

The relation between internal friction and tensile creep deformation on alumina ceramics

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Abstract

The properties of internal friction and tensile creep deformation of alumina ceramics are compared. The internal friction was measured by a torsion pendulum-type testing equipment, with increasing temperature up to 1450 °C. Tensile creep deformation was measured by a dead weight-type creep deformation testing equipment and an optical extensometer, at 1350, 1400 and 1450 °C. The internal friction increases exponentially with temperature, and shows no characteristic peaks with temperature scanning. The activation energy of internal friction obtained from changing the mechanical vibration frequency was 505–587 kJ mol⁻¹. The activation energy obtained from creep deformation was 584–684 kJ mol⁻¹. However, the grain size dependence of internal friction and creep deformation show different results. The grain-size dependence is significant for creep deformation, and the grain size exponent is 1.8–4.1. On the contrary, grain-size dependence is not clearly observed for internal friction.

1. Introduction

Engineering ceramics are expected to be used as structural materials at high temperature, because of their excellent properties against heat and corrosion. For high temperature application, it is essential to evaluate the deformation properties of the material. Many studies of the creep deformation properties of ceramic materials exist [1]. However, the largest disadvantage of the creep deformation measurements is that it takes a long time. If we want to obtain some data for the life prediction of the material, it sometimes requires several months or longer for one test.

Therefore, we think that internal friction can be useful to evaluate the deformation properties. If the deformation is caused by the transition of the material from elastic to ductile, it can be related to the damping of the mechanical vibration of the material. Moreover, once the relation is found, we can estimate the deformation properties in a short time [2–5].

In this study, we used alumina ceramics for a comparison of the internal friction and the tensile creep deformation properties, because alumina is one of the most typical structural ceramics, and sintered samples without sintering additives may be obtained easily on a commercial base.

2. Experimental details

The tested alumina ceramic sample was SSA-999H, which is commercially provided by the Nikkato Co.

The purity of the alumina was 99.9%. The mean particle diameter was measured by the intercept method with a scanning electron micrograph, as 6.2 μm.

The internal friction was measured by using a torsion pendulum testing equipment, supplied by Rhesca Co. The samples were rectangular bars with dimensions of 5 × 1 × 80 mm³ or 5 × 0.7 × 80 mm³. Both ends of the bars were gripped by fixtures made from silicon carbide with a gauge length for measurements of 50 mm. The frequency of the pendulum was varied by changing the thickness of the specimen and the inertia of the pendulum, and thus obtained four steps of frequencies between 1.27 and 12.0 Hz.

The apparent activation energy was obtained from shifts of the internal friction *vs.* temperature with the vibration frequency. First, the relation between temperature and internal friction measured at each vibration frequency is fitted by eqn. (1).

$$Q^{-1} = C \cdot \exp(-m/T) \quad (1)$$

The obtained data can be fitted by this equation in the range of internal friction between 5 × 10⁻³ and 50 × 10⁻³. Damping of the vibration by external reasons cannot be neglected for values smaller than 5 × 10⁻³, and damping of the vibration is too large to measure the internal friction precisely for values larger than 50 × 10⁻³. The temperatures for internal friction of 10 × 10⁻³ and 20 × 10⁻³ are obtained from each frequency by this fitting. The relation between the fre-

quencies and the temperatures at the same internal friction level is plotted on the Arrhenius chart.

The tensile creep deformation was measured by using a dead weight creep tester with an air atmosphere furnace and an optical extensometer. The testing temperatures were 1350, 1400 and 1450 °C, and the testing stresses were 20, 40 and 60 MPa, respectively. Steady-state creep appeared after transient creep in every testing condition, and the steady creep rate was used for analysis to obtain the stress exponent, n , and the apparent activation energy, E , determined by eqn. (2) [6].

$$\dot{\epsilon} = [A \cdot \sigma^n / P^d] \cdot \exp(-E/RT) \quad (2)$$

The influence of grain size on internal friction and creep deformation is also investigated. The grain size of alumina ceramics was changed by heat treatment of the samples at 1600 °C for 24 h in an air atmosphere furnace. The average grain size was changed from 6.2 to 9.0 μm by this annealing.

3. Results

Figure 1 shows the typical change in the internal friction of alumina ceramics with increasing temperatures. It shows no special peaks and increasing of the internal friction seems to follow the exponential equation. Figure 2 shows the relation between the frequency and the temperature for two internal friction values. The activation energies are obtained as 505 kJ mol^{-1} for $Q^{-1} = 10 \times 10^{-3}$, and 587 kJ mol^{-1} for $Q^{-1} = 20 \times 10^{-3}$.

Activation energies are also obtained from creep deformation with eqn. (2). Figure 3 shows the temperature dependence of the creep strain rate, which is plotted on the Arrhenius chart. The activation energies

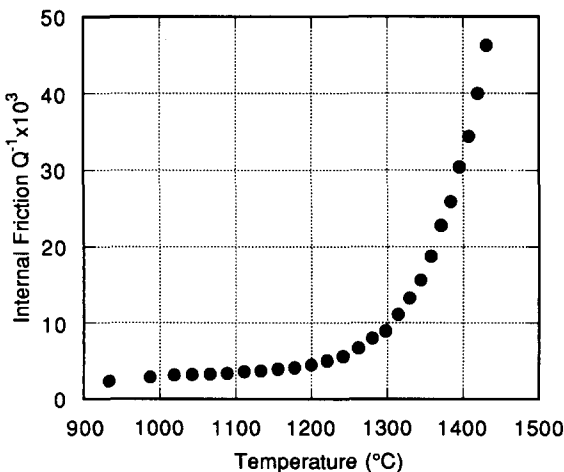


Fig. 1. Temperature dependence of internal friction on alumina ceramics. Vibration frequency is 1.27 Hz.

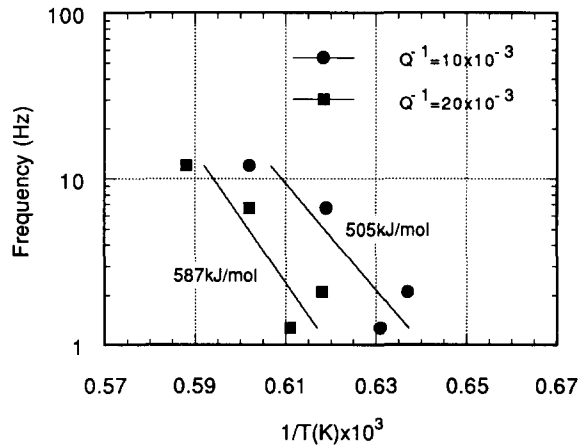


Fig. 2. Variation of internal friction by changing the vibration frequency.

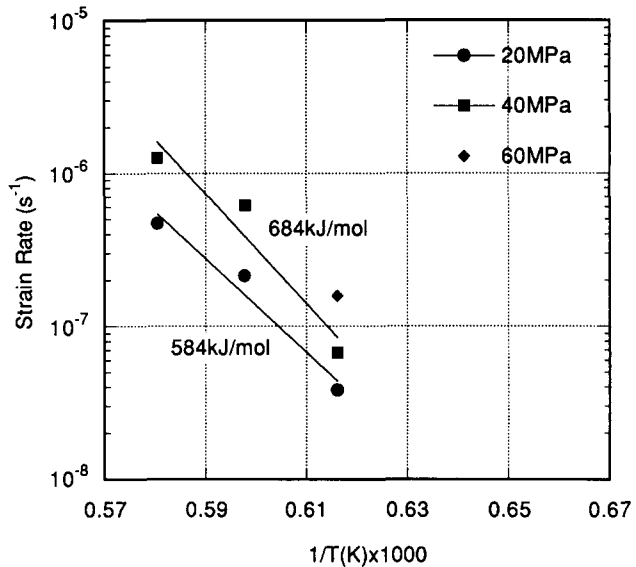


Fig. 3. Temperature dependence of steady-state creep strain rate between 1350 and 1450 °C.

are obtained as 584 kJ mol^{-1} for stress of 20 MPa, and 684 kJ mol^{-1} for 40 MPa.

The same tests are conducted on heat-treated specimens. Figure 4 shows the frequency dependence of internal friction. The activation energies were 1008 kJ mol^{-1} for $Q^{-1} = 10 \times 10^{-3}$ and 870 kJ mol^{-1} for $Q^{-1} = 20 \times 10^{-3}$, but the scattering of the data is large on these tests. The values of internal friction did not decrease with grain coarsening, as can be found from the comparison between Figs. 2 and 4.

Figure 5 shows the temperature dependence of creep deformation for heat-treated specimens. The activation energies were obtained as 693 kJ mol^{-1} for 20 MPa, 784 kJ mol^{-1} for 40 MPa and 687 kJ mol^{-1} for 60 MPa. The grain size exponent, d , in eqn. (2) is calculated at every temperature and stress value. It is scattered between 1.8 and 4.1, but the grain size dependence of

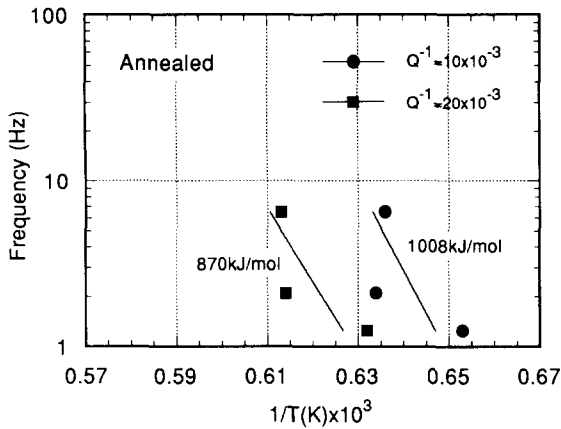


Fig. 4. Variation of internal friction by changing the vibration frequency on heat-treated specimens.

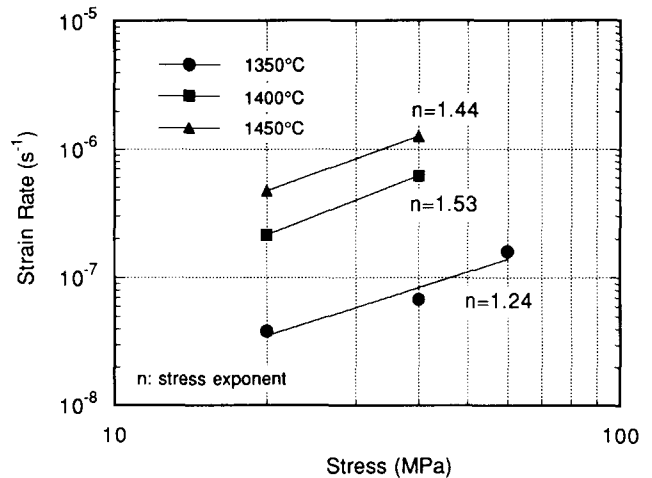


Fig. 6. Stress dependence of creep strain rate. The stress exponents were 1.24 at 1350 °C, 1.53 at 1400 °C and 1.44 at 1450 °C.

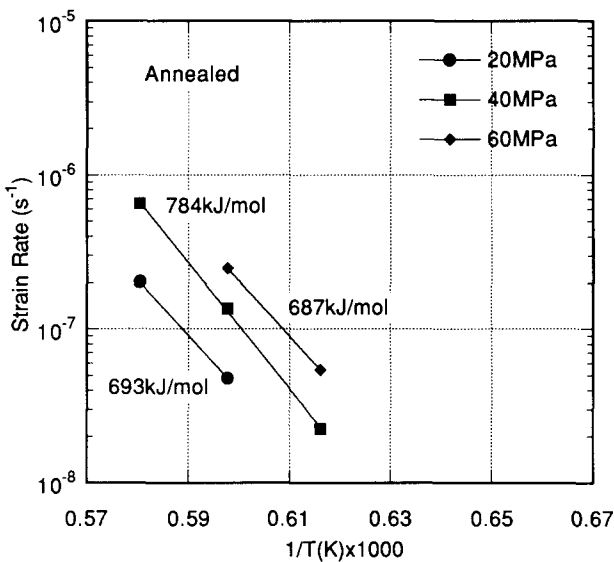


Fig. 5. Temperature dependence of steady-state creep strain rate on heat-treated specimens between 1350 and 1450 °C.

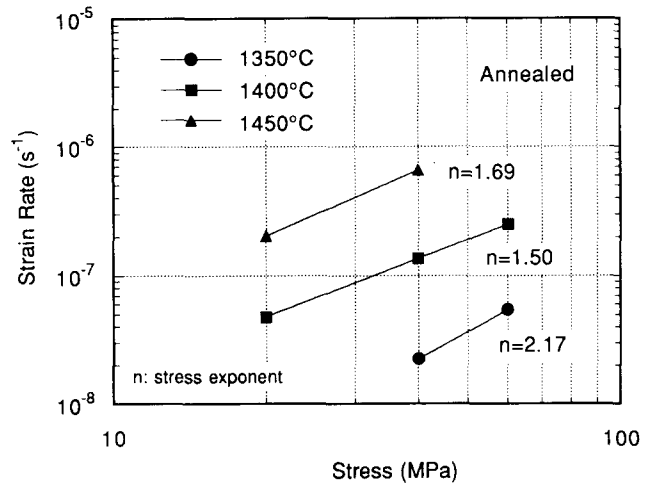


Fig. 7. Stress dependence of creep strain rate on heat-treated samples. The stress exponents were 2.17 at 1350 °C, 1.50 at 1400 °C and 1.69 at 1450 °C.

TABLE 1. Summary of the activation energies obtained from internal friction and creep deformation (unit: kJ mol⁻¹)

	Internal friction		Creep deformation		
	10 × 10 ⁻³	20 × 10 ⁻³	20 MPa	40 MPa	60 MPa
As-received	505	587	584	684	—
Annealed	1008	870	693	784	687

the creep deformation is always clearly observed. The activation energies from internal friction and creep deformation are summarized in Table 1.

Figure 6 shows the stress dependence of the steady-state creep rate for alumina without grain growth at three temperature levels. The stress exponent is obtained between 1.24 and 1.53. Figure 7 shows the stress dependence of creep deformation on heat-treated alumina.

The stress exponent is obtained between 1.50 and 2.17. The stress exponent increases slightly with grain coarsening.

4. Discussion

If the change in internal friction results from the same reason as the change in creep deformation, it should follow an exponential-type equation, because the steady-state creep follows eqn. (2). As shown in Fig. 1, the temperature dependence of internal friction shows no characteristic peaks. That means the increase in internal friction may correspond to deformation of the material. Moreover, creep deformation should be related to damping of the mechanical vibration of the materials. We compared the apparent activation energy obtained from internal friction and creep deformation.

As shown in Figs. 2 and 3, the apparent activation energies show good correspondence with each other.

On the other hand, if the increase in internal friction and creep strain rate are caused by the same phenomenon, the grain size dependence of these values should show the similarity. The creep strain rate strongly depends on the grain size, if deformation is controlled by grain boundary diffusion [1]. As the grain size exponent is not zero for this alumina ceramic, the grain boundary must take an important role in creep deformation. Moreover, the stress exponent is larger than 1, and creep fracture was found after creep deformation. It means that grain boundary diffusion and cavity formation control creep deformation for this alumina ceramic. On the other hand, internal friction shows less dependence on grain size. Thus, we cannot conclude that the increase in internal friction is directly related to the properties of the grain boundary. The increase in internal friction may be related to some damping mechanisms inside the grains. However, it requires further research as the range of tested grain size is not wide enough.

5. Conclusions

The properties of internal friction and tensile creep deformation of alumina ceramics are compared. The

influence of grain size on these properties is investigated. The apparent activation energies were 505–587 kJ mol⁻¹ from the internal friction, and 584–687 kJ mol⁻¹ from creep deformation, without grain growth by heat treatment. They are close values, but it is concluded that these activation energies may represent different phenomena, because the grain size dependence of these properties differs. Creep deformation shows significant dependence on grain size, but internal friction does not show grain size dependence clearly. From these results, we estimate that creep deformation should be controlled by grain boundary properties, and internal friction may represent the properties inside the grains.

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