Flexible Termination – Reliability in Stringent Environments

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Abstract

Failure due to board flex cracks persists as the dominant failure mode in multi-layer ceramic capacitors (MLCC). Board flex-crack failures are sometimes detected at in-circuit test or at functional test; but in a more critical point, they may be found in the field by the end customer. For high capacitance (HiCV) MLCC, the introduction of the flexible termination option (also referred to as soft termination or polymer termination) gives board designers an option to reduce the risk of board flex failure when board flex stress cannot be systematically removed from the board assembly process. In automotive and other market segments, board flex failures cannot be tolerated and long-term reliability is paramount. Some under-the-hood (UTH) environments now have ambient temperatures up to 175°C. Other applications exhibit long-term, low-frequency vibration, and other applications may allow multiple bend events to occur. All of these specialized application environments lead to questions about the fatigue capabilities of the flexible termination solution when exposed to high stress environmental conditions. This paper is intended to show the impact of temperature cycling, high-temperature life tests, and multiple bend exposures to the MLCC with this flexible termination.

Purpose

The additional layer of conductive-epoxy in the termination is to allow a break to occur in the termination and not in the ceramic. Conductive-epoxy is a conductive flake laden epoxy, which does not have as much mechanical strength as the metals in the termination. In KEMET's device in Figure 1, this epoxy is applied after the fritted metal termination (copper) is fired on, but before the nickel and tin platings occur.[1]

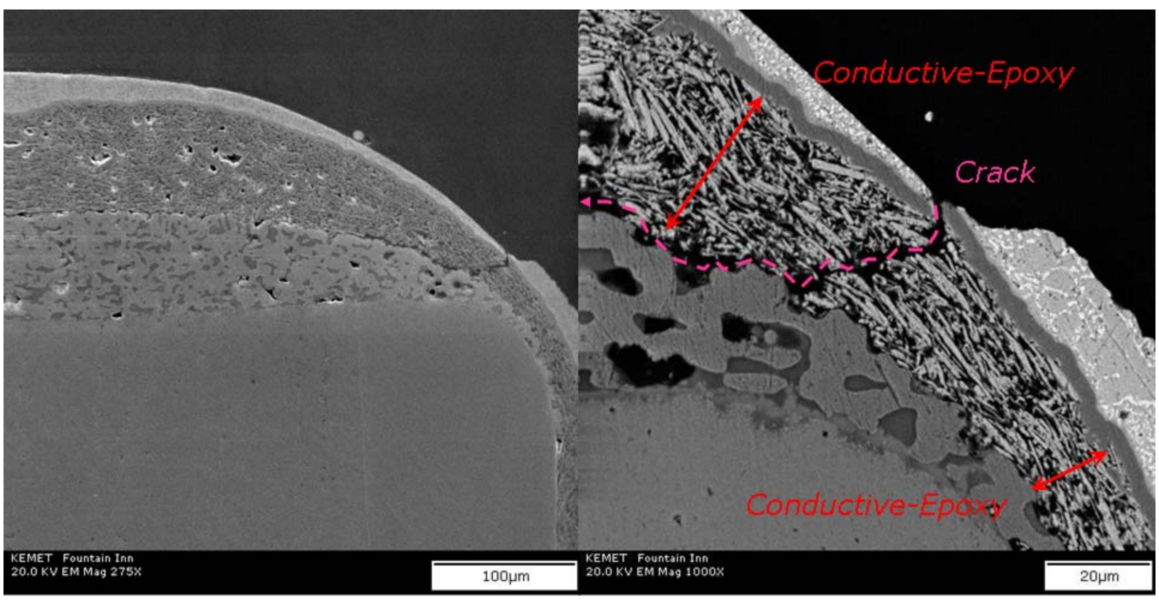

Figure 1. Conductive-epoxy layer within termination layers allows termination to tear apart before ceramic cracks.[2]

The benefits of this termination have been previously presented and are shown in Figure 2. This represents one batch of 2225 chip capacitors of 2.2 uF with 78 pieces terminated with standard termination and another 78 pieces terminated with the flexible termination. The crack initiations were detected by a sudden change in capacitance and each was verified with DPA for the presence of the flex crack. The minimum crack detection for the standard was at 2.25 mm while it was 8.20 mm for the flexible termination.

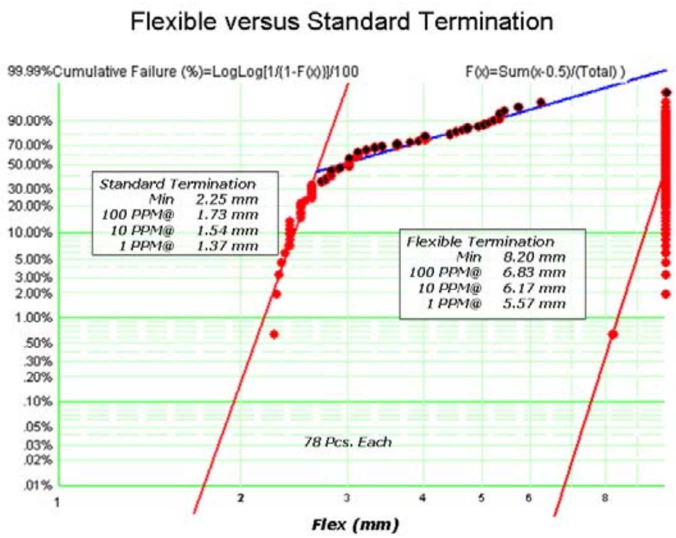

Figure 2. Flex crack detection of standard versus flexible.

The addition of the conductive polymer layer in the termination of the MLCC introduces questions as to long-term reliability of this new system in environmental extremes. The situation of the conductive-polymer in the termination layers presents a series connection of this element within the electrical connection. As such, if this system were to degrade the most evident change would probably be in the ESR or DF reading of the capacitor. In Figure 3, the plots shows the average ESR for 1 uF capacitors with flexible terminations before and after 1,000 hours of life testing at 125°. There is no increase in ESR attributable to the insertion of the conductive epoxy in the termination layers.

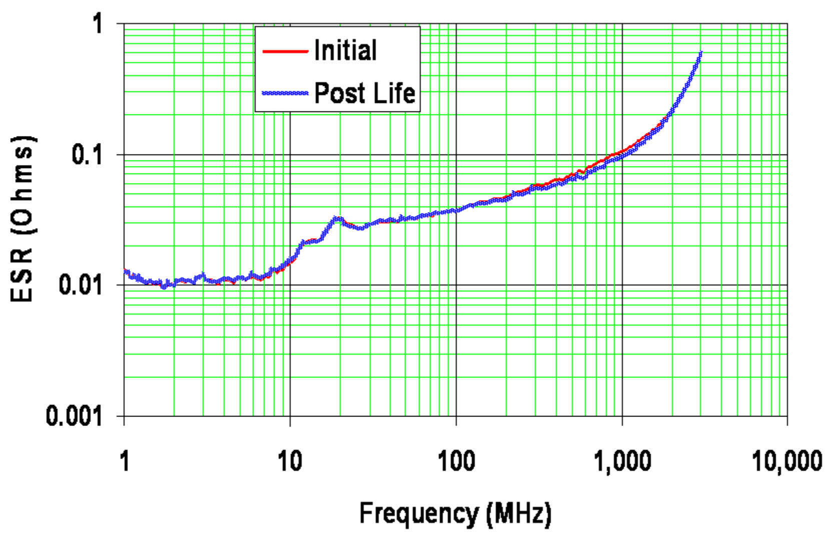

Figure 3. ESR versus Frequency for 1206, X7R, 1 uF capacitor before and after 1000 hours life.

Looking at the following chart in Figure 4, of the thremogravimetric analysis of the conductive-epoxy material, one thing that is evident is that exposure of the conductive-epoxy to temperatures in excess of 250°C, for timeframes > 20 minutes, can lead to a degradation of the microstructure. It can also be deduced that exposure of conductive-epoxy to temperatures below or equal to 150°C will not lead to a degradation of the microstructure.

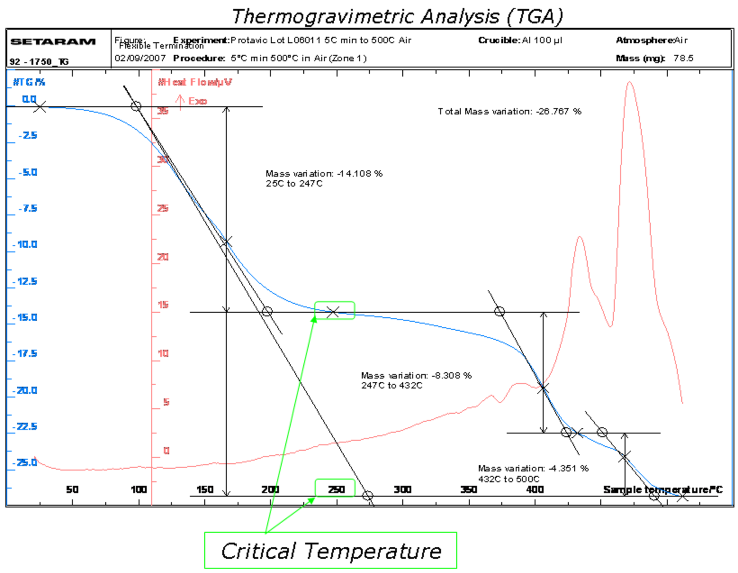

Figure 4. Thermogravimetric (TGA) of conductive-epoxy material.

Experimental Plan

Many of these concerns were pointed out by a single customer and we laid out a plan of experiments to evaluate these concerns. Because of the critical temperature pointed out in Figure 4, we agreed to run the life test at 165°C. We planned to run the temperature cycling between -55°C and 165°C. We wanted to do multiple flex exposures and see if the failure rate changes with repetition. All of this testing will look at "standard" terminations versus the "flexible" terminations or terminations with the conductive-epoxy layer, as shown in Figure 5.

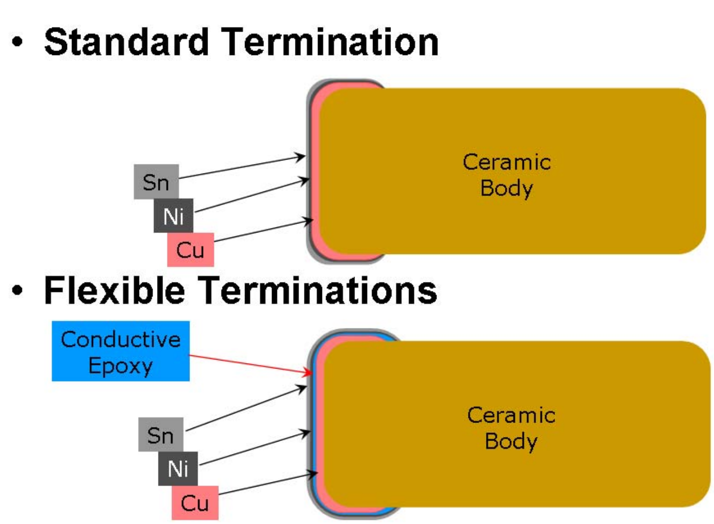

Figure 5. "Standard" versus "Flexible" terminations.[3,4]

We built several lots of 0805 and 1206 capacitors. We also created “shorted” capacitors (Figure 6) with electrode layers running from one termination to the other for the 0805 and 1206 chip sizes, allowing us to measure DC resistance with better resolution than ESR.

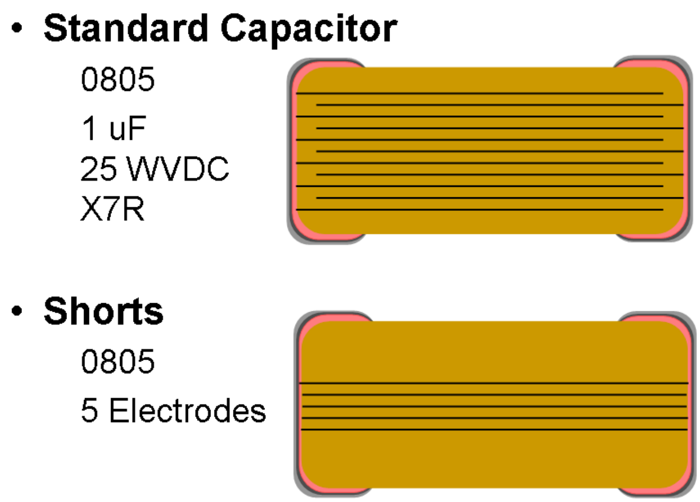

Figure 6. “Capacitor” electrode pattern versus “short” electrode pattern.

Life Test Results

We did all the initial measurements on the capacitors and shorts mounted on the FR-4 boards, and put these devices in the oven with bias applied to the capacitors at 160°C. When we removed the boards at 1000 hours, we were dismayed when we found that the FR4 boards did not hold up under this temperature exposure. The epoxy became brittle, the boards did swell slightly, and the trace elements were easily displaced off the board. Although the FR4 boards would not hold up under these conditions, this is the board requested by our customer, representative of what they use in their applications.

Repetitive Flex Exposures

We pulled unique 10-piece samples for each of these test cells. We flex tested one group to 3 mm with one flex cycle. Meanwhile, another 10-piece group was flexed to 3 mm with 5 cycles, another group with 10 cycles, and another group with 20 cycles. In Figure 7, the flexure starts at 0 mm flexure, goes to 3 mm flexure, returns to 0 mm, and repeats this application four more times.

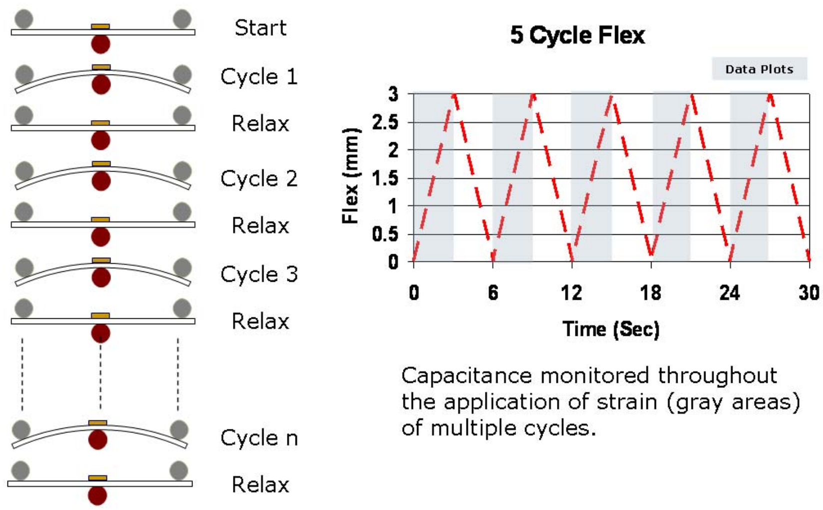

Figure 7. Five repetitive flex exposures to 3 mm.

The capacitance is monitored during the application of the flexure (in going from 0 mm to 3 mm at 1 mm per second). Once the device reaches 3 mm flexure, it returns to 0 mm at a speed of 10 mm per second. The subsequent applications are manually activated.

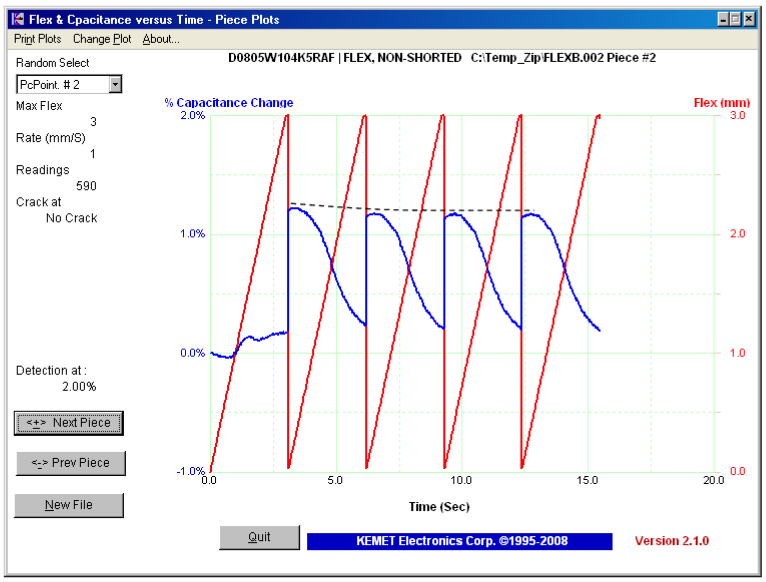

Figure 8. Capacitance monitored during 5 cycles of flex application.

In Figure 8, although the cycles appear to take place repetitively and instantaneously, the time between the peak flexure at 3 mm and 0 mm is uncertain. The data is collected only during the ascension to 3 mm, and appended to the same data collected during the previous application of flexure to 3 mm.

It is relevant that the capacitance after the first application appears much higher than the initial capacitance, and decays as the ascension increases to 3 mm. It is also noted that this peak capacitance decays as the number of cycles increase – possibly denoting a less rigid or more plastic state of the solder. It could also denote that the repetitive cycling of the solder joint could be causing the solder to break some structures, elongate and cause the chip to rise higher off the board. More investigation needs to verify these or other explanations of this phenomenon. Figure 9 shows this same effect for the 20 cycle test.

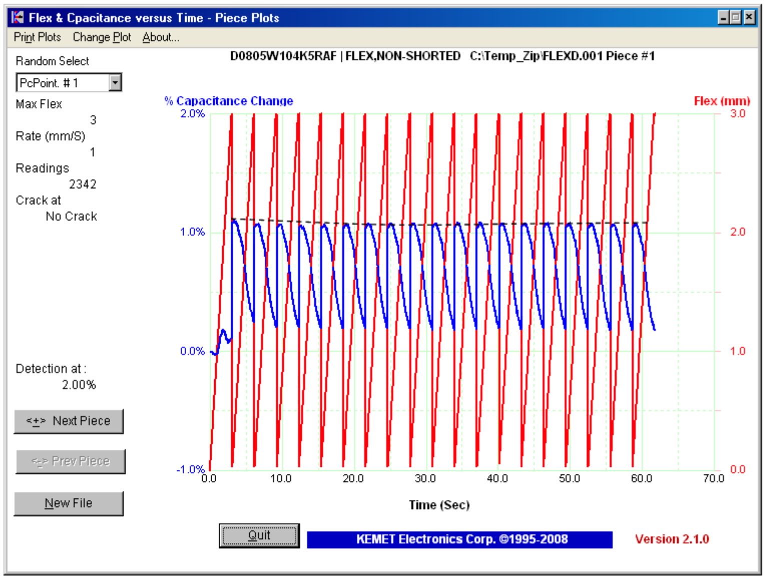

Figure 9. Capacitance monitored during 20 cycles of flex application.

A compilation of these results is given in Table 1. For the standard designs, the failure rate of 80 to 90% appears to be consistent regardless of the number of flex cycles. For the flexible design, the group tested at 10 mm showed a failure, while all other cycle counts showed no failures.

Table 1. Multiple flex cycles results.

	D0805W104K5RAB	D0805W104K5RAF
Number of Bends to 3mm	Standard	Flex
1	8	0
5	9	0
10	8	1
20	9	0

10 Pieces each sample group
No pieces used in multiple groups
8 groups required test of 80 pieces

FR Constant

Temperature Cycling

Unlike the life test boards, which were effectively destroyed in that test, the boards held up in these periodic exposures of 165°C. The transition times were limited to 15 minutes, while the dwell times at each temperature extreme were also held at 15 minutes.

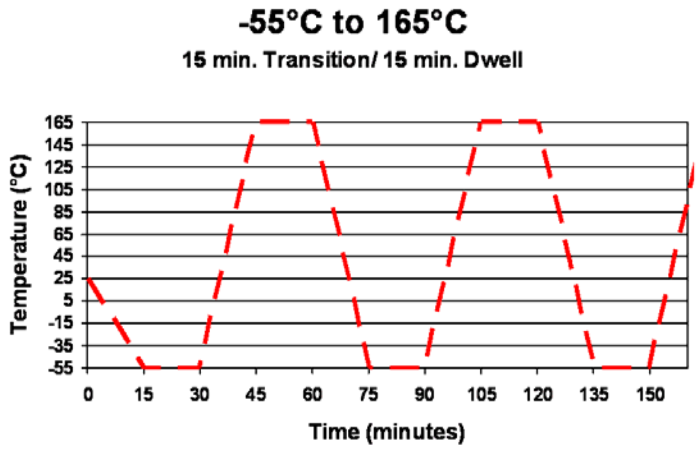

Figure 10. Cycle temperature-time profile.

After 1000 and 2000 cycles, the pieces were then subjected to a shear force until the piece was displaced from the board. In the following figure (Figure 11), the distributions of shear force in pounds are shown for the flexible termination on the left and the standard termination on the right. The pre-test results are shown as black circles, the 1000 cycles shown as red squares, and the 2000 cycle data shown as green diamonds. There is an apparent decay in shear strength with increasing temperature cycles, but the decay is faster with the standard terminations. We have no theories to explain this difference at this time.

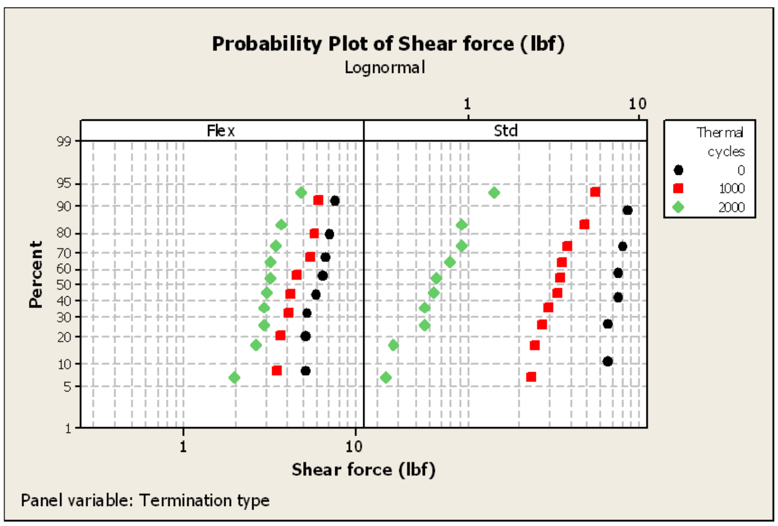

Figure 11. Plot of shear force for standard versus flexible.

We also looked at the DC resistance of the shorts when exposed to this cycling. In the standard termination group at 1000 hours, there is one piece with a DC resistance that is 10 times the normal. In the flexible termination groups, there is one piece at 2000 hours that also shows a DC resistance that is 10 times the normal distribution. The three groups of 0, 1000, and 2000 cycles data appears to be consistent through these three groups for the flexible terminations. The initial (0 cycles) distribution of DC resistance for the standard termination does appear unusual. Again, we have no theory to explain this deviation.

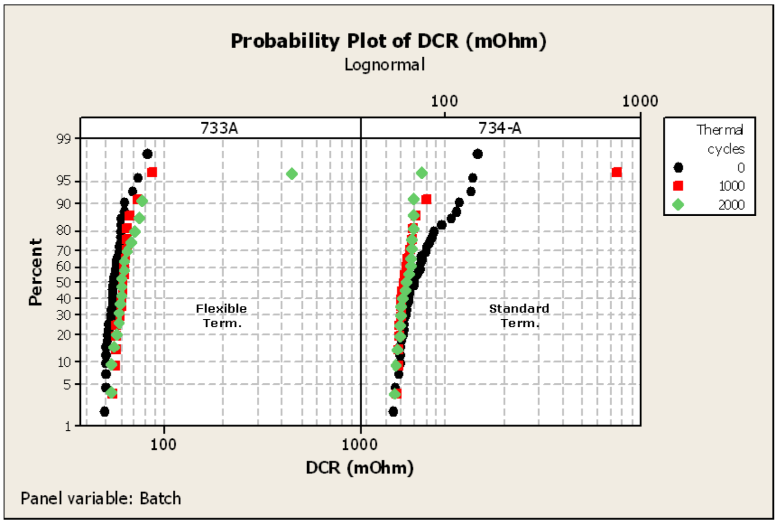

Figure 12. Effects of temperature cycles on DC resistance of shorts.

Conclusion

Based on these tests, we see no evidence of any degradation of the capacitor utilizing a flexible termination. The life test needs to be repeated at temperatures above 125°C using polyimide boards or alumina substrates to see if there is any decay in the conductive epoxy structure at temperatures between 125°C and 175°C. This testing, although the temperature cycling was run up at 165°C, does not verify continuous applications above 125°C.

References

[1] "Introducing Flex 'Fail-Open' Capabilities for MLC Chip Capacitors", E. Chen, K. Lai , T. Ashburn , J. Prymak , M. Prevallet , KEMET Electronics Corp., Proceedings CARTS Asia 2005, Taipei, Taiwan, Components Technology Institute, Inc., Huntsville, AL

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[3] "Flexible Termination – Reliability in Stringent Environments", Prymak, Antoniades, Blais, Hill, Lai, Riedl, Schmidt, Sloka, Staubli, Kemet Electronics Corp., Slide Presentation - Proceedings from Components for Military and Space Electronics 2009, Feb 2009, San Diego, CA

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