Thermal shock testing of ceramics

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Introduction

Most of the thermal shock testing methods were performed by either of heating or cooling techniques. However, there are few reports in which the thermal shock test using both of heating and cooling techniques were performed to the same material and the thermal shock resistance was estimated uniformly by the same thermal shock parameters. We estimated the thermal shock resistance of ceramics using infrared radiation heating (IRH) and water flow cooling (WFC) methods. In this study, thermal shock resistance of commercially available alumina and mullite specimens were estimated experimentally and theoretically using the thermal shock parameters by both of the methods.

Experimental Procedure

We used commercially available alumina and mullite specimens for the thermal shock test. Disk-shaped ceramic specimens were prepared for the $\boldsymbol{R_{1c}}$ test, and a V-notch with 2 mm length was produced on the disk edge for the $\boldsymbol{R_{2c}}$ test in the IRH method. After the disk was uniformly heated to the pre-heating temperatures, $\boldsymbol{\theta_i}$, thermal shock fracture occurred by means of IR rays entering from both sides of the specimen. The WFC method was newly developed water-flow cooling technique. The initial heating temperatures of the specimen were changed from 250 to 350℃, and cooled to 20℃. Start time of crack propagations was determined with an acoustic emission sensor in both methods. Thermal shock parameters were characterized by two parameters, namely, thermal shock strength, $\boldsymbol{R_{1c}}$ that represents the resistance to thermal shock fracture and thermal shock fracture toughness, $\boldsymbol{R_{2c}}$ that denotes the resistance to initiation of the crack propagation. These two parameters are defined as

$$R_{1c} = \frac{\lambda \sigma_f}{E\alpha} \quad [\mathrm{W \cdot m^{-1}}] \quad (1) \qquad R_{2c} = \frac{\lambda K_{IC}}{E\alpha} \quad [\mathrm{W \cdot m^{-0.5}}] \quad (2)$$

where $\boldsymbol{\lambda}$ is the thermal conductivity, $\boldsymbol{\sigma_f}$ is the fracture strength, E is the Young's modulus $\boldsymbol{\alpha}$ is the thermal expansion coefficient, and $\boldsymbol{K_{IC}}$ is the fracture toughness of the material. Eqs. 1 and 2, which were defined combination of the material properties at the fracture point temperatures were notated 'calculated values' of the thermal shock parameters.

The experimentally obtained thermal shock parameters were defined combinations of the experimental conditions and the critical thermal stress in the specimen was notated 'experimental values'. This critical thermal stress is the maximum tensile thermal stress calculated numerically on the failure time determined by AE signals.

Results and Discussion

Fig. 1 shows the comparison of $\boldsymbol{R_{1c}}$ of alumina and mullite at the temperature of fracture points. The experimental values of the thermal shock parameters measured by the WFC and IRH methods accord with the calculated values. Thus, the thermal shock test using the thermal shock parameters enable to estimate with uniformity between the thermal shock data measured by heating or cooling method. Comparing with $\boldsymbol{R_{1c}}$ near the room temperature, it notes that the thermal shock strength of alumina is higher than that of mullite. This is because the thermal conductivity of alumina is much higher than that of mullite. However, the thermal shock fracture strength of alumina decreases rapidly compared to mullite with the rise in temperature of the fracture point. This difference is attributed to the higher decreasing rate in the thermal conductivity and higher increasing rate in the thermal expansion coefficient of alumina than those of mullite. Comparing with the calculated values, the difference of R1c between alumina and mullite decreases with the rise in temperature, and $\boldsymbol{R_{1c}}$ are almost same around 600℃

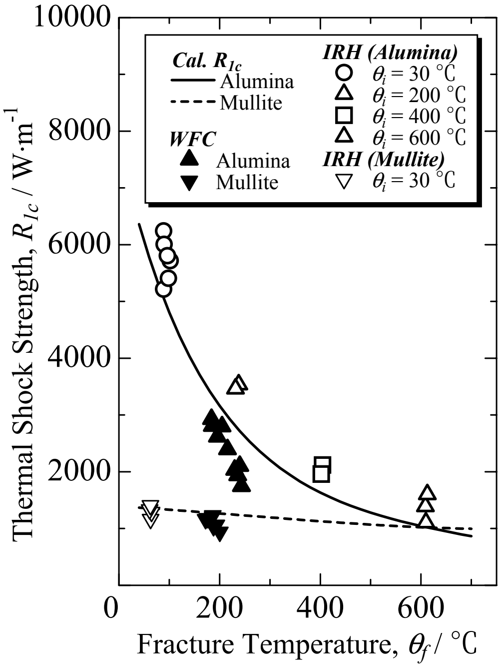

Fig. 1 $\boldsymbol{R_{1c}}$ of alumina and mullite at temperatures of fracture points.

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