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Evaluation of Rheological Properties, Anisotropic Shrinkage, and Heterogeneous Densification of Ceramic Materials during Liquid Phase Sintering by Numerical-Experimental Procedure

Authors : Hamed Yaghoubi, Esmaeil Salahi, Fateme Taati

Abstract : The effective shear and bulk viscosity, as well as dynamic viscosity, describe the rheological properties of the ceramic body during the liquid phase sintering process. The rheological parameters depend on the physical and thermomechanical characteristics of the material such as relative density, temperature, grain size, and diffusion coefficient and activation energy. The main goal of this research is to acquire a comprehensive understanding of the response of an incompressible viscose ceramic material during liquid phase sintering process such as stress-strain relations, sintering and hydrostatic stress, the prediction of anisotropic shrinkage and heterogeneous densification as a function of sintering time by including the simultaneous influence of gravity field, and frictional force. After raw materials analysis, the standard hard porcelain mixture as a ceramic body was designed and prepared. Three different experimental configurations were designed including midpoint deflection, sinter bending, and free sintering samples. The numerical method for the ceramic specimens during the liquid phase sintering process are implemented in the CREEP user subroutine code in ABAQUS. The numerical-experimental procedure shows the anisotropic behavior, the complete difference in spatial displacement through three directions, the incompressibility for ceramic samples during the sintering process. The anisotropic shrinkage factor has been proposed to investigate the shrinkage anisotropy. It has been shown that the shrinkage along the normal axis of casting sample is about 1.5 times larger than that of casting direction, the gravitational force in pyroplastic deformation intensifies the shrinkage anisotropy more than the free sintering sample. The lowest and greatest equivalent creep strain occurs at the intermediate zone and around the central line of the midpoint distorted sample, respectively. In the sinter bending test sample, the equivalent creep strain approaches to the maximum near the contact area with refractory support. The inhomogeneity in Von-Misses, pressure, and principal stress intensifies the relative density non-uniformity in all samples, except in free sintering one. The symmetrical distribution of stress around the center of free sintering sample, cause to hinder the pyroplastic deformations. Densification results confirmed that the effective bulk viscosity was well-defined with relative density values. The stress analysis confirmed that the sintering stress is more than the hydrostatic stress from start to end of sintering time so, from both theoretically and experimentally point of view, the sintering process occurs completely.

Keywords : anisotropic shrinkage, ceramic material, liquid phase sintering process, rheological properties, numerical-experimental procedure
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