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Detection of cracks in multilayer ceramic capacitors by X-ray imaging

C. Andersson [a,*], J. Ingman [b], E. Varescon [a], M. Kiviniemi [b]

[a] ABB Switzerland Ltd., Corporate Research, Segelhofstrasse 1K, 5405 Baden-Dättwil, Switzerland
[b] ABB Oy, Hiomotie 13, P.O. Box 184, 00381 Helsinki, Finland

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ABSTRACT

A non-destructive method using X-ray imaging to find cracks in multilayer ceramic capacitors (MLCCs) mounted in different orientations with respect to the bending direction is presented. In total 300 MLCCs were investigated by 2D and 3D X-ray imaging after bending to varying levels of strain, and cross-section analysis was done to verify the findings. With X-ray imaging it was possible to not only detect the continuously cracked MLCCs, but also the cracked ones which were mounted 45° to the bending direction. These non-continuous cracks are difficult to identify even with cross-section analysis because the crack can be absent at the selected interface. None of the cracks could be identified by external optical inspection of the components using optical microscopy. The MLCCs mounted perpendicular to the bending direction were not cracked during the experiments, whereas the MLCCs mounted 45° or parallel to the bending direction were cracking at 3100 and 4300 μStr, respectively. Finding cracks with a non-invasive technique such as X-ray imaging is very advantageous because of its possible implementation as a screening test in a production environment.

1. Introduction

In all kind of electronic hardware capacitors are employed to store energy, e.g. for stabilizing DC voltage levels or for filtering. During manufacturing, handling and testing of PCBAs, mechanical stress can result in small cracks in multilayer ceramic capacitors (MLCCs), which with state of the art measurement techniques cannot be easily detected [1]. This defect can under critical conditions result in a failure. One common failure mode for cracks in MLCCs is in the form of an open connection, which in most application where e.g. DC voltage levels are being stabilized is unfortunate but not necessarily detrimental for the functionality of the overall circuit. However, if a crack reaches through the electrodes from both terminals, and a combination of humidity and voltage is stressing the component, the failure mode will instead of an electrical open be an electrical short, which is far more serious for most electrical circuits. Because the cracked MLCCs cannot be detected by electrical measurements or be eliminated through burn-in testing, it is crucial to find a screening test which detects the crack before it can turn into a short in the field. One proposed method is by X-ray imaging and even though experiments to detect cracks in MLCCs with X-rays have been done in the past [2], to our knowledge no large-scale examinations have been published so far.

2. Methods

2.1. Experimental setup

Instead of the more commonly used three-point bending test setup [3], a four-point bending setup was used in order to provide approximately the same strain level over all the MLCCs in columns of 10 MLCCs in each (see Fig. 1) [4].

During the bending, which was done at 50 mm/min, electrical measurements of the voltage drop over a shunt resistance were performed. Ten test boards were bent to different crosshead travel distances (0–18 mm), for which the strain was calculated according to Eq. (1).

$$\varepsilon = \frac{\delta \times 6t}{(L_S - L_L)(L_S + 2L_L)} \tag{1}$$

where ε is the global strain, δ is the crosshead travel distance, t is the thickness of the PCB, L_S is the support span and L_L is the load span which is centred within the support span [4].

The calculated strain values were also compared to strain values which were measured with rosette type strain gauges [5] on several places on a test board (see Fig. 1). Even though the strain values are expected to be identical throughout the test board for a four-point bending setup, there were some small but reproducible differences. Therefore a table translating the bending displacement in mm to the real local strain measured by strain gauges at the 10 different locations of the MLCCs in the column was used for the evaluation of the data.

* Corresponding author.
E-mail address: caroline.andersson@ch.abb.com (C. Andersson).

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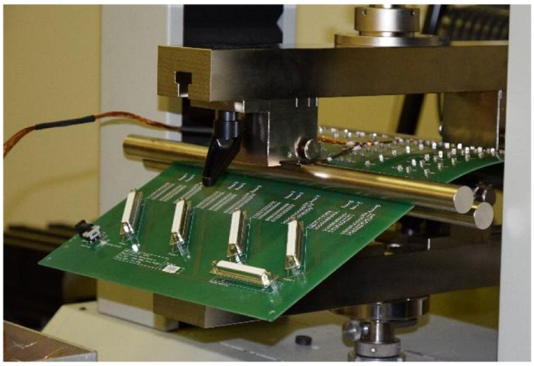

Fig. 1. Four-point bending test setup according to the IPC/JEDEC-9702A [4], during strain gauge measurements.

2.2. Design of ceramic capacitor test boards

Test boards with a thickness of 1.55 mm and two Cu traces were used for examinations of the commercially available 1812-sized MLCCs that are reported on in this publication. The capacitors were mounted with a 96.5Sn-3.0Ag0.5Cu solder and the components had capacitance values of 22 μF with a rated voltage of 25 V and standard end terminations. Ten MLCCs with identical conditions were placed in one column to enable good statistical evaluation of the resulting data. Three different orientations of the MLCCs (90°, 45° and 0°) to the axis of bending were examined (see Fig. 2) in order to understand the impact of bending angle on the cracking of MLCCs.

The size of the test boards was 30 × 40 cm with a total of 120 MLCCs on each of them. However, only the results of one type of component corresponding to 30 MLCCs per test board, are reported on in this publication. The 30 MLCCs are from the three rows with 10 in each of the three mounting orientations.

2.3. Examination methods

During the bending tests the AC voltage was measured with the aim to detect an electrical open that recovers after the board is unbent, which would correspond to a crack [1]. Before and after the bending tests, also DC voltage was applied to screen for any possible small leakage currents indicating an electrical short. After the bending tests, the MLCCs were examined in a Phoenix Nanomex X-ray machine that has a resolution of 200 nm [6]. For the 2D X-ray imaging, 160 kV and 120 μA was used, and 160 kV and 150 μA was used for the 3D X-ray imaging. The software x|act was used for 2D X-rays and VGStudioMAX together with Phoenix datosx acq 2 reconstruction was used for the 3D X-ray computer tomography. Top-view optical microscopy images were recorded using a Keyence VHX-1000 digital microscope, and the cross-section images were made with a Nikon Eclipse MA200 optical microscope. The results of cracked or uncracked MLCCs were recorded as a function of the real local strain levels, calculated from the position of the MLCC on the test board.

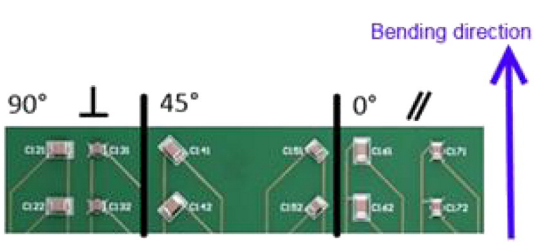

Fig. 2. Mounting direction of the MLCCs on the test board compared to the bending direction of the individual capacitors.

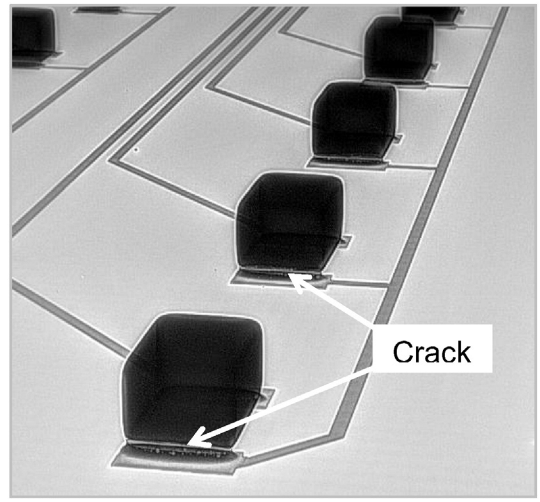

Fig. 3. Overview 2D X-ray image showing several 1812-sized MLCCs placed parallel (0°) to the bending direction, where cracks in all five MLCCs can be seen.

3. Results and discussion

3.1. Crack detection of MLCCs mounted at 0° using 2D X-ray imaging

After the bending experiments had been done to various strain levels the test boards were examined with the Nanomex X-ray system. Fig. 3 shows an example of an overview 2D X-ray image take with the detector tilted to 70°, and the cracks in all of the five MLCCs mounted parallel to the bending direction can be seen. This test board was bent to $\delta = 16.5$ mm corresponding to an overall bending strain of 5800 μStr.

If one MLCC is selected for further magnification, such as for example in the following case the second from below in Fig. 3, the crack is even better visible (see Fig. 4). Still the same detector tilt of 70° is used but a slightly different rotation shows the crack even better. For this image still several smaller cracks are visible as well as voids in the solder are easily detectable, and even the crack in the MLCC behind the centre component is visible at this angle and magnification. The darker area

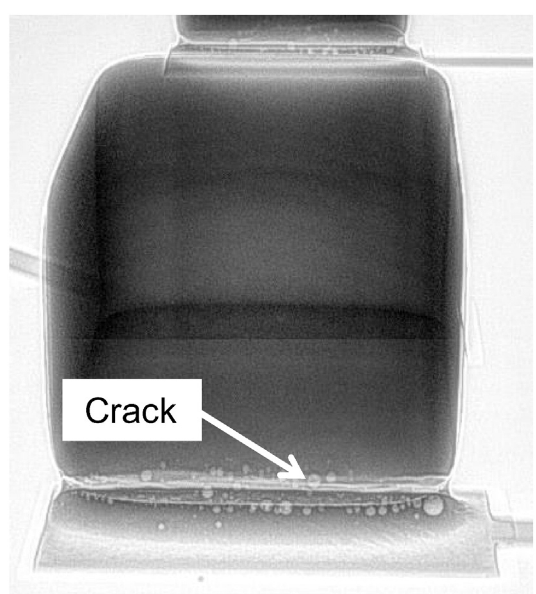

Fig. 4. Magnified 2D X-ray image of the second from below MLCC in Fig. 3. At the angle of 70° of the detector, the crack in the MLCC is clearly visible.

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