Ceramics International 42 (2016) 17366–17373

Contents lists available at ScienceDirect

Ceramics International

journal homepage: www.elsevier.com/locate/ceramint

Sintering behavior and anisotropic sintering parameters of uniaxially constrained LTCC tapes

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ARTICLE INFO

Article history:
Received 7 July 2016
Received in revised form
5 August 2016
Accepted 5 August 2016
Available online 5 August 2016

Keywords:
Constrained sintering
LTCC tape
Anisotropic sintering parameters
Uniaxial loading

ABSTRACT

The constrained sintering behavior of uniaxially loaded commercial LTCC tapes was studied by recording sintering strains through an optical dilatometer. By adjusting the applied uniaxial load, zero uniaxial strain rates can be achieved at several densities. Pores were found to be more inclined to elongate along the loading direction and a pore orientation factor around 1.2 was observed in uniaxially constrained tapes. Uniaxial sintering stress was determined for the uniaxially constrained tape, showing an obvious misfit with the theoretical prediction. Moreover, by utilizing the simplified anisotropic continuum mechanical formulation, the uniaxial viscosity and viscous Poisson's ratio can be determined. Comparing with those in isotropic sintering cases, a larger anisotropic uniaxial viscosity and a lower viscous Poisson's ratio were obtained as a result of the evolved anisotropic microstructure. Reasons responsible for the observed discrepancies were discussed in detail.

1. Introduction

Macroscopic sintering behavior of a powder compact could be regarded as its deformation response to the sum of the applied external stress and the internal thermodynamic driving force, i.e., the sintering stress [1,2]. To study the sintering behavior of green bodies, an isotropic continuum mechanics model incorporating a few sintering parameters has been developed on the basis of a viscoelastic analogy [3–12]. In the past decades, advances have been made in using this approach to understand a variety of constrained sintering problems, including pressure-assisted densification, multi-layered systems, composites and constrained films [4–12]. However, a big difference still existed between the experimentally measured and theoretically predicted densification behavior [13–18]. In 2006, anisotropic constitutive laws were proposed by Bordia et al., where anisotropic sintering parameters were needed for the description of constrained sintering behavior [19]. However, the experimental determination of anisotropic sintering parameters proved to be not easy to achieve. Up to date, a few efforts have been made only based on theoretically predicted anisotropic sintering parameters [19–21].

In past decades, constrained sintering has drawn increasing attention in the low-temperature co-fired ceramic (LTCC) industry as well as in the newly developed ultra-low-temperature co-fired ceramic (ULTCC) materials [22–30]. A variety of constrained sintering technologies including pressure-assisted, pressureless and self-constrained sintering have been extensively explored, through which zero shrinkage can be achieved in a given plane [24–27,30]. Nevertheless, it should be of significance to build up a fundamental understanding of the response of the LTCC sample to outer constraints and to correlate it with its microstructure evolution. Emphasis of LTCC constrained sintering was ever placed on the measurement of the compressive stress required for shrinkage-free sintering and the experimental determination of isotropic continuum mechanics sintering parameters [30–36]. Huang and Jean determined the uniaxial compressive stress for achieving a fully-constrained sintering through a series of continuous loading experiments [30]. By utilizing a laser-assisted dilatometer, zero radial shrinkage was successfully achieved by Zuo et al. and the required uniaxial compressive load was simultaneously recorded [31]. The uniaxial viscosities of LTCC compacts or tapes have been experimentally determined through a few improved sinter-forging [32–36]. The vertical sintering technique, in which a ceramic thick film was vertically hung during sintering, has been recently applied to determine the uniaxial viscosity of LTCC tapes [37,38]. In addition, a couple of experimental work on LTCC sintering was reported, in which multilayer composite structures were specially designed in order to provide an effective constraint [39–43]. However, a valid theoretical description of LTCC sintering behavior under a constraint proved still insufficient probably owing to the formation of anisotropic microstructure.

In this work, constrained sintering behavior of uniaxially constrained LTCC tapes was investigated by means of a lab-designed optical dilatometer [37]. A uniaxial load was applied to the tape

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http://dx.doi.org/10.1016/j.ceramint.2016.08.035
0272-8842/