LOW TEMPERATURE AND HIGH STRAIN RATE SUPERPLASTIC FLOW IN STRUCTURAL OXIDE CERAMICS INDUCED BY FLASH EVENT

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High-strength oxide ceramics are known to be brittle, with limited plastic deformability, even at high temperatures above 1000°C. However, structural ceramics with grain sizes of 1 μm or less can exhibit superplasticity, i.e., tensile elongation exceeding 100% via grain boundary sliding (GBS). Because deformation by GBS requires diffusion of atoms (ions) as a stress-relaxation process, a short accommodation length, i.e. a small grain size is critical for achieving superplasticity in ceramics. Superplastic forming is currently employed as a manufacturing technology for metals and alloys, typically at operation temperatures <1000°C and strain rates $>10^{-3}$ s^{-1}. In contrast, in typical superplastic ceramics such as Y_2O_3-stabilized tetragonal ZrO_2 polycrystals (TZP), superplastic deformation only occurs at higher temperatures (>1400°C) and lower strain rates ($<10^{-4}$ s^{-1}), though an average grain size of superplastic TZP is usually in a range of 0.3-0.5 μm. Some of nano-grained ceramic composites have been shown to exhibit superplasticity at higher strain rates, but only at higher temperatures beyond 1600°C. In order to reduce the superplastic temperature and to increase the deformation speed, an approach other than grain-size refinement is required to activate GBS in structural ceramics.

The application of a strong electric field during sintering is known to enhance densification in ceramics by accelerating diffusion mass transport. The use of flash sintering, in which a material is directly exposed to heat and a strong electrical field beyond threshold values, enables rapid sintering to achieve a fully dense sample at significantly lower furnace temperatures than conventional sintering. Field-assisted sintering and flash sintering have been used for fast manufacturing of TZP and other ceramic materials. The rapid densification during flash sintering is a result of accelerated self-diffusion and is accompanied by a non-linear increase in the electric conductivity of the material. Electron energy-loss spectrometry revealed the existence of extrinsic oxygen anion vacancies in flash-sintered Y_2O_3 and TZP, suggesting that flash sintering proceeds via the generation of atomic defects under the strong electric field. In addition, it has been pointed out that grain growth in Y_2O_3-stabilized ZrO_2 is accelerated by an electric current as well as by reduction in N_2+5%H_2 atmosphere. Thus, one can expect that the application of a strong field could also facilitate high-temperature mass-transport phenomena, such as GBS.

We demonstrate in this paper that by employing flash event under a strong DC field higher than 50 $V\cdot cm^{-1}$, conventional TZP ceramics can exhibit superplastic deformation with an elongation to failure of >150%, at a lower furnace temperature of 800°C and a higher strain rate of 2×10^{-3} s^{-1} compared to previous methods. The flash event can also enhance bending deformation as well as tensile deformation. The flow stress-strain rate relationship indicated that the enhancement in the plastic flow of TZP resulted not only from increased specimen temperature due to Joule heating but also from accelerated diffusion by electric field and/or current. The field/current effect was equivalent to increase in temperature of about 200ºC.