論文 / 著書情報
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Title(English)	Materials Design of Nanocrystalline Si3N4 for High-strain-rate Superplasticity
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論 文 要 旨

THESIS SUMMARY

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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

Superplastic forming is an attractive method for complex-shaped components of silicon nitride (Si_3N_4)-based materials which are quite hard and brittle due to their nature of strong covalent bonding. Superplasticity is defined as an ability of polycrystalline materials to exhibit very high tensile elongation The strain rate of typical superplasticity in Si_3N_4 ceramics is the range of 10^{-6}-10^{-3} s^{-1} that takes very long time for shaping. High-strain-rate superplasticity (HSRS) at strain rates higher than 10^{-2} s^{-1} is desirable to increase the production efficiency for industrial applications. However, high-strain-rate superplasticity of Si_3N_4-based materials had not been achieved due to the increase of flow stress (strain hardening) caused by extensive microstructural development such as grain growth, elongation and alignment along the tensile direction, and the unusual increase of flow stress at higher strain rates in compression, which is referred to shear thickening. Furthermore, the glassy phase existing at grain boundaries and multigrain junctions plays an important role on deformation, because grain-boundary sliding of neighboring grains is facilitated by the viscous flow of the glassy phase.

In chapter 2, the superplastic flow behavior of nano-grained Si_3N_4 ceramics containing Y_2O_3-Al_2O_3-MgO glass system (YAM) was investigated in the terms of microstructural evolution and the changes of glass chemistry during deformation. YAM sample deformed homogeneously without necking to the elongation of >300% with initial strain rate of $5x10^{-4}$ s^{-1} at 1650 ºC. Flow stress was maintained less than 4 MPa up to the elongation of 130%, but extensive strain hardening was observed in the later stage of deformation. Grain growth, elongation and alignment have been observed in deformed YAM sample by TEM analysis. The chemical analysis by STEM/EDS revealed that most additive cations are segregated along grain boundary and at interface between grain and glass pocket in as-sintered sample. After deformation, additive cations accumulate at glass pocket owing to the reduction of glass phase and interface area due to grain growth. Although the major cause of strain hardening is the microstructural evolution, the change in glass chemistry is also suggested to affect the flow behavior.

In chapter 3, Si_3N_4 materials containing Si-Y-Mg-O-N glass phase was used to study the effect of CaO addition to the glass on compressive deformation at an initial strain rate of 10^{-4} s^{-1} at 1500-1700 ºC. CaO addition to glass melts decreased the flow stress, but not affected the microstructure. It is suggested that adding CaO reduces the viscosity of intergranular glass phase. The addition of CaO further improves the thermal stability of glass phase by suppressing the vaporization at elevated temperatures.

In chapter 4, the influence of MgO (YAM) and CaO (YAC) addition to Si-Al-Y-O-N glass system in Si_3N_4 ceramics on superplastic flow behavior was investigated at 1700 ºC with various strain rates ranging 10^{-4}-10^{-3} s^{-1} in compression. The significant strain hardening was observed at higher strain rates, indicating that the origin of strain hardening was not the microstructural evolution. In this study, strain hardening was caused by the shear thickening. The critical stress of shear thickening in YAC sample, which was around 10~20 MPa, coincided with the stress where strain hardening occurred in stress-strain curves. Therefore, CaO addition to glass melts hinders superplastic deformation in compression.

In chapter 5, Si_3N_4 nanoceramics added with MgO (YAM) was selected for high-strain-rate superplasticity because it has lower viscosity of glass phase, and the problem of shear thickening is minimized. To attain HSRS in Si_3N_4 ceramics, the further refinement of grains is necessary. The nanograined Si_3N_4 ceramics with the average diameter of 56±13 nm successfully densified at extremely low sintering temperature 1300 ºC with high pressure 300 MPa under nitrogen atmosphere. The HSRS in Si_3N_4 nanoceramics have been achieved at strain rate of 10^{-3} -10^{-2} s^{-1} up to the strain of 1.1 with an absence of cavity damage and cracking. The grain coarsening and vaporization of glassy phase were suppressed due to the short deforming time, so that, significant strain hardening was not observed. The achievement of HSRS in Si_3N_4 ceramics in this study can be utilized for the industrial application of the superplastic forming.