Imaging Detects Cracks in Multilayer Ceramic Capacitors

Multilayer ceramic capacitors (MLCCs) play a vital role in all kinds of power electronic applications, especially the variable speed drives (VSDs) manufactured by ABB. A significant issue for the industry is that the mechanical stresses involved in the assembly, handling and testing of the circuit boards holding MLCCs can cause small cracks in them that present a risk of component failure. **C. Andersson, ABB Corp. Research, Switzerland; J. Ingman, E. Varescon, and M. Kiviniemi, ABB Oy, Finland**

The most common failure mode for cracks in MLCCs is an open connection, which is detrimental to performance, but not catastrophic. However, if a crack reaches through the electrodes from both terminals, and the component is stressed by a combination of humidity and voltage, the failure mode will be an electrical short, which is far more serious for most circuits. Because a flex-cracked MLCC 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 promising method is X-ray imaging. This had been the subject of previous experiments, but not on a large-scale basis. Therefore, ABB decided to investigate the potential X-ray imaging.

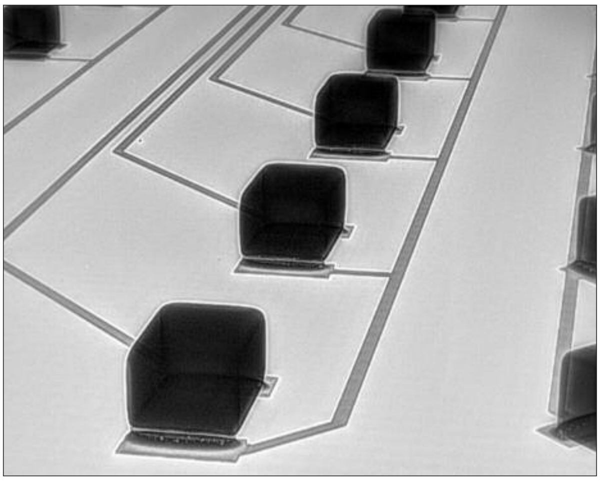
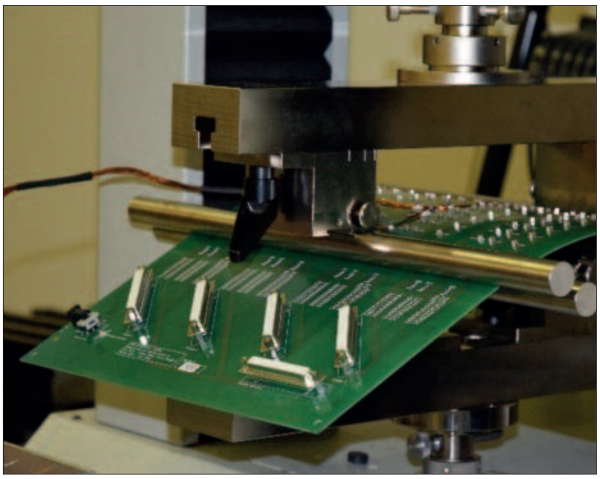


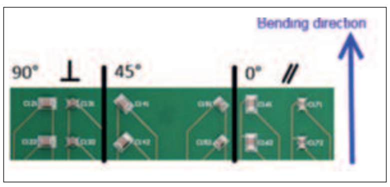
Figure 3: Overview 2D X-ray image showing several 1812-sized MLCCs placed parallel (0°) to the bending direction, where cracks in all five MLCCs can be seen

The test program

Test boards with a thickness of 1.55 mm and two copper traces were manufactured to examine commercially available 1812-sized MLCCs from different manufacturers.



RIGHT Figure 1: Four-point bending test setup



LEFT: Figure 2: Mounting direction of the MLCCs on the test board compared to the bending direction of the individual capacitors

A four-point bending setup was used to provide approximately the same strain level over all the MLCCs arranged in columns of 10 to enable good statistical evaluation of the resulting data (see Figure 1).

Three different orientations of the MLCCs (90°, 45° and 0°) to the axis of bending were examined (see Figure 2) to help understand the impact of bending angle on the cracking of MLCCs. Following the bending tests, the MLCCs were examined in a Phoenix Nanomex X-ray machine that has a resolution of 200 nm.

The test results

Figure 3 shows an example of an overview 2D X-ray image in which the cracks in all of the five MLCCs mounted parallel to the bending direction are can be seen. One MLCC was selected for further magnification under which the crack is even more easily visible, as shown in Figure 4. Several smaller cracks can be seen as well as voids in the solder.

For comparison, the same capacitor was viewed with an optical microscope, which showed no signs of a crack inside the MLCC – see Figure 5. This shows that optical inspection of MLCCs is not effective for the detection of flex cracks. During the test program 300 MLCCs were optically inspected as well as viewed with X-ray imaging and no component showed any external signs of cracks.

To verify the findings of the X-ray imaging, cross-sections were made and Figure 6 shows the same MLCC as in Figures 4 and 5. From the optical microscopy image of the cross-section the

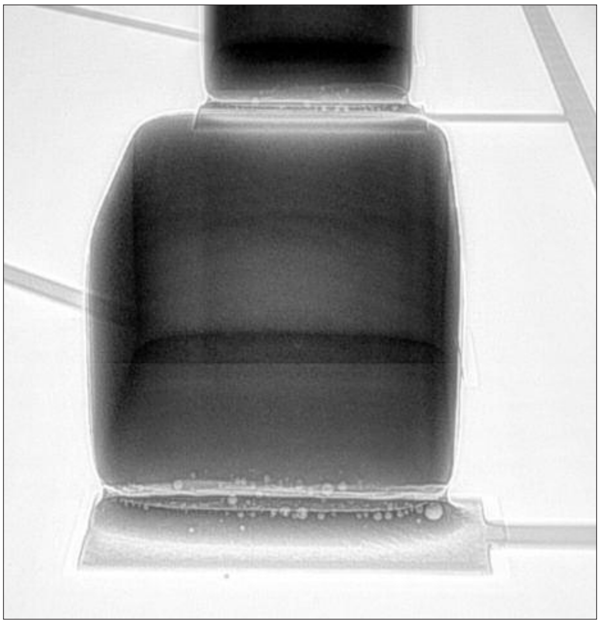


Figure 4: **Magnified 2D X-ray image of an MLCC in which the crack is clearly visible**

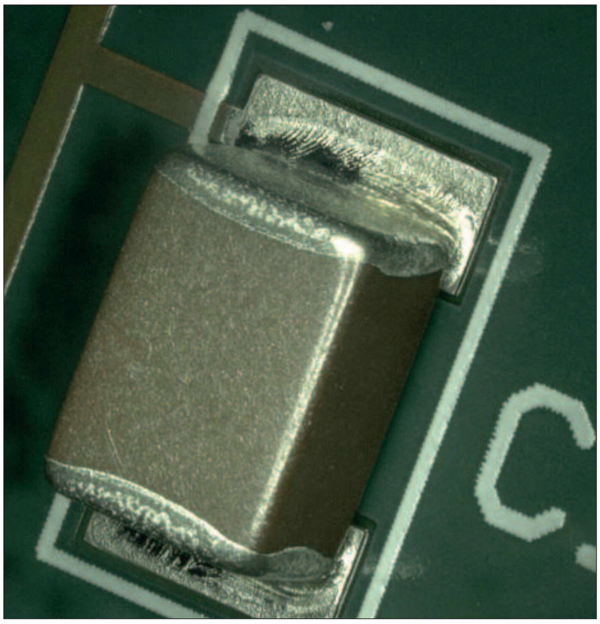


Figure 5: **Optical microscopy image of the same MLCC showing no external sign of a crack**

presence of cracks in the MLCC is confirmed. Furthermore, it could be seen that the flex cracks reach all the way into the active area where the over-lapping electrodes are positioned. There are also smaller cracks seen on the left side (the rear face of the MLCC in Figure 4). The solder looks undamaged which explains its normal external appearance. The probable reason for this is that the relatively soft solder is able to absorb the strain that is applied though the bending test whereas the more brittle ceramic cracks.

The MLCCs mounted 45° to the bending direction produce discontinuous and less obvious cracks than the ones mounted 0° to the bending direction.

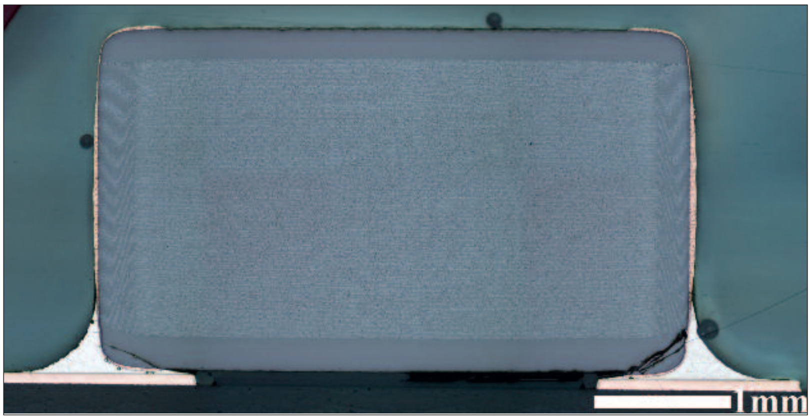


Figure 6: **Cross-section of the MLCC shown in Figures 4 and 5, confirming the presence of a crack into the active electrode area**

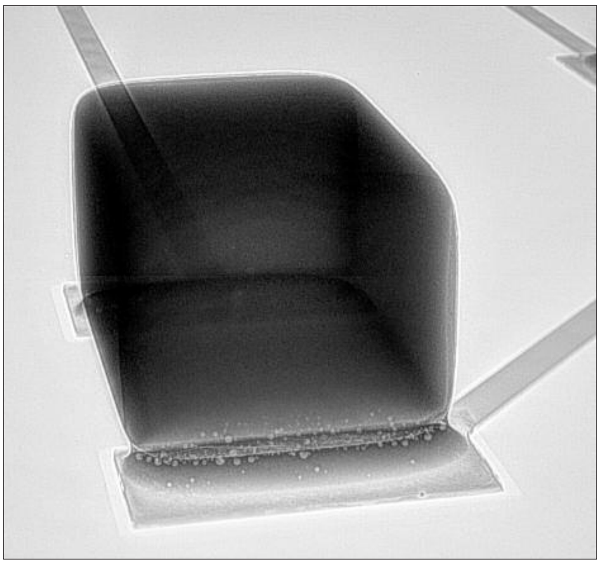


Figure 7: **Zoomed in X-ray image of an MLCC mounted 45° to the bending direction. Several small cracks are identified especially in the magnified inset at the top**

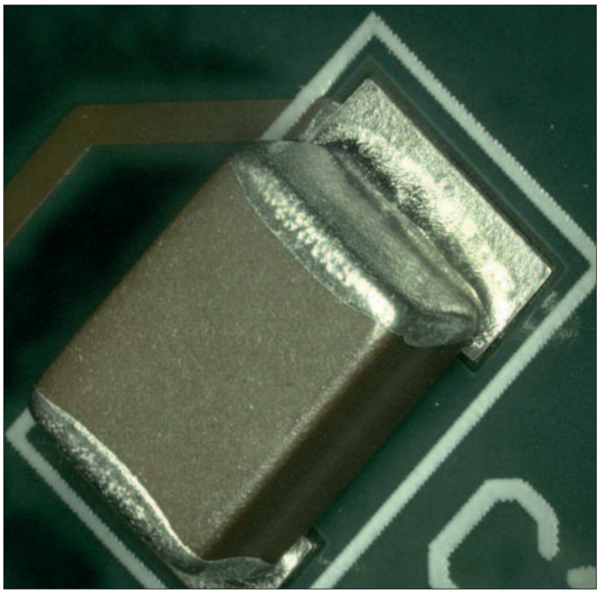


Figure 8: **Optical microscopy image of the same MLCC as shown in Figure 7. No external sign of a crack can be observed**

Figure 9: Cross-section of the MLCC shown in Figures 7 and 8, confirming the presence of a crack into the electrode area

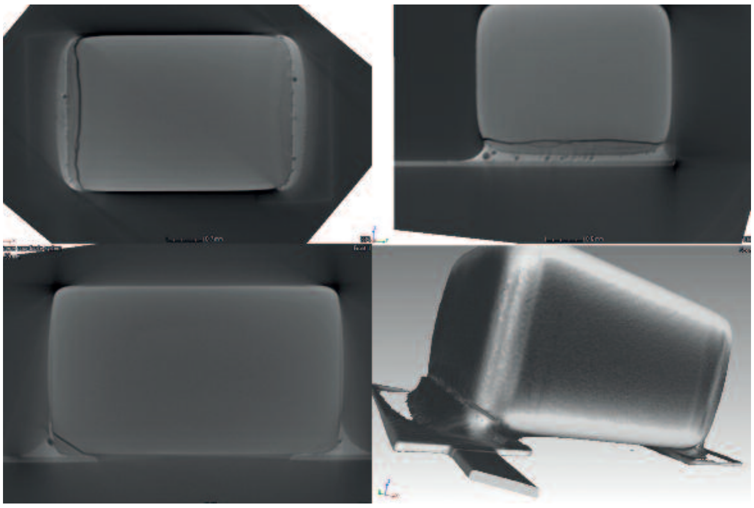


Figure 10: Non-destructive virtual 3D slicing images and 3D reconstruction of the cracked MLCC from Figures 4 to 6 for even better crack identification

Figure 11: 3D CT X-ray images of the MLCC shown in Figures 7 to 9 showing a small and discontinuous crack

However, even these smaller and discontinuous cracks can be seen by 2D X-ray imaging as shown in Figure 7. The cracking profile is different for the MLCCs placed 45° to the bending direction compared to the ones placed parallel. This is most probably because the forces inside the components are different when it is bent at 0° which gives clear and linear cracks, while 45° results in more slanted cracks.

The MLCCs mounted at 45° to the bending direction also showed no external signs of cracks under optical inspection – see Figure 8. A cross-section was made to confirm the finding of small cracks in the X-ray images as seen in Figure 9. It is important to note that a cross-section is at one point of depth in the MLCC. So there is always the risk of not finding a discontinuous crack. While both cross-sectioning and chemical etching are useful techniques to find cracks after an MLCC failure has occurred, X-ray imaging has the added value of being non-invasive as well as non-destructive. It can therefore also be used in screening and sampling as well as failure analysis.

3D CT X-ray analysis

Even better resolution of the cracks can be achieved if a 3D computer tomography (CT) X-ray analysis is performed as shown in Figure 10.

The top-left image shows an X-ray 3D slice from below the MLCC with part of the solder and the continuous crack on the left-hand side. The top-right image shows a slice into the side of the MLCC from one of the end terminals. The lower-left image shows a slice corresponding to the mirror image of the cross-section in Figure 6 with the cracks in both sides visible, and the lower-right image shows the full 3D model. These 3D X-ray images show clearly the presence of cracks as well as making it possible to follow their propagation into the depth of the capacitor.

The same 3D analysis was carried out for the MLCCs mounted 45° to the bending direction as shown in Figure 11. In this case, the cracks are much more difficult to detect due to their non-continuous nature.

3D X-ray analysis definitively has advantages and possibilities which 2D X-ray imaging does not have such as the detection of very small cracks and the possibility to see crack propagation paths from three dimensions. At the same time, it also has some disadvantages in that it is time-consuming, needs a small enough sample in order to rotate at least 220° and it is difficult to capture all the information from the 3D model in a 2D representation.

Impact of strain levels

A total of 300 MLCCs were examined visually and by X-ray after the bending tests. Figure 12 summarises the number of cracked and uncracked MLCCs for the different mounting orientations as a function of the level of bending strain they were subjected too.

MLCCs perpendicular to the bending direction were not found to be cracked. Whereas MLCCs at 45° or 0° orientation started showing cracks as the level of strain increased.

Conclusion

X-ray imaging shows significant potential as a non-invasive method of detecting cracks in MLCCs that could be implemented as a screening test in a production environment.

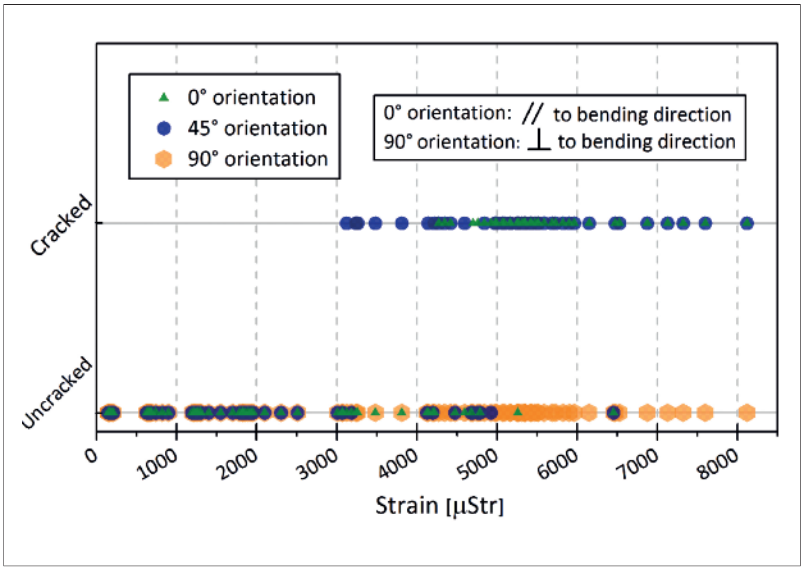


Figure 12: Indication of cracked or uncracked MLCCs for different strain levels and orientations

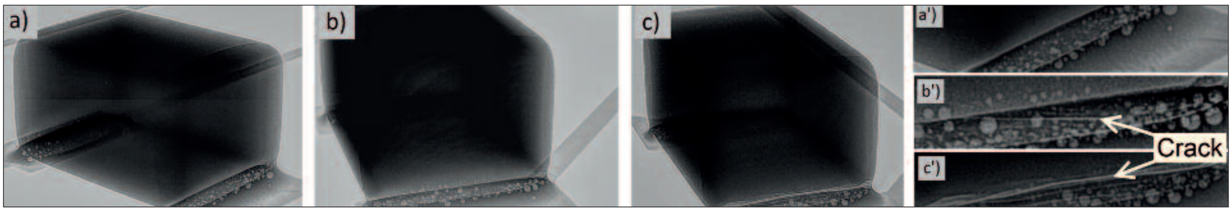


Figure 13: Cracks of different orientations