

NASA Electronic Parts and Packaging (NEPP) Program

Cracking Failures in Ceramic Capacitors and the Existing Screening and Qualification Procedures

Alexander Teverovsky

Jacobs Technology Inc.

Work performed for Parts, Packaging, and Assembly
Technologies Office, NASA GSFC, Code 562

Alexander.A.Teverovsky@nasa.gov

List of Acronyms

BI	burning-in	PME	precious metal electrode
BME	base metal electrode	PWB	printed wiring board
COTS	commercial off-the-shelf	QCI	quality conformance inspection
C-SAM	C-mode scanning acoustic microscopy	RH	relative humidity
ECM	electrochemical migration	RSH	resistance to soldering heat
ESA	European space agency	S&Q	screening and qualification
FA	failure analysis	SCD	source control drawing
HSSLV	humidity steady state low voltage	THB	temperature humidity bias
IM	infant mortality	TSD	terminal solder dip
JAXA	Japan Aerospace Exploration Agency	TTF	time to failure
MLCC	multilayer ceramic capacitor	VBR	breakdown voltage

Abstract

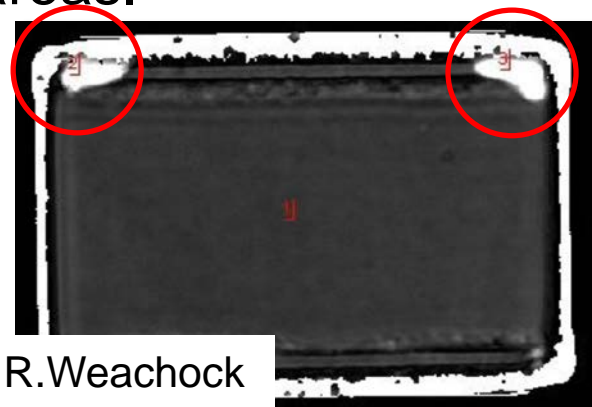
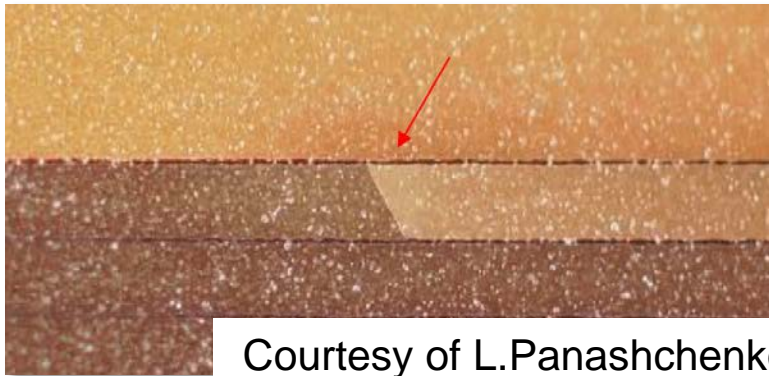
This presentation gives a review of recent project failures caused by cracks in ceramic capacitors and discusses deficiencies of the existing screening and qualification procedures that can reveal the propensity to cracking and effects of soldering stresses.

Outline

- ❑ Recent history cases.
 - Effect of hydrogen.
 - A case when derating does not work.
 - Defect-related infant mortality.
- ❑ How different S&Q procedures assess the presence of cracks and address the effect of soldering?
 - Military, space, and automotive industry requirements.
 - Common mistakes.
 - Manual soldering.
- ❑ Conclusion

History Case 1

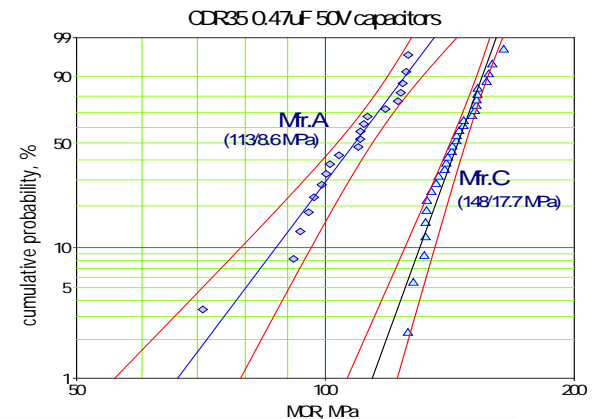
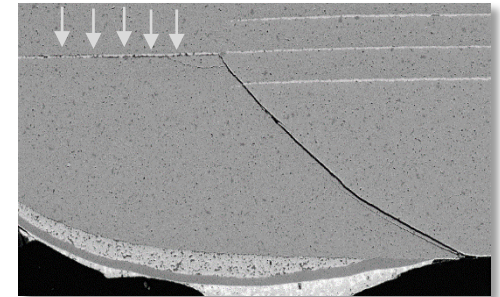
- ❑ On-orbit anomalies after months of operation were attributed to excessive leakage currents in CDR35 capacitors.
- ❑ The parts were soldered manually and suspected of having cracks.
- ❑ Testing of a spare unit on the ground also showed increasing leakage currents after several weeks of operation.
- ❑ FA: the failure was due to delaminations and cracking in the part.
- ❑ No external cracks on the failed lot were observed.
- ❑ Acoustic microscopy showed that a substantial proportion of parts had delaminations at the termination areas.



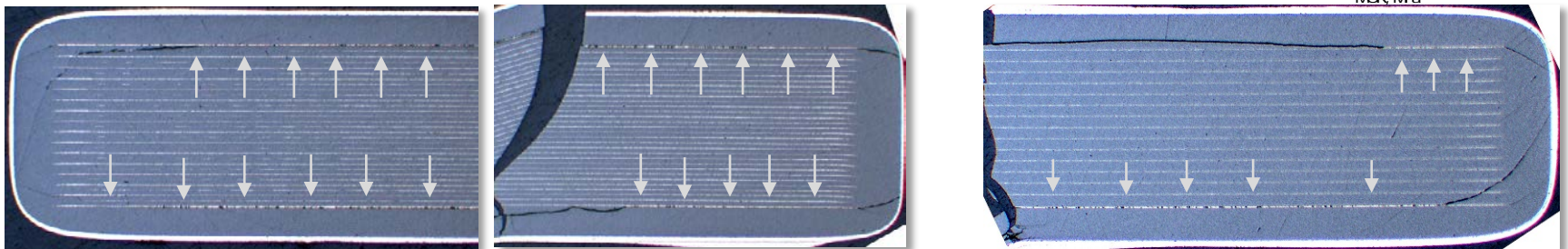
Courtesy of L.Panashchenko and R.Weachock

History Case 1, Delaminations

- ❑ Cracks in lot A started from the surface and continued as metal/ceramic delamination.
- ❑ To evaluate interaction of cracks with delaminations, virgin and post-TSD samples were fractured in the middle.
- ❑ No delaminations on virgin samples from lot A and on both virgin and post-TSD samples from lot C.



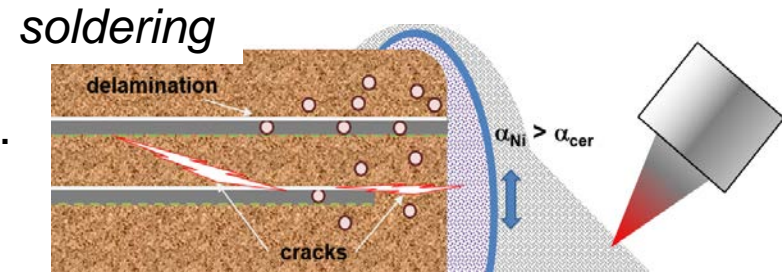
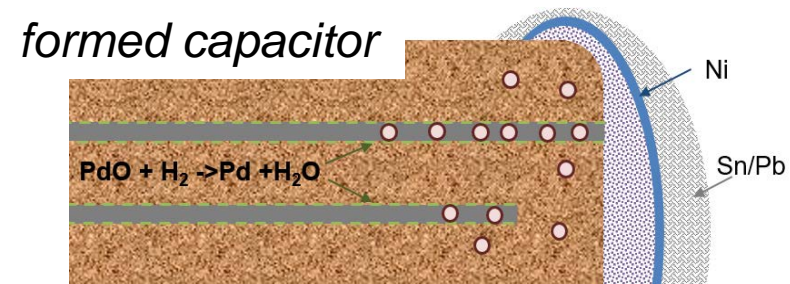
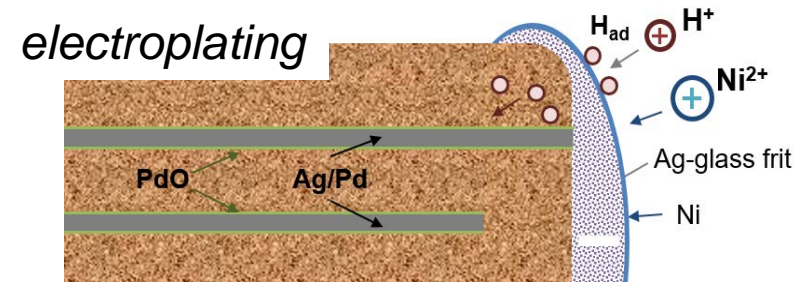
Fractured post-TSD samples



- ✓ TSD testing and fracturing revealed delaminations located mostly at electrodes close to the surface of capacitors.

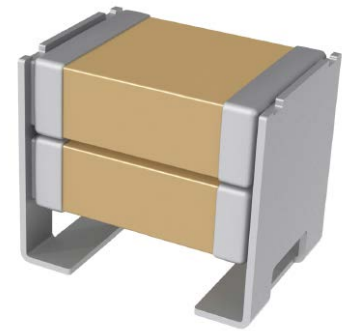
History Case 1, Failure Mechanism

- ❑ The probability of failures after manual soldering was increased due to the presence of delaminations.
- ❑ Corner location indicates that delaminations might be due to formation of terminals.
- ❑ Reasons for corner delaminations:
 - Generation of H_2 during electroplating:
 - Decreases fracture toughness of ceramics;
 - Removes PdO barrier on Ag/Pd electrodes, weakens the interface and facilitates ECM of Ag.
 - Fast evolution of H_2 might cause pop-corning during soldering.

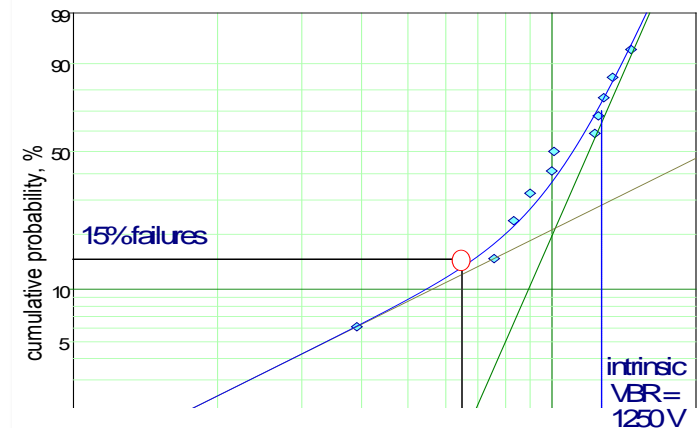
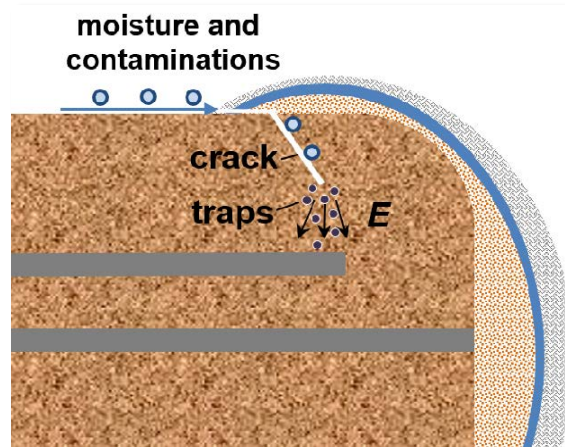
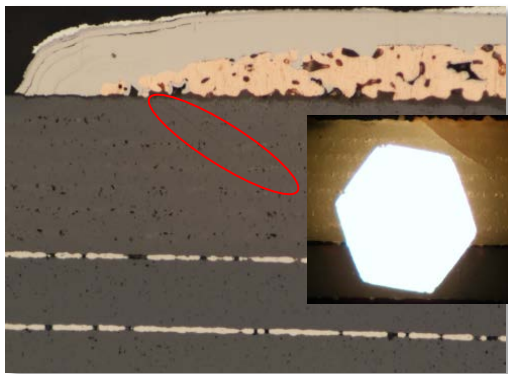


- ✓ Failures were likely due to anomalies in electroplating processes that resulted in excessive H_2 generation
- ✓ Cracking and delaminations caused by electroplating occur more often with PME than with BME capacitors.

History Case 2

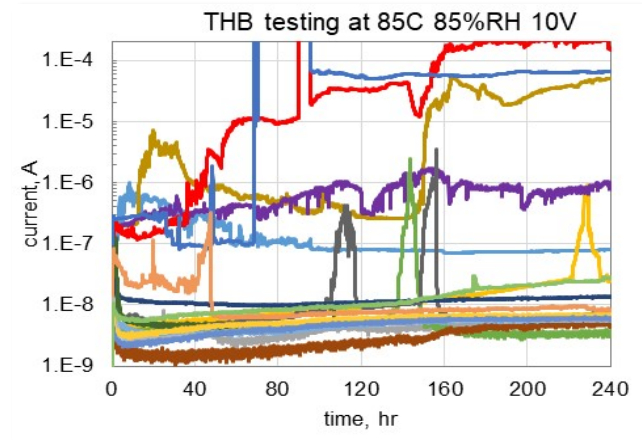


- ❑ A lot of commercial BME capacitors rated to 250V that had reduced microphonic noise was intended to use at low voltage (~ 5 V) applications.
- ❑ The lot had multiple failures during qualification life testing.
- ❑ Analysis of distributions of VBR revealed a substantial proportion ($\sim 15\%$) of defects.
- ❑ Failures at voltages close to the rated can be explained by the presence of shallow cracks near terminals.



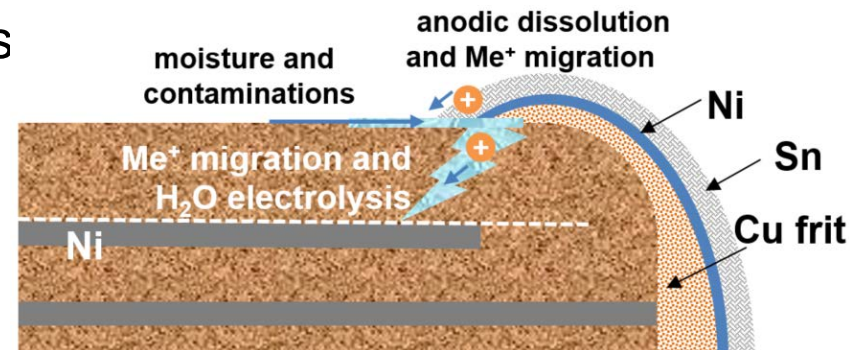
History Case 2, Cont'd

- ❑ The parts passed HSSLV testing at 85C/85% RH, 1.3V for 240 hr increasing the hope that they can operate reliably at low voltages.
- ❑ Contrary to PME, HSSLV testing is not effective for BME capacitors.
- ❑ THB testing at 85C/85% RH and 10V for 240 hrs resulted in 3/18 failures.
- ❑ Post-THB examinations revealed delaminations that might be due to hydrogen generated by electrolysis of water penetrated through cracks.
- ❑ Anodic dissolution of Sn or Cu from terminations provide materials for conductive deposits or dendrites in cracks.



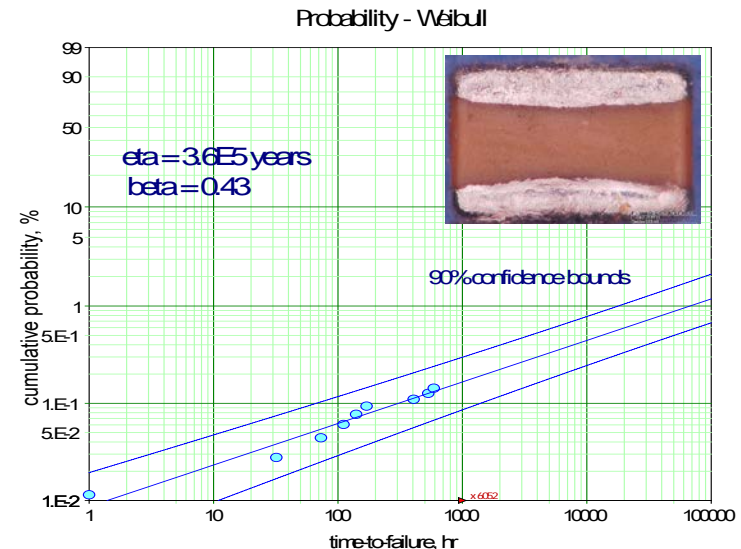
Post-THB delamination

✓ Derating might not help in cases of failures related to cracking.



History Case 3

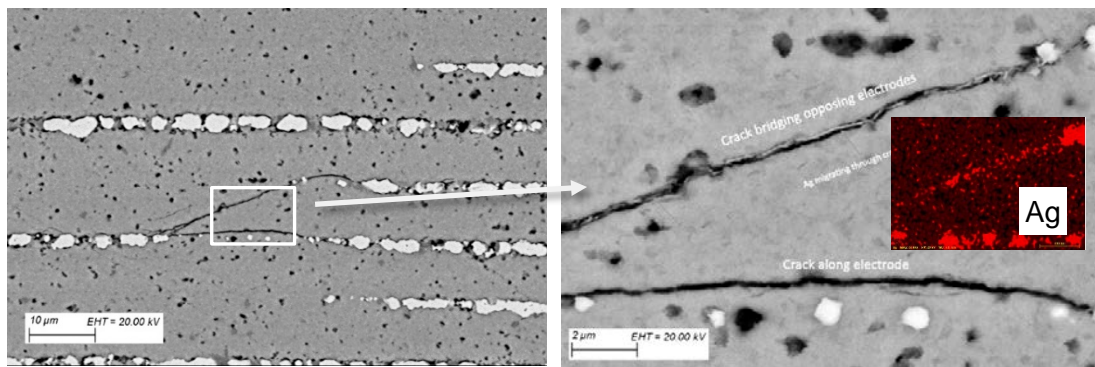
- ❑ Several failures were observed during system-level testing in a project that employed ~5700 commercial PME MLCCs upscreened to an SCD.
 - ❑ Extensive evaluations and testing of parts from the failed lot revealed three more failures in the suspected lot and no failures in a reference lot.
 - ❑ FA revealed delamination in one case and a delamination with a connected tiny crack between electrodes that allowed for silver electromigration in another.
 - ❑ In the third case, a part had a delamination and anomalies during testing at room conditions, the recovered after soldering and failed eventually during THB testing.
 - ❑ Distribution of TTFs corresponds to IM failures and indicate the presence of preexisting defects that likely further developed after soldering.
- ✓ No failures during life testing and 1/24 failure during THB testing.
✓ All failures occurred after soldering, at derated voltages and low temp.



History Case 3, Cont'd

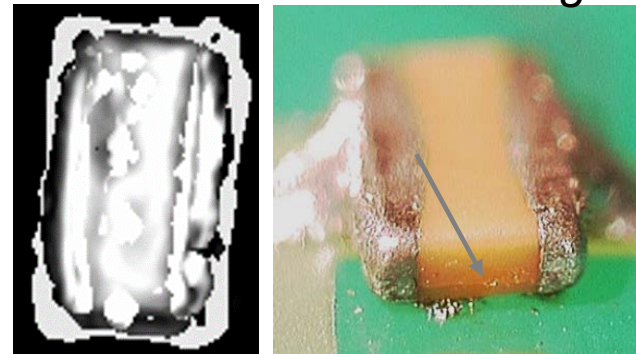
Examples of failed capacitors

A sample failed after 55 hr at 6V and 60C

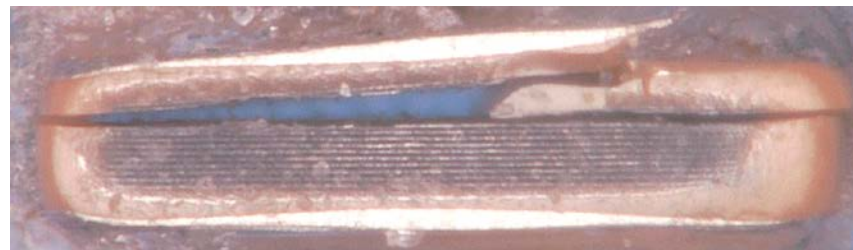


Pictures courtesy of Ron Weachok

CSAM before THB and a crack after THB testing



Failed capacitor cleaved along the crack

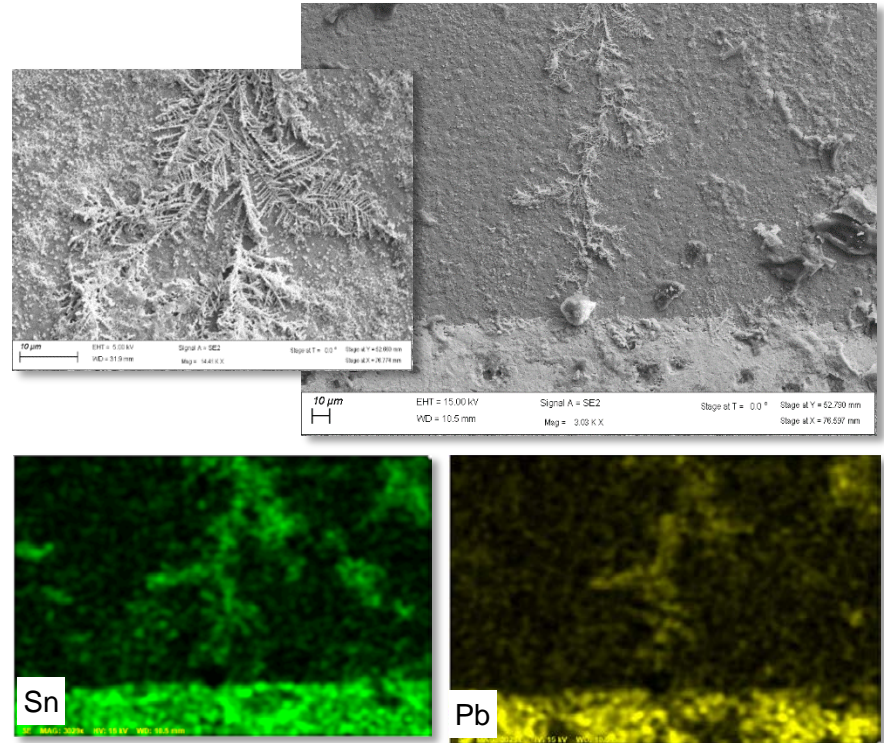
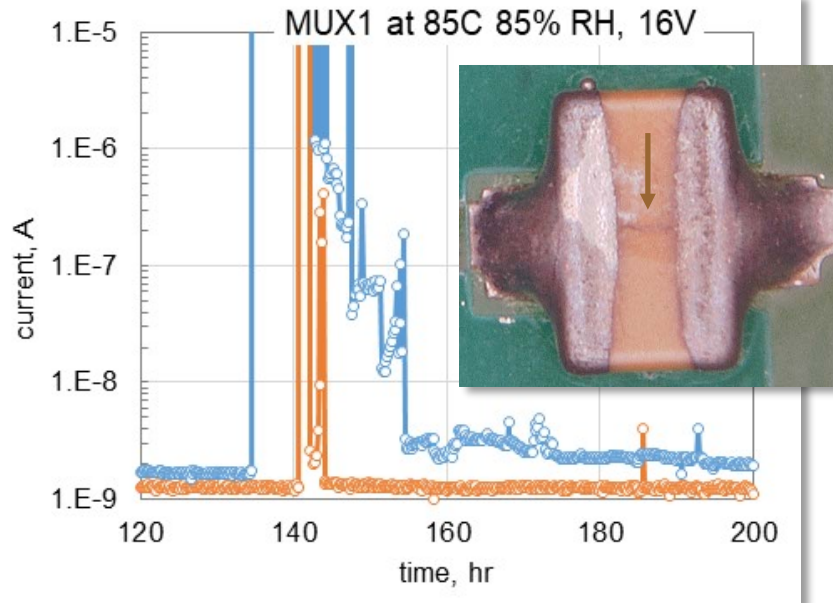


- ✓ Comparative testing of the failed and a reference lot with another LDC showed that this is a lot-related problem.
- ✓ Why S&Q testing per SCD that followed military specifications did not reveal defective parts?

Risks of Humidity Testing

- ❑ Two out of 164 tested samples had anomalies during THB testing at 85 °C 85% RH, 16V.
- ❑ FA revealed Sn/Pb dendrites on the surface of the parts.

Leakage currents in 2 failed MLCCs



- ✓ THB is effective for revealing cracks in the parts, but has a risk of resulting in shorts on PWB or the surface of MLCCs.

How Specifications Address Cracking and the Effect of Soldering?

1.	→ INTRODUCTION → → → → → → → → →	5¶
2.	→ MANUFACTURING PROCESSES AND TYPES OF MLCCS → →	8¶
	2.1. → DIELECTRIC MATERIALS¶	
	2.2. → ELECTRODE MATERIALS¶	
	2.3. → TERMINATION MATERIALS¶	
	2.4. → DESIGN¶	
3.	→ TESTING AND QUALITY ASSURANCE → → → → →	19¶
	3.1. → COMPARATIVE ANALYSIS OF SPECIFICATIONS¶	
	3.2. → QUALIFICATION PROCEDURES AND CRACKING PROBLEMS¶	
4.	→ CHARACTERISTICS OF MLCCS → → → → → → →	32¶
	4.1. → CAPACITANCE AND DISSIPATION FACTOR¶	
	4.2. → INSULATION RESISTANCE AND LEAKAGE CURRENTS¶	
	4.3. → BREAKDOWN VOLTAGE¶	
	4.4. → MECHANICAL CHARACTERISTICS¶	
5.	→ FAILURE MECHANISMS IN MLCCS WITH CRACKS → → →	44¶
	5.1. → DEGRADATION OF PME AND BME CAPACITORS IN MOISTURE¶	
	5.2. → DEGRADATION IN DRY ENVIRONMENTS¶	
6.	→ SPECIAL CASES OF MLCC CRACKING → → → → →	52¶
	6.1. → HYDROGEN RELATED CRACKING¶	
	6.2. → EFFECT OF PICK AND PLACE MACHINE¶	
	6.3. → ELECTRO-MECHANICAL RESONANCE¶	
7.	→ REVEALING CRACKS → → → → → → → → →	57¶
	7.1. → OPTICAL EXAMINATIONS¶	
	7.2. → ELECTRICAL MEASUREMENTS¶	
	7.3. → ELECTRO-MECHANICAL EFFECTS¶	
8.	→ CRACKING CAUSED BY MANUAL SOLDERING → → →	62¶
	8.1. → WORKMANSHIP RECOMMENDATIONS¶	
	8.2. → SELECTING CAPACITORS¶	
9.	→ CONCLUSION → → → → → → → → →	67¶
10.	→ REFERENCES → → → → → → → → →	68¶



NASA Electronic Parts and Packaging (NEPP)
Program

NEPP Task: Guidelines for Selection of Ceramic Capacitors for Space
Applications

Cracking Problems in Low-Voltage Chip Ceramic Capacitors

Alexander Teverovsky

ASRC Federal Space and Defense
Alexander.A.Teverovsky@nasa.gov

Worked performed at NASA Goddard Space Flight Center

2018

NEPP report available at

<https://ntrs.nasa.gov/search.jsp?R=20190001592>

Comparison of Specifications

❑ Specifications.

- Military: MIL-PRF-123, MIL-PRF-55681 (CDR-style), MIL-PRF-32535.
- Space: S-311-P829, S-311-P838, ESCC #3009, JAXA QTS-2040.
- Automotive: AEC-Q200.

❑ Screening procedures.

- Difference in BI (MIL up to 264hr@2VR, ESA 96hr@2VR, JAXA: 21hr@ 3VR)
- CSAM during screening: not used in M55681 and ESCC#3009.
- Gr. B: TS/life and THB not used in M55681 and ESCC#3009;
RSH: only in S-311-P838 and JAXA;
HSSLV: only in M123, S-311-P-829, ESCC and JAXA.

❑ Qualification procedures.

- TS cycles and SS from 100c/186pcs in M123 to 5c/18pcs in M55681. (Auto-1kc).
- No RSH requirements for ESCC#3009.
- Flex testing is not required for M123 and ESCC#3009.
- Requirements for life and humidity testing are relaxed for some data sheet numbers in M32535.

❑ JAXA approach: automotive grade BME MLCCs are solder dipped, screened by CSAM, BI and derated. Periodical QCI (relaxed voltage stress for thin dielectric capacitors) and extensive additional testing.

Soldering Stresses during Qualification

❑ Mounting before testing.

- M123 does not specify mounting before qualification testing.
- M55681 does not have mounting requirements for life or HSSLV testing.
- M32535: mounting for humidity testing is optional.
- S-311-P-829 does not have mounting requirements at all and P-838 does not require soldering before life testing.

Warning: “the substrate and mounting process shall be such that it will not be the cause of, nor contribute to, failure of any test for which it may be used”.

❑ Resistance to soldering heat.

- The test should verify the robustness of MLCCs against soldering stresses and simulate the worst case soldering conditions.
- MIL-STD-202 TM210 specifies 8 versions of the test. Only two and at relaxed requirements are used (solder dip for M123 and IR reflow for M55681). Commercial parts are tested at much higher temperatures.
- Soldering iron test that can simulate manual soldering is not used.

Sample Size and Typical Misconceptions

- ❑ Qualification tests in MIL specifications that are copied by SCDs are typically using a relatively small sample size, from 6 to 22 pcs.
- ❑ To assure that the proportion of defective samples in a lot is below P_f the number of samples with zero failures:
$$N(P_f) = \frac{\ln(1-c.l.)}{\ln(1-P_f)} \approx -\frac{\ln(1-c.l.)}{P_f}, \text{ where } c.l. \text{ is the confidence level.}$$

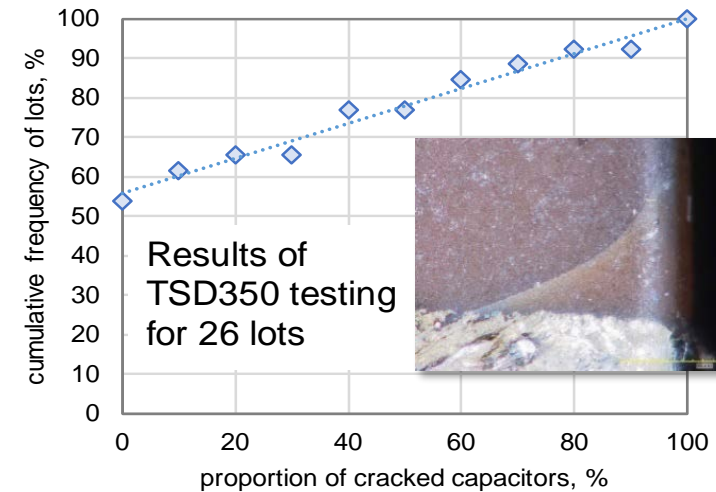
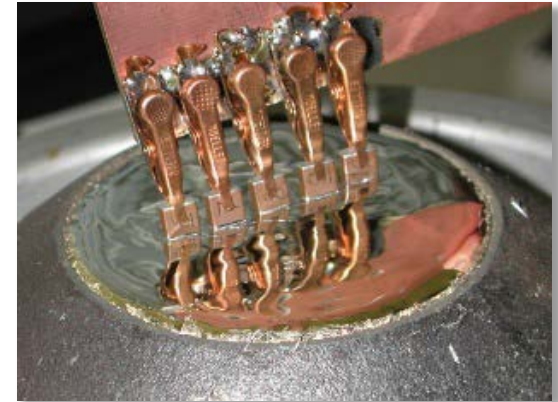
At $P_f = 0.1\%$ and $c.l. = 60\%$ $N \approx 1000$.
- ❑ Using a relatively small sample size might be sufficient for mature technologies with known consistent and successful results of testing.

✓ Successful testing of a lot of COTS components to MIL requirements does not guarantee the same quality of the product.

Susceptibility to Cracking during Manual Soldering

- ❑ Tests and inspections that can be used:
 - (i) TC after soldering onto test boards followed by monitored humidity testing, (ii) TSD350, and (iii) ultrasonic inspections (C-SAM).
- ❑ Depending on the project level or criticality of application, different combinations of tests are suggested.
- ❑ Visual examinations and electrical measurements after TSD350 to mitigate risks for L3 projects:
 1. Initial C, DF, and IR measurements (20 pcs.)
 2. TSD350, 2 sides 3 cycles
 - Visual examination. Reject if >10% of parts have cracks.
 - EM (C, DF, IR) – no failures allowed.

Terminal Solder Dip testing



Conclusion

- ❑ Cracking remains the major cause of MLCCs' failures in space instruments.
- ❑ Cracking is due to a combination of built-in internal stresses, manufacturing defects and external, soldering-related stresses.
- ❑ The most popular, CDR-style MLCCs are not screened by C-SAM and do not have requirements for mounting during qualification.
- ❑ Existing specifications are focused mostly on quality of as build capacitors and do not address properly effects of soldering.
- ❑ S&Q of commercial MLCCs to MIL-like SCDs does not assure the same quality of the parts.
- ❑ Procedures to mitigate risks of manual soldering and select the most robust parts are suggested.