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INTERNAL FRICTION AND MECHANICAL PROPERTIES OF NEW CERAMICS

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Abstract- Stress amplitude and temperature dependences of internal friction in polycrystal and single crystal aluminas and aluminas subjected to thermal shock, were measured. Microcracks introduced by water quenching were detected by internal friction measurement. An increase in internal friction due to softening at the grain boundary in the polycrystal alumina was observed above 600 C. The flexural strength and the hardness decreased with increasing internal friction.

1. Introduction- Much attention has recently been paid to structural ceramics, such as alumina, silicon nitride, silicon carbide, and partially stabilized zirconia, serviceable at elevated temperatures-1,2,3). Instantaneous decrease in strength of alumina subjected to thermal shock has been investigated by Hasselman4,5). In order to examine the strength behavior of brittle ceramics with microcracks, internal friction and Young's modulus are measured. Usually, low melting point compounds, such as SiO₂ and MgO, are used as a sintering additive. The mechanical properties, such as strength, hardness, and Young's modulus, of the ceramics decrease above the softening temperature of a second phase at the grain boundary. If the mechanical properties of ceramics are determined by a nondestructive test, this test can be utilized as a strength test instead of a destructive test.

2. Experimental Procedure- The flexural vibration method was used for internal friction and Young's modulus measurements at about 2-5 KHz frequency. One end of the specimen was coated with carbon as an electrode. The specimen was vibrated by electrostatic force between the specimen and the driver. The strain amplitude and temperature dependences of internal friction and Young's modulus are measured.
The polycrystal specimen used in the present study was pressureless sintered commercial alumina (A-3997, Narumi China Co.) containing 0.3%MgO, 0.01%SiO2 and 0.06%CaO. The density was 3.92g/cm³. The single crystal specimen was also used and its longitudinal direction was parallel to the [1102] direction. Thermal shock tests were made by ice-water-quenching the specimens after held for at least 30 min. in a furnace maintained at predetermined temperatures. Flexural strength of specimens was tested by a three point bending method on a 80mm span at room temperature. Hot hardness was measured in vacuum using a microvickers tester.

3. Experimental Results- The flexural strength (σf), Young's modulus (E) and internal friction (Q⁻¹) are shown as a function of quenching temperature difference (ΔT) in Fig.1.

![Fig.1](image1.png)  
![Fig.2](image2.png)

**Fig.1** Quenching temperature difference (ΔT) dependences of flexural strength (σf), Young's modulus (E) and internal friction (Q⁻¹). E and Q⁻¹ were measured at 10⁵ Pa in stress.  

**Fig.2** Stress amplitude dependence of internal friction in quenched specimen. ΔT condition are indicated in the figure.
The strength behavior in the present study was in good agreement with that reported by Hesselman\textsuperscript{1}). The values of strength, Young's modulus and internal friction of the non-quenched specimen are about 275MPa, 370GPa and 0.3\times 10^{-3}, respectively. The fact that each of the three values kept constant up to 200°C in $\Delta T$ suggested that there were no microcracks in the specimen. In the temperature range 250 to 300°C, the strength markedly decreased due to the nucleation of microcracks and crack propagation in the specimen. Corresponding to an instantaneous decrease in strength, internal friction increased from 0.3\times 10^{-3} to 0.75\times 10^{-3} and Young's modulus decreased by about 6GPa. In the quenching temperature range from 300 to 400°C, the value of internal friction was constant. This fact means that the amount and size of cracks in the specimen quenched from 300°C were almost the same as those of 400°C. The stress amplitude dependence of internal friction is shown in Fig.2. When the $\Delta T$ was less than 200°C, the stress dependence of internal friction was very small. On the other hand, the internal friction in alumina quenched from the temperature range from 300 to 400°C increased under stress amplitude above about 3MPa. It is expected that cracks formed by quenching from 300

![Fig.3 Temperature dependences of internal friction and Young's modulus in poly and single alumina crystal.](image1)

![Fig.4 Temperature dependences of Vickers hardness and internal friction in poly and single alumina crystal.](image2)
or 400°C were very small both in size and in amount. But the effect of cracks on the strength was much greater than that on internal friction because of the stress concentration at the end of cracks. With increasing ΔT over 500°C, strength and Young's modulus decreased and internal friction increased gradually. This behaviour of strength, Young's modulus and internal friction in alumina should result from the growth and combination of cracks.

Temperature dependences of internal friction and Young's modulus in polycrystal and single crystal aluminas are shown in Fig.3. Young's modulus of the single crystal alumina decreased linearly with increasing temperature and the temperature coefficient of Young's modulus of the polycrystal alumina slightly decreased above 600 C. Internal friction in the single crystal alumina increased monotonously with increasing temperature. On the other hand, internal friction in the polycrystal alumina markedly increased above 600 C. Vickers hardness and internal friction in the polycrystal and single crystal aluminas are plotted against temperature on logarithmic scale in Fig.4. The Vickers hardness versus temperature plot for the polycrystal alumina could be divided into two lines, at 600 C. The internal friction versus temperature plot could be also divided into two lines at 600 C. This inflection point, 600 C, has to be associated with grain boundary characteristics. The polycrystal alumina contains MgO, CaO and SiO₂. These additives concentrate at the grain boundary. Increase in internal friction and decrease in hardness above 600 C should relate to the softening of these additives.

References