Flex Capabilities Improved with Modified MLC Chip Capacitors

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Abstract

The primary fault created in surface-mount MLC capacitors is related to flex cracking. This fault is created by a shear force applied to the ceramic element suspended between the terminations faces in contact with the PCB. The fault creation probability is proportional to the size of the ceramic chips in that smaller chips have a greater flex capability than larger chips. Utilizing this ceramic device in more circuitry requires larger chips in order to achieve higher capacitance at higher voltages.

Early attempts of thicker cover plates, extended end margins, and soft terminations to mitigate this problem have not been 100% effective as the crack is still capable of being created. We will present a review of those attempts as well as two new variations in design that can influence the levels at which the crack occurs or eliminates the crack.

The 'Flex Crack'

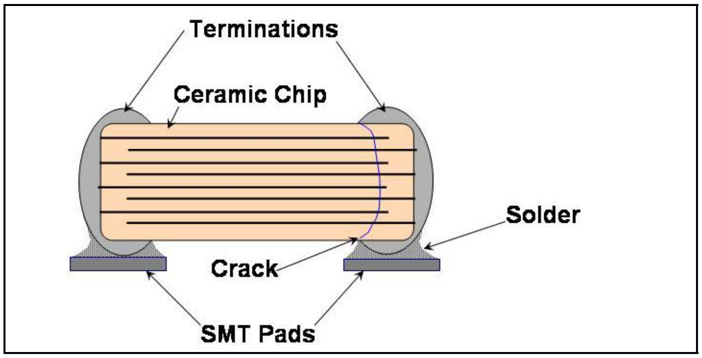


Figure 1. Flex crack signature

The flex crack itself is denoted with a specific signature as the crack starts on the bottom side of the chip, at the end of the termination wrap that extends beneath the chip. It always, Always, ALWAYS, starts at this specific point and then propagates, as a straight line perpendicular or angled to the bottom face, or as a curved arc upward into the capacitor body (Figure 1). The problem is that once the crack is created, it is nearly impossible to detect. All too often, it is a failure found by the end customer. [1]

This fault is created in the capacitor after it is mounted to the PCB. The point of origin for this crack is the delineation within the body where part of the body is under strain and part of the body is held rigid by the termination that wraps under the chip. It is at this point along the bottom face of the MLC capacitor that the crack is initiated (Figure 2).

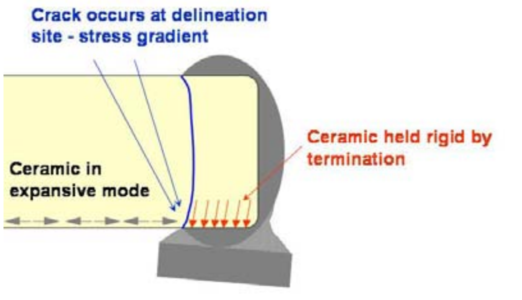


Figure 2. Crack always, Always, ALWAYS starts at the bottom termination edge.

Once the crack is created, there may not be any apparent change in the properties of the capacitor. It may still maintain the same capacitance as previously, the same DF (dissipation factor) or ESR (effective series resistance), the same leakage or IR (insulation resistance). It can continue to appear as a 'good' capacitor for hours, for days, for weeks, even for months after the fault is created; but the creation of the crack establishes a site for future electrical failure.

The crack is created under strain and at the instant the crack is created, there is a likely separation of the body at that crevice and this may momentarily cause a loss of some capacitance. Yet, once the strain is removed, the device is allowed to 'fit' back together and as the electrodes rejoin, the apparent loss of capacitance does not exist. [2, 3]

The term "Flex Crack" defines that this crack is likely the result of bending or flexing the PCB after the capacitor is mounted to it. Unfortunately, this is not the only method of creating this crack. It can also be created because of mismatches between the capacitor's and the board's coefficients of thermal expansion (CTE). If the board undergoes a higher expansion than the capacitor, then there is a strain force generated on the capacitor.

It is our belief that the electrical fault requires some ionic penetration carried in by moisture. The lengths and thicknesses of these cracks vary greatly. A very 'tight' crack will likely require more time for ionic penetration as opposed to a crack, which is wider or more open. [3]

This crack and subsequent failure can create more than a nuisance in the circuit if the fault site is exposed to a high current source. Such exposure can lead to a localized heating within the fault, fracturing, and involving more ceramic in the vicinity, resulting in higher current draw and a glowing, very hot element sitting on the board. Transition from a 'leaky' circuit to a 'dead-short' circuit can take place in a very short time. In Figure 3, the unit on the right is one of several units that were found in the immediate vicinity of the unit on the left (6 in parallel). The top view is of the capacitors removed from the board, and the bottom view is a cross-section into the part (the red line defines approximate depth of cross-section). The flex cracks apparent in all of the near-vicinity capacitors leads us to believe the catastrophic failure on the left was prefaced by a flex crack – the weakest fault channels all the current at failure.

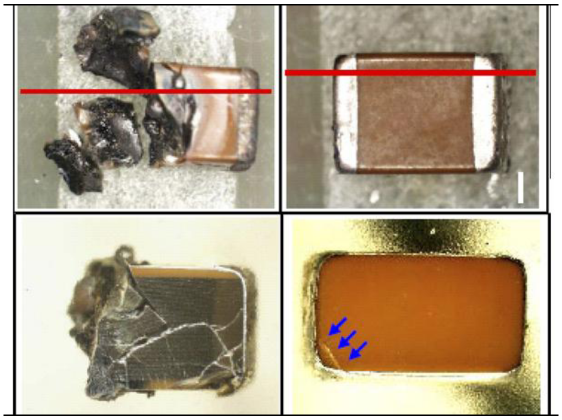


Figure 3. As removed and cross-sectioned capacitors from failed board.

Reducing the Crack

There are ceramic materials used for engine components. Why can't we use some of that technology to create stronger ceramics? The answer lies in the intended use for these ceramics. The electrical property characteristics desired with the class of ceramics in use, prohibit the transition to the mechanically stronger materials because they do not exist.

We have collected extensive data on deflection vs. failure rate for different size chips. Based on this history, the plot of Figure 4 defines the flexure required to achieve a certain failure rate for a given chip size..

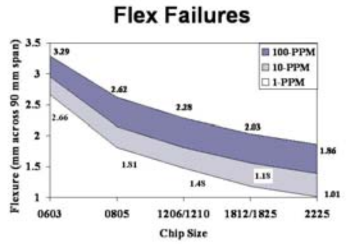


Figure 4. Flexure levels for 1, 10, and 100-PPM failure rates.

There is a great deal of literature available that describes this failure mechanism, and a large number of these materials deal with cautions required in manufacturing when applying these devices to the circuit boards. Mapping out the strains generated by position on a PCB could define some problem areas that demand solutions. The solution could be as simple as rotating the placement of the capacitor by 90°. Once the strains are defined for each location, the plot of Figure 4 would be helpful if the vertical scale were given as strain instead of mm of flexure. The conversion of flexure to strain is given by Equation 1.

$$\sigma = \frac{6T\delta}{L^2}$$ **Equation 1.**

Where

T**,** represents the board thickness (mm),
L**,** represents the span between supports (mm),
δ, represents the flexure (mm), and
σ, represents the calculated Strain.

All of the data that we normally collect as failure rates versus flexure (mm) can easily be converted to strain. Since we standardized the span (90 mm) and the board thickness (1.6 mm) , the equation can be reduced to the following:

$$\mu\sigma = 1185\delta$$ **Equation 2.**

The average flexures (mm) to achieve specified failure rates of 100, 10, and 1-PPM failure rate levels have been converted using Equation 2, and the plots are shown in Figure 5 as Strain x 10^{-6} (µStrain) versus chip size for the specified failure rates.

Looking at the susceptibility of the capacitors by size (Figure 5) shows that the larger the capacitor, the lower the level of strain which is required to create the specified failure rates. Suppose that a circuit is showing a failure rate of 100-PPM (2,200 uStrain) for a specific 2225 chip capacitor. In order to drop the failure rate at that strain level by 90% to near 10-PPM, the 2225 chip would have to be replaced with the 1210 chip capacitor based on the plot of Figure 5.

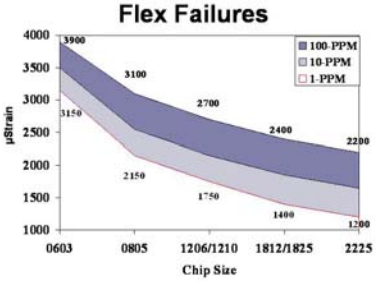


Figure 5. Chip size versus strain required to achieve 100, 10, and 1 PPM Failure rates – typical.

First, the big question is "How many 1210 capacitors must be used to duplicate the capacitance achieved with the 2225 capacitor?" By comparison, the 2225 chip has almost five times the volume of the 1210 chip. If the failure rate per chip is 10 times better, but five chips are needed, then the improvement could be as low as a factor of two instead of ten.

Improving the Existing Structures

The mechanics of the fault creation are well understood and there are some design solutions that have been proposed that will reduce the failure rate or change the failure mode of the circuit. [4] In one solution, the cracks may still be initiated, near the same flexure as the previous devices, but the crack occurs in benign regions of the capacitor and the potential for the high current failures is reduced when the crack begins to conduct. Another solution adds another element to the MLC structure in an attempt to allow the strain to create a breakage outside the ceramic body, and in the termination region.

Improvement A – Additional Cover Layers

In this design modification, additional cover layers are added to the MLC structure to create thicker cover margin areas in the 'top' and 'bottom' regions of the chip capacitor (see Figure 6). Since orientation of 'top" and 'bottom" of the chip capacitor is not maintained, additional thickness must be applied to both in order to ensure that the bottom face has this effect with the random placement of these devices.

Figure 6. Thicker cover margins.

Again, a flex crack created in the capacitor as shown in Figure 6, will always start at the end of the bottom termination edge. It may start upward then turn into the termination end face as shown with the solid line. If the crack does not turn sharply but continues in a more vertical direction, as shown with the dashed line starting at the termination edge, then it will cross into the electrode overlap region, creating a potential for a short-circuit type of failure.

This device may show a higher level of flexure or strain in order to initiate the crack, but any crack localized in the cover margin area will not cut across any portion of the electrode pattern and the result will not be a change in capacitance. However, this crack may be detectable if the dielectric body has piezoelectric properties. In this case, the capacitance would trend downwards as the strain increases on the capacitor. A crack in the margin area, as shown with the solid line, may allow the capacitor to 'slip' slightly, reducing the strain and creating a sudden increase in capacitance.

During our testing, if we see any of these capacitance inflections, we count that flexure as the point of crack inception. There is too much of a random prediction of what direction the crack will take – any crack detected, regardless of penetration into the electrode regions or not, is a crack initiated in the structure of the component and recorded as such. Only if a mechanism were created in the device to restrictively channel the crack in the margin area, would this be an improvement to be depended upon as a safety solution.

This improvement has shown to have a minimal impact on eliminating the final electrical failure potential of a flex-cracked unit. The random nature of the crack propagation is such that it offers no guarantees of elimination of 'short-circuit' failures.

Improvement B – Added End Margins

If the crack penetrates only electrodes terminated on one end of the capacitor, then the 'short-circuit' condition could be eliminated. The crack would still exist and still be detectable (as a sudden change in capacitance during the application of the strain), but if the crack becomes conductive, these electrode plates are already tied together at the termination end – no fault is generated.

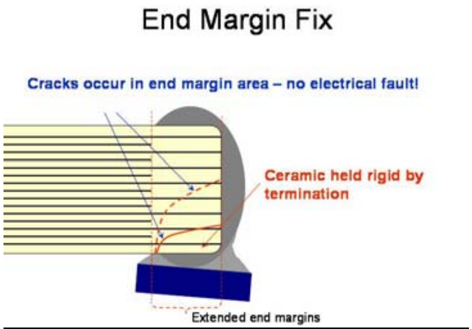


Figure 7. Larger end margins

The drawing in Figure 7 shows the effects of the crack initiated at the end of the bottom termination edge moving in two paths up into the body of the ceramic. The 'end margins' are defined as that area extending from the end termination face, along the electrode paths, until it meets the floating edges of the electrodes terminated from the opposite face. The crack represented by the solid line cuts through two common electrodes then travels into the end termination face of the device. The second path moves more vertical, up through over half of the electrodes in the end margin area, but all of a common termination.

Both of these cracks may lead to a loss of capacitance, intermittent or high DF, but not the dreaded 'short-circuit' failure. Additionally, there is no leakage path created which might lead to increased parallel conduction over time.

Although there is randomness among the flex crack propagating from perpendicular to within an acute angle to a curved path, the flex crack has never appeared to propagate away from the near termination face or deeper into the body of the ceramic. By choosing the end margin to encompass the susceptible area within this structure, this solution is 100% effective in eliminating the ‘dead-short’ scenario in the MLC capacitor.

We tested 500 pieces of five different part numbers and 20 different batches for flex and created cracks in 100% of the pieces tested. The pieces were then put on life test at 125°C, with twice-rated voltage applied for 2,000 hours. Cross-sectional analysis of the flex ‘cracked’ devices reveals typical flex crack signatures, but the cracks are all confined to the end-margin regions. No failures (leakage above initial limits or fuse failures indicative of ‘dead-short’ events) were detected in this sample. Repeated testing of additional groups has confirmed these results – no leakage related failures.

Improvement C – Soft Termination

This modification leaves the margins in the capacitor body as small a possible, allowing higher capacitance than capacitors with the margin modifications. This modification though, does create a new layer in the end termination intended to pull apart under strain. Figure 8, shows the layered structure of this modification. The base metallization is as standard, a fitted metal compound that is fired onto the ceramic body.

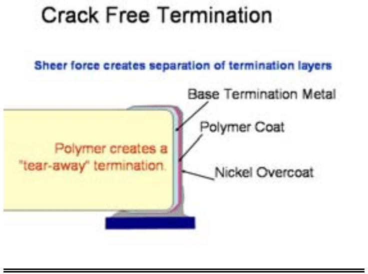
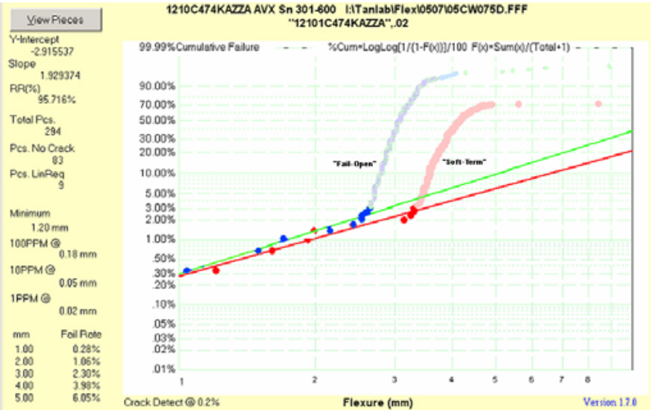


Figure 8. Soft (polymer based) termination layer.

The next layer is the modification over standard terminations. A thin layer of a conductive epoxy is applied over the fired, base termination - the “soft termination.” After this is cured, the surface is nickel-plated and then tin plating is applied over the nickel.

This modification presents the conductive epoxy to the MLC capacitor that was never used before. Under strain, the solder attachment to the nickel cap (the tin plating has been blended into the solder termination during the reflow) transfers the strain to the epoxy, transferring the strain to the base metal and eventually to the ceramic body. The shear strength of the solder, nickel, fritted base metal and ceramic attachments have already been proven as being stronger than that of the ceramic body (flex testing as never revealed a termination pull-off). If the activation of this mechanism is consistent with the polymer having the lowest shear strength, there should never be a crack created within the body of the ceramic.

Yet when we run the flex test, monitoring capacitance as we flex, we see a distribution of ‘failures’ that mirrors the results we see in the fail-open, extended end margins. Figure 9 shows the results of the flex testing of a 1210 capacitor with the polymer layer and of a similar capacitor with the extended end margins and standard terminations.


1210C474KAZZA AVX Sn 301-600 I:\Tanlab\Flex\0507\05CW075D.FFF
"12101C474KAZZA",.02

Y-Intercept -2.915537
Slope 1.929374
RR(%) 95.716%
Total Pcs. 294
Pcs. No Crack 83
Pcs. LinReg 9
Minimum 1.20 mm
100PPM @ 0.18 mm
10PPM @ 0.05 mm
1PPM @ 0.02 mm

mm	Fail Rate
1.00	0.28%
2.00	1.06%
3.00	2.30%
4.00	3.98%
5.00	6.05%

Crack Detect @ 0.2%

Figure 9. Flex failures for polymer layer termination vs. fail-open with standard termination.

Although the polymer-layered terminations appear to have moved up the average distribution point to 4 mm as opposed to the 3 mm value for the extended end margin (hard termination?) parts, the lower flex levels, or problematic grouping, appear to be similar in both. With the standard termination, there are 4 points that appear to leave the distribution with much lower flex failures, and with the polymer termination, there are 4 points that are similar. This highlights how imperative that the sample size be large enough (100 or more pieces) to allow this affected segment of the population to appear. Be wary of analysis devoted to 20 piece samples.

The application of the polymer film in the MLC capacitor is something new. Variations in thickness of coverage may still leave some parts with poorer tear capability than others. This conductive polymer, or a very similar material, has been used in surface mount tantalum capacitors for nearly 20 years. The difference here is that the polymer is blanketed in a plastic case for the tantalum and outside in a metal blanket for the MLC. Solder heats are high enough to begin the decay of some of the polymers in this application, whereas they were blanketed in the surface mount tantalum. If the polymers are overheated, they may loose some of their elastic capability, thereby becoming brittle, hardened barriers.

From the failures with the soft-termination, we wanted to analyze if the drop in capacitance resulted from crack formation. Since the flexure was set to 2% capacitance change during the test, cracks found in these pieces would only verify those failures found at 2% change, but we changed the criteria for the additional test from a detection level of 2% down to 1% for this data analysis. What we had to do was run another group of 20 pieces and set the tester to stop at a lower percentage change. We set the detection level to 0.2% as a criterion for stopping the test, as we claim that this level is susceptible to piezoelectric noise and some of these pieces should show no cracks.

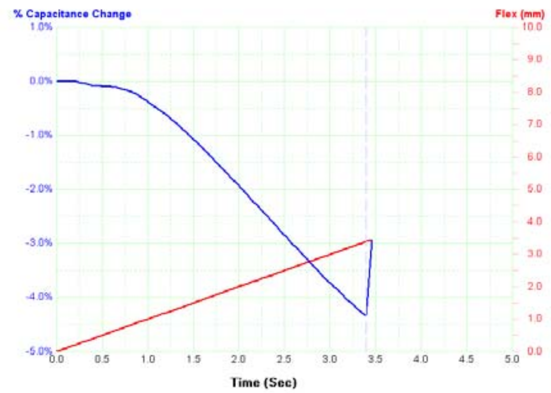
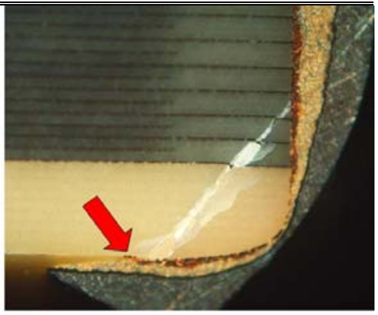


Figure 10. Capacitance & Flex versus Time for Unit #5.

Looking at the capacitance versus time for the lowest five pieces of this group of twenty, we could see that the capacitance indeed jumped up suddenly, for each of the pieces. Figure 10 shows the sudden capacitance jump for unit #5, at 3.4 mm flexure. At first, we thought that a crack might not be evident as the piezoelectric relief could be responsible for that sudden jump. When we cross-sectioned the lowest five detected cracks, we found one device (Unit #5) with the typical flex crack signature (Figure 11).



Arrow indicates end of wrap-under termination with frit bonding to ceramic.

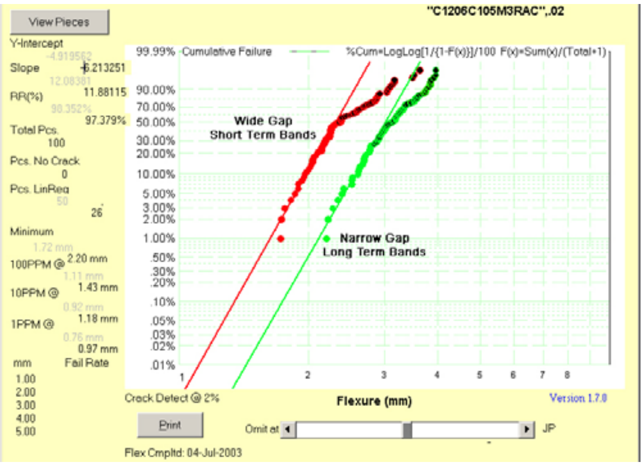
Figure 11. Cross section of soft-term flex failure detected at 0.2% capacitance change (Unit #5 – 3.5 mm).

In theory, the elimination of the crack creation with the soft termination would be desirable; but it is apparent that this technology needs more time to eliminate any inconsistencies in thickness and effects of decomposition during repetitive solder processes.

The soft-termination technique does move the average up, and in our group of twenty tested for 0.2% capacitance change, only one out of five cross-sectioned revealed a crack; but it does not appear to eliminate the lower distribution of faults created at flexures well below that average.

Extended Wrap-Under Terminations [4]

At one time in the earlier testing for flex, we split one batch up into two groups of 200 pieces each. We then terminated one group with a very large termination overlap, and the other with a very small overlap. The pieces originated from the same batch, were tested on the standard solder pads on boards for that specific chip size (1206). We were amazed to see a definite shifting of the flex capability created by the difference in the termination overlap. In the plot of the flexures for these two groups (Figure 12) the difference is highlighted by the number of piece in the group which fails below 2 mm. With the large overlap (narrow gap between opposing terminations), there were no pieces failing below 2 mm. For the small overlap (wider gap between termination edges on bottom face of chip), there were 10 pieces (10%) failing below 2 mm, while the narrow gapped units projected only 0.5% failing at 2 mm.



"C1206C105M3RAC",.02

Y-Intercept -4.919562

Slope 6.213251

12.08381

RR(%) 11.88115

98.352%

97.379%

Total Pcs. 100

Pcs. No Crack 0

Pcs. LinReg 50

26

Minimum 1.72 mm

100PPM @ 2.20 mm

1.11 mm

10PPM @ 1.43 mm

0.92 mm

1PPM @ 1.18 mm

0.76 mm

0.97 mm

mm	Fail Rate
1.00	
2.00	
3.00	
4.00	
5.00	

Crack Detect @ 2%

Flex Cmpltd: 04-Jul-2003

Figure 12. Flex results of Wide vs. Narrow termination gaps.

Based on the effects realized here, we attempted to exaggerate the effects on a 2225 chip. This chip was the focus on many new power supply designs because of its inherently low ESR, high capacitance (>2 uF) at moderate voltages (50 and 10 VDC). The biggest problem in using these capacitors was that, in surface mounting the devices, they were extremely susceptible to flex cracks. An extension of the termination was created on the bottom face of the chip that results in a gap that is narrower than standard. A visual comparison of the terminations is shown in Figure 13.

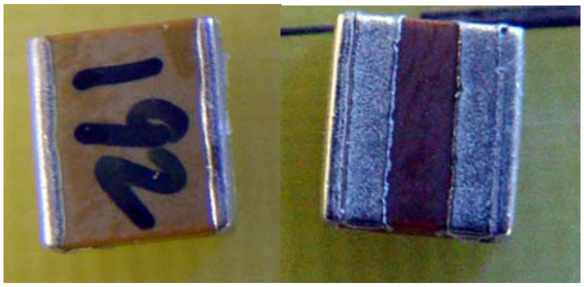
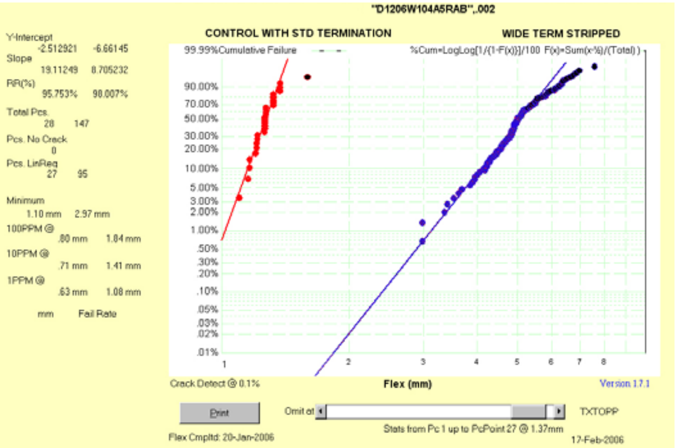


Figure 13. Ceramic 2225 SMD chips with standard termination (left) and extended termination (right).

These pieces were once again out of the same production batch (the color difference is my inexperience with the camera). We separated the one batch into one group to be processed as standard chips and into another group to be processed with the extended terminations along the bottom face of the chip.



"D1206W104A5RAB",.002

	CONTROL WITH STD TERMINATION	WIDE TERM STRIPPED
Y-Intercept	-2.512921	-6.66145
Slope	19.11249	8.705232
RR(%)	95.753%	98.007%
Total Pcs.	28	147
Pcs. No Crack	0	
Pcs. LinReg	27	95
Minimum	1.10 mm	2.97 mm
100PPM @	.80 mm	1.84 mm
10PPM @	.71 mm	1.41 mm
1PPM @	.63 mm	1.08 mm
mm	Fail Rate	

Crack Detect @ 0.1%

Stats from Pc 1 up to PcPoint 27 @ 1.37mm

Flex Cmpltd: 20-Jan-2006

17-Feb-2006

Figure 14. The flexure of '2225' chips with standard terminations on the left vs. extended terminations on the right.

From Figure 14, 90% of the standard termination chips have all failed by 1.3 mm flexure, while the first failure for the extended termination parts does not occur 3 mm. In order to have 90% fail for the extended termination parts, the flexure has to extend through 6 mm. The medium points (50% flexure) moves from 1.2 mm for the standard terminations to 5 mm for the extended terminations.

Clip-on-Leadframe [5]

The leadframe attached to the ceramic is an old and well-trusted method of decoupling any forces between the board and the ceramic by allowing the leadframe to bend to absorb these forces. The problem with the leadframe approach is that it is costly and cumbersome. Special fixturing is required to mount the leadframe to the ceramic. Special packaging is required to protect the leadframe and chip assembly. Special handling is required to mount the chip and leadframe to the board. All of this additional handling equates to higher costs.

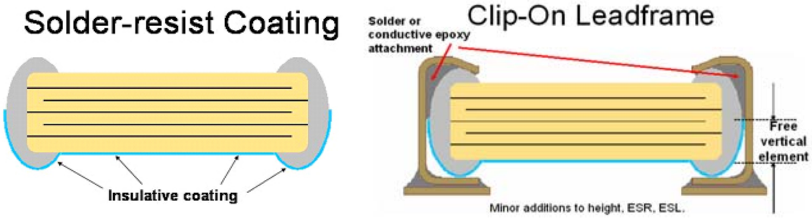


Figure 15. Insulative coating on MLCC and Clip-On-Leadframe attached.

The key to the clip-on-leadframe (COLF) device is the thin insulative coating applied to the bottom surface of the chip, with some extension along the vertical faces. Once dried, the leadframe is clipped onto the termination with metal-to-metal contact along the vertical edge (termination face) and metal-to-coating along the bottom face. Attachment (metal-to-metal) is accomplished with high temperature solders, or conductive epoxies. The solder attachment is by normal soldering processes with the bottom of the leadframe in contact with the solder pads on the board.

The flex capability of this device will match the old leadframe designs, but with a reduced impact on cost. The pieces will be packed in standard tape-and-reel packaging, and be placed using standard pick-and-place technologies. The primary focus of this device is the elimination of flex cracking.

Conclusion

There are a couple of improvements not presented here, as these are not proven as feasible for production at this time. There is an old modification that entirely eliminates flex cracking – using leadframes to create a mechanical isolation between the chip and the PCB. This modification is extremely effective but expensive.

Of the first three improvements discussed, the cover margin solution is most unreliable. The end margin solution is 100% effective in eliminating the dead-short results of the flex crack, but does not eliminate the flex crack. The theory behind the soft termination is that it eliminates the flex crack from appearing but testing has shown this is not the case.

As the move to lead-free processes continues, the projections are that this will increase the susceptibility to flex crack failures. [6] In light of this, any optimizations of the device to withstand these failures or allowances for the failure to present itself in a benign manner must be pursued. In addition, a full understanding of the process and handling variations for reducing the occurrence of these faults must also be fully developed. [7]

The last two offerings are intended to improve flex capability (extended terminations) and to eliminate the flex cracking (clip-on-leadframe). [8]

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