Avoiding flex cracks in ceramic capacitors: Analytical tool for a reliable failure analysis and guideline for positioning cercaps on PCBs

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A R T I C L E   I N F O

Article history:
Received 21 May 2015
Received in revised form 18 June 2015
Accepted 21 June 2015
Available online xxxx

Keywords:
Ceramic capacitors
Flex cracks
Failure analysis
Etch preparation
Crack pattern
depaneling

A B S T R A C T

In every electronic assembly line where ceramic capacitors are used and printed circuit boards are depanelized the quality risk “flex cracks” is widely known. Unfortunately flex cracks in “cercaps” always extend under the metal terminations of the capacitors and electrical tests only reveal about 1% of the affected parts. With a new method—etching away the terminations and looking at the otherwise hidden cracks—it is possible to identify all sources of mechanical bending and warping. In the course of failure analysis it is helpful to know that most of the time not only the failed ceramic capacitor shows a crack pattern but all the surrounding cercaps as well. Well-founded knowledge of different crack patterns and failure modes also allows us to discover unsafe bending and warping lines on the PCB. This gives us a guideline on how to place the ceramic capacitors in optimal orientation not only to depaneling lines but also in the vicinity of mounting and screw openings. Finally we will review the different kinds of cercaps with internal layouts that prevent boards from failing even if flex cracks should show up.

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1. Flex cracks as most common failure mode

Ceramic capacitors, also known as cercaps or MLCCs (“multi-layer chip capacitors”) have been used in electronic devices for more than 50 years. Today more than 1 trillion (10¹²) parts are installed each year.

One of the most common failure modes concerning ceramic capacitors in the production of printed circuit boards (PCBs) or in returns are the so called “flex cracks” (“bending” or “flexural” cracks). Therefore every manufacturer of printed circuit boards has a vital interest to eliminate the sources of this failure. While, fortunately, not every crack means an electrical failure, this implies, at the same time, that only about 1% of de facto existing flex cracks can be found with a high voltage test. Unfortunately, a visual inspection also cannot detect flex cracks because they always extend under the metal terminations of the capacitors.

To find the sources of quality risks in the production line we need an analytical method to analyze a huge number of ceramic capacitors with regard to cracks and fractures in a fast, cost-saving and reliable way. Metallographic cross sections (see Fig. 1) in some cases are the right way to find the root cause of a particular failure, but with flex cracks a different method is required.

2. Analytical tool for a reliable failure analysis

Here a method is presented that permits us to analyze a lot of desoldered ceramic capacitors with high accuracy and still it is cost-effective, easy to perform and fast. To this end the solder and the complete terminations of the cercaps are etched away with hot concentrated nitric acid. The trick is the intermittent application of an ultrasonic bath during the etching and the subsequent cleaning of the ceramic bodies with water. The nickel layer under the solder, incidentally, is not etched but only undercut and washed away by the ultrasonic cleaning (see Fig. 2). Cracks are not affected by the use of ultrasonic, even after a couple of minutes.

By means of this method all the critical manufacturing steps like depaneling, setting press fit contacts and all the processes at the back end assembly can be reviewed and quality risks can be eliminated. For example it is recommended for the control of a depaneling equipment to desolder all ceramic capacitors on all depanelized PCBs of a complete panel with hot air and analyze them, separated by the single PCB, with respect to cracks and fractures. Only if not even a single small cleft is found the manufacturing step can be classified as uncritical. On a first examination you can etch countless capacitors in a single beaker (see Figs. 3 and 4). That cuts down the effort and the cost. Depaneling methods like milling or the use of vertical cut knives are superior to circular blades. If the process flow is thoroughly examined also punching can be a secure way to separate the PCBs. For all the other manufacturing steps with possible mechanical stress examinations before and after the step are recommended.

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3. Flex cracks are a group phenomenon

The analysis of many thousands of capacitors resulted in the following most important discovery: Under mechanical stress, that is bending and torsion of a PCB, not only one single ceramic capacitor will suffer a rupture but several of the capacitors in the field of force of the mechanical stress (see Fig. 4). That means that a critical process can be found much more easily than expected and also in the course of a failure analysis the analysis of adjacent ceramic capacitors can give you the clue where to find the root cause of the failure (see Fig. 5).

4. Fracture patterns of bent ceramic capacitors

4.1. Bending tests on ceramic capacitors

The resistance of ceramic capacitors against bending loads can be measured with a test as described in IEC 60068-2-21. It is specified to survive a bending of the PCB of 3 mm on a length of 90 mm. The bending tests are always done perpendicular to the length of the capacitor. Our investigations on bent components mounted under 45° demonstrated that in that case cracks will already appear at a bending of only 0.5 mm (see Fig. 6).

4.2. Punctiform bending sources like screw holes

The spreading of the cracks in the ceramic of the affected capacitors, the fracture pattern, includes the information about the nature and direction of the implied forces. With the help of the fracture pattern it is possible to identify not only the torsions at depaneling but also punctiform sources like screw holes, deadlocks in the housing or actually a bending up and down when manually depaneling PCBs.

4.3. Cracks from other sources than bending

If we find visible cracks outside the terminations of ceramic capacitors that haven't failed electrically we can assume that in this case not a bending or twisting of the PCB is the root of the failure but a force from outside with a direct impact to the capacitor. Normally on soldered cercaps forces can only be brought in via the solder joints. Exceptions are temperature changes in molded housings or high vibration/shock loads.

4.4. Cracks and capacitor failures

Cracks that are induced under bending or torsion forces will close again when the strain ends (see Fig. 7). Cut off capacitor plates may get electrical contact so that you cannot judge by electrical measurements that there was a failure (see Fig. 8).

But under a subsequent excess voltage a sparkover can occur in the crack. Cracks can also grow under thermomechanical stress. Humidity and heat may also lead to silver migration along the crack (see Fig. 9) so that without excess voltage after years of normal duty a ceramic capacitor can fail abruptly.

A completely burnt cercap has not only lost its capacitive feature but most of the times turns into a resistor with a resistance of about 1 Ω. In certain circumstances this can provoke a steady current without tripping a fuse that lets part of the PCB burn with red heat.

5. Answers to the crack problem [1,2]

To prevent board failures by failing ceramic capacitors the suppliers of the components took measures to stop catastrophic breakdowns even if they cannot entirely prevent the cracks themselves.

First to name is the capacitor design called “open mode” or “fail open” (see Fig. 10). Here the overlapping capacitor plates are located only in the ceramic body way apart from the terminations. Flex cracks always extend under the terminations so no crack can cross the overlapping region where sparkovers can happen. A crack still can separate a plate and therefore the capacity can decrease but no catastrophic breakdown will happen.
The next concept is the “floating electrode” design (see Fig. 11). Here the plates are arranged in a manner that they are not connected to the terminals but are “floating”. The idea is that if an electrical short on one side occurs there still is no conducting path to the other terminal. Unfortunately simultaneous cracks on both sides will lead to simultaneous sparkovers (see Fig. 12). Torsion forces generate just such cracks. Multiple floating electrodes work, but there is the problem of achieving enough capacity (see Fig. 13). Often both designs are combined, “floating electrodes” and “fail open”.

Another approach is to eliminate the formation of cracks in the ceramic by using a flexible interlayer between ceramic and metallization (see Fig. 14). Mechanical stress does not induce a crack but a delamination of the termination (see Fig. 15).

The flexible interlayer is a conductive polymer that will mostly maintain electrical contact even if the capacitor is displaced by the mechanical force. The functionality of this approach called “Flex-Cap” or “Soft-Cap” should be verified by bending tests according to IEC 60068-2-21 because not all suppliers provide the same quality (see Figs. 16 and 17).
6. Measures against flex cracks

As a matter of principle avoiding the formation of flex cracks should have already begun with the conception of the PCB. Design rules as “5 mm from edges” are not always sufficient. The orientation of the ceramic capacitors to possible sources of bending and warping has to be considered. An alignment parallel to the bending will completely prevent the formation of cracks. An alignment perpendicular to the bending will stand some stress, but under 45° a bending of just 0.5 mm compared with the above mentioned 3 mm will generate flex cracks. If we take this into account, we can avoid sources of subsequent failures from the start by looking onto the PCB and minding potential bending or warping lines (see Fig. 18).

If you nevertheless have problems with certain cercaps, a redesign of the PCB is one possibility. Place the cercap at risk in the right orientation or hide it behind big components, using their stiffening effect on the PCB (see Fig. 19). Or you can buy a ceramic capacitor with the improvements mentioned above.
7. Summary

For a failure analysis of single ceramic capacitors metallographic cross sections are very useful. But if you want to identify the sources of cracks from bending and warping in the manufacturing process of PCBs you need another method. The terminations of desoldered ceramic capacitors can be removed by etching them with hot concentrated nitric acid while applying ultrasound. Thousands of cercaps have been analyzed with this method and the analysis showed that most of the found flex and torsion cracks did not result in electrical failures. But over the time cracks can grow on account of thermomechanical stress or silver migration can occur in a crack. If you find flex cracks the crack pattern gives valuable information about the source of the mechanical stress so it can be eliminated. The knowledge about the formation of flex cracks by bending and torsion forces can help in the course of positioning cercaps. 

Fig. 15. “Soft termination”—design of ceramic capacitor. A flex crack stays in the flexible interlayer.

Fig. 16. “Soft termination”—design of another supplier. Here nonetheless cracks occur.

Fig. 17. “Soft termination”—design of another supplier. Some cracks are found at the test after IEC 60068-2-21.

Fig. 18. Aligning the ceramic capacitors to possible sources of bending and warping.

Fig. 19. Hiding ceramic capacitors in regions save from bending and warping.
designing a new PCB so that risky placements of ceramic capacitors can be avoided. Furthermore the suppliers of ceramic capacitors have developed several internal designs that prevent the devices from catastrophic failures originating from flex cracks (“open mode”, “fail open”) or prevent cracks altogether (“soft termination”).

References