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Low-pressure, thermo-compressive lamination

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Abstract

Lamination of green ceramic tapes is one of the most important technological processes in multilayer ceramic technology. Lamination affects the quality of all 3D structures (e.g., channels, chambers, membranes, etc.). Novel chemical methods of lamination reduce the deformation of 3D structures. However, these methods are useless in the fabrication of thin membranes and structures with thick-film electronic components or electric vias. Therefore, thermo-compressive lamination is still the best solution for the lamination of green ceramic tapes. Low-pressure thermo-compressive lamination with an insert material is presented in this paper. The influence of pressure and Low Temperature Cofired Ceramics (LTCC) material on the compressibility and shrinkage of LTCC, as well as the influence of the insert material on deflection and distortion of the membranes are presented and discussed in this paper.

Keywords: Lamination; Low pressure; LTCC; Joining; Bonding; Green tape; Insert; Ceramics; Low temperature; Thermo; Compressive

1. Introduction

Low-Temperature Cofired Ceramics (LTCC) technology has been developed over the past few decades.[1–3] The technique was first used in the fabrication of multilayer electronic substrates and passive components.[4] Since the early 1990s, LTCC has been used in the fabrication of sensors, actuators and microsystems.[5,6]

Tape machining of LTCC tapes,[7,8] thick-film deposition,[9] lamination (tape bonding in the green state)[10] and the sintering profile affect the parameters of sensors, actuators and microsystems. Therefore, all these processes must be very carefully optimized. The quality of 3D structures depends primarily on the lamination and on firing. The most popular lamination method is thermo-compression. The tapes are joined at elevated temperatures (70–90 °C)[11] using high pressure (5–20 MPa)[11] for a certain amount of time (3–10 min).[12] The lamination of green tapes is schematically presented in Fig. 1. Single tapes presented in Fig. 1a consist of ceramic particles, glass and organic material (mainly binder). Tapes during lamination are heated and pressed together. Hence, the organic material becomes plastic, and the tapes can be joined. Moreover, the applied pressure forces the ceramic particles and glass from all the tapes together. Therefore, if the pressure is high the lamination strength between the tapes is strong. During firing, the organic material is driven off, and the glass melts, wets and joins the ceramic particles together.

The final bonding strength between LTCC ceramic tapes depends on three main mechanisms[13]:

- joining of the melted resinous constituents (occurs during lamination),
- the mechanical joining of rough surface (occurs during lamination),
- viscous flow of the glass material (occurs during firing).

The simplest model of green LTCC is that of an elastic–plastic material. Therefore, good lamination can occur only if the lamination pressure is higher than the yield point of the organic material. Moreover, the yield point decreases if the temperature increases, and therefore, lower lamination pressures can be used if the laminated stack is heated more. A more complicated model should also include the influence of the organic material, the ceramic particles and the glass material contents. The organic material should enable proper mechanical properties of the green tape. However if there is too much organic material, the ceramic particles are too far apart, and there is no possibility for proper firing of such a structure.[14]

The organic material is driven off during the cofiring process. The melting of the glass plays a dominant role in the

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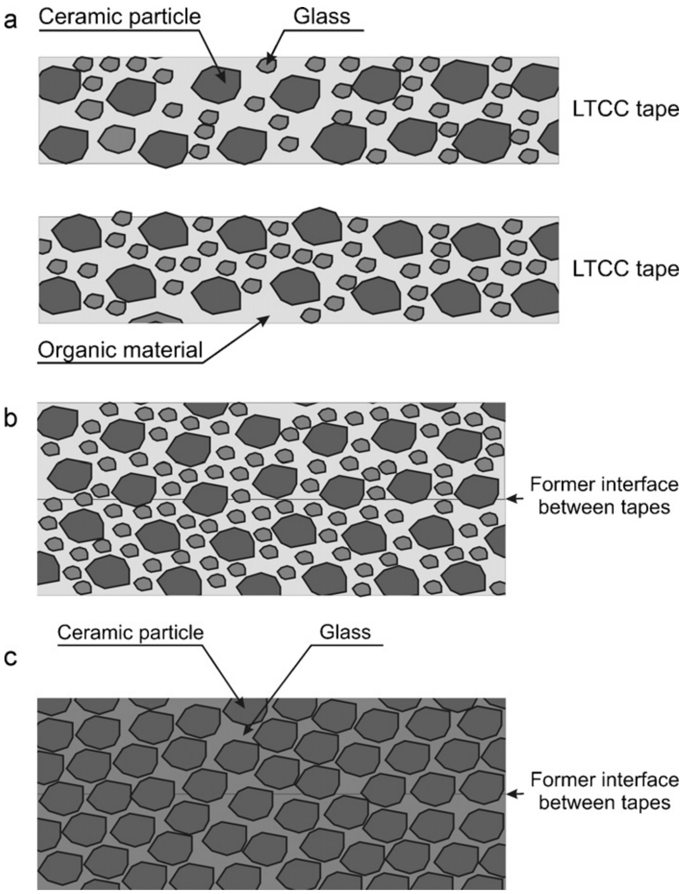

Fig. 1. Bonding of LTCC tapes: (a) before lamination, (b) after lamination, and (c) after firing.

viscous-flow mechanism among the constituents, and hence the glassy material used in LTCC tapes is very important for proper bonding and sintering of glass/ceramic composites.[13] The glass melts above the softening temperature and penetrates the void space between the ceramic particles. The viscous flow of the glass depends on the ceramic-powder particle size, glass and ceramic particle content, glass softening point and glass melting point.[13] The melted glass wets ceramic particles and enables to achieve strong final structure. Therefore, the glass material enables a lowering of the LTCC firing temperature below 900 °C. Structure warping, distortion and other deformations occur during sintering and are associated with viscous flow.[13] Therefore, in many cases, the structure after sintering is more deformed than after lamination. The deformation can also be multiplied by the shrinkage of the LTCC during firing. The penetration of the glass material between the ceramic glass can also bond tapes together. If during firing the tapes are joined together, then viscous flow occurs not only in a single tape but also between tapes. Therefore, ceramic particles from laminated tapes can be permanently bonded. Thermo-compression does not affect the properties of thick, passive films and enables the fabrication of structures that have more than 40 layers. However, high pressure and temperature can very easily damage thin membranes, wide channels and large chambers.

Therefore, chemical lamination, lamination with fugitive phases and lamination with inserts were proposed.[10] The first chemical bonding was reported by Roosen.[12,15–18] The tapes are joined with double-sided adhesive tape, which ensures temporary adhesion between the tapes before sintering. The tapes are permanently joined during a cofiring process. The method enables a reduction in the deformation of 3D structures and does not dissolve the tape surfaces. However, the ceramics should have relatively high porosity to ensure sufficiently high forces, which join the tapes during the firing. Moreover, structures with a higher number of tapes tend to crack. The method enables bonding of metallized tapes. However, the influence of the method on the reliability of thick–film components and electrical vias has not been reported. Upgraded versions of the deposition of a joining medium onto the tapes have been reported.[17,18] Other chemical methods, which have also been reported, are very similar. Temporary bonding between the tapes is achieved by applying some adhesive agent onto the tapes.[19–22] Then, the tapes are permanently joined during cofiring. The tapes can also be joined using solvents.[23–25] A diluted fluid applied onto the green tape dissolves both the joined surfaces and bonds the tapes together. However, this method affects the parameters and reliability of electrical vias and thick-film components.[25] The adhesive-based chemical methods might also affect the properties of vias and thick-film components. Therefore, alternative lamination methods have been developed. Thermo-compressive lamination with a fugitive phase is the best solution for the fabrication of closed chambers and channels. In this method, the tapes are bonded at high pressure and at elevated temperature, but the chambers and the channels are filled with a sacrificial material,[26–29] which protects the 3D structures from damage during lamination. The fugitive phase is intended to disappear during the sintering process. The sacrificial material can also protect the structure from deformation during the debinding process. However, the firing process must be extended to ensure proper burning out of the sacrificial material. The alternative is to replace the sacrificial material by an insert material.[10] Open 3D structures are filled with the insert material, which protects the structures from deformation during lamination. After the process, the insert is removed. Moreover, the insert is not present during firing, and therefore, a standard cofiring profile can be used.

Isotactic, thermo-compressive lamination with inserts under very low pressures has not been widely discussed in the literature. Therefore, the influence of the lamination pressure in the range from 0.5 to 20 MPa and of the LTCC material on the bonding quality, LTCC tape compressibility and shrinkage of LTCC were analyzed. Moreover, the relative membrane deflections for various membrane dimensions and tape types were investigated. The membrane deflections of the structures laminated with and without the inserts were compared and discussed. The authors wish to show that viscous flow of glass during firing can be a dominant joining mechanism and can ensure good bonding quality.

2. Experiment

The experiment was carried out on four different commercially available LTCC tapes: HL800, HL2000, DP951 and