Textures and Microstructures, 1991, Vols 14–18, pp. 409–414
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TEXTURE FORMATION IN THE SURFACES OF GROUND TETRAGONAL ZIRCONIA POLYCRYSTALS

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ABSTRACT

Texture development, changes in crystal structure and residual stress in the surface layers of yttria-doped tetragonal zirconia polycrystalline (Y-TZP) ceramics unidirectionally ground with SiC abrasive papers were investigated using various X-ray diffraction techniques. The formation of the rhombohedral phase and a little amount of the monoclinic phase by the stress induced transformation was observed in the ground surfaces. Grinding brought about not only the transformation but also the alignment of a **c** axis along the direction normal to the ground surface in the tetragonal phase, which was due to ferroelastic domain switching under stress applied by grinding. For the roughly ground and subsequently annealed Y-TZP, the development of a (001)[110] texture was closely associated with the stress induced transformation into the rhombohedral phase. A remarkable increase of flexural strength with grinding may be caused by compressive residual stress which arises through the transformation in the surface layer.

INTRODUCTION

Zirconia ceramics are well known to exhibit high toughness which results from the stress induced transformation from a tetragonal (t) to a monoclinic (m) polymorph near the crack tip. Recently, Virkar and Matsumoto[1] reported that the development of a (001) texture was observed in the ground surfaces of ceria-doped tetragonal zirconia polycrystals with no transformation into the m phase and it would occur on the basis of ferroelastic domain switching which was the conversion between one of the **a** axes and a c axis in the *t* phase, and they proposed domain switching as a toughening mechanism in zirconia ceramics. It was, however, presented by Li *et al.*[2] that the significant contribution of domain switching to toughness was not likely to be expected because of a high critical stress for domain switching. The formation of a metastable phase with the rhombohedral (*r*) structure in the unidirectionally ground surfaces of yttria-doped tetragonal zirconia polycrystals (Y-TZP) was also observed with the formation of a (001)[110] texture[3]. In this work, the textures formed by unidirectional grinding have been measured in the surface layers of Y-TZP, and the change in structure with grinding and subsequent annealing in the ground surfaces have been investigated in detail using X-ray diffraction in order to know whether the $t \rightarrow m$ and $t \rightarrow r$ transformations occur by grinding.

EXPERIMENTAL PROCEDURE

Y-TZP sheets containing 5wt%Y_2O_3 were prepared by sintering at 1500°C and fine polishing. They were unidirectionally ground with SiC abrasive papers and annealed at 1300°C for 3.6ks. X-ray diffraction profiles in the ground surfaces were measured using CuKα radiation to identify transformed phases due to grinding. Three pole figures (111), (002) and (200) for the *t* phase were determined by the reflection method using CoKα radiation. Furthermore, X-ray residual stress measurements in the ground surfaces were made at a peak of *t*(026) by the side-inclination method using CuKα radiation. In order to estimate toughness, three-point bend tests in which the direction of tensile stress applied by bending had angles of 0°, 45° and 90° to the grinding direction were carried out on a 15mm span by using test pieces with a section of 6mmx0.5mm.

RESULTS

Figure 1 shows the variations in X-ray diffraction profile of Y-TZP with grinding and annealing. For ground specimens, broadening to a lower angle side is observed at (111), (202) and (113) peaks compared with an initial material. It is more pronounced as the number indicating roughness of an abrasive paper decreases, that is, abrasive papers become rougher. In addition, grinding with rougher abrasive papers brings about the appearance of the *m* phase and the reversal of intensities of (002) and (200) peaks. The latter is maintained even after annealing at 1300°C, though the above broadening and the *m* phase disappeared. The broadening to a lower angle side at specified peaks implies the existence of the *r* phase as reported by Hasegawa[3,4]. The separation of overlapped peaks in X-ray diffraction profiles was performed by the use of a computer. The result shown in Figure 2 can prove the formation of the *r* phase which is caused by the stress induced transformation during grinding. The lattice constants determined from diffraction angles are a=0.5096nm, c=0.5179nm for the *t* phase and a=0.3672nm, α=59.5° for the *r* phase.

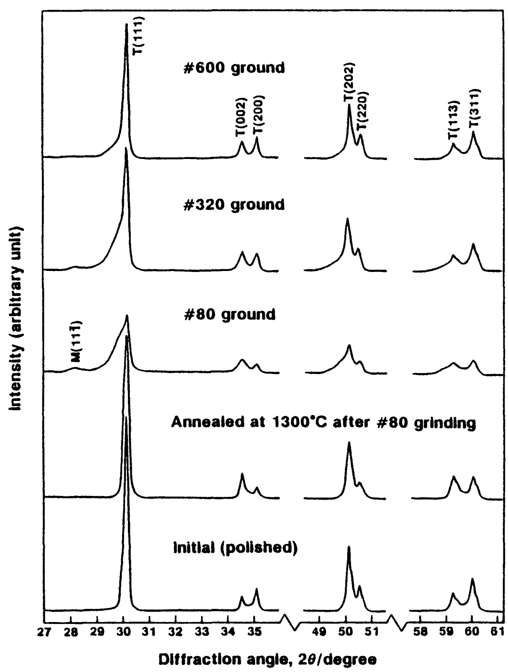

Figure 1 X-ray diffraction profiles for the ground surfaces of Y-TZP.

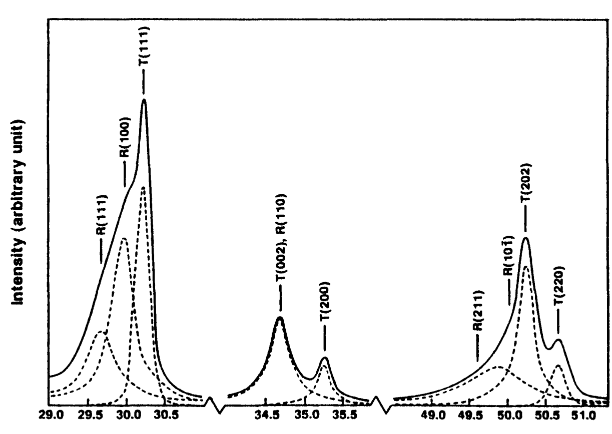

Figure 2 X-ray diffraction profiles for the #80 ground surface of Y-TZP showing peak separation.

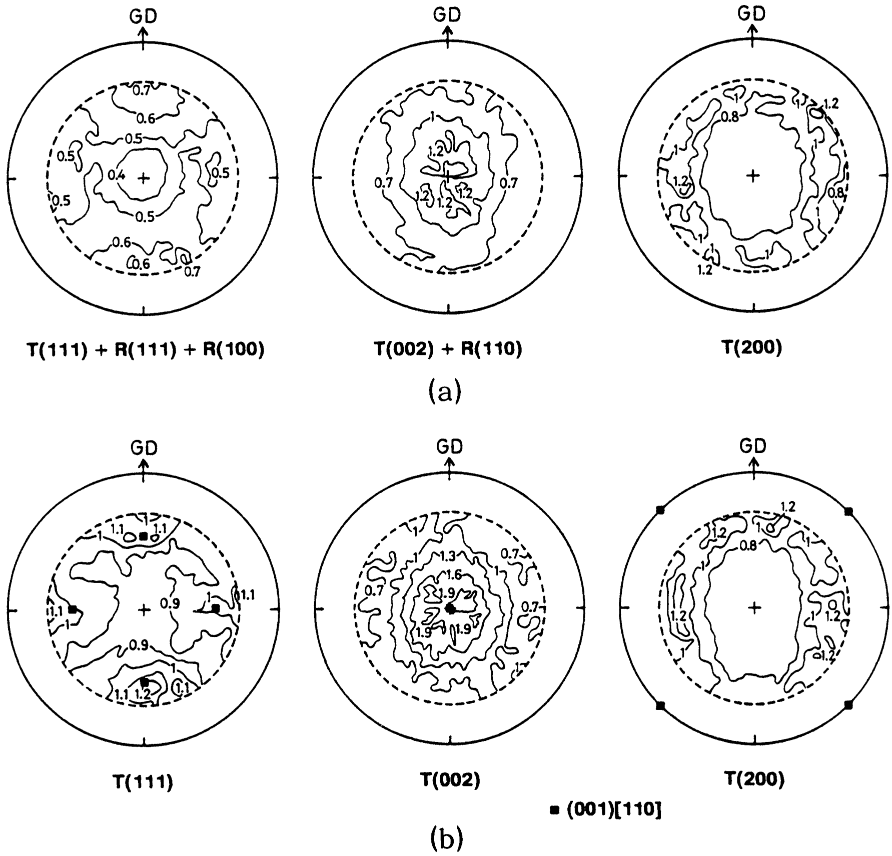

Figure 3 Pole figures of Y-TZP ground with a #80 abrasive paper (a) and annealed at 1300°C (b).

There was no preferred orientation in the surface layer of an initial material. Therefore, it was used as a random oriented sample for pole figure measurement. Figure 3 shows pole figures for the #80 ground surfaces of Y-TZP before and after annealing at 1300°C. For the ground material, a pole figure of T(200) shows that a (001) texture was formed in the *t* phase. From a pole figure of T(111)+R(111)+R(100) determined by using a diffraction angle of about 34.5° (CoKα), the texture with specified directions parallel to the grinding direction seems to be developed in the *r* phase. Pole density of this pole figure is considerably lower than 1 within the measured range. This is due to large broadening of the diffracted beams. For the ground and annealed material which is composed of the *t* phase, the development of a (001)[110] texture with the spread in orientation about GD is clearly observed. On the other hand, the #600 ground and annealed material had a (001)[uv0] texture with no specified direction on the (001) plane. Since grinding with rougher abrasive papers is easy to lead to both the formations of the (001)[110] texture and the *r* phase, the (001)[110] texture is likely to be closely associated with the $t \rightarrow r$ transformation. Pole density of a (001) plane parallel to the ground surface increases gradually with roughing abrasive paper.

Table 1 The results of three-point bend tests and X-ray residual stress measurements.

Specimen	Angle from GD (degree)	Flexural strength (MPa)	Young's modulus (GPa)	Residual stress (MPa)
Initial	—	1171	251	-11
Annealed	—	1045	234	0
Ground (#80)	0	1361	237	-106
Ground	45	926	222	-88
Ground	90	1001	232	-123
Gr. + An.	0	1054	237	-30
Gr. + An.	45	901	226	-37
Gr. + An.	90	853	229	-33

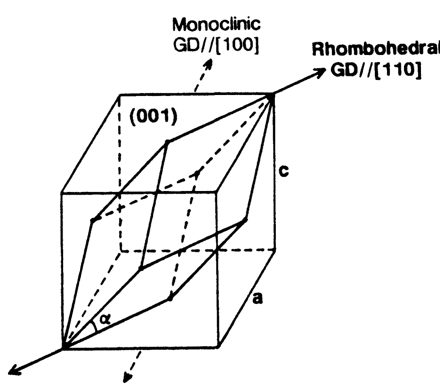

Figure 4 Schematic illustration showing the formation mechanism of a (001)[110] texture.

Table 1 shows the results of three-point bend tests and residual stress measurements. In the case of ground materials, the flexural strength to directions of 45° and 90° from GD is considerably lower than that to a direction of 0° in spite of compressive residual stresses of about 100MPa, because scratches on the ground surface give rise to notch effects. A remarkable increase in flexural strength with grinding is observed for bending to a direction of 0°. This may be due to compressive residual stress which results from expansion of lattice through the $t \rightarrow r$ transformation in the surface layer. Hence, the possibility of surface modification based on this transformation is expected.

DISCUSSION

Grinding with rough abrasive papers brought about not only the $t \rightarrow m$ transformation but also the development of the (001)[110] texture. The formation of this texture can be explained by the following mechanism. In the first place, a (001) texture in the t phase will be formed by ferroelastic domain switching under the stress state applied by grinding such as biaxial compression[2]. We cannot ignore shear stress which acts to a direction parallel to the grinding direction on the ground surface. It is considered that shear stress to a [110] direction leads to the $t \rightarrow r$ transformation in the (001) textured tetragonal phase as shown in Figure 4. If shear stress acts to a [100] direction, the $t \rightarrow m$ transformation will occur. However, this transformation is not easier to occur than the $t \rightarrow r$ transformation because of elastic anisotropy which shows a high elastic modulus for [100] and a low for [110][3]. Therefore, a great part of the transformed phase consists of the r phase and the (001)[110] texture in the t phase is developed by the reverse transformation during annealing.

CONCLUSION

Grinding brings about the tetragonal to rhombohedral transformation and the formation of a (00.1) texture by domain switching in the tetragonal phase. A (001)[110] texture was observed in the ground surface of Y-TZP ground and annealed at 1300°C. This is closely associated with the formation of the rhombohedral phase. The increase of flexural strength with grinding may be due to compressive residual stress caused by the tetragonal to rhombohedral transformation.

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