Fumihiro Wakai, Prof.
Department of Materials Science and Engineering

1. Main Research Results

We aim to develop technology for increased reliability of ceramics, which will be key components for realizing secure systems. The main challenges are to provide basis for developing highly efficient superplastic forming of toughened ceramics. Furthermore, we are developing modeling and simulation technology to make more reliable ceramic components by controlling microstructural heterogeneity during sintering. The main research results are as follows;

1) Grain boundary network dynamics

(1) Local vs. global approach in the analysis of sintering kinetics

The sintering stress, which is the driving force of pore shrinkage in sintering, is evaluated by assessing the chemical potential difference in the system. For polycrystalline materials, a compressive normal traction, which is proportional to the grain boundary energy and inversely proportional to the grain size, arises from the force acting along grain boundary triple junctions. The sintering stress calculated by this local approach is the same with that obtained by the global approach.

(2) Anisotropic viscosities and shrinkage rates in sintering

Macroscopic shrinkage in sintering is described as a linear function of sintering stress tensor and viscosity tensor, which is determined by taking into account the grain boundary diffusion mechanism and the anisotropy in microstructure. For a simple orthorhombic structure in equilibrium, the anisotropic shrinkage rate is dominated by the deviatoric component of viscosity tensor, which is approximately proportional to the logarithm of the aspect ratio of a volume element, and acts so as to deform the elongated structure to be more isotropic.

(3) Effect of grain boundary sliding on shear viscosity and viscous Poisson's ratio in macroscopic shrinkage during sintering

Macroscopic quantities such as strain rate and viscosity diring sintering can be obtained from the microscopic motion of particles normal and tangential to grain boundaries. When grain boundary diffusion is the dominant transp;ort mechanism of sintering, the viscous shear modulus and viscous Poisson's ratios are dependent on the grain boundary diffusion coefficient and the microscopic viscosity of grain boundary sliding. The microscopic viscosity is not constant, varying with microstructural evolution during sintering. The viscous Poisson's ratio decreases

with increasing microscopic viscosity, and increases with relative density.

2) Superplasticity of nanocrystalline ceramics

1) Interpretation of superplastic flow of non-oxides in terms of threshold stress

Silicon carbide is one of the materials with good hardness and strength for structural application, and studies of plasticity and creep is thus important requirements for assessing its structural capability. The fine-grained B, C-doped b-SiC, which contained minimum amount of oxygen impurity, exhibited a characteristic deformation behavior similar to superplastic alloys and Y2O3-doped tetragonal ZrO2 polycrystals (Y-TZP): an apparent transition of stress exponent from n ~ 2 at high stresses to n > 3 at low stresses. The exponent of the inverse grain size was p > 2, and the activation energy was similar to that of lattice diffusion for Si and C. The transition of stress exponent with stress can arise from the presence of a threshold stress which decreases strongly with increasing temperature. The threshold stress may arise from, for example, 1) the inhibitory effect of dispersed graphite particles, which were formed from free carbon in the starting powder, on grain boundary sliding, or 2) the interaction between grain boundary dislocation and impurity atoms segregated at grain boundaries.

2. List of publications (original article, comment/book)

Original Paper

1) **Comment on "Local vs. global approach in the analysis of sintering kinetics"**
Fumihiro WAKAI
Scripta Materialia, **62**, 117-119 (2010).

2) **Anisotropic viscosities and shrinkage rates in sintering of particles arranged in a simple orthorhombic structure**
Fumihiro WAKAI and Takashi AKATSU
Acta Materialia, **58**, 1921-1927 (2010).

3) **Effect of grain boundary sliding on shear viscosity and viscous Poisson's ratio in macroscopic shrinkage of sintering**
Fumihiro WAKAI and Zoran S. NIKOLIC
Acta Materialia, **59**, 774-784 (2011).

Review & Books

1) Superplasticity; F. Wakai: pp.568-574 in Handbook of functionalization of ceramics, Ed. O. Fukunaga, NTS, (2011). (in Japanese)

3. Invited/Plenary Talks in Conference

1) Interpretation of superplastic flow of non-oxides in terms of threshold stress
   Fumihiro WAKAI, 3rd International Symposium on Sialons and Non-Oxides, 1-4 June, 2010, Cappadocia, Turkey.
2) Macroscopic shrinkage predicted from local structures and microscopic dynamics in sintering
   Fumihiro Wakai, Materials Science & Technology 2010 Conference, 17 -21 October, 2010, Houston, Texas, U.S.A.
3) Mechanical Principles of Sintering in micro- and macro scale
   Fumihiro Wakai3rd International Congress on Ceramics, 14-18 November, 2010, Osaka, Japan
4) Threshold stress in superplastic flow of silicon carbide
   T. Tokiyama, Y. Shinoda, T. Akatsu and F. Wakai, The Symposium on Hybrid Nano Materials Toward Future Industries, 19-20 November, 2010, Nagaoka University of Technology, Nagaoka, Japan

Domestic Conferences

1) F. Wakai: Grain boundary sliding and its related phenomena –superplasticity and sintering; 107th Meeting on Metal properties, Ehime University, Matsuyama, 27 August, 2009.
2) Advances in sintering theory based on grain boundary sliding; 144th Meeting on superplasticity, 21 January, 2011, NIMS, Tsukuba.

3. **Other**s

1) **J. Am Ceram Soc.** Associate Editor
2) **Science of Sintering**, Associate Editor
3) **Materials Science and Engineering A**, Editorial member
4) **Materials Transaction**, Editorial member