Robust LTCC/PZT Sensor-Actuator-Module for Aluminium Die Casting

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Abstract

The present paper reports on a new module design based on LTCC-PZT laminates. The assembly of modules is achieved by packaging of ceramic PZT plates between LTCC green layers and subsequent sintering of the evolving multilayer. The challenge exists in avoiding tension cracks at shrinking of LTCC layers on the already sintered piezoceramic during the firing process. Thermal characteristics of several LTCC green ceramic products were investigated, systematically, to obtain crack free ceramic modules. The advantages of a module with full integrated PZT ceramic tiles are the mechanical stabilisation of the piezoceramic, the electrical insulation and the shielding of external environmental influences. More general, our approach combines LTCC microsystems technology and piezo technology and allows for a tremendous improve of functional integration, e.g. sensing, actuation, buried electronic circuits, and strain-stress transformation. After preparation, the ceramic modules were introduced in the manufacturing chain of aluminium die casting. Thus aluminium components with integrated sensor-actuator modules could be prepared by die casting for the first time (in cooperation with the University of Erlangen-Nuremberg). The piezoelectric modules survived this manufacturing step without deterioration and fortify the concept of adaptive metal structures in automotive and machine building industry. The functions of the moulded LTCC/PZT modules are estimated by electro-mechanical characterisation methods (e.g. measuring and determination of dielectric coefficient, loss angle tan δ, remanent polarisation and deflection).

Key words: LTCC/PZT, Sensor-Actuator-Module, Multilayer-Packaging, Aluminum Die Casting

Introduction

Usually, active structures are produced in separated steps, covering production of functional modules with sensing and actuation capability, production of the mechanical load carrying structure and final assembly by the application of the functional module on the structure. This process has disadvantages, as for example limited productivity, limited functionality due to restriction of allowed module positions, and reliability risks due exposure to environmental influences.

An alternative approach with improved achievement potential is seen in the integration of functional modules directly during the fabrication of the load carrying structure. Aluminium die casting can serve as example. Here, modules are cast-in during structure fabrication. But as clear requirement, the module has to be robust enough to survive this production step. During metal die casting high thermal and mechanical loads occur: aluminium melt temperature is higher than 660 °C, filling time is in less than 50 ms and causes high temperature gradients (thermo shock conditions) and pressures is up to 1000 bar.

Polymer based packaged piezoelectric modules were already die casted [2, 3 and 6], but they have a limited performance because of there low temperature stability and low couplimg rigidity of the polymer. Also you have a property mismatch between metal and polymer.

Here we report on our new fully ceramic multilayer-packaged piezoelectric-module with the focus on design and fabrication such as charaterization.

Materials and Methods

Design and Fabrication

For fabrication of fully piezoelectric modules made by multilayer-packaging technology a 3-ply LTCC (= Low Temperature Cofired Ceramic) was used which is the carrier material for mechanical stabilization and electrical termination of the PZT in one. The module size was choosen as (L x W x T: 45 mm x 20 mm x <1 mm).

The design is shown in fig. 1 and 2.

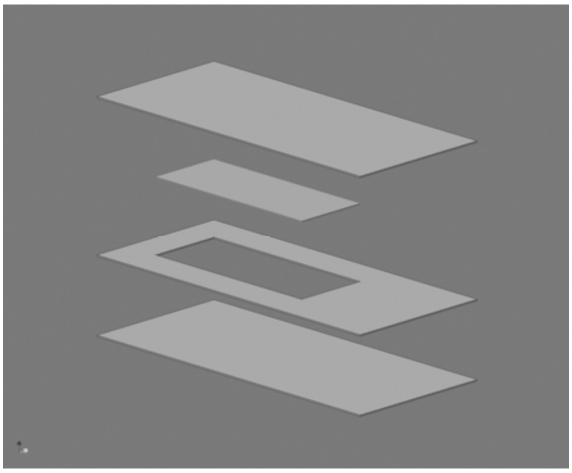

Figure 1: Explosion image of LTCC/PZT-module - without electrical termination; small plate: PZT (schematic)

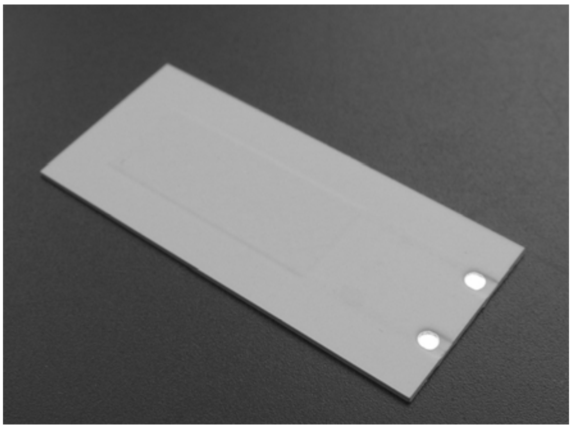

Figure 2: LTCC/PZT-module with electrical termination and soldering pads

Two kinds of LTCC were used: DuPont 951 Green Tape™ [4] and Heraeus HeraLock® Tape-HL2000 green sheets [5]. Before laminating, LTCC green sheets have to be preconditioned in a convection box oven by 10 minutes at 80 °C. Lamination of the LTCC/PZT-modules with an already sintered PZT-plate from "CeramTec" (Sonox® P53) of (L x W x T: 26 mm x 11 mm x 0,2 mm) was done in an isostatic lamination system (IL 4008) with recommended parameters of approximately 210 bar at 70 °C for 10 minutes for LTCC DuPont 951 respectively approximately 170 bar at 75 °C for 10 minutes for LTCC HeraLock® Tape-HL2000.

Afterwards the modules were sintered in a box oven with a special burnout and firing profile. Firing peak temperature was 850 °C for DuPont 951 Green Tape™ and 865 °C for HeraLock® Tape-HL2000, respectively.

Aluminium die casting was done at the Institute of Science and Technology of Metals, University of Erlangen-Nuremburg.

Microstructure evaluation and measurements

"Procon X-Ray CT-Compact" device (acceleration voltage of 130 kV, current of 100 µA and analysis software "XRay-Office") was used for making cross-section images of 3-ply LTCC/PZT-modules. As well conventional polished microsection preparation was done.

For deflection measurements the sintered LTCC/PZT-modules were glued with a 2-component resin (EP 20A-natur + Hardener 158) on steel benders (1.4301 – V2A) as shown in fig. 3. The steel benders were fixed in a measuring set-up (fig. 4) at one side and deflection measurement took place on the free end of the bender using laser triangulation (Micro-Epsilon). Measurements were performed in static mode with electrical field strength of E_S = 2 kV/mm and dynamic mode with E_D = 0,05 kV/mm.

Figure 3: LTCC/PZT-module glued on steel bender

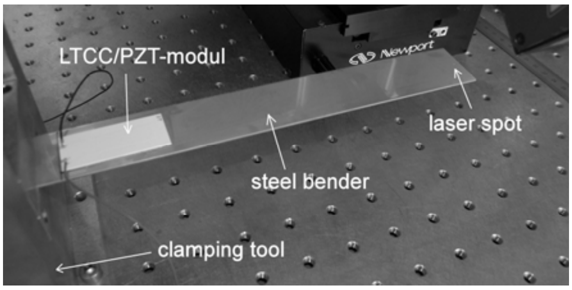

Figure 4: Steel bender with LTCC/PZT-module in measuring set-up

The dielectric constants were determined at 1 kHz, using a Hewlett Packard 4194A Impedance Analyzer before and after polarisation at air and room temperature at E_{pol} = 2 kV/mm and t = 5 min. Measurement of the parameters were done at least 24 h after poling.

Results and Discussion

From a multiplicity of tested carrier materials in previous examinations [7] two kinds of Low Temperature Cofired Ceramics LTCC DuPont 951 Green Tape™ and LTCC Heraeus HeraLock® Tape-HL2000 were selected which are containing alumosilicates [8].

LTCC/PZT-modules with LTCC DuPont 951 as carrier structure showed crack formation and bowing after sintering caused by approximately 13 % shrinkage in x/y-plane of the LTCC (fig. 5).

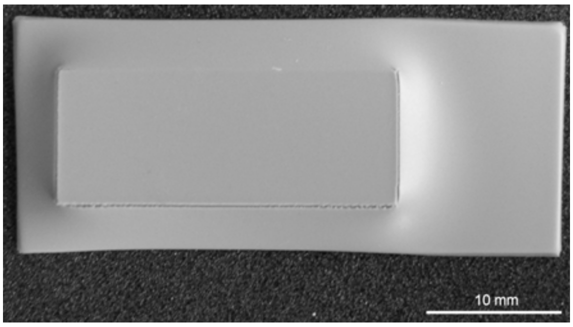

Figure 5: LTCC DuPont 951 with embedded PZT-plate after sintering

To suppress these defects LTCC HL2000 could only be used (fig. 6). It has only a shrinkage in z-direction effected by the special fabrication of the self-constrained tape [1] combined with a near zero shrinkage in x/y-plane. As shown in fig. 6 a carrier material for production of LTCC/PZT-modules was found. With this kind of tape fitting steps which have to be used in general in multilayer-packaging technology could be avoided.

Figure 6: LTCC HL2000 with embedded PZT-plate after sintering

Sonox® P53 PZT-material in polarised situation reveals significant lower capacity values when it´s embedded and sintered in the LTCC carrier material. For this purpose clamping of the PZT-plate through the LTCC carrier material is responsible. Standard polarisation field strength is too small to exhaust full dielectric properties.

For functionality tests the produced piezo-modules were glued on steel bender and deflection measurements were done. The deflection in static mode is around 130 µm and in dynamic mode with a resonance frequency f_R = 19,70 Hz is around 550 µm as shown in fig. 7 and 8.

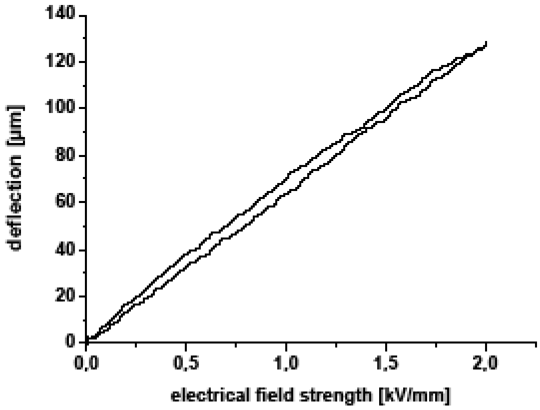

Figure 7: Deflection measurement in static mode

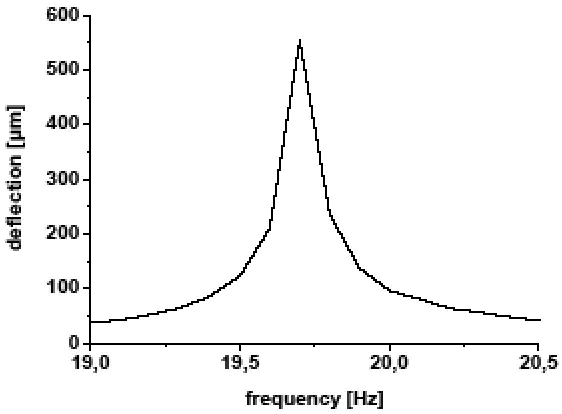

Figure 8: Deflection measurement in dynamic mode

3-ply LTCC/PZT-modules with embedded PZT-plates were used for aluminium die casting tests to evaluate crack formation during aluminium die casting. Also the bonding of LTCC on aluminium metal matrix was investigated.

Fig. 9 and 10 show X-ray analysis and polished microsection with the aluminium die casted plates with integrated LTCC-modules. As observed, there is almost no crack formation in LTCC as well as in PZT-plates that can be attributed to the die casting process.

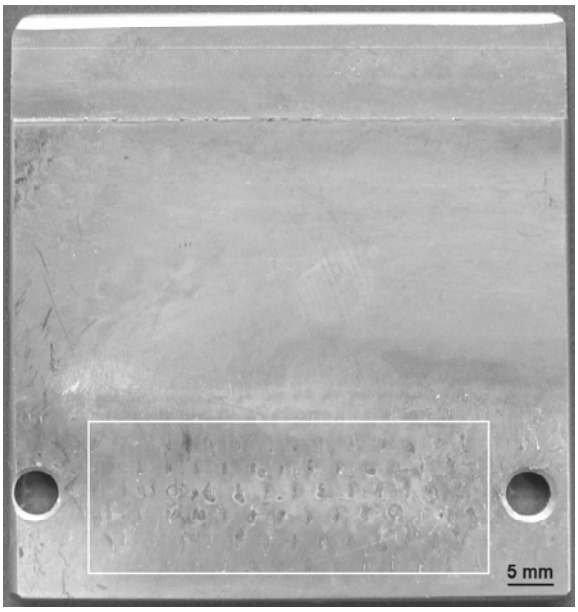

Figure 9: Aluminium die casting plate (white box: position of LTCC/PZT-module)

Figure 10: X-ray image of aluminium die casting plate with integrated LTCC/PZT-module

The multilayer-packaged technology is considered as a successful approach for producing ceramic LTCC/PZT-modules which is shown by the smooth interface between LTCC/PZT-plate and LTCC/aluminium. No air locks or cavities were detected (fig. 11) and so you have a perfect bonding to aluminium.

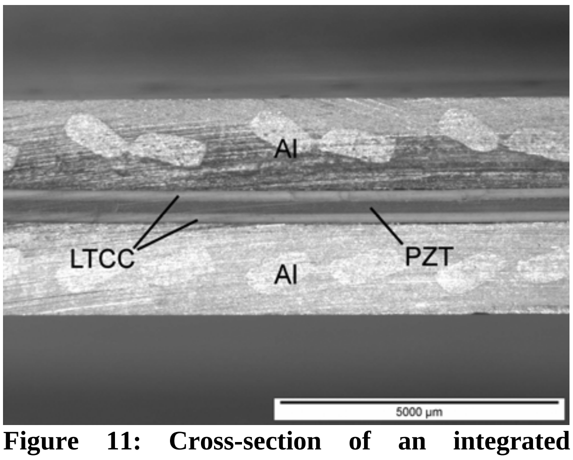

Figure 11: Cross-section of an integrated LTCC/PZT-module

Conclusion and Outlook

Multilayer-packaging technology was successfully used to obtain a robust LTCC/PZT-sensor-actuator-module with the advantages of mechanical stabilization and electrical termination of the piezo-ceramic material, frictional connection to metal matrix, electrical insulation and withstanding mechanical and thermal loads during metal die casting.

It was made out of an already sintered PZT ceramic plate with LTCC Heraeus HeraLock® Tape-HL2000 green layers with a near 0 % shrinkage in x/y-plane and subsequent sintering. Moreover LTCC Heraeus HeraLock® Tape-HL2000 is an outstanding material for aluminium die casting.

Functional demonstration of the installation was done by dielectric measurements which showed less performance than an unembedded PZT-plate. The explanation is the clamping of the PZT in the substrate material. Nevertheless deflection measurements in static and dynamic mode were successfully done, so actuator function was demonstrated.

Further examinations will be focused on clamped PZT and it´s dielectric properties and aluminium die casted piezo-modules with full electrical termination.

Long-time performance tests of LTCC/PZT-modules are in progress.

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