

Fumihiko Wakai

Department of Materials Science and Engineering

a. Highlights in 2007

We are developing a new forming method for making ceramic components by using superplasticity, a phenomenon in which fine-grained polycrystalline solids can be stretched extraordinarily without fracture. The micromechanical principle of the superplasticity is the dynamics of grain boundary networks, which is also the principle of microstructural evolution at elevated temperatures, e.g., sintering. We aim to propose new concepts and fundamental principles in this field.

(1) Dynamics of grain boundary networks

(1-1) Anisotropic shrinkage induced by particle rearrangement in sintering

Sintering is a thermal process that transforms a powder compact into a bulk material; it is used for mass production of complex-shaped components. Dimensional control of components is fundamental to the avoidance of geometrical distortion and to meet required tolerance specification. While sintering is simply described as densification macroscopically, it is expressed as motion of center of mass of particles driven by the thermodynamic force. A microscopic model was presented which describes the anisotropic shrinkage induced by particle rearrangement during sintering. The shrinkage rate was shown to become anisotropic as the particle coordination number changed with rearrangement.

(Ref. 1)

(2-2) Enhance shrinkage by the formation of surface singularity at pore channel closure

As nano particles are transformed into dense bulk material, the interconnected pores are pinched off and closed pores are formed during sintering. We showed that a singularity, where the surface curvature diverges, is formed at the pore channel closure. The shrinkage was promoted by the enhanced atomic diffusion near the singularity. (Ref. 2)

(2) Deformation and Superplasticity of nanocrystalline ceramics

(2-1) Deformation of α -SiAlON

SiAlONs are the solid solutions in which aluminium and oxygen atoms dissolve into Si₃N₄. A Ca- α SiAlON nanoceramic was fabricated from Ca_{0.8}Si_{9.6}Al_{2.4}O_{0.8}N_{15.2} nanopowder without using any sintering additive. The flow stress of the SiAlON nanoceramics, which contained almost no glass phase, was higher than that of liquid phase sintered SiAlONs containing a large amount of glass phase. The deformation was characterized by Newtonian flow in a wide range of stresses, and shear-thickening creep, which has been reported in liquid containing SiAlONs, was not observed. (Ref. 3, 9)

(2-2) Enhancement of high-temperature deformation in fine-grained silicon carbide with Al doping

Fine-grained SiC (grain size 0.3 μm) was hot-pressed with Al, B, and C additives under 150 MPa at 1850 °C. Al was detected at grain boundaries by using energy dispersive X-ray spectroscopy. The strain rates of Al, B,C-doped SiC in the low stress region was one order of magnitude faster than those of B, C-doped SiC. The stress exponent of Al, B, C-doped SiC was 1.4 in the higher stress region, and increased to 2.6 with decreasing stress. The transition of the stress exponent, which is often observed in the superplasticity of metals and oxides, e.g., zirconia, appeared in fine-grained SiC also.

b. Articles

<Original articles>

1. Anisotropic shrinkage induced by particle rearrangement in sintering

Fumihiko WAKAI, Kentarou CHIHARA and Michiyuki YOSHIDA

Acta Materialia, **55**, 4553-4566 (2007).

2. Pore channel closure in sintering of a ring of three spheres

Fumihiko WAKAI, Diego GOMEZ-GARCIA, and Arturo DOMÍNGUEZ-RODRÍGUEZ

J. Euro. Ceram. Soc., **27**, 3365-3370 (2007).

3. High temperature deformation of α -SiAlON nanoceramics without additives

Kentarou CHIHARA, Daisuke HIRATSUKA, Junichi TATAMI, Fumihiko WAKAI and Katsutoshi KOMEYA

Scripta Materialia, **56**, 871-874 (2007).

4. Three-dimensional simulation of coarsening and grain growth in sintering

Fumihiko WAKAI

Mater. Sci. Forum, **539-543**, 2359-2364 (2007).

5. Superplastic flow of silicon nitride-based nanocomposite at high strain rates

Kentarou CHIHARA, Yutaka SHINODA, Takashi AKATSU and Fumihiko WAKAI

Mater. Sci. Forum, **551-552**, 597-600 (2007)

6. **Interplay between Surface and Grain Boundary in Sintering**

Fumihiko WAKAI

Mater. Sci. Forum, **558-559**, 1029-1034 (2007).

7. **Fabrication of $\text{Ni}_{52.5}\text{Nb}_{10}\text{Zr}_{15}\text{Ti}_{15}\text{Pt}_{7.5}$ bulk metallic glassy matrix composite containing dispersed ZrO_2 particulates by spark plasma sintering**

Guoqiang Xie, Dmitri V. Louzguine-Luzgin, Hisamichi Kimura, Fumihiko Wakai and Akihisa Inoue

Mater. Sci. Forum, **561-565**, 1291-1294 (2007).

8. **High-temperature deformation of $\text{Si}_3\text{N}_4/\text{Si}_3\text{N}_4\text{-SiC}$ hybrid composites with belt-like network structure of $\text{Si}_3\text{N}_4\text{-SiC}$ composites**

K. Yamada, N. Kamiya, N. Kondo and F. Wakai

9. **High-temperature compressive deformation of $\beta\text{-SiAlON}$ polycrystals containing minimum amount of intergranular glass phase**

Kentarou Chihara, Daisuke Hiratsuka, Yutaka Shinoda, Takashi Akatsu, Fumihiko Wakai, Junichi Tatami, Katsutoshi Komeya

Mater. Sci. Engn. B, **148**, 203-206 (2008).

10. **Enhancement of high-temperature deformation in fine-grained silicon carbide with Al doping**

Takuya Tokiyama, Yutaka Shinoda, Takashi Akatsu and Fumihiko Wakai

Mater. Sci. Engn. B, **148**, 261-264 (2008).

11. **Integrated molding of nanocrystalline tungsten carbide powder with stainless steel**

Yutaka Shinoda, Takashi Akatsu and Fumihiko Wakai

Mater. Sci. Engn. B, **148**, 145-148 (2008).

12. **Microstructure and properties of ceramic particulate reinforced metallic glassy matrix composites fabricated by spark plasma sintering**

Guoqiang Xie, Dmitri V. Louzguine-Luzgin, Fumihiko Wakai, Hisamichi Kimura and Akihisa Inoue

Mater. Sci. Engn. B, **148**, 77-81 (2008).

13. Large-size ultrahigh strength Ni-based bulk metallic glassy matrix composites with enhanced ductility fabricated by spark plasma sintering

Guoqiang Xie, Dmitri V. Louzguine-Luzgin, Hisamichi Kimura, Akihisa Inoue and Fumihiro Wakai
Applied Physics Letters., **92**, 121907 (2008).

<comment/book>

1. Development of Nanoceramics; Application to Diffusion Bonding

M. Yoshida, Y. Shinoda, T. Akatsu and F. Wakai

pp. 85-90, in Ceramic Transactions, vol. 198, Characterization and Control of Interfaces for High Quality Advanced Materials II, (2007).

2. New Properties by nano/nano composite

F. Wakai, pp. 224-225, Technology of Nanomaterial, Edited by M. Koizumi, Y. Sakka, S. Nakajyo and K. Niihara, CMC publication (2007).

3. 6.2.3 Creep/Superplasticity

Fumihiro WAKAI, pp. 329-332, in Nanoparticle Technology Handbook, Edited by M. Hosokawa, K. Nogi, M. Naito and T. Yokoyama, Elsevier (2007).

c. Presentation in international/domestic conferences

1. Interplay between surface and grain boundary in sintering, The 3rd International Conference on Recrystallization and Grain Growth

F. Wakai, Jeju island, Korea, June 10 – 15, 2007. Invited.

2. A micromechanical principle of sintering in particle-scale length

F. Wakai, 10th International Conference of the European Ceramic Society, Berlin, Germany, June 17 – 21, 2007. Invited.

3. Dynamics of grain boundary networks in superplasticity, grain growth and sintering

F. Wakai, JSPS-KOSEFAsian Core Program The Third Japan-Korea Workshop on Metallic Glasses, Miyagi Zao Royal Hotel, Miyagi, Japan, September 27-28, 2007. Invited

4. Thermodynamic driving forces in quasi-equilibrium and non-equilibrium processes of

sintering

F. Wakai, Focused Workshop on Contemporary Topics in Sintering, Orange County Resort, Coorg District, India, December 2-6, 2007. Invited

4. Micromechanical principle of microstructural evolution in sintering at particle scale

F, Wakai, Workshop of Joint Project in Kyoto Prefecture, Doshisha University, September, 20 2007.

d. Others

1. Joint forming method of super hard alloy to metals and the jointed components, Y. Shinoda, T. Akatsu, Patent submitted 2007-135504

J. Am Ceram Soc. Associate Editor

Science of Sintering, Associate Editor

J. Ceram. Soc. Japan, Editor member