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ScienceDirect
Journal of the European Ceramic Society 29 (2009) 2737–2745
www.elsevier.com/locate/jeurceramsoc

Study of deformation and porosity evolution of low temperature co-fired ceramic for embedded structures fabrication

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Received 7 November 2008; received in revised form 27 February 2009; accepted 16 March 2009
Available online 15 April 2009

Abstract

The deformation behaviors of suspended low temperature co-fired ceramic (LTCC) laminates over a cavity and the evolution of open porosity of LTCC are studied for the fabrication of embedded structures in a multi-layer LTCC platform using carbon material. The effects of the type of LTCC materials (self-constrained and unconstrained LTCC), cavity width, laminate thickness, and lamination conditions on the deformation of the suspended LTCC laminate over a cavity are studied. For suspended three-layers and six-layers LTCC laminates over cavity width ranges from 10 to 25 mm, the self-constrained LTCC laminates were more dimensionally stable (sagged by less than −120 μm) after sintering as compared to the unconstrained LTCC. The evolution of open porosity and the distribution of open pores in the self-constrained LTCC with changes in sintering temperature and laminate thickness are also studied for process optimization.

Keywords: Sintering; Porosity; Substrate; Sensors; Low temperature co-fired ceramic

1. Introduction

Maintaining the structural dimensional stability in the fabrication of embedded structures in a multi-layer low temperature co-fired ceramic (LTCC) platform remains as a challenge. The suspended LTCC material over the embedded structures is susceptible to deformation during fabrication. During lamination of LTCC green tapes, the suspended green tapes over the embedded structures could deform or sag due to a high lamination pressure (10.3–20.7 MPa).[1–4] The suspended laminated green tapes (or laminate) could also deform due to the body force induced by the softening of glass component in the LTCC material during sintering.[1–4]

To minimize the deformation of suspended LTCC laminate, techniques have been developed to sustain the embedded structures during lamination and/or sintering.[5–13] Techniques include the employment of temporary inserts,[5,6,10] fugitive materials (such as carbon material,[1,2,4,13] waxes[11] and polymeric materials[11,12]), and lead bi-silicate glass[2] as supporting medium and using adhesive materials[7–9] for low pressure lamination. Among these techniques, fabrication of embedded structures using carbon material is one of the most popular techniques.[1,2,4,13]

In the fabrication of embedded structures in multi-layer LTCC platform, carbon material is used to support the structures during lamination and/or sintering. The carbon material is required to be completely removed from the embedded structures before the full densification of the LTCC. During sintering, glass component in the LTCC material starts to flow and thus the suspended portion of the embedded structures might deform. The open pores in LTCC material decreases with densification. Simultaneously, carbon material decomposes and diffuses away through the porous LTCC material at this temperature range. As a result, the carbon burnout process tends to compete with the elimination of open pores in LTCC. The intrinsic nature of this process, which involves phase change and deformation of the materials, is complicated. Thus, the understandings of material behaviors, such as carbon burnout, densification of LTCC, pore evolution in LTCC, and deformation of suspended LTCC, are important in optimizing the fabrication process for embedded structures in a multi-layer LTCC platform. Carbon burnout and densification of LTCC material were investigated in our previ-

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0955-2219/$ – see front matter
doi:10.1016/j.jeurceramsoc.2009.03.009

ous paper.[14] To further understand this fabrication process, our current investigation focuses on the deformation of suspended LTCC and open porosity evolution in LTCC during sintering. Hitherto, the deformation behavior of suspended LTCC material over a cavity, especially during sintering, have not been fully understood and investigated. Bau et al.[1] studied the deformation or sagging of a single layer of unconstrained LTCC tape (DuPont 951-C2) suspended over a cavity. However, the sagging of the suspended LTCC tape was overestimated because the material flow of the tape was not constrained by lamination.

2. Methodology

2.1. LTCC and carbon materials

Commercially available self-constrained LTCC tape (HL 2000, Heraues, Germany), unconstrained LTCC tape (CT 800, Heraues, Germany), and carbon tape (Harmonics Inc., USA) were used. For the subsequent discussions, the HL 2000 and CT 800 tapes are referred as the self-constrained and unconstrained LTCC tapes, respectively. The self-constrained LTCC tape consists of three sub-layers.[15] The top and bottom sub-layers consist of glass ceramic composite and organic binder. The middle sub-layer is a refractory ceramic layer that does not shrink during co-firing. Due to the rigidity of this refractory ceramic sub-layer, the shrinkages of the tape are constrained by this refractory ceramic sub-layer in the x- and y-directions. However, due to the porosity of this refractory sub-layer, the glass component in the top and bottom sub-layers melts and infiltrates mostly into this refractory ceramic sub-layer, contributing significantly to the shrinkage in the z-direction. The unconstrained LTCC tape is made of glass ceramic composite particles and organic binder. This material encounters shrinkage in three directions during sintering.

2.2. Deformation of suspended LTCC laminates

2.2.1. Deformation of suspended LTCC laminate during lamination

The deformation behavior of suspended self-constrained LTCC (HL 2000) laminates during lamination but before sintering was studied. Channel of 1 mm in width, 10 mm in length, and 0.125 mm in depth was individually formed on four LTCC tapes. Subsequently, these four tapes were stacked and laminated with another three layers of LTCC tapes to form a LTCC laminate with an open channel of 0.53 mm in depth. The LTCC laminate with open channel were then laminated again with a three-layers LTCC laminate on the open side of the channel to form an embedded channel; see Fig. 1(a). During lamination, the LTCC laminate containing the embedded channel was sandwiched with silicone rubber and glass plates. To study the effect of lamination pressure on the sagging of a suspended LTCC laminate over an embedded channel, three different lamination pressures were explored, namely 0.1, 0.4, and 2.1 MPa. The maximum deformation or deflection of the suspended LTCC laminate after lamination was measured using a stylus profilometer (Form Talysurf Series 2, Taylor–Hobson); see Fig. 1(b) and (c).

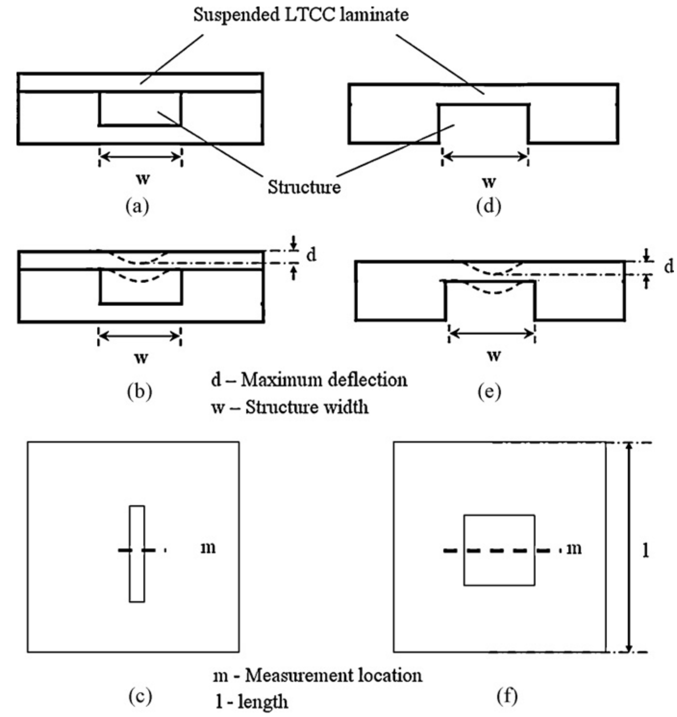

Fig. 1. (a) Cross-section of suspended LTCC laminates over open channel with dimensions of 1.0 mm × 10 mm × 0.50 mm, (b) maximum deformation of suspended LTCC laminate after lamination, (c) top view of measurement location of maximum deformation of surface profile, (d) cross-section of suspended LTCC laminates over open cavity with depth of 0.53 mm and area of either 10 mm × 10 mm, 15 mm × 15 mm, 20 mm × 20 mm, or 25 mm × 25 mm, respectively, (e) maximum deformation of suspended LTCC laminate after sintering, and (f) top view of measurement location of maximum deformation of surface profile.

2.2.2. Deformation of suspended LTCC laminate during sintering

Deformation behaviors of two types of suspended LTCC materials during sintering were studied and compared. These materials are self-constrained LTCC (HL 2000) and unconstrained LTCC (CT 800). Suspended LTCC materials over embedded structures could deform after lamination and/or sintering. To identify the contribution to deformation by sintering alone, and the complication of introducing deformation during the lamination stage, a suspended LTCC laminate over an open cavity was used instead; see Fig. 1(d).

Deformation of a suspended LTCC laminate consisting of a single layer of LTCC tape over a cavity was not studied. This is because suspended single layer LTCC was too weak to obtain stable surface profile before sintering for subsequent analysis. Instead, suspended LTCC laminates made of three and six layers of tapes over a cavity width of 10, 15, 20, and 25 mm were studied, respectively.

To fabricate a suspended LTCC laminate, cavity consisting of four layers of LTCC tapes (with tape area of 75 mm × 75 mm) was obtained by punching each layer individually. These four