Generic investigation on 0-shrinkage processed LTCC

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Abstract

Free sintered **L**ow **T**emperature **C**ofired **C**eramics (LTCC) substrates are often assessed in their dimensional accuracy concluding that the overall x/y-shrinkage and tolerances at sintering might be responsible for component assembly problems. The tolerance effect increases in relation with substrate size. The geometrical accuracy and substrate flatness are of importance to fine-pitch mounting processes especially with mouldings and cavities.

The paper describes results of our initial investigations concerning the shrinkage behaviour of substrates made out of varying tape material counts of DuPont 951 using release tape 953A6 following the pressureless and pressure assisted sintering (PLAS and PAS) procedures. Our focal point was the realisation and assessment of cavities and holes.

Results are available both for cofired surface prints in combination with release tape and partial single side usage of release tape.

Introduction

Free sintering is the most used method for production of substrates, one may also call it the „**U**n**c**onstrained **S**intering“ (**UCS**) method.

The most talked about disadvantage of this inexpensive LTCC sintering process is the shrinkage of tiles in all directions with relative high tolerances of up to $\pm$ 0.5%. The typically achieved $\pm$ 0.2% for x- and y-direction still causes problems for device mounting and requires post processing to provide acceptable catch pad tolerance.

Additionally module waviness caused by TCE mismatch of conductor inks lead to more problems at assembly. The relative high lamination pressure often generates deformation of cavities and holes.

Constrained sintering essentially almost eliminates the x/y-shrinkage. Two constrained sintering processes are known. The **P**ressure **L**ess constrained **S**intering (**PLAS**) and **P**ressure **A**ssisted constrained **S**intering (PAS).

Besides the costs of additional release tapes and their removal after sintering, the installation of a special hot pressure-sintering furnace have to be considered. Advantages (+) and disadvantages (-) and some technical characteristics are listed in figure 01:

<table>
<tr><th>UCS</th><th>PLAS</th><th>PAS</th></tr>
<tr><td>+ modules immediately finished for post processes</td><td>- removal of release tapes</td><td>- removal of release tapes</td></tr>
<tr><td>+ cofired conductors on surfaces possible,
additional postfire prints possible</td><td>- surface conductors usually in post process</td><td>- surface conductors usual in post process</td></tr>
<tr><td>shrinkage
- x, y = 12 ± 0,2 %
z = 17 %</td><td>shrinkage
+ x, y = 0 ± 0,1 %
z = 41%</td><td>shrinkage
+ x, y = 0 ± 0,05 %
z = 41%</td></tr>
<tr><td>- lamination pressure 3000psi</td><td>+ lamination pressure down 1000psi</td><td>+ lamination pressure down 1000psi</td></tr>
<tr><td>+ nearly unlimited number of layers</td><td>only first layers total fixed by release tape for 0-shrinkage, therefore
- limited number of layers</td><td>+ nearly unlimited number of layers</td></tr>
<tr><td>- full conductor layers in cofiring impossible, waviness and inhomogene shrinkage caused by TCE mismatch of inks</td><td colspan="2">+ improved waviness, full conductor areas (better shielding and EMC), integration of new and TCE matched materials (ferrite or high K-tapes and inks) results in exchanged ranges of LTCC applications</td></tr>
<tr><td>+ cavities, holes, channels and mouldings possible</td><td colspan="2">- cavities, holes, channels and mouldings yet unknown</td></tr>
<tr><td>- high mean variation of printed element values caused by shrinkage in all directions</td><td colspan="2">+ Improved accuracy of printed (also buried) elements by 0-shrinkage in x-and y- direction</td></tr>
<tr><td>- requires post processed catch pad layer for fine pitch realisation</td><td colspan="2">+ smaller or no catch pads necessary due to 0-shrinkage in x- and y-direction and higher yield</td></tr>
<tr><td>+ full standard ink system exists</td><td colspan="2">- new ink system for cofired application necessary, range of inks is limited</td></tr>
</table>

Fig. 01: Advantages and disadvantages of the different sintering processes [1-4]

This paper discusses first results of our investigations using PLAS and PAS methods and possibilities of overcoming some of the mentioned problems. A special furnace was used for the PAS process; modules of up to 4 inches can be sintered under pressure. A uniaxial force of up to 50 kN can be applied during sintering.

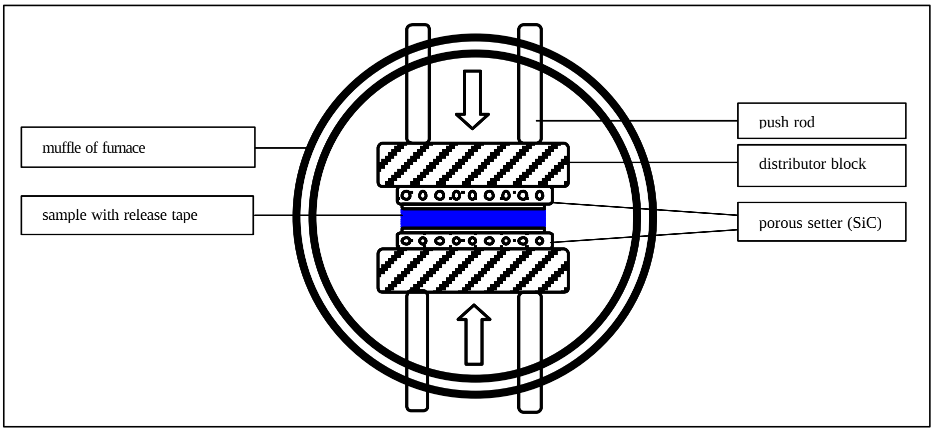

Fig. 02: Scheme of the used furnace for the PAS process

PLAS and PAS Investigation

In the standard zero shrinking technology the substrate material is cofired within layers of release tape. Outer conductors are then applied as postfire prints. Cofiring of surface conductors is possible; however, the release tape will influence their sintering behaviour. Bonding and/or soldering performance of such cofired conductor has to be reassessed. Important are the percentage of glass in the prints, characteristic of the release tape and the method for removing it after sintering.

Methods of Release Tape Removal after Sintering

For the removal of the release tapes some quite inexpensive methods with different features are possible. Special requirements may dictate what method to choose. One important criterion is the use of printed elements on the surface and vias through the surface.

Brushing: It's the cheapest way to remove the release tape from the LTCC surface. Still a slight grey gleam is visible at the surface. Cofired surface prints are worse in performance concerning bonding and soldering. Vias up to the surface increase their resistivity.

Sand- or Glassball- Blasting: With this method the complete removal of the release tape is possible but there is a strong mechanical stress involved especially on the module surface. Additional grinding and cleaning is often required. Cofired conductors and vias decrease in conductivity.

Water Blasting: The effectiveness of this process starts at pressures of 150 bar. In combination with abrasives the feature is comparable with sand- and glassball-blasting but the fine-tuning and handling characteristic is better.

Cofiring of Surface Prints

Surface prints change their properties with release tape in contact at cofiring. The influence of the release tape depends on the wetting characteristic and the amount of glass in the prints. Some encapsulants may get totally absorbed. Conductors loose their performance in bonding and soldering. In most cases removal processes based on grinding may restore performance features but at the expense of reduced thickness of the conductor.

Another approach to manage cofired prints and maintain their performances is by placing openings in the release tape. They should be located just at the places where the performing prints are (solder and/or bond pads, printed resistors) and at one side of the module. Dimensions of about 400 mm² per opening are possible. With rising dimensions the risk of deformation and increased tolerances need consideration. Between several openings and the module rim a distance of at least 15 mm, depending on module dimension, is necessary.

In any case of using release tape openings it may not be necessary to remove the release tape after the end of the process. To prevent detachment of release tape powder it can be fixed with lacquer.

The following table shows the advantages and disadvantages of using openings in the release tape.

Advantages	**Disadvantages**
• cofired bond and solder pads, glazes and resistors at the surface are not influenced by the release tape • no postfire prints are necessary • no grinding processes for removing of the release tape are necessary • removal of release tape may not be necessary.	• only a part of the surface is usable • risk of deformation and tolerances rises • openings on both sides are possible but should not overlap • vias in the zone of openings are critical.

Fig. 03: Advantages and disadvantages of openings in the release tape for cofired surface prints

Shrinkage Behaviour

Experimental Procedure

The investigation of the shrinkage behaviour was realised on modules of 6 and 8 layers of LTCC with top and bottom layer of release tape. Silver filled vias in different distances arranged around a centre via were used for the measurement procedure. The vias positioned in the middle layers were measured before and after the sintering process using an X-ray microscope.

Investigated Shrinkage

A disadvantage of the UCS-process is high absolute shrinkage and especially the tolerance of 0.2%. Additional influence caused by conductor TCE-mismatch enlarges the problem.

The investigation shows that the absolute shrinkage with the PLAS process is restricted to under 0.3%, whereby the PAS process controls the shrinkage by use of the pressure (Fig. 04). If the pressure is too high then the module expands in x- and y-direction.

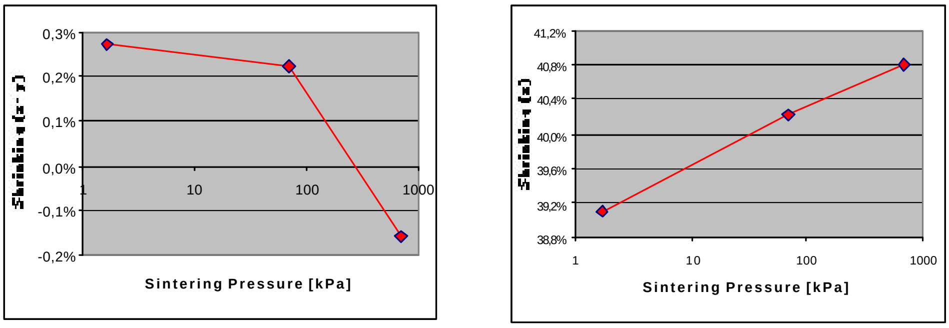

Fig. 04: Effect of applied sintering pressure on via location (inner layer) and z-shrinkage of substrate

Fig. 04 also shows the shrinkage in z-direction. As expected it depends on the sintering pressure and is about the volume shrinkage. Not all areas are shrinking with at the same rate. At lower pressures the rate is nearly constant, at higher pressures differences between inner and outer areas rises (Fig. 05).

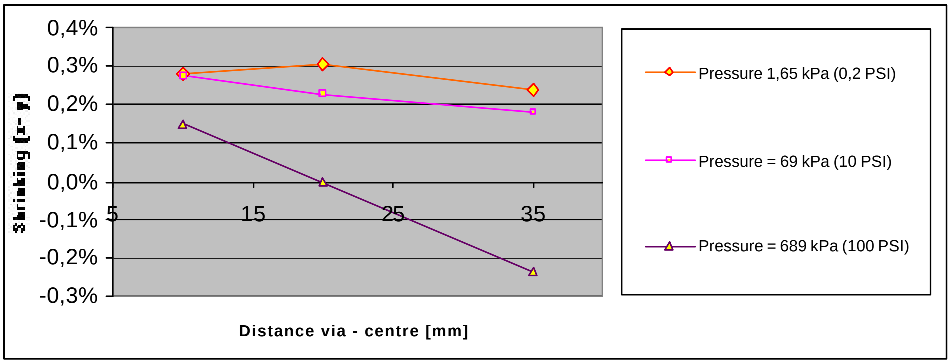

Fig. 05: Effect of distance from centre for shrinkage (negative value = expansion)

Another special issue is the shrinkage close to edges. Using the PLAS process the edges and nearby placed vias become concave. The effect is restricted to the area of 2 mm around the edge. Using the PAS process this problem can be avoided (shown at Fig. 07).

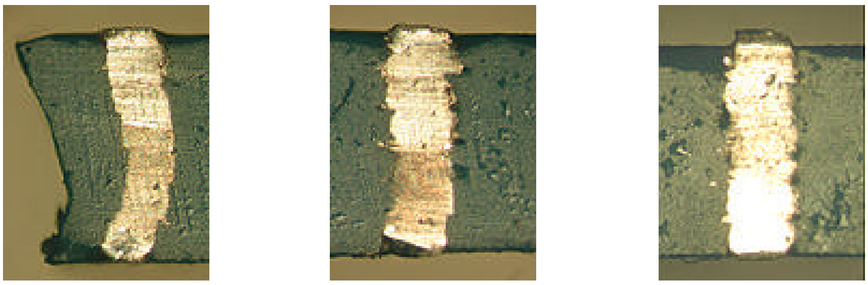

Fig.06: Shrinkage effects nearby edges (distance edge to via around 0,5 mm; 1,5 mm; 2,5 mm)

Cavity Formation in 0-Shrinking LTCC

An advantage of the constrained sintering processes is the lower lamination pressure in use. It leads to lower tolerance after lamination. Besides the loading of edges is strongly sinking. This leads to better results in realising of cavities or holes.

Edges

The PAS process offers additionally the control on edge deformation. (Fig. 07). The shape of vertical edges is directly dependent on the applied sintering pressure.

An example is a module with 6 layers. At no pressure during the sintering, a strong shrinking of the inner layers is visible. The best result was achieved at a pressure of 10 psi (0.7 bar), at a pressure of 100 psi (7 bar) bulges show up. The optimal pressure depends on the LTCC material and the number of layers.

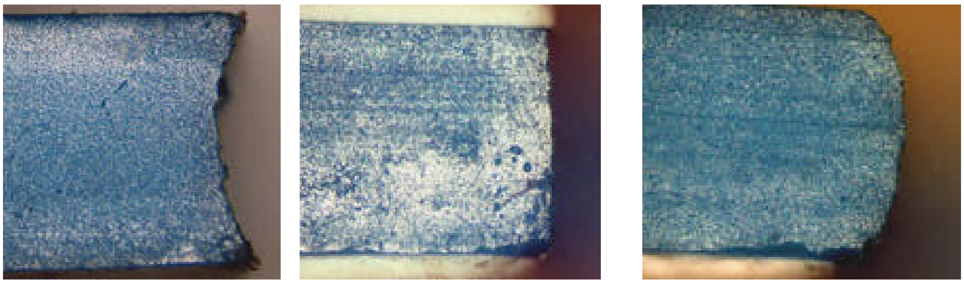

Fig. 07: Forming of vertical edges in perforations dependent on the sintering pressure (module of 6 layers sintered thickness 0,9 mm)

Cavities

Despite of the lower pressure needed at lamination, producing holes without removable inlays are only possible in a uniaxial process. A problem of this process is the insufficient pressure transfer to the top and bottom layers around the hole. This leads to delamination between release tape and LTCC (Fig. 08).

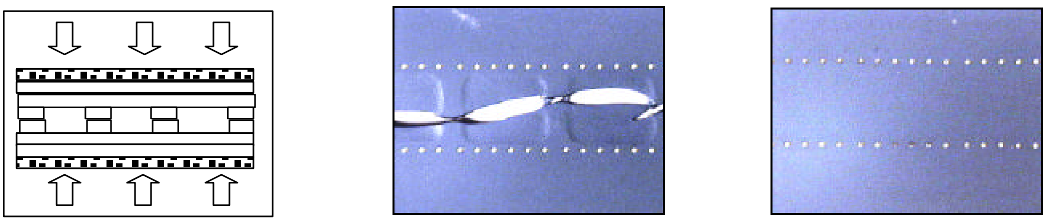

Fig.08: Bottoms of holes (scheme left) with cracks because of delamination between release tape and LTCC (middle), bottoms of equally holes after separate lamination of the top and bottom layers with release tape before the main lamination

A solution for this problem is the separate prelamination of the top and bottom layers with release tape. With this procedure delamination will be avoided and the following main lamination can also be made 1000 psi lower. This leads to lower deformation around the hole area.

Integration of Inlays in LTCC

Constrained sintering leads to new perspectives to realise inlays. Especially inlays with low hights (foils, wires) are qualified. Howe ver one problem remains is the different TCE in case of using metals or variant glasses and ceramics. Therefore only the PAS process is usable for larger inlays. Without external pressure during sintering the thermal mechanical forces destroy the module.

Summary

The main advantage of the 0-shrinking processes is lower shrinkage tolerances. This initial work confirms the expected behaviour and one can say that the PLAS process can be used to control shrinkage to better than 0.3%. The PAS process allows control of the shrinkage below 0.1% whereby the tolerances behave similarly.

Besides the 0 -shrinking technologies, especially the PAS process offers new possibilities by realisation of edges and holes. Modifications in uniaxial lamination technology and applying release tapes lead to improved manufacturing of cavities. In addition it allows new kinds of inlay integration.

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