Oxygen Partial Pressure Dependence of Creep
on Yttria Doped Ceria Ceramics

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Rare earth-doped ceria is a possible candidate as an electrolyte and in medium-temperature (600~800°C) SOFC. Doped ceria is, however, partially reduced under high temperature reducing atmospheres like the fuel environment in SOFC. This effect causes expansion of the crystal lattice and doped ceria will show a relative expansion at the reducing side. This phenomenon leads to the internal stress in the materials. The magnitude of this stress was estimated by Atkinson, and he found that relatively high stress generates at practical SOFC operating condition (1). For this reason, it is very important to investigate mechanical properties of the component materials of SOFC to design and fabricate a unit cell and stack. But, the mechanical properties (strength, creep behavior, toughness etc.) for rare earth-doped ceria have not been studied enough for practical operating condition. Especially, creep behavior of pure or doped ceria is very little known.

In this study, creep behavior of $(CeO_2)_{0.8}(YO_{1.5})_{0.2}$ (20YDC) was investigated at 20-39MPa and 1045-1125°C to obtain the stress exponent and activation energy for creep and to estimate creep rate in SOFC operating condition. The creep behavior was also investigated by changing oxygen partial pressure from 0.21 to 10^{-16} atm.

$(CeO_2)_{0.8}(YO_{1.5})_{0.2}$ sample was synthesized by the conventional co-precipitation process. The sintered bar was cut and polished to make a creep specimen of approximately 37mm x 4mm x 1mm. After polishing, the specimen was annealed at 1000°C for 3*h* to remove induced residual stress. The relative density of the specimen was greater than 95% of theoretical value and the average grain size of the specimen was about 4.4μm.

Creep behavior was observed by four-point bending creep test at constant road in controlled oxygen partial pressure using H_2-CO_2 mixture gas. The loading points and supporting points were made of SiC because of its mechanical stability in high temperature.

Typical creep curves at 39MPa are shown in Fig1. Just after the load applying, the elastic deformation followed
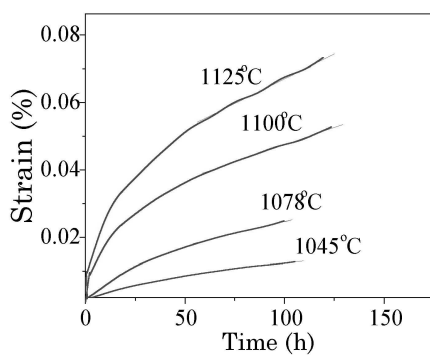
by transition creep was observed. Apparent steady state creep was observed after it. The steady state strain rate, $\dot{\varepsilon}$, depends on absolute temperature, T, and applied stress, σ, and is generally described by Eq.[1]

$$\dot{\varepsilon} = A\sigma^{n}\ \exp\left(-\frac{Q}{RT}\right) \qquad [1]$$

where n is the stress exponent for creep, Q is activation energy for creep, R is the universal gas constant, and A is a parameter that depends on the material and test conditions. The experimental value of n and Q can be compared with theoretical values and combined with the microstructural observations to determine the rate controlling deformation mechanism.

The stress exponent, n, was calculated to be 0.96 ± 0.1 for 20YDC at 1100 °C in air. Furthermore, it is revealed from SEM observation that the grain structure does not change during deformation. These results indicate that creep was controlled by a diffusion mechanism. The activation energy for creep rate of 20 YDC at 39MPa is estimated to be about 264kJ/mol. This value is almost the same as that previously reported on undoped ceria (314kJ/mol) at the similar condition (2). Since the activation energy for anion diffusion in 20YDC is much lower (about 77kJ/mol) than this activation energy, it is considered that creep was controlled by cation diffusion mechanism. The magnitude of the strain rate of 20YDC was very small (about 10^{-10} s^{-1}) even at measured temperature range. So, it can be concluded that the effect of creep behavior on strength of 20YDC at practical operating temperature (600-800°C) is very little.

The oxygen partial pressure dependence of creep rate on 20YDC at 1100°C is shown in Fig.2. The creep rate increases with decreasing oxygen partial pressure until $PO_2=10^{-14}$ atm. The creep rate shows a peak at that
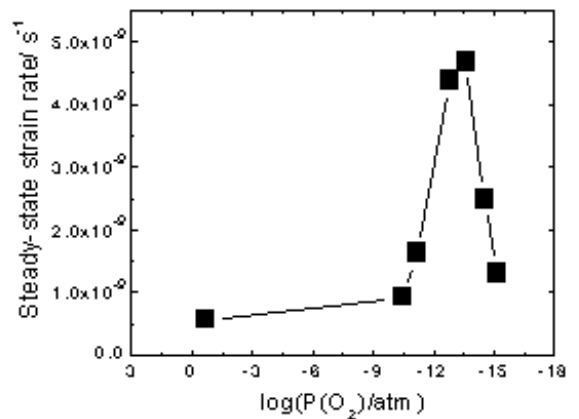

Figure 2 PO$_2$ dependence of creep rate on 20YDC

pressure, and then decreases at lower PO$_2$ range. The peak position of creep rate is very close to that of total electrical conductivity of 20YDC. This result strongly suggests that the creep due to slow cation diffusion can be connected with the first oxygen diffusion process in this material. The creep mechanism in reduced atmosphere will be discussed using defect chemistry models.

[1] A.Atkinson, Solid State Ionics, **95** (1997) 249
[2] Y.Ikuma et al, J. Mater. Sci. Lett. **16** (1997) 1637

Figure 1 A typical temperature dependence of Creep curves.