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ScienceDirect

Ceramics International 41 (2015) 7860–7871

CERAMICS INTERNATIONAL

www.elsevier.com/locate/ceramint

Investigation of High Temperature Co-fired Ceramic tapes lamination conditions

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Received 30 December 2014; received in revised form 6 February 2015; accepted 23 February 2015
Available online 28 February 2015

Abstract

The main goal of this paper was to analyze the influence of lamination process conditions and High Temperature Co-fired Ceramic (HTCC) tape composition on the lamination quality (existence of delaminations). The second aim was to estimate the influence of lamination conditions and HTCC tape composition on three process outputs: compressibility, surface roughness and density of High Temperature Co-fired Ceramics and to recognize if these outputs can be useful from lamination quality investigation point of view. The bonding quality was investigated using scanning acoustic microscopy (SAM). The analyzed ceramics was fabricated using water based slurries in the frame of tape casting process. The paper additionally discusses limitations and drawbacks of the used investigation methods and experiment design.

Keywords: Ceramics; Lamination; Water based tape casting; HTCC

1. Introduction

Multilayer ceramic technology can be divided into two main parts: Low Temperature Co-fired Ceramics (LTCC) and High Temperature Co-fired Ceramics (HTCC). LTCC contains glass which gives a firing temperature compatible with silver and gold, and LTCC is utilized in the fabrication of wireless components (e.g. antennas), sensors, actuators, chemical reactors and microsystems [1–3]. HTCC is fired at higher temperature (1500–1600 °C) and is used in applications where higher chemical or thermal stability is needed [4], moreover, it can be used as well in RF devices or packages [5,6] and automotive applications [5].

Both LTCC and HTCC are fabricated in the frame of tape casting process from various slurries [7]. The slurry composition decides about mechanical and electrical properties of both green and fired tapes. The trend of toxicity reduction of materials caused the necessity of slurry composition changes. The possibility of utilizing more environmental and user friendly water based solvents instead of high flammable and toxic organic solvents was previously reported [8–10]. After tape casting the laser cutting systems, punching units or embossing machines permit the fabrication of structures in each single tape. The structured tapes are aligned and stacked, in order to build up 3D components. Then the lamination is conducted. This process is extremely important due to the fact that it affects the homogeneity of tapes in region of the tapes interface. In other words if the process is carried out improperly, delaminations between tapes on the tapes interfaces will occur. There are two groups of lamination techniques which are worth to be mentioned thermo-compressive lamination [11,12] and chemical laminations [13–15]. The usefulness of the chemical methods is mainly limited to the special complicated 3D structures without electrical components. On the other hand standard thermo-compressive methods are widely used but can cause high deformation of 3D structures fabricated using single tapes. After lamination the tapes are co-fired in a furnace. This process drives off all organic materials from the tapes and permits sintering of the ceramic grains together. Hence, the hard dense ceramics is obtained.

The quality of sintered ceramics can be investigated from several points of view, e.g. surface roughness, delaminations,

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http://dx.doi.org/10.1016/j.ceramint.2015.02.123
0272-8842/

compressibility or density value. Given the level of surface roughness for ceramics, the most useful method of measuring is mechanical profilometry. The surface roughness depends mainly on the size of the ceramic grains and its optimal level depends on the application. This material property is not correlated with the other ceramic properties mentioned above. Delamination is a frequently investigated output, since it can indicate an insufficient lamination process or variation in the material composition.

The quality of sintered ceramics can be examined using several different inspection methods, of which the most promising are non-destructive [16], such as Scanning Acoustic Microscopy (SAM) [16,17]. SAM permits the detection of delaminations in ceramic structures [16,17] and therefore it is also very useful in LTCC and HTCC structures inspection [16,18,19]. SAM is a very sensitive control method of delaminations, since inclusion of air causes a total reflection in the signal. Therefore, SAM inspection was used as a reference investigation method in order to validate the other inspection methods applied in this work.

Measurement of density through the Archimedes method permits detection of closed porosity; if any close gas voids exits between layers the measured density will be lower than the expected mean value. However, the limitation is the fact that open delaminations will not be detected by this method. The compressibility is correlated with delaminations through the expectation that some compressibility is needed for proper lamination, hence, if the compressibility is low, this indicates delaminations. The measurement of compressibility is, however, dependent on the tape thickness variation and might be misleading. In the present study delaminations were detected only for samples with low compressibility.

Optimization from laser cutting and sintering point of views of the tapes presented in this paper were done before [20,21]. The aim of this paper was to investigate the influence of the lamination process conditions and tape composition on the lamination quality (existence of delaminations). Three measures of quality of lamination were proposed in this paper: compressibility and surface roughness of the green tapes, and density of the fired tapes. The usefulness of these three outputs on the lamination quality analysis was verified in the frame of the experiment. Moreover, the tape compressibility, sintered ceramics surface roughness and density were investigated for different values of a number of process parameters, and the bonding quality was investigated using Scanning Acoustic Microscopy (SAM). The experiment was planned using Design of the Experiment (DoE) [20,21] and the data were analyzed using analysis of variance and orthogonal contrasts methods [20,21]. The paper additionally discusses limitations and drawbacks of the used investigation methods and experiment design.

2. Experiment

In the investigation of lamination quality, the compressibility of the tapes, and surface roughness and density of sintered samples were analyzed and the following process conditions were investigated: duration time of tapes preheating at lamination temperature, lamination time, lamination temperature, lamination pressure, binder content and binder composition. The investigated inputs are given in Table 1. The preheating means that tapes were left in the laminating machine for a particular period before the lamination pressure was turn on. This solution is used to provide even temperature distribution for all laminated tapes. The value of each of the lamination conditions as well as binder content and tapes composition was chosen based on the expert knowledge. This knowledge was gained in the frame of earlier investigations [20,21]. The samples used in the study were laminates of two HTCC square tapes $20 \times 20\ mm^2$, around 180 μm thick (in green state). The tapes were made by aqueous tape casting using alumina powder (AKP30, Sumitomo Chemical), dispersant (Dolapix PC21, Zschimmer & Schwarz) and latex binder (Resicel E50N, Lamberti Speciality Chemicals, or LDM 7651S, Celanese Emulsions).

Table 1
Investigated process parameters.

Factor	Factor acronym	Factor level		
		−1	0	+1
Preheating of structure at lamination temperature	*A*	10 min	–	0 min
Lamination time	*B*	2 min	11 min	20 min
Lamination temperature	*C*	26 °C	50 °C	80 °C
Lamination pressure	*D*	5 MPa	12.5 MPa	20 MPa
Binder content	*E*	20%	25%	30%
Resicel/LDM ratio	*F*	100/0	50/50	0/100

The compressibility was calculated as the ratio between prelaminated green tape and laminated sample thicknesses multiplied by 100. The density was measured using the Archimedes method in water and its value is given as a relative value of theoretical alumina density given in percent. The average roughness results were calculated based on 10 mm long surfaces scans of the ceramic (Taylor-Hobson mechanical profilometer). The experiment consists of three runs; three samples were measured from up and down sides (total cardinality was equal to 108). The cardinality of each of the runs for compressibility verification was 10 with two replications (total cardinality was equal to 360). The density was measured as average density of 3 samples with three replications (total cardinality was equal to 162). The results are given only as average values of all achieved results to simplify the form of tables.

All statistical calculations were conducted according to an analysis of variance method (ANOVA) and the type influence of inputs on outputs was found using an orthogonal contrasts method. The second solution permits to find if the relation between input and output is linear, square or mixed linear-square [22].

3. Design of the Experiment (DoE)

Taking account that influence of 6 inputs were investigated at once it was decided to apply Design of the Experiment (DoE) methodology in the analysis [22,23]. This solution permits the reduction of costs and time of the experiment. The most sufficient experiment design would be full factorial design, which enables