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Coping with the Risk of Board Flexure Damage to Multilayer Ceramic Capacitors [2]

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Techniques are emerging to minimize the incidence of a PCB component defect that can cause problems in devices in the field.

Failures of multilayer ceramic capacitors (MLCCs) caused by printed circuit board (PCB) flexure have received considerable attention recently, not only because of product reliability concerns, but also because there is no screening method available for detecting cracked capacitors after they are assembled onto circuit boards.


[5]

(click to enlarge)
[5]Multilayer ceramic capacitors are susceptible to board flexure failures.

Board flexure control is especially important in medical applications because of the potential for serious failures resulting from high-current shorting to affect components surrounding the failed capacitor.

As the number of MLCCs per application increases, board-flexure MLCC cracking may translate into an unacceptably high field failure rate for medical devices. Further, subcontractors that process PCB assemblies for multiple customers are increasingly involved in equipment manufacture. Such involvement may make this issue more serious than it would be if OEM production lines were developed specifically to manufacture one particular OEM device.

True, flex-cracking problems with MLCCs have led to board-handling process improvements at OEM and subcontracting establishments, to tests for capacitor resistance to flex cracking, and to improved design standards for circuit boards. Nonetheless, cracking remains a predominant failure mode for these capacitors. The failures usually start as leakage failures and a loss in insulation resistance (IR) or in capacitance. Flexure damage readily appears in large-case-size MLCCs. It is much less obvious in small-case-size MLCCs located in possibly flexure-sensitive areas of the PCB.

MLCC manufacturers have made capacitor improvements that mitigate cracking problems caused by board flexure, developing three different approaches to addressing this failure mode in MLCCs. One is open-mode designs. In this case, the MLCC is designed so that any board-flex cracking does not penetrate the active electrode area so as to cause IR loss and shorting. Alternatively, the use of polymer terminations allows greater flexure before cracking occurs, and the cracking does not result in IR loss or short circuits. The third approach involves optimizing solder land design on the circuit board, which is another way of minimizing the stress level during flexure.

Flexure and Cracking

When a circuit board is deflected, it forms an arc. The outer surface of the solder pads and the end of the terminated soldered capacitor chip move apart. This in turn places the capacitor chip in tension.

When ceramic capacitors are soldered to a circuit board and the board is bent, forces are transmitted through the solder to the capacitor termination and to the ceramic material just under the termination. These forces are not pure tensile forces; there may be some torque involved during board flexure, and the forces are modified also by the amount and shape of the solder fillet. However, two general types of cracking occur: cracking produced by primarily tensile forces, and cracking produced by primarily compressive forces. Both types of force can cause cracking under the MLCC terminations, but, for the most part, ceramic materials such as those used for MLCCs are more susceptible to tensile-type forces.

[6]

Figure 1. (click to enlarge) [6] Stresses from board flexing due to process handling are transmitted to the capacitor termination and underlying ceramic.

Cracks generated by flexure are found usually on the bottom surface of the MLCC, under the termination where the part is mounted to the PCB (see Figure 1). They are rarely found on the top of the part. When the applied flexural forces exceed the strength of the ceramic, a crack forms from the edge of the termination and moves toward the chip layers.

Ceramic capacitors are made of fine grains of ceramic material that are diffusion-bonded during firing. The ceramic structure resulting from the production process makes for a very brittle material. Ceramics have great strength under compression but fail easily in tension or in shear. Under tensile or shearing stress, they sustain brittle fractures. The result is a typical crack pattern that will vary with the manner in which the forces are applied (see Figure 2).

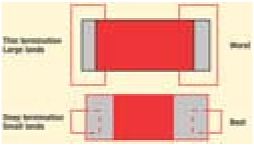
[7]

Figure 2. (click to enlarge) [7] The cross section of an MLCC (left) reveals a typical board flexure crack in the corner of the MLCC. The diagram on the right shows electrode layers in an MLCC and indiccates where tension forces form the crack.

Because of variability in the size of capacitors and the solder fillet shape, tensile cracks can completely sever the termination end from the rest of capacitor in some cases, or they may simply break a corner off the capacitor. The capacitor remains held together by termination material in the latter case. In both cases, the cracks allow ingress of humidity and contaminants that will ultimately cause MLCC failure.

Design for Reducing Board Flexure

PCB manufacturers use proven design standards for circuit board pad layout and component location in order to mitigate board flexure. These usually require a 5-mm space between a board's edge and a ceramic capacitor. Standards also typically indicate the orientation of the mounted capacitor relative to the board edge—parallel to the edge is usually better—and they call for routed reliefs along the board parting lines to reduce stress during the depaneling process. Manual bending of boards to depanel, as well as 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 a variety of high-reliability medical electronic assembly operations.



[8]

Figure 3. (click to enlarge) [8]A board layout in which the solder lands for mounted MLCCs are kept small is best for discouraging capacitor cracking.

In addition, control of solder lands can help reduce the forces that crack ceramic capacitors by minimizing the exposed surfaces (see Figure 3). This is not a total cure, but it is an area to consider when designing ceramic capacitors into circuit board and soldering processes.

Flexure Measurement and Testing

The Japanese industrial standard JIS C 5101-1, published in 1998, contains standards for measuring flex-cracking resistance in MLCCs and a description of methodology. (A similar process is published in IEC 60384-1, the analogous European standard of the International Electrotechnical Commission.)

Data from controlled flex testing conducted in accordance with the JIS C 5101-1 standard have provided a method of evaluating the flexure strength of a particular MLCC design. They have also been predictors of the effect of customers' production processes. Most manufacturers using MLCCs have established a limit for board flexure and often specify the allowable amount of flexure in their MLCC product requirements.

The JIS C 5101-1 standard establishes the maximum permissible board flex across a 90-mm span as 2 mm. This 2-mm flexure limit accommodates most MLCC customers' specifications and most MLCC manufacturers' capabilities. The standard's 2-mm allowance also has a requirement component in that capacitors must not fail due to flexure of the board up to the specified limit.

Preventive measures can be taken to determine where in the OEM or subcontractor manufacturing process board flexure could be a problem. This involves evaluating each process in which the populated PCB is handled to discover occasions of potentially excessive board flexure.

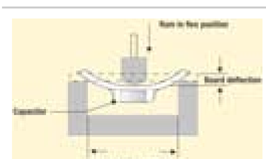
To develop a baseline of data, as well as provide actual measurement data for further evaluation, each manufacturing process that could subject the populated PCB to tension should be tested on the production line. Strain gauges are effective measurement devices that can be used.

Simple tests that can be run involve installing miniature strain gauges at or very near the capacitor site and running the boards through the production process while recording strain. Such miniature instruments are available and have been used to perform many evaluations of strain levels at various board locations on PCBs that contain MLCCs that were intended for incorporation into medical electronic equipment.

The equation for converting board flex in millimeters into strain (σ) in terms of microstrain (μσ) applied to the board is

$$\sigma = \frac{6T\Delta}{L^2},$$

where T is the board thickness, L is the span between supports, and σ is the board flexure, all as measured in millimeters.



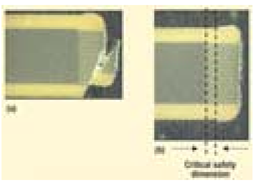
[9]

Extensive board flexure testing was performed on open-mode-design capacitors soldered onto epoxy resin boards. The boards were subjected to an 8-mm flexure on a special fixture (see Figure 4). The capacitance was monitored during the flexure, and failures were reported as the capacitance shifted outside the permitted tolerance. IR for each capacitor was tested. The open-mode capacitors met the standard of an IR greater than 100 ?F in all cases. However, commercial-grade capacitors did not pass the IR limit.

Figure 4. (click to enlarge) [9]Setup for testing the effect of board flexing on capacitor performance.

Minimizing Flexure Problems

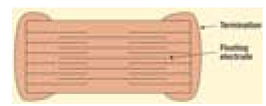
MLCCs are being developed that have designs or termination techniques that enhance the components' resistance to damage caused by flexure. Some remove the active capacitor surface from the cracking area, others stack electrodes, and those in a third category employ an alternative termination material.



[10]

Figure 5. (click to enlarge) [10]An open-mode MLCC with an induced board flexure crack (a) and with an indication of the safety dimension in this design (b).

Open-Mode Design. An MLCC of open-mode design is similar to a standard MLCC except for the overlap, or active area of the part. In open-mode design, 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 then forms, it will not penetrate the active overlap area of the capacitor (see Figure 5). And because the crack does not penetrate the active area, there is no pathway for the part to short. Capacitance loss does occur. However, the critical safety dimension built into this MLCC design allows the failure to remain open.



[11]

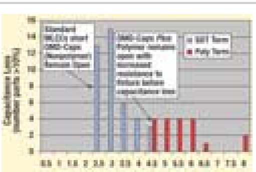
Figure 6. (click to enlarge) [11] Diagram of a serial, or floating-electrode, MLCC.

Serial Designs. Serial, or floating-electrode, MLCCs can resist failures owing to flexure because of the nature of the electrode stacking in their design. Serial designs, which have electrodes said to float because they do not connect the terminal ends, were originally developed for high-voltage ratings above 500 V dc (see Figure 6).

Similar to the open-mode design, the floating-electrode design provides no pathway for the part to short circuit. Thus, these capacitors also have an open type of design. The disadvantage of the serial design is that, because the overlap area is significantly smaller, more layers are necessary to achieve the same capacitance at the same active thickness. This adds to the expense of the capacitor. For this reason, MLCCs of this design type are best used for applications rated for 500 V dc and higher.

Polymer Terminations. A third approach to mitigating the effect of board-flexure cracks is not another design alternative. Rather, polymer terminations are applied to the ends of capacitors as a means of increasing compliance. The materials used for polymer terminations, along with the processing, add some cost to the final MLCC product.

Polymer is a cured epoxy rather than a fired thick-film material like standard terminations. Conductive epoxies have been used for many years on flexible hybrid circuit boards.

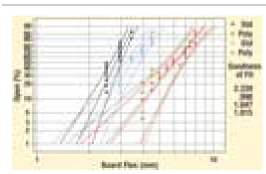


[12]

Figure 7. (click to enlarge) [12] Comparison of capactiance loss in MLCCs of case size 2220 with standard and polymer

Capacitance-loss failures have been found to occur at lower levels of board flexure with standard terminations than with polymer terminations (see Figure 7). The data presented in Figure 7 come from two production lots of MLCCs with each type of termination; all of these capacitors failed open.

A Weibull analysis of each lot was performed (see Figure 8). The Weibull probability plot clearly shows the improvement in resistance to flexure cracking introduced with use of the polymer termination. The results of this test are reproducible. The strain on the boards for the range of board flexure of interest was calculated using the equation introduced previously (see Table I).



[13]

Figure 8. (click to enlarge) [13] Weibull

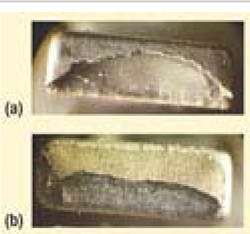
terminations. Bars represent the number of capacitors shorting at each level of board flexure. All capacitors remained open after failure.

probability plot of the resistance of standard-versus polymer-terminated MLCCs, analyzing the data presented in Figure 7.

Board Flexure (mm)	μStrain
1.5	1778
2.0	2370
2.5	2963
3.0	3555
3.5	4147
4.0	4740
8.0 (maximum)	9840

Table I. Board flex converted to μStrain for case size 2220 tests.

The 2.5-mm flexure that marks the onset of standard-termination failures is equivalent to a microstrain of 2963. For the polymer-terminated MLCCs, failures begin to occur above 4 mm, which is equivalent to a microstrain of 4740. However, it should be noted that the lower 95% confidence lines cross 0% failures at around 1.5 mm (microstrain of 1778). Therefore, to ensure a low failure rate for the tested MLCC (2220 case size), a microstrain of below 1700 should be targeted during assembly.

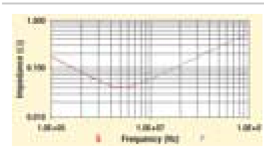


[14]

Figure 9. (click to enlarge) [14] Capactiance-loss failures due to board flexure in an MLCC with a standard termination (a) and in one with a polymer termination (b).

In all the standard terminations, cracking through the ceramic occurred, whereas the polymer-terminated samples exhibited only delamination (see Figure 9). Delamination of the polymer termination will cause a capacitance loss to the part, but these failures typically occur at greater levels of board flexure than is the case with standard-terminated parts. The main advantage of the polymer termination is its ability to sustain greater flexure before capacitance loss occurs.

Polymer terminations overplated with nickel and tin are little different from standard capacitor terminations in terms of thermal shock susceptibility. Standard soldering procedures can be used for both. Also, impedance relative to frequency is no different for polymer-terminated MLCCs (see Figure 10).



[15]

Figure 10. (click to enlarge) [15] Impedance with respect to frequency for standard- and polymer-

Although polymer terminations offer more-reliable performance with respect to board flexure, some concerns remain regarding certain applications. The potential for outgassing, for example, may present a liability for critical military, aerospace, and, of course, medical life-support circuits. More research needs to be done in this area, and more field performance information gathered, before the polymer termination option can be recommended for these applications.

terminated (S and P, respectively) MLCCs.

Conclusion

MLCCs are prone to catastrophic failure because of flexure damage. Other active and passive electronic components used on the PCB are also subject to damage caused by board or processing flexure, but MLCCs are probably the highest-risk component on the board in this regard. Therefore, taking preventive action to eliminate possible board or processing flexure damage to MLCCs should be a circuit board supplier's highest priority.

The circuit often can be further protected from serious shorting of an MLCC damaged by flex cracking by the addition of a diode in parallel with the part. Unfortunately, however, no electrical or visual test regimes are available to screen out possible MLCCs with flexure damage.

The performance of MLCCs with respect to board flexure failures cannot be 100% guaranteed. Still, engineers have developed several MLCC design techniques that represent an advance in the effort to minimize capacitor failures due to board flexure.

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