pieces are listed in Table 1. As compared with as-fired, the bending strengths of the ground specimens increased with the exception of one specimen ground with a very coarse grinding wheel. The results shown in this table also reveal that both compression stress and surface roughness increase with increase of wheel grain size.

Table 1. Test results.

Sample	Bending strength (kgf/mm^2)	Compression stress (kgf/mm^2)	Roughness R_{max} (μm)
as-fired	86.1	5.4	3.5
270/325	90.9	18.8	3.4
170/200	94.1	42.6	8.0
80/100	93.7	89.7	8.2
30/40	75.5	186.4	15.7

Fig. 2. X-ray diffraction patterns of as-fired and ground surfaces.

X-ray diffraction patterns of as-fired and ground surfaces are shown in Fig. 2. As compared with that as-fired, (111) reflection profiles of the tetragonal phase on ground surfaces were broader and more asymmetric, and the peak positions shifted to lower angle side. At the same time, (111) reflection intensity of the monoclinic phase became weak. Gupta¹⁾ found generation of the monoclinic phase on a ground surface, whereas Hasegawa³⁾ detected a rhombohedral phase on a polished surface. However, Lanteri et al.⁶⁾ reported that no rhombohedral phase was found in any ZrO₂ ceramics that they so far has studied. Urabe⁷⁾ observed expansion and disorder of the lattice on the ground surfaces of the ceria-yttria-TZP. The compression stress may be caused by such abnormal changes in lattice spacing. With increasing wheel grain size, these changes became obvious and compression stress in the ground surface layer was increased.

Both grinding force components, F_n and F_t , are measured as an accumulation of single grinding force acting on a cutting edge, f_n and f_t . The average number of abrasive grains per unit area, N_p , is given by the following equation:

$$N_p = 6 v_g / \pi d_v^2$$

where v_g is volumetric grain ratio and d_v is average grain diameter. Assuming that the protruding height of abrasive grain from bond level is constant, f_n and f_t can be calculated from N_p and grinding forces components, F_n and F_t , shown in Fig. 1. Measured and calculated data are listed in Table 2. F_n showed the highest value in the case of 270/325 grinding wheel but F_t was almost the same in all cases. However, both f_n and f_t increased with increase in grain size. During grinding, the material just under the cutting edge suffers an extraordinary distortion by grinding force. Therefore, high grinding force with coarser grain causes a large compression stress to the ground surface. When ground by 30/40 grinding wheel the compression stress caused to the surface of Y-TZP was greatest, but the bending strength showed the lowest value. The very low bending strength in the case of 30/40 grinding wheel is considered to result from larger

Table 2. The theoretical average number of grain per unit area (N_p), average grinding force (F_n , F_t) and calculated grinding force acting on a cutting edge (f_n , f_t).

	N_p	F_n (kgf/mm)	F_t (kgf/mm)	f_n (kgf)	f_t (kgf)
270/325	576	13.34	1.68	0.02	0.003
170/200	294	6.84	1.56	0.02	0.005
80/100	56	8.64	1.62	0.15	0.029
30/40	9	11.16	1.68	1.24	0.287

crack length which is inferred from roughness listed in Table. 1.

4. Conclusions

Y-TZP ceramic materials were ground by grinding wheels of various diamond grain sizes and the following conclusions were obtained:

(1) Grinding force acting on a cutting edge increased with increase in grain size.

(2) Changes in compression stress and surface roughness were consistent with changes in grinding force.

(3) Bending strength showed the highest value for the specimen ground by 170/200 grinding wheel and the lowest value for that ground by 30/40.

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