

Board Flexure Damage Can Be Hazardous to the Health of Your MLCCs

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About Board Flexure Failures

Failures of MLCCs from board flexure have received considerable attention recently. This is due in part to reliability concerns, but also because there is no known screening method available to detect cracked capacitors after assembly onto circuit boards. In medical applications, board flexure control is especially important because of the risk for potentially serious failures that can result from high-current shorting, possibly affecting components surrounding the failed capacitor.

As the number of MLCCs per application increases, board flexure cracking may translate into an unacceptably high field failure rate. Furthermore, the increased use of subcontractors that process multiple customer circuit board assemblies may be more prone to this issue than OEM product lines that have been developed to manufacture a specific design.

Flex cracking problems with multilayer ceramic capacitors have led to board handling process improvements at OEMs and subcontractors, tests for capacitor resistance to flex cracking, and improved design standards for circuit boards. Nonetheless, it remains a predominant failure mode for MLCC capacitors. The failures usually start as leakage failures with a loss in insulation resistance (IR) capacitance. Flexure damage appears more often in small- and larger-case-size MLCCs that are located in possible flexure-sensitive areas of the printed circuit board.

Manufacturers of MLCCs have been working on capacitor improvements that mitigate the cracking problems caused by board flexure. Vishay has developed three different approaches to addressing this failure mode in MLCCs.

How Board Flexure Causes MLCC Cracks/Fractures

When a circuit board is deflected, it attempts to form an arc. The outer surface of the solder pads, or the end of the terminated solder capacitor chip, moves apart, placing the capacitor chip in tension. When ceramic capacitors are soldered to circuit boards and the board is bent, forces are transmitted through the solder to the capacitor termination and the ceramic material just under the termination. The forces are not pure tensile forces, and they are modified by the amount and shape of the solder fillet. There are two general types of cracking that occur: cracks produced by primarily tensile forces, and cracks produced by primarily compressive forces.

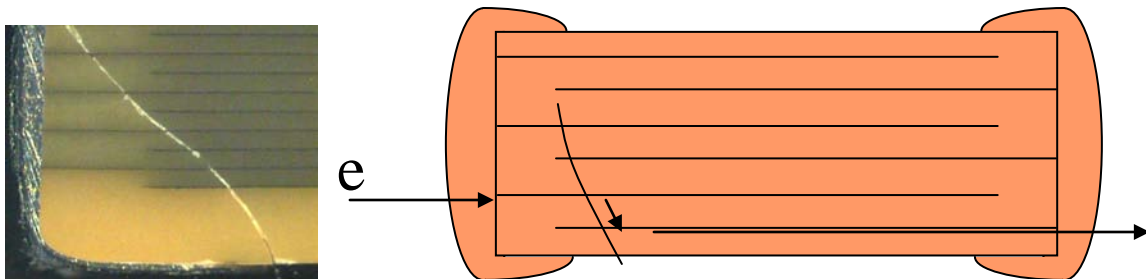
Board Flex Stresses Due to Process Handling Methods



When these forces exceed the strength of the ceramic, a crack forms from the edge of the termination and moves toward the chip layers.

MLCC Capacitor Structure

Ceramic capacitors are made of fine grains of ceramic material that are bonded together by diffusion during firing. The resulting ceramic structure is a very brittle material. Ceramic capacitors have great strength in compression, but fail easily under tensile or shearing stress. Under such conditions, brittle fractures can occur, resulting in a typical crack pattern that depends on the way the forces are applied. An example of such a typical board flexure crack in the corner of an MLCC is shown below.



Due to the variability in capacitor sizes and solder fillet shapes, tensile cracks may completely sever the termination end from the rest of capacitor, or they may simply fracture a corner off the capacitor. In the latter case, the capacitor is held together by termination material.

In both cases the cracks permit ingress of humidity and contaminants that will ultimately cause MLCC failure.

Board Design Rules for Reducing Board Flexure

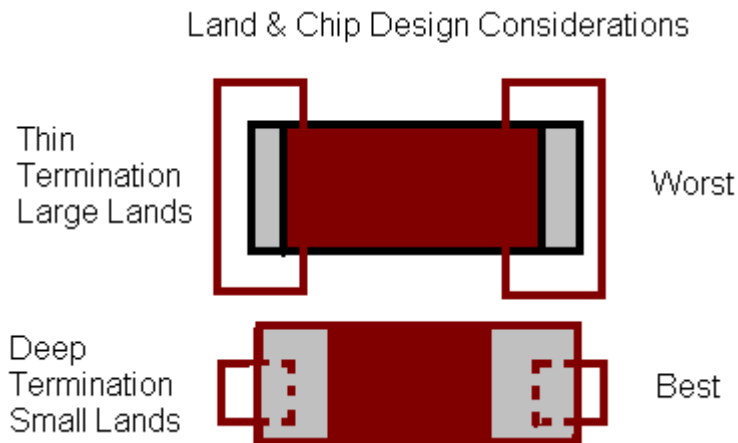
Industrial Standard JIS-6429 contains a description and standards for measuring flex cracking resistance in MLCCs. A similar process is published in the appropriate IEC (European), standard. Vishay uses the JIS-6429 method, with all Vishay standard commercial-grade MLCC products meeting or exceeding a 2-mm flex under the conditions of this specification.

Circuit board manufacturers use proven design standards for circuit board pad layout and component locations to mitigate board flexure. These usually require a 5-mm space between a board edge and a ceramic capacitor. They also typically indicate the direction of mounting the capacitor relative to the board edge (parallel to the edge is usually better), and they also call for routed reliefs along the board parting lines to reduce stress in the de-paneling process.

Manual bending of boards in de-paneling and other methods that permit flexing of the boards, such as scoring and wheel cutting, have been eliminated in favor of punching and routing. The latter processes, combined with routed reliefs along most of the parting lines, are used in high-reliability medical electronics assembly operations.

Lands Control Can Help

Solder land control can help reduce the forces that crack ceramic capacitors by lowering the exposure surfaces. This is not a total cure, but a factor to consider in soldering processes and when designing ceramic capacitors into circuit boards.



Measurement of Board Flexure and Prevention

Data from controlled flex testing conducted per JIS-6429 has provided a value of flexure strength for customer production processes. The maximum board flex permitted across a 90-mm span is 2 mm, according to most customer specifications, and capacitors must not fail within these limits.

Simple tests can be run by installing miniature strain gauges at or very near the capacitor site and running the boards through the production process while recording strain. Vishay offers miniature strain gauge equipment from its Vishay Measurements Group, and has performed evaluations with medical customers to determine strain levels on various board locations.

To convert board flex in millimeters to μ Strain applied to the board, use the following equation:

$$\text{Calculated strain} = \sigma = \frac{6T\delta}{L^2}$$

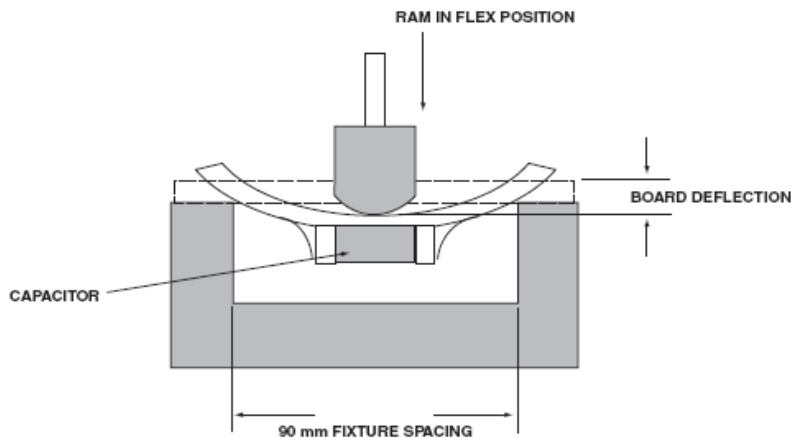
T = board thickness (mm)

L = span between supports (mm)

δ = board flexure (mm)

Flexure Strength Testing of Individual MLCCs

Extensive board flexure testing has been performed on open mode design (OMD) capacitors soldered onto epoxy resin boards. The boards were subjected to an 8-mm flexure as shown on the fixture below. The capacitance was monitored during the flexure, and failures were reported as the capacitance shifted outside the permitted tolerance. Insulation resistance (IR) was also tested for each capacitor. The OMD capacitor met an IR >100 ohm farad in all cases, while commercial-grade products did not pass the IR limit.



Different MLCC Products for Flexure Problems

Open Mode Designs

The OMD is similar to standard MLCC designs except for the overlap, or active area, of the part. In OMD the overlap is shifted away from the termination pad with the surface of the capacitor away from the area of crack occurrence.

If a board flex crack occurs, then it does not penetrate the active overlap area of the capacitor (Figure 1). Since the crack does not penetrate the active overlap area, although capacitance loss does occur, there is no pathway for the part to short, so the failure can remain "open."

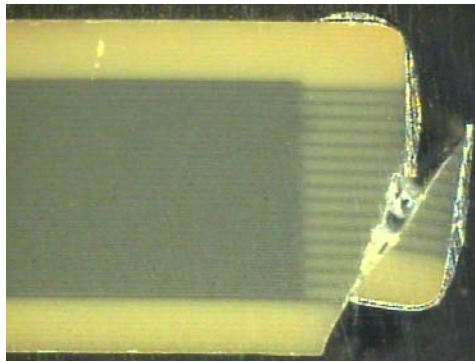
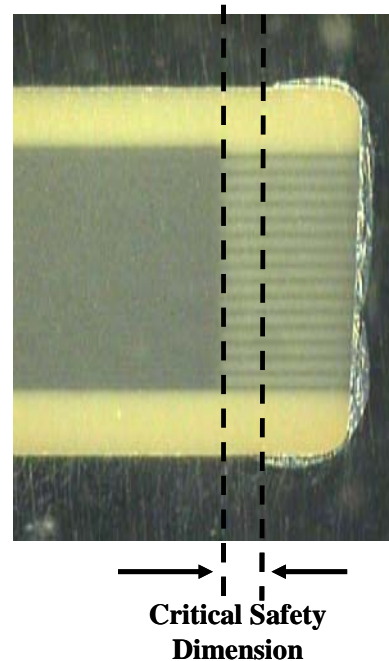


Figure 1. Open mode MLCC with induced board flexure crack (above) and critical safety dimension (side)



MLCC Serial Designs for Flexure problems

The serial or floating electrode design MLCC can prevent failures due to flexure resulting from electrode stacking. These designs have a commonly known floating electrode and were originally developed for high voltage ratings above 500 VDC (Figure 2).

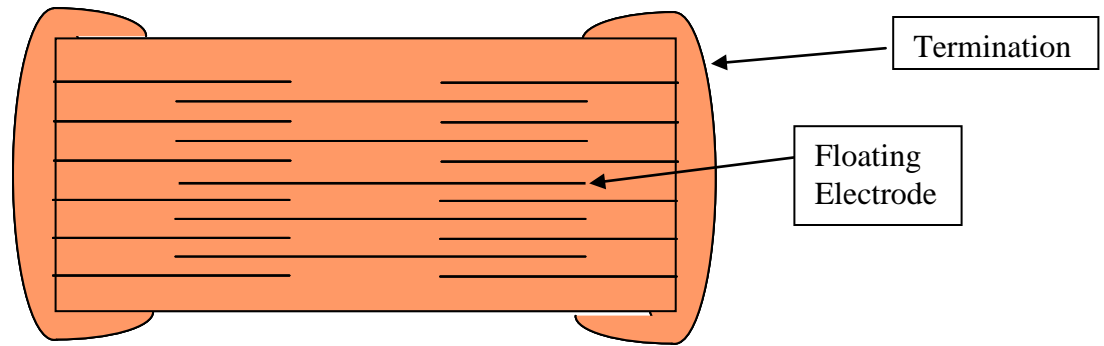


Figure 2. Diagram of Floating Electrode or Serial MLCC

Similar to the OMD, the floating electrode design provides no pathway for the part to short, so these are also an "open" design type. The disadvantage of the serial design is that the overlap area is significantly reduced, so more layers are required to achieve the same capacitance at the same active thickness, which adds to the expense of the capacitor. For this reason, this design type is only used for ratings 500 VDC and greater in our current OMD-capacitor offering.

MLCCs With Polymer Terminations

Unlike approaches that use design to try and mitigate the effect of board flexure cracks, polymer terminations are applied to the end of capacitors to increase compliance. A diagram comparing these types is shown in Figure 3.

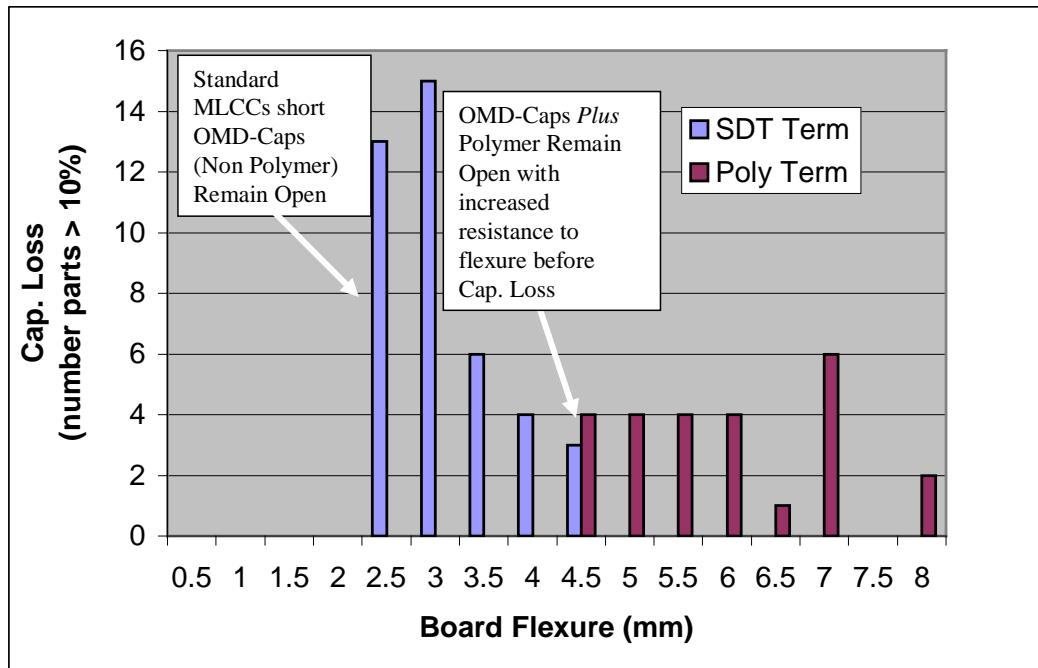


Figure 3. Capacitance Loss Comparison for Standard Vs Polymer Terminations for Case Size 2220

In the case of the standard terminations, capacitance loss failures occur at lower levels of board flexure than with polymer terminations. It should be noted that all these capacitors failed when open. The data shown in Figure 3 is from two lots of each termination type, and a Weibull analysis of each lot was performed and is shown in Figure 4.

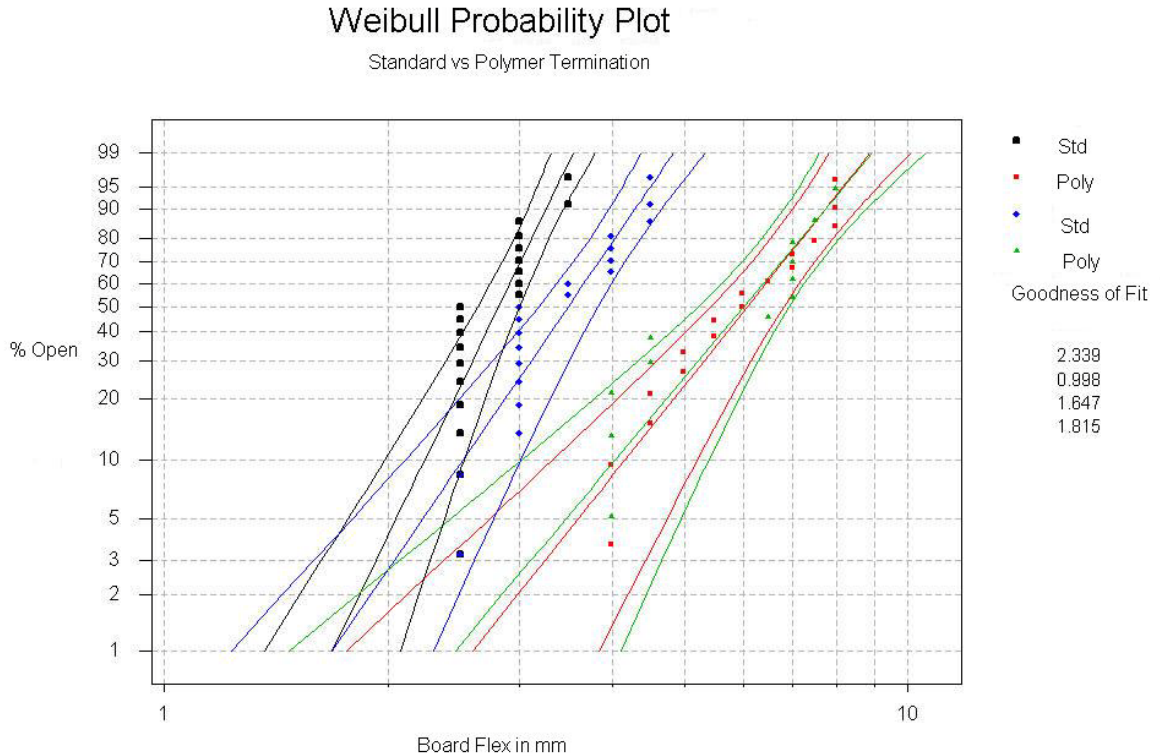


Figure 4. Weibull Analysis of Case Size 2220 Capacitance Loss Data for Standard and Polymer Terminations

Two production lots were tested for both standard- and polymer-termination board flexure. The Weibull analysis clearly shows the improvement with the polymer termination, and the results are reproducible.

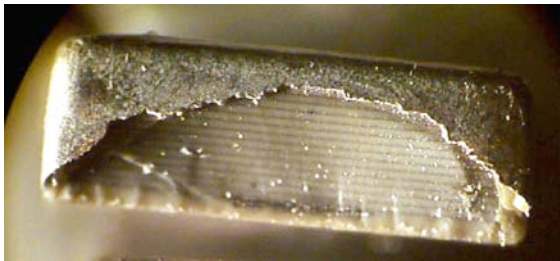
Using the equation noted above, we calculated the strain on the boards for the range of board flex of interest, as shown in Table 5 below.

Board Flex (mm)	μ Strain
1.5	1778
2.0	2370
2.5	2963
3.0	3555
3.5	4147
4.0	4740
8.0 (maximum)	9840

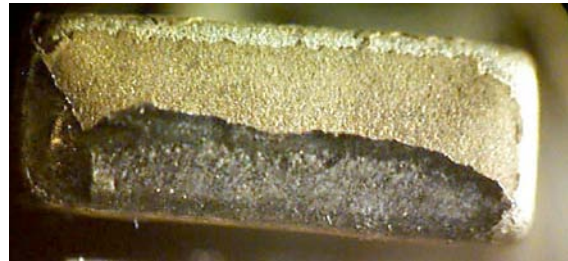
Table 5. Board Flex Converted to μ Strain for Case Size 2220 Tests

The onset of standard termination failures at 2.5 mm is equivalent to a μ Strain of 2963, whereas for polymer terminations, failures at 4.0 mm are equivalent to a μ Strain of 4740. It should be noted, however, that the lower 95 % confidence lines cross 0 % failures around 1.5 mm, or a μ Strain of 1778. So for low failures of the 2220 MLCC, μ Strain <1700 should be targeted during assembly.

In all the standard terminations, cracking occurred through the ceramic. In the polymer-terminated samples, however, delaminating of the polymer occurred (Figure 6).



Standard Termination



Polymer Termination

Figure 6. Board Flexure Capacitance Loss Failures

The main advantage of the polymer termination is the ability to sustain greater flexure before capacitance loss occurs, and this is being offered as a termination option for OMD-capacitors.

Polymer terminations are plated with nickel and tin and shown little difference in terms of thermal shock susceptibility. Standard soldering guidelines apply.

Impedance versus frequency is no different for polymer-terminated MLCCs when compared to standard terminations, as shown in Figure 7.

Impedance vs. Frequency of Standard and Polymer Terminations

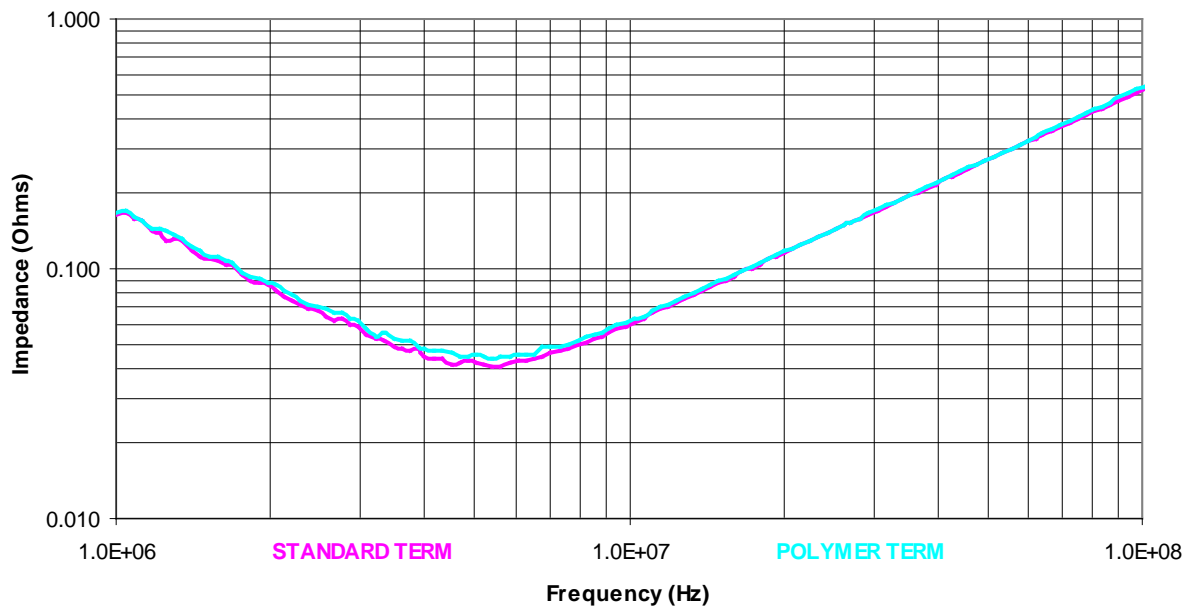


Figure 7. Impedance Vs Frequency for Standard and Polymer Terminated MLCCs

Although polymer terminations offer more reliable performance with respect to board flexure, some concerns remain with respect to certain applications. Specifically the potential for out-gassing may present a liability for military, aerospace, and medical life support circuits. More work needs to be done in this area, and more field performance testing is required before it will be possible recommend this option for these applications.

Summary and Conclusion

Although the performance of MLCCs with respect to board flexure failures cannot be 100 % guaranteed, there are several new MLCC products offered that are a step in the right direction for reducing failures due to board flexure.

For more information and data sheets on the products mentioned in this article, please visit our website at Vishay.com