TECHNICAL PAPER

AVX MLCC Flexiterm™: Guarding Against Capacitor Crack Failures

Mark Stewart
Technical Marketing Manager
Technical Marketing – MLC Products, AVX Ltd.
Coleraine, Northern Ireland

Abstract

The huge popularity of MLCC capacitors in comparison with alternative technologies is primarily a result of their superb reliability record and low cost. However, in certain circumstances problems can occur due to cracking in the ceramic portion of the component. These failures result from mechanical damage caused after soldering to the PCB; normally a consequence of PCB mishandling or when the assembly is located in extreme environmental conditions.

This article outlines the main benefits and features of AVX's 'FlexiTerm™,' a soft termination system that minimizes these failures by relieving the mechanical stress applied to the ceramic.

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AVX MLCC FLEXITERM™: GUARDING AGAINST CAPACITOR CRACK FAILURES

by Mark Stewart, Technical Marketing Manager
Technical Marketing – MLC Products, AVX Ltd.
Coleraine, Northern Ireland

The Cracking Problem

As the dominant capacitor technology in terms of component quantities, the Multilayer Ceramic Chip Capacitor's (MLCC) popularity with circuit designers is principally due to its high reliability record and low cost. However, due to the nature of ceramic material the MLCC body can be liable to cracking if mishandled during assembly or used in extreme environments. For this reason cracking in an MLCC body is the most common mode of failure for PCB mounted MLCC components.

Fractures in MLCC components are most commonly a direct consequence of flexing the PCB board where the component is attached. This flexing may result from mechanical induced forces found in assembly manufacturing as well as in harsh operating conditions in the field. In the worst case a low resistance fracture failure can lead to extremely high temperatures when the component is connected to a power line and with ample current supply could result in catastrophic damage to the immediate area of the circuit board.

Typically, board flex induced cracks initiate where the ceramic/termination interface is soldered onto the PCB and propagates to a point approximately halfway up the height of the ceramic capacitor termination. An example of this is shown in Figure 1.

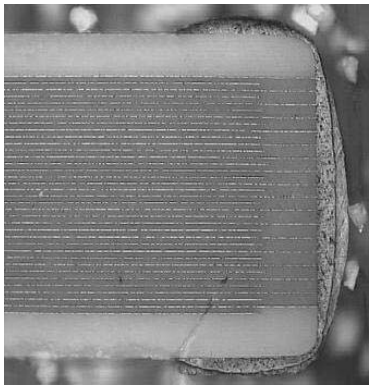

Figure 1. Standard Termination MLCC exhibiting Typical Board Flex Crack

FlexiTerm™ Absorbs the Stress

AVX recognized that there was a need to improve the MLCC's mechanical performance to provide a more reliable product when severe external forces are being applied to the component. FlexiTerm™ was developed as an additional flexible termination layer added to the component thus ensuring electrical integrity is maintained while external forces are applied (Figure 2). FlexiTerm™ is used in conjunction with BME (Base Metal Electrode) technology. This offers the advantage of eliminating the problems of high material cost associated with PdAg capacitor technology as well as providing increased reliability performance. The improvement in flex and thermal performance results in a more reliable solution where board flex in manufacturing is a problem or where the component is operated in extremely demanding environments.

Mismatching coefficient of thermal expansion (CTE) between the component and PCB can also cause excessive forces at the connection site of the dissimilar materials. This can particularly be an issue in power converter bricks due to large fluctuations in temperature caused by varying load conditions. FlexiTerm™'s flexible properties reduce the risk of failure to the system by lessening the stresses on the component.

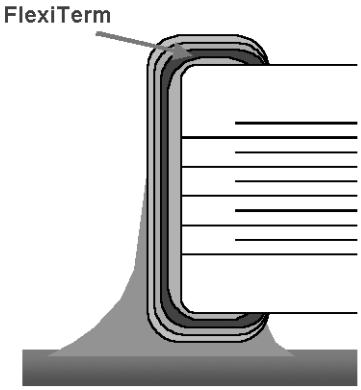

Figure 2. Additional FlexiTerm™ Layer for Increased Resistance to Mechanical Flexure

AVX offers FlexiTerm™ on a wide range of values in X7R dielectric including automotive, power supply input capacitors as well as with standard commodity products.

Applications Needing Protection from Fracture Failures

MLCC fractures can be most problematic in high cost and high power applications since a greater amount of damage is possible on a circuit where higher current is available. High-risk applications include Automotive, Power Supplies, Converters, Telecoms, Basestations, PCs and Laptops, PDAs, Medical and Instrumentation. In general all types of PCB assemblies are susceptible to ceramic capacitor failures during manufacture and additionally some are vulnerable to failures because of harsh working environments.

The automotive sector is an example of an industry where ceramic capacitor failures are already widely recognized as being a critical failure in their applications. Emerging trends in automotive electronics include the drive for higher levels of reliability at the component level, miniaturization, increased functionality, and the placing of integrated electronics in high temperature, harsh environments in the car such as the engine, clutch, and gearbox. Automotive electronic system manufacturers have hence played an important role in recognizing the limit of the ceramic capacitor and helped define the requirements for a more suitable MLCC product for the future.

Power supplies and converters are technologies that also require protection from MLCC crack failures. Advances made in ceramic capacitor technologies have led to an increase in their use in power supply applications; these developments include higher available capacitance values and lower Equivalent Series Resistance (ESR) compared to alternative capacitor technologies.

Failure of a component such as an MLCC due to mechanical or thermo-mechanical stress can compromise critical safety systems and halt the operation of the entire system in many applications. In addition, the cost of failure in high-end modules and units is also significant to automotive and power supply manufacturers both financially and vitally to their reputations. More disturbingly, an MLCC shorted on a 48V or even 12V line supplied with a few amps, which is easily available from a car battery, can heat to around 1000 degrees Celsius, potentially causing substantial damage!

Addressing the Fracture Failures

Failure due to a fracture is not restricted to particular MLCC manufacturers but across the range of minor as well as major suppliers. Causes of failure are normally well understood by the electronic assembly manufacturer. The most common areas for failure are PCB depanelization, component placement, board assembly insertion sections and where MLCCs are placed too close to the edge of the PCB.

Measures to reduce failures are well documented but when this type of failure arises it can be unexpected, a long time to detection and difficult to determine root cause. Examples of assembly manufacturers spending thousands of dollars per month in detection, containment and repair are not uncommon. Solutions such as redesign of component layout can also have a long turnaround time before obtaining confirmation that it is a solution to the problem.

The fracture failure can sometimes be so common to a contract manufacturer and understood to be caused during assembly that they do not highlight the problem to their supplier or customer. In some cases only the quality engineer is aware of the extent of the problem and cases are known where the failures are not recorded or tracked by production staff. This may occur because it is presumed that the more severe failures can be located at end of assembly testing, a critical error since component fractures may not initially be obvious using capacitance and Q factor testing. The actual MLCC component's operation may not degrade until moisture ingresses into the crack causing a low resistance path between adjacent electrodes, this may only become apparent after exposure to moist atmosphere. For this reason some ceramic fractures may be found in capacitors by measuring its change of insulation resistance (IR). IR testing is a standard test used to confirm a capacitors proper operation but is as a rule not possible once the component is attached to the circuit board.

FlexiTerm™ – The Solution to Cracking

AVX found that to stop ceramic fractures from occurring the structure of the capacitors termination needed to be flexible and after much research and development, "FlexiTerm™" was identified. The new high conductivity termination material with flexible properties was added to the AVX standard X7R dielectric ceramic capacitor to produce the new range of FlexiTerm™ MLCC capacitors. This Flexible Termination is specifically designed to enhance the mechanical and temperature flexure performance of the component preventing failures in the system due to cracking.

Examples exist where experienced capacitor users who accepted high rates of board flex failures due to unknown causes in manufacturing removed the failures completely by replacing the capacitors with parts from the AVX FlexiTerm™ range.

Cost is always a determining factor on whether a circuit designer or manufacturing engineer can use a certain component. It may rely on the quality engineer to determine the real cost saving in cases where board flex failures can be removed by introducing the FlexiTerm™ component. This is more appropriate for lower cost, small value capacitors. Where capacitance values are larger with corresponding increase in price the cost of FlexiTerm™ becomes less significant. For the high capacitance value input capacitor range AVX provides FlexiTerm™ as standard since the additional material and manufacturing cost is a small proportion of the overall cost of the component.

While other manufacturers are known to offer ceramic capacitors with a flexible termination technology, AVX is

currently the only manufacturer to offer this type of technology on a BME capacitor providing a lower cost alternative to those components using precious metal materials. Meanwhile, some manufacturers are offering an alternative method of flexure protection. This method uses an adapted internal electrode design where an increased gap is made between the end of the electrode and side of the chip. This design helps to reduce low resistance and short circuit failures due to the higher chance of the crack only passing through one polarity group of electrodes and not the worst-case scenario of shorting through both polarities. However, depending how high the crack propagates through the component an increasing loss of capacitance will be incurred due to the disconnection of electrodes. Another disadvantage of this technique is that this type of component may not be available in maximum capacitance values and where available the thickness is increased above the normal dimension to compensate for the lost capacitive area at the ends of the electrodes.

How FlexiTerm™ Works

FlexiTerm™ is a flexible termination comprising a conductive polymer that ensures electrical integrity is maintained during and after external forces are applied to the component. FlexiTerm™ is used in conjunction with BME (Base Metal Electrode) technology. BME replaces the higher cost Palladium-Silver (PdAg) with a Nickel (Ni) electrode and Copper (Cu) termination. FlexiTerm™ is achieved by coating the Cu termination with conductive polymer, which is then plated with Nickel (Ni) and Tin (Sn).

Resistance to mechanical failures are provided by FlexiTerm™'s ability to reduce the transfer of mechanical stress exerted on the component body. In normal operation this prevents the component from being damaged by board flex during manufacture as well as damage from the environment caused by board flexing, vibration and temperature expansion.

While FlexiTerm™ offers much better mechanical and thermo-mechanical performance, it is designed so that if there were to be a failure due to flexing, it would be in the termination area and in open mode. Open circuit is a preferred failure mode as it stops the supply of current, removing the possibility of circuit damage that may arise from a short circuit failure. This is especially important on power lines where failure could involve fire damage due to short circuit. In the case of FlexiTerm™ the open circuit occurs in a small area of the termination meaning little or no degradation to the capacitor's performance.

Testing FlexiTerm™'s Mechanical Flexibility

Electronic component performance is such a concern in automotive electronics that Ford, Chrysler and GM created the Automotive Electronics Council in 1993. The goal of this council is to create common qualification specifications as a possible way to improve supplier attention. Shortly thereafter an Automotive Electronics Council Component Technical Committee created a qualification requirement and test method in the document AEC-Q200 to precisely define stress test qualifications for passive components.

AEC-Q was used by AVX to evaluate the ability of a capacitor to withstand mechanical stress; two relevant tests used to compare standard termination with FlexiTerm™ are the board bend flex test and temperature cycling test.

The bend test requires a component to be reflow soldered to a printed circuit board and placed on two supports 90mm apart as shown in Figure 3. The board is then bent up to 10mm at 1mm per second. Once the load is applied, the deflection where the part starts to crack is recorded using a highly sensitive current detection circuit or by sectioning the component after a defined bend deflection. The AEC-Q200 specified flexure test defines a minimum flex requirement of 2 mm.

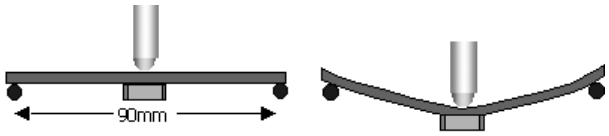

Figure 3. Board Bend Flex Test per AEC-Q200 Test Qualification

The board bend flex test found that AVX FlexiTerm™ parts do not fail when flexed to 5 mm. This improvement gives a 2 to 4 times increased bend resistance compared to standard capacitor technology.

Temperature Cycling is another automotive test conducted by AVX to determine the resistance of a part to extremes of high and low temperatures by alternative exposure to those extremes. The component is mounted to an FR4 PCB allowing the test to simulate the stresses caused by the mismatch in temperature expansion between the component and the circuit board. AEC-Q200 requires the standard ceramic X7R capacitor to withstand 1000 cycles from -55 to 125 degrees Celsius. 3000 cycles are achievable from parts in the FlexiTerm™ range without damage to the component. This means that FlexiTerm™ offers improved reliability performance in applications where there is extreme temperature variation, e.g. outside cabin circuits in automotive and aviation applications.

The equivalent series resistance (ESR) is an important parameter where high rms-current carrying capability is required. An investigation to determine if any change in ESR occurred in the capacitors with FlexiTerm™ was performed by AVX using the long-term reliability tests, operational life and temperature cycling both defined by the AEC-Q200 specification. The components ESR value was measured at intervals throughout the duration of the long-term tests and found not to change throughout the recommended test duration. This proved that the interconnection between the electrodes and termination showed no degradation even after severe operation conditions of voltage and temperature.

Board Flex Test in Terms of Strain

Measurement of the external forces exerted on a component during board flex can be demonstrated using a strain gauge. A maximum permitted strain value can therefore be supplied for MLCC components allowing a safe margin in the manufacturing process window to be applied. The increased resistance to strain provided by FlexiTerm™ offers the circuit designer and assembly process engineer a guide to component choice where high levels of strain cannot be avoided or where safety is critical to the application.

Strain may be calculated for a PCB board bent in a uniform radius. This provides a relationship between the strain subjected on a component and the test method specified by AEC as a deflection in mm. The calculation is verified by a strain gauge measurement on the board bend flex test board and is presented in Figure 4. In the application strain may be measured at the PCB's high flexure site by attachment of a Strain Gauge to the component side of the PCB. The defined strain requirement for the capacitor can now be compared with the components allowable strain and if required an alternative such as 'FlexiTerm™' can replace standard components for improved reliability.

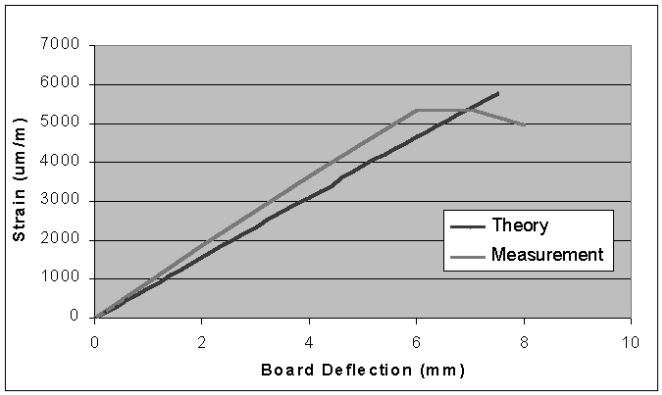

Figure 4. Calculated and Measured Strain versus Board Bend Test Deflection

Reliability Reduces Costs

The key benefit of FlexiTerm™ is its ability to deliver excellent mechanical and thermo-mechanical performance leading to higher levels of reliability.

The location of a component on the printed circuit board may influence the level of thermal or mechanical stress to which the component is exposed. FlexiTerm™ enables manufacturers to use a wider process window with respect to board layout. This may, in some cases, alleviate design and manufacturing constraints and expensive redesigns of a problematic circuit board.

Further, the performance offered by FlexiTerm™ technology also lends itself to applications that are demanding higher levels of reliability such as in telecom servers, mobile phone basestations and remote measurement systems as well as in high-end value equipment where failure implies high costs.

Expanding FlexiTerm™ Product Range

A large range of standard X7R MLCCs are available with the option of FlexiTerm™. This was first provided to our automotive customers but are now provided to other product manufacturers such as instrumentation, power supplies, etc. AVX's continuous investment in Research & Development and enhanced manufacturing techniques allows the expansion of the High CV Ceramic capacitor line. As higher value X7R capacitors become available in different case sizes they will also be included in the FlexiTerm™ range.

The AVX MLCC high capacitance products are suited to a wide range of applications in power distribution systems. The X7R 50V and 100V ranges have primarily been developed for use as input filters in a DC-DC converter where the inherent low ESR of the MLCC parts reduces the ripple voltage across the input terminals. The addition of FlexiTerm™ to the input capacitor range at no extra cost offers AVX components the distinct advantages of excellent Bend Test and Temperature Cycling performance with obvious benefits to circuit designers. Other uses for "input capacitors" include Power over Ethernet applications.

Conclusion

Significant progress has been made in the development of enhanced termination systems to reduce MLCC failures caused by mechanical damage. Polymer based FlexiTerm™ systems offer increased system performance and reliability by minimizing stresses transferred to MLCCs. This results in greater than 2x standard board deflection capability with enhanced termination technology devices. Additionally, this translates into significant temperature cycling capability (roughly 3x standard termination devices). Applications for FlexiTerm™ now extend well beyond automotive sectors with significant volume used in Power Supplies, Telecoms, Basestations and Instrumentation.

A KYOCERA GROUP COMPANY

NORTH AMERICA
Tel: +1 864-967-2150

ASIA
Tel: +65 6286-7555

CENTRAL AMERICA
Tel: +55 11-46881960

EUROPE
Tel: +44 1276-697000

JAPAN
Tel: +81 740-321250

WWW.AVX.COM