RESIDUAL-STRESS EFFECT ON FRACTURE STRENGTH OF CERAMICS

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ABSTRACT

The X-ray diffraction method was used to measure the near-surface distribution of the residual stresses of ground alumina and silicon nitride and of quenched alumina. The compressive residual stress due to grinding and quenching improved the bending strength of ceramics. Heavy grinding can introduce flaws in ceramics, reducing the beneficial effect of the compressive stress. The effect of the residual stress on the relation between the bending strength and the defect size was discussed on the basis of fracture mechanics. A model is proposed to assess the effects of the residual stress and the material defect on the bending strength of ceramics.

INTRODUCTION

Brittleness of advanced fine ceramics hinders their wide use as engineering materials in machine structures. Manufacturing processes such as firing, quenching, grinding, coating and joining introduce residual stresses into ceramics. Those residual stresses are expected to have a big influence on the strength of ceramics against brittle fracture. In the present paper, the residual stress was introduced into sintered alumina and silicon nitride by grinding and by quenching. The X-ray diffraction technique was used to measure the distribution of the residual stress on and beneath the surface. The effect of the residual stress on the bending fracture strength was discussed on the basis of fracture mechanics.

EXPERIMENTAL PROCEDURE

Materials and Testing
The experimental materials were pressurelessly sintered alumina (Al₂O₃) and silicon nitride (Si₃N₄). Alumina has two different purities: 99% and 92%.
Table 1 summarizes the bulk density and the elastic properties of materials. Al₂O₃ with 99% purity and Si₃N₄ were ground with diamond wheels of #200 and #80 diamond grain-size numbers. These grinding conditions are here called 200HG and 80HG. The grinding condition and the roughness of the ground surface in the grinding direction are given in Table 2. Up-cut grinding was conducted pumping soluble-type grinding fluid (JIS W2-1) by 20 liter per minute. The specimen was about 3.4mm in height, 4mm in width and 54mm in length. The specimens made of Al₂O₃ with 92% purity were quenched from 1200°C in silicon oil with 100cs and 10000cs viscosities at room temperature. Some specimens were finished by lapping, followed by annealing at 1200°C for 2hr in vacuum in order to obtain the reference data of the bending strength of the materials. The specimens were broken by four-point bending.

**X-Ray Stress Measurement**

The parallel-beam slits were attached to an X-ray diffractometer. The diffractions from Al₂O₃ (2.1.10) plane by Fe-Kα radiation and from Si₃N₄ (411) plane by Cr-Kα radiation were used for residual stress measurements. The stress value was obtained by the $\theta-\sin^2\psi$ method. The X-ray elastic constants of the present experimental materials were determined in our previous studies [1, 2]. The value of $s_p/2=(1+\nu)/E (E=$Young's modulus, $\nu$=Poisson's ratio)$ was $3.57\times10^{-3}$ GPa⁻¹ for (2.1.10) plane of Al₂O₃ with 99% purity, $3.97\times10^{-3}$ GPa⁻¹ for (2.1.10) plane of Al₂O₃ with 92% purity, and $4.06\times10^{-3}$ GPa⁻¹ for (411) plane of Si₃N₄.