Flexibility of Multilayer Ceramic Capacitors

Automotive grade Multilayer Ceramic Capacitors and mechanical crack resistance.

Today, with the continued drive for more technical features in conventional cars and the inevitable rise of electric vehicles, the challenges facing electronics designers are ever increasing, with lower costs and smaller form factors, MLCC's are being used in ever more harsh applications and in ever increasing numbers. This is driving board population density upwards and with it concerns for reliability and particularly the likelihood of mechanical cracking. Thus electronic designers are now demanding flexibility that exceeds the current Automotive Electronic Council bend test specification (AEC-Q200 Rev D June 1, 2010).

Mechanical cracking resistance can be increased by two methods;

1. *Reduce the mechanical stress being exerted on the capacitors by PCB design/assembly processes.*
2. *Increase the mechanical strength of the component.*

In this article we are going to look at both approaches and will examine our approach to increasing the mechanical strength through FlexiCap™

FlexiCap™ termination material is a silver loaded epoxy polymer that is flexible and absorbs mechanical strain between the Printed Circuit Board and the ceramic component. Components terminated with FlexiCap™ withstand greater levels of mechanical strain when compared with sintered terminated components. Types of mechanical strain where FlexiCap™ terminated capacitors offer enhanced protection include mechanical cracking (which is the largest cause for ceramic component failure) and also in applications where rapid temperature changes can occur.

FlexiCap™ when tested in accordance with AEC-Q200 exceeds the minimum specification limits by more than double and thus Knowles Precision Devices are able to offer a guaranteed 5 millimetre bend test deflection on AEC-Q200 components.

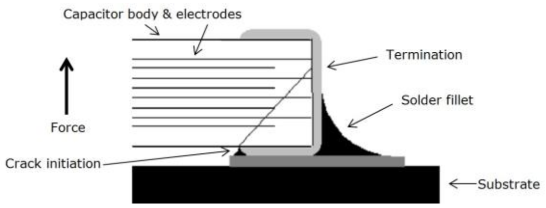
1 Mechanical Cracking

In this section we are going to discuss some of the causes of mechanical cracking in multilayer capacitors and measures that can be taken to avoid this in manufacturing PCBs.

1.1 Introduction

Due to its brittle nature of Ceramic, multilayer ceramic capacitors are more prone to excesses of mechanical stress than other components used in surface mounting. One of the most common causes of capacitor failures is directly attributable to bending of the printed circuit board (PCB) after solder attachment. Excessive bending will create mechanical crack(s) within the ceramic capacitor, see Figure 1. Mechanical cracks, depending upon severity, may not cause capacitor failure during the final assembly test. Over time moisture penetration into the crack can cause a reduction in insulation resistance and eventual dielectric breakdown leading to capacitor failure in service.

Figure 1: Mechanical crack



Example of capacitor issued by customers to Knowles Precision Devices for failure investigation:

1.2 Potential Causes

Mechanical cracks are created by excessive mechanical stress after the capacitors have been soldered onto the substrate.
Excessive mechanical stress can be the result of the following:

Exceptional Circumstances
☐ Interference fit. For example, physical abuse.

Normal Circumstances
☐ Assembly design.

☐ Board de-panelling causing the PCB to bend.

☐ Automatic test equipment employing a "bed of nails" as contacts. Faults often occur at, or in close proximity to, support pillars within the test jig. Vacuum fixtures can also cause excessive PCB bend.

☐ PCB distortion/ warp caused by storage conditions or uneven PCB designs. Frequently distorted PCBs are straightened after the soldering process causing the capacitors to mechanically crack.

☐ Radial/ through hole component insertion especially if there is a tight fit between the radial leads and PCB hole.

☐ Attachment of rigid fixtures such as heat sinks.

☐ Fitting IC's, connectors into solder mounted sockets with no support.

☐ Methods of transportation/ storage and handling during process stages allowing the PCB to bend.

☐ Fixing completed sub-assemblies into the final assembly. For example, employing a snap fit operation or by over-tightening fixing screws.

1.3 Evasive Actions

Extensive bend tests performed at Knowles Precision Devices including bench-marking against competitor's products has proven that:
i. Knowles Precision Devices capacitors pass the International Specifications (1) defining robustness of termination criteria.

ii. The bend test performance of Knowles Precision Devices's sintered termination capacitors is comparable with competitor's sintered termination product.

(1) For International Specifications and Knowles Precision Devices Bend Test Methods refer to the Bend Testing section.

The only effective methods of resolving mechanical cracking issues are:
i. Reduce the mechanical stress being exerted on the capacitors.

ii. And/or increasing the process window so that the mechanical stress exerted onto the ceramic section of the capacitor is reduced.

Automatic Test Equipment (ATE), functional tests and reliability tests have limited success in identifying capacitor failures caused by mechanical cracking.

1.3.1 Assembly Design/ Manufacture Considerations

Mechanical stress can be influenced by a number of different factors associated with the design of the assembly and assembly manufacture. These factors include:

☐ PCB design – copper power and ground planes.

☐ A PCB design resulting in an uneven metal distribution (usually caused by large power or ground planes) can result in PCB warpage during the soldering process caused by the different Thermal Coefficient of Expansion rates between the copper and the epoxy fibre glass. If large power/ ground planes are required then cross hatching the copper area may prove to be useful.

☐ Position/ orientation of the capacitor on the PCB in relation to the edge of the PCB and other components/ attachments.

Figures 2 to 4 give guidance on the orientation and positioning of the capacitor to reduce the likelihood of mechanical damage.

Figure 2: PCB Corner

Capacitor placement not recommended in the corner of the PCB

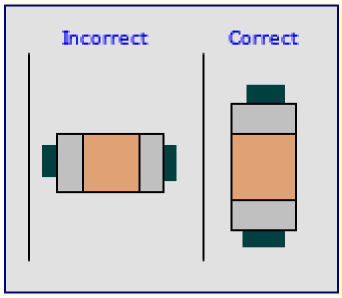


Figure 3: PCB Edge

Recommended capacitor orientation with respect to PCB edge (denoted by black lines).

Note: Stress zone is typically with 5mm of PCB edge or fixing point.

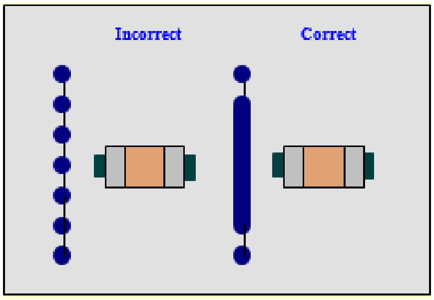


Figure 4: PCB depanelisation

Using a slot along the depanelisation edge can reduce the level of stress exerted onto the capacitor by approximately 50%

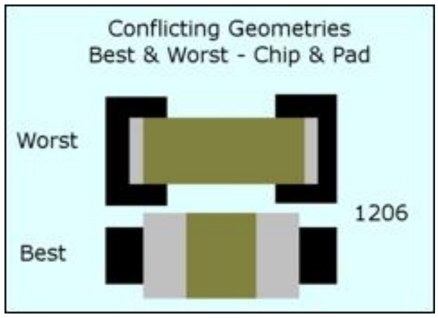
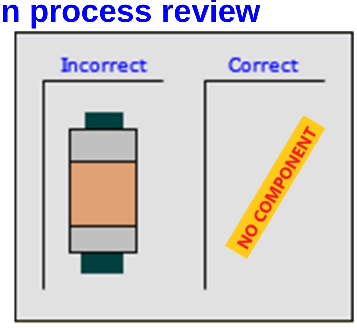


Figure 5 gives guidance on the pad/ land size to capacitor component to reduce the likelihood of mechanical damage.

Figure 5: Pad & Chip geometries

Reducing the pad / land size can reduce the level of stress exerted onto the capacitor by approximately 50%

1.4 Production process review



Mechanical cracking occurs after the capacitors have been soldered into position. Subsequent flexing of the PCB creates mechanical stress within the capacitor that if sufficient can result in the capacitor being mechanically cracked.

When mechanical cracking has been identified as the cause for capacitor failures the typical approach for customers is to review the production process for any obvious process stage including handling and transportation that may be bending the PCB. If no obvious stage is identified then the next step is to remove samples of capacitors from assemblies at different process stages and then subject the capacitors to sectioning/ internal examination to determine if the capacitors have been cracked. The shape of mechanical cracks is shown in Figure 1.

An example of a typical investigation would be to remove capacitors from assemblies after completing the following stages:

- Soldering
- Depanelisation
- Insertion of radial components including connectors and IC's into sockets
- ATE
- Fixing the completed sub-assembly into the final assembly.

1.5 Mechanical failure Identification

There is no 100% guaranteed method for being able to test capacitors that have been mechanically cracked. The success of the tests conducted relies on the extent of the mechanical cracks – wider cracks are more likely to fail.

Examples of tests conducted by customers:

- Dry Heat/ Steady State. Assemblies powered in a hot dry environment to accelerate the breakdown of the capacitors.
- Damp Heat/ Steady State. Assemblies powered in a hot humid environment to try to drive moisture into the crack and cause capacitor failure.
- Temperature Cycling. Assemblies are temperature cycled with the purpose of opening the crack to cause capacitor failure.
- Vibration and Shock. Assemblies are subjected to vibration/ shock tests with the purpose of opening the crack to cause capacitor failure.
- X-Ray. Customers have tried to employ x-ray solder joint inspection equipment to try to detect mechanical cracks with very limited success.
- Scanning Acoustic Microscopy.

The tests conducted have depended upon the equipment available to customers and the success of tests has varied.

2 Bend testing

Given the measures and analysis discussed in the previous section, sometimes there is nothing further that can be done on the PCB production process side and attention turns to the physical robustness of the capacitors themselves. In this and the next section we are going to review some of the bend testing that we subject our devices to in order to examine their ability to resist cracking.

2.1 International specifications

The international requirement for bend testing is referred to in several different specifications.

1. IEC 60384-1:2001 Fixed capacitors for use in electronic equipment Part 1: Generic Specification section 4.35 Substrate bending test refers to IEC 60068-2-21.

2. IEC 60068-2-21: 2006 Environmental testing: Test U: Robustness of Terminations and Integral Mounting Devices. Section 8 test Ue specifies the test required

to assess the mechanical robustness of surface mounting device terminations when mounted on a substrate. Test Ue_1 specifies the substrate bend test.

The purpose of test Ue_1 is to verify that the capacitors can withstand bending loads that are likely to be applied during normal assembly or handling operations.

IEC 60068-2-21 refers to requirements such as deflection and acceptance criteria as being included in the "relevant

specification". Knowles Precision Devices maintains IECQ CECC (International Electrotechnical Commission Quality certification programme- CENELEC Electronic Components Committee) product approval and the "relevant specification" is QC 32100-A001:2007.

3. QC 32100-A001:2007 Table 2 – Periodic Tests defines board flex minimum requirements as:

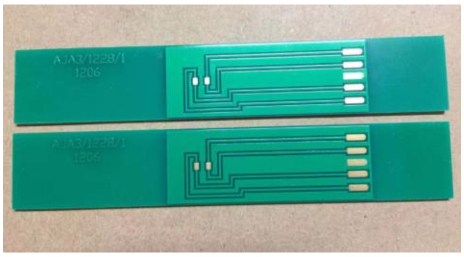
   Class I C0G/NP0 (1B/CG): All types. Class II X7R (2R1): Y and H only (FlexiCap™).
   - 3mm deflection Class I
   - 2mm deflection Class II
   - X7R (non – FlexiCap™ termination) 1mm deflection

4. AEC-Q200-005, Board Flex / Terminal Bond Strength Test. Minimum requirements stated in table 2 stress test reference 21: 2mm (min) for all except 3mm for Class I.

2.2 Bend test method

Knowles Precision Devices has designed a series of bend test boards using FR4 materials. The board dimensions are approximately 100 mm x 40 mm x 1.6 mm and the track thickness is 35+/-10 Microns, see Figure 6.

Figure 6: Example of PCB Used



Samples of capacitors are mounted using manual pick and place equipment, see Figure 7, onto stencilled SAC305 (96.5/3/0.5 Sn/Ag/Cu) solder.

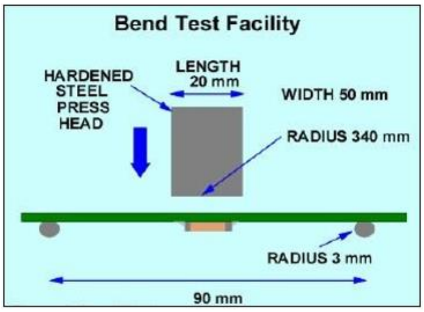
Figure 7: Capacitor placement method

The PCB are then subjected to bend testing in accordance AEC–Q200-005 using Knowles Precision Devices purpose build bend test facility, Figure 8.

Figure 8: Knowles Precision Devices Bend test facility

Figure 9 shows the bend test fixture, the hardened steel press head is programed to follow a deflection profile, with a ramp rate of 1mm/s and dwells in accordance with AEQ–Q200-005

Figure 9: Knowles Precision Devices bend test method



The AEC-Q200-005 requirement is for 30 components from each product sample to be subjected to the bend test. Knowles Precision Devices Test PCBs are mounted with one capacitor and deflected automatically until the capacitor breaks. The software analyses the change in capacitance measured by the Agilent 4288A capacitance meter. As soon as the capacitance change is greater than 10% the bend deflection distance is recorded in millimetres. The maximum deflection of the machine is 10mm.

Each of 30 components result are saved as a sample group to the Knowles Precision Devices network.

3 Results of bend testing

3.1 Dielectric analysis

Based upon an analysis of field failures, no case can be made that any one size of chip is more vulnerable to failure by cracking than another. One factor does stand out, however, Class I C0G/NP0 (1B/CG) capacitors seldom feature in 'cracking incidents'.

This difference in mechanical strength is shown in the mean bend analysis of the sinter termination for the two class types;

Figure 10: Class I C0G/NP0 with sintered termination

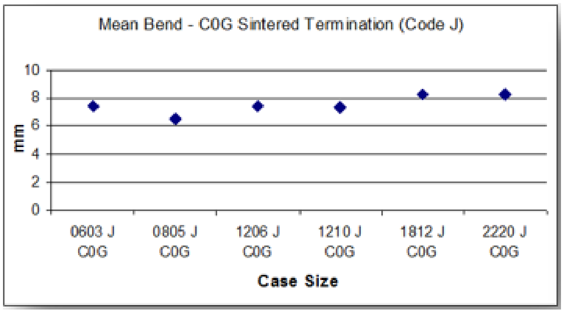
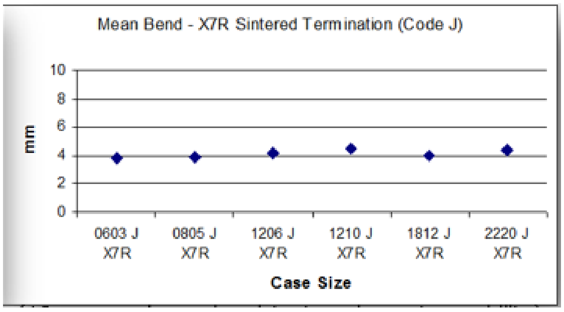


Figure 11: Class II X7R (2R1) with sinter termination



It can be seen that mean bend distance achieved by Class I C0G/NP0 (1B/CG) is typically 7mm while Class II dielectrics have a mean value of typically 4mm.

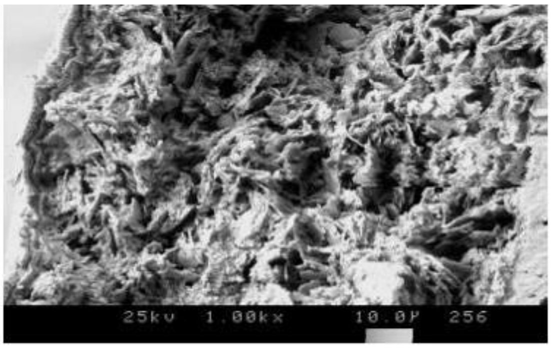
3.2 Knowles Precision Devices Capacitor Flexible Enhancement

In 1999 Knowles (UK) Ltd (Formerly known as Syfer Technology Ltd) introduced FlexiCap™ and became the first multilayer capacitor manufacturer to offer a flexible termination to customers.

Then in 2008 Her Majesty The Queen conferred the Queens Award for Innovation upon Syfer Technology Ltd for recognition of outstanding achievements in Innovation with respect to FlexiCap™.

FlexiCap™ polymer termination with its fibrous structure effectively reduces the mechanical stress being exerted onto the ceramic section of the capacitor by approximately 50%, see Figure 12.

Figure 12: Polymer termination Microstructure

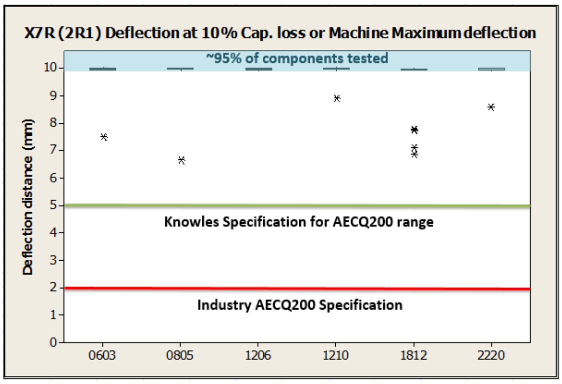


Its mechanical and electrical properties remain largely unaffected by extremes of heat and chemical treatments.
After the polymer termination process stage, the capacitors are plated with Nickel and Tin using the same methods employed for industry standard sintered Silver/Copper terminated capacitors. Therefore the soldering characteristics are unchanged and thus no changes to the customer's assembly process are required.
Some 10 million polymer terminated Class II X7R (2R1) capacitors were supplied to customers for evaluation. The applications targeted were those known to have a long history of problems due to capacitor cracking. During the course of these trials, not a single part was identified to have failed as a result of chip fracture.

3.2.1 Flexible termination analysis

Applying the FlexiCap™ termination material to the Class II X7R (2R1) dielectric provides the dielectric with significant protection from the mechanical stress when subjected to bend testing in accordance AEC–Q200-005.

Figure 13: X7R (2R1) with FlexiCap™



The Figure 13 box plot shows the results of subjecting 160 samples of a range of case sizes from all Knowles Precision Devices AEC-Q200 Class II X7R (2R1) materials. It can be seen that the majority of parts, ~95% meet or exceed the bend test machines maximum deflection of 10 mm which typically equates to a weight of 10 Kilograms being placed on the PCB. It should also be noted that all of the remaining ~5% of parts tested exceed the AEC-Q200 specification of 2mm deflection by more than double with the lowest single value measured in this sample group having a deflection of 6.67mm.

3.2.2 Periodic bend testing

Knowles Precision Devices performs periodic sampling as required by all relevant specifications. Samples are selected from production lots and testing performed as per the requirements on page 10 of the Knowles Precision Devices MLC catalogues.

Knowles Precision Devices Catalogues

This includes test reference P12, Board Flex (Bend testing) to the AEC-Q200-005 specification. This provides assurances of the consistence of Knowles Precision Devices FlexiCap™ termination to meet/exceed the minimum standard flexibility requirement.

4 Conclusions

4.1 Mechanical crack detection

Detection of mechanical cracking in capacitors post assembly and depanelisation not only requires additional equipment for temperature change, increased moisture, mechanical shock and vibration, and or X ray analysis, these methods have also been shown to have limited success in detecting mechanical cracks. Thus effort has been targeted in reducing the likelihood of mechanical cracks by increasing resistance.

4.2 Mechanical crack resistance

Mechanical cracking resistance can be increased by only two methods;
1. Reduce the mechanical stress being exerted on the capacitors by PCB design/assembly processes.
2. Increase the mechanical strength of the component.

4.2.1 Reduce Mechanical stress

While section 1.2 highlights some of the potential design and assembly causes of Mechanical cracking and 1.3 has some of the corrective actions, the drive by electronic design engineers to increase the components density on boards has increased not reduced the mechanical stress being exerted on components.

Therefore electronic design engineers now have a requirement for components with mechanical resistance that far exceeds the minimum industry standard.

4.2.2 Increase Mechanical strength

The dielectric analysis in section 3.1 has shown that Class II X7R (2R1) dielectric materials using sintered termination materials are mechanically weaker when compared to Class I C0G/NP0 (1B/CG) dielectric materials with sintered termination. In fact Class I C0G/NP0 (1B/CG) has close to double the mechanical strength of Class II X7R (2R1), and thus Class II X7R (2R1) would clearly not meet the electronic design engineers demand for increased mechanical crack resistance.

The Polymer termination analysis in section 3.2.1 clearly shows that by selecting Knowles Precision Devices FlexiCap™ termination material for Class II X7R (2R1) dielectrics the components resistance to mechanical cracking is significantly enhanced by the absorption of stress in the termination material. Thus by reaching this higher level of mechanical performance Knowles Precision Devices can offer a guaranteed 5 millimetre bend test deflection on AEC-Q200 components.

It should also be noted that FlexiCap™ can also be applied to Class I C0G/NP0 (1B/CG) components to achieve a similar deflection distance as per the results of the Class II X7R (2R1) components.

5 Summary

a) The drive of electronic functionality in smaller form factors has led to an increase in component density on boards increasing the mechanical stress on components. Which in turn has led to higher mechanical strength requirements from electronic design engineers on component manufacturers.
b) Knowles Precision Devices remains the front runner for Flexible termination having introduced the award winning FlexiCap™ in 1999.
c) Components terminated with FlexiCap™ have a higher resistance to mechanical cracking meeting the demand by electronic design engineers for components that far exceed the minimum industry standard for flexibility, and enabling Knowles Precision Devices to offer a guaranteed 5 millimetre bend test deflection on AEC-Q200 components.