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Grain boundary dynamics in ceramics superplasticity

F. Wakai*

Abstract Superplasticity refers to an ability of polycrystalline solids to exhibit exceptionally large elongation in tension. The application of superplasticity makes it possible to fabricate ceramic components by superplastic forming (SPF), concurrent with diffusion bonding, and superplastic sinter-forging just like superplastic metals. Furthermore the superplastic deformation plays an important role in stress-assisted densification processes such as hot isostatic pressing (HIP) and hot pressing (HP). The ceramics superplasticity has been one of intensive research fields in the last decade. Although most of reports are still limited to those of zirconia[1], new developments have been achieved in superplasticity of Si_3N_4 and SiC in recent years. It is clearly demonstrated that the superplasticity is one of the common natures of fine-grained ceramics and nanocrystalline ceramics at elevated temperatures.

Keywords Grain boundaries. Ceramics. Superplasticity. Modelling.

Dinámica de fronteras de grano en la superplasticidad de cerámicas

Resumen La superplaticidad se refiere a la capacidad que posee un sólido policristalino de presentar alargamientos excepcionalmente elevados en tracción. La aplicación de la superplasticidad hace posible la fabricación de componentes cerámicos por conformado superplástico, soldadura por difusión y forja-sinterizado superplástica, igual que en metales superplásticos. Además, la deformación superplástica tiene un rol importante en los procesos de densificación asistidos por tensiones, tales como la compactación isostática en caliente y el prensado en caliente. Las cerámicas superplásticas han sido uno de los campos donde se ha realizado una investigación más intensa en la última década. Aunque, la mayoría de los informes se limitan a la circonia[1] se han alcanzado nuevos desarrollos en superplasticidad de Si_3N_4 y SiC. Está claramente demostrado que la superplasticidad es una propiedad intrínseca de las cerámicas de pequeño tamaño de grano y de las cerámicas nanocristalinas a temperaturas elevadas.

Palabras clave Fronteras de grano. Cerámicas. Superplasticidad. Modelado.

1. TOPOLOGICAL CHANGE IN SUPERPLASTICITY

The grain boundary of polycrystalline solids forms complex three-dimensional network structure. The structure is neither periodic nor random. If the distribution of grain size maintains the self-similar shape which is independent of time, it is known as the steady structure in normal grain growth. The topology of the network changes by movement of grains (superplasticity) and by boundary motion of curvature (grain growth). The elemental process of topological change in superplasticity is grain switching (T1 process). The sliding of rigid grains generates cavities and cracks inevitably. Then the essential mechanism of superplasticity is the accommodation process of grain boundary sliding so that the polycrystalline materials can be stretched extensively without fracture. The three-dimensional simulation indicates how the dynamical change in shape of grain occurs in compatible deformation where individual grain contacts and separate from other

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(*) Center for Materials Design, Materials and Structures Laboratory Tokyo, Institute of Technology, 4259 Nagatsuta, Midori, Yokohama 226-8503 (Japan)

grain (Fig. 1). A vector in figure 2 represents the motion of individual grains in superplastic flow. The length of arrow is proportional to the velocity of grain. The displacement of the centers of mass of the grains is similar to the movement of molecules in viscous flow of liquids (or amorphous).

The idealized grain growth in three-dimension (3D) was studied by a program that models the process of boundary motion by curvature to minimize the boundary energy[2]. Even starting from arbitrary packing of uniform grains, the boundary network reached to a steady structure in time after incubation period and transient period. The parabolic law in grain growth was observed only in a region where the steady structure was maintained. The more general von Neumann-Mullins law on kinetics of grain growth held in both transient period and normal grain growth period. The grain size distribution function and the distribution of number of faces in steady structure were analyzed in 3D, and compared with the microstructure in cross section. The perimeter law and Aboav-Weaire law in 3D on topological nature of boundary network structure held not only in the steady structure but also in transient structures.

2. SUPERPLASTICITY ENHANCED BY INTERGRANULAR LIQUID SI_3N_4[3-6]

The structure and the nature of grain boundary effects significantly acommodation processes in grain boundary sliding. In many metals and ceramics impurity atoms segregate at grain boundaries, but no glass film has been detected by highresolution transmission electron microscopy (HRTEM). On the other hand, glass phase pockets remain frequently at grain boundaries of liquidphase sintered ceramics. The glass phase behaves as a viscous fluid (super-cooled liquid) at temperatures higher than those of the glass transition. When the glass wets the crystal completely, thin glass film with the thickness from 0.5 to a few nm is observed at twograin junctions.

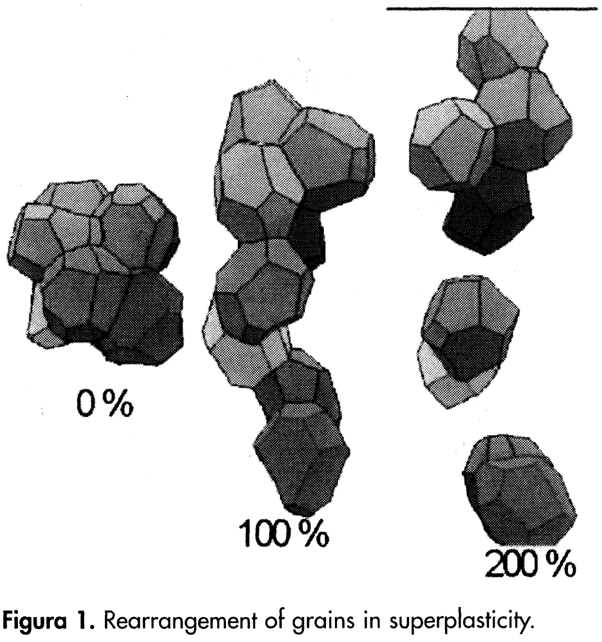

Figura 1. Rearrangement of grains in superplasticity.

Figure 1. Reorganización de granos en superplasticidad.

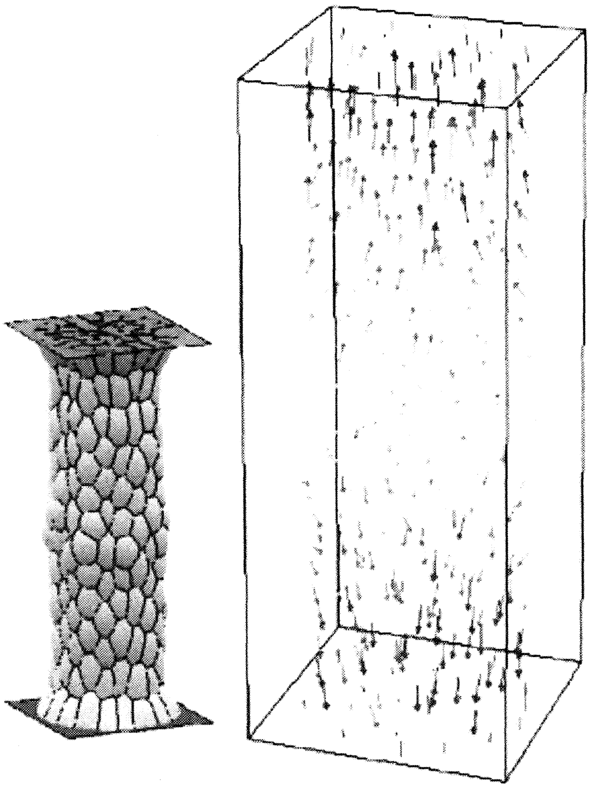

Figura 2. Motion of grains in deformation.

Figure 2. Movimiento de granos durante la deformación.

The glass phase acts as a lubricant for grain boundary sliding, and also as a path for matter transport through solutionprecipitation process. Then the mechanism of superplasticity for glasscontainig ceramics will be different from the intrinsic superplasticity of metals and ceramies that do not contain glass film. The SiYA10N glass phase exists at grain boundaries of the Si_3N_4 which were sintered with Y_20_3 and Al_20_3 as additives. It has been already known that even the materials which contain rodshaped (Si_3N_4 grains can be superplastically deformed assisted by glass phase. In this 'NonClassical" superplasticity the anisotropic (grains tend to align with strain, producing a fiberstrengthening effect. These phenomena lead a strengthening and toughening of Si_3N_4 by compressive superplastic deformation. The enhancement of superplastic deformation by intergranular glass phase was also applicable very recently to liquidphase sintered SiC.

3. INTRINSIC SUPERPLASTICITY IN COVALENT CERAMICS - B, C DOPED SiC[7-9]

Is the superplasticity of covalent polycrystalline solids possible where no help of intergranular glass phase is expected? The superplastic elongation was achieved for B, C-doped SiC which was fabricated by hot isostatic pressing[2,3]. The intergranular glass film was not detected under TEM observation. This result illustrates that the phenomena of superplasticity can be observed in all fine-grained polycrystalline solids regardless of the difference in atomic bond and structure of grain boundaries.

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