Cracking Failures in MLCCs and Military Specifications

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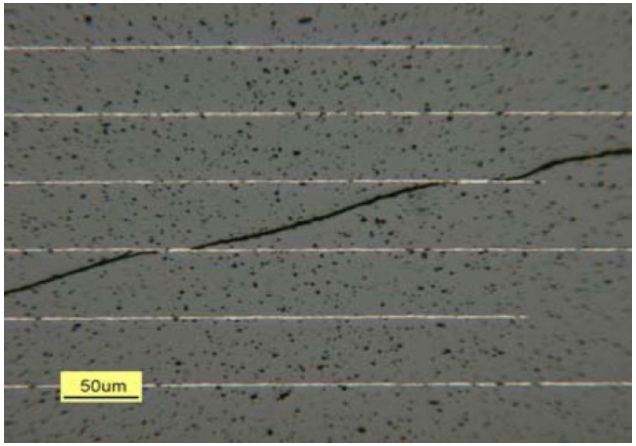
Abstract

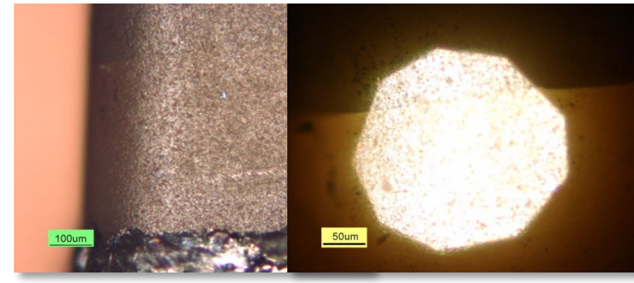
Failures of MLCCs during applications might indicate problems with the screening and qualification system used. Several cracking related failures of military-grade MLCCs that have been observed over the last few years require analysis of the efficiency and completeness of the procedures used in military specifications. This presentation discusses deficiencies of the currently used procedures to reveal and prevent cracking failures in space projects and possible ways of their improvements.

Outline

- Introduction.
- Is cracking due to manufacturing defects or users' abuse?
- Efficiency of S&Q procedures to prevent cracking failures.
  - DPA
  - Screening procedures.
    - Electrical tests (C, DF, IR, DWV)
    - Ultrasonic examinations
    - Burn-in
  - Qualification procedures.
    - Humidity tests
    - TC and Life
    - RSH
- Are changes in MIL specs viable?

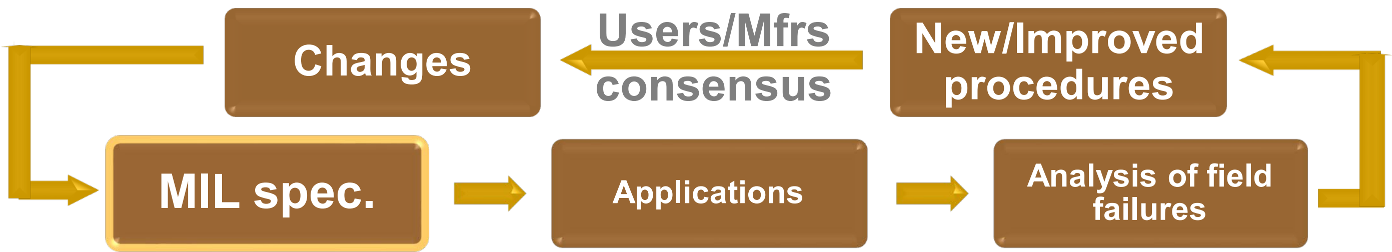


Introduction



- Most failures of MLCC are due to cracking and have a long history.
- Initially, most failures were due to manufacturing defects, but now majority of problems occur after soldering.
- Respectively, MIL specs were focused on reducing production defects, whereas soldering issues were not addressed properly.

Improvements in MIL-specs in an ideal world



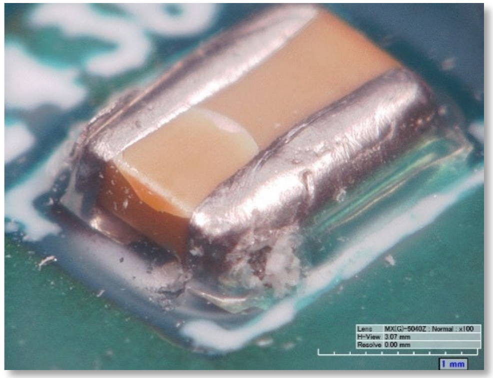
- A feedback is essential for the efficiency of MIL specifications, but
  - failures are rare and not all always reported;
  - cracks are difficult to reveal and root causes not always found;
  - efficiency of procedures are difficult to evaluate, hence problems with improvement or development of new tests.

✓ This presentation suggests areas for improvement for future discussions.

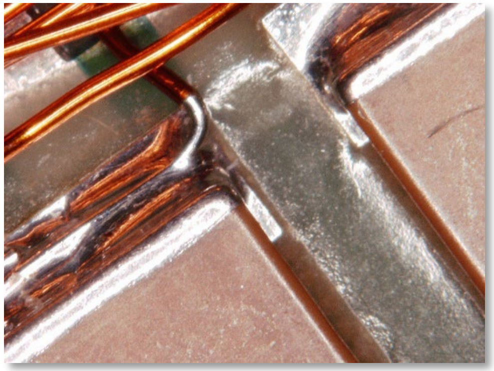
Is Soldering-Induced Cracking Parts or Workmanship Issue?

- ❑ Parts activities should assure that capacitors are robust enough to withstand stresses associated with soldering and handling of MLCCs. This should be achieved by using adequate screening and qualification procedures.
- ❑ Workmanship control should assure that there are adequate soldering and handling requirements and they are followed in practice.

- ✓ Cracking is often due to a combination of flaws introduced during manufacturing and assembly-related stresses.
- ✓ Except for obvious cases of workmanship violation, most failures are due to insufficient or non-adequate screening and qualification process.



Reflow soldered 0.1uF 16V MLCC. Courtesy of L. Panashchenko



Cracked MLCCs after hand soldering of magnet wires. Courtesy of J. Brusse.

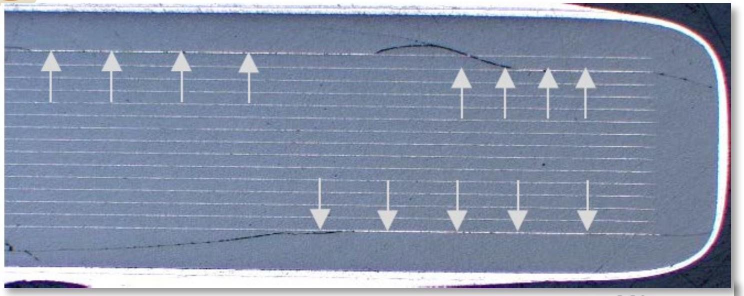
Manual Soldering Issue?

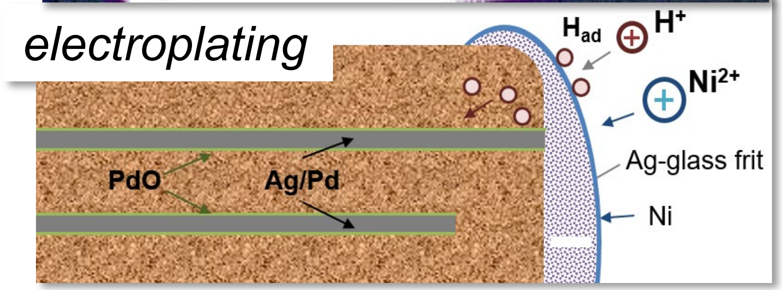
- ❑ On-orbit anomalies were observed with CDR35 caps after several months of operation.
- ❑ Delamination was likely due to generation of H_2 during electroplating that:
  - decreases the fracture toughness;
  - removes PdO barrier on Ag/Pd electrodes;
  - reduces the volume of electrodes;
  - weakens Me/ceramic interface;
  - facilitates electromigration of Ag.
- ❑ Higher CTE of termination materials compared to ceramic creates tension stresses facilitating delamination.

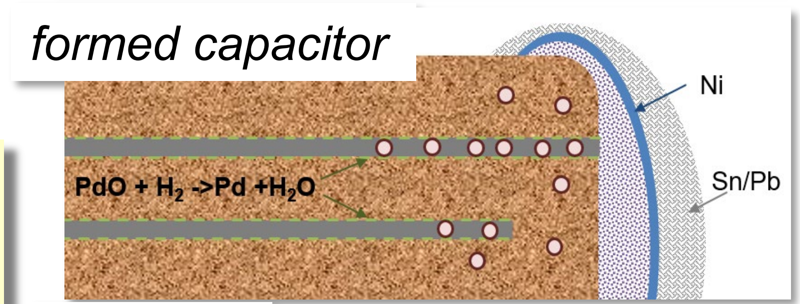
✓ Manual soldering accelerated cracking in a lot with preexisting defects.

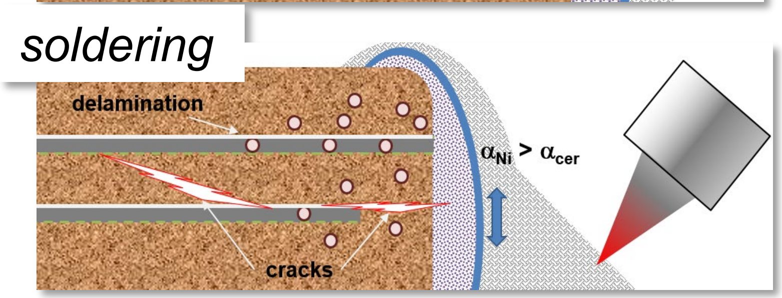
✓ Failures caused by cracking might happen in vacuum.

✓ Terminal solder dip test have been demonstrated effective in revealing lots susceptible to cracking.



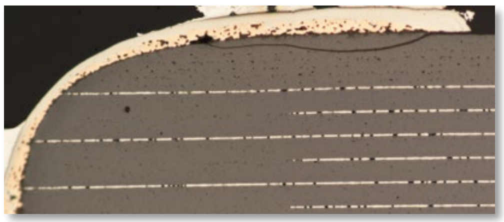


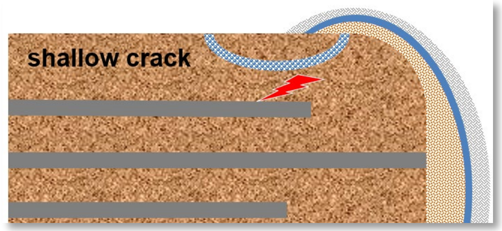


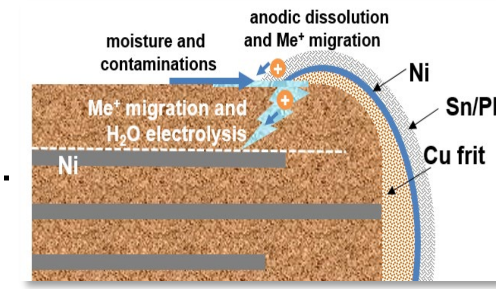


DPA: Corner Cracks and Margins

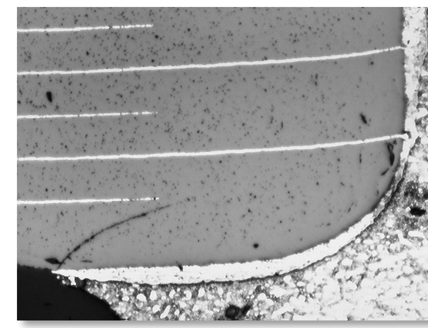
- ❑ Cracks at terminations are common defects in MLCCs.
- ❑ They can form a path for moisture and contaminations.
- ❑ Shallow cracks (<50% margin size) might be acceptable.







- ❑ The larger the cover plates and end margins, the lesser is the probability of failure.
- ❑ All MIL specs, except for M55681 (does not require DPA) refer to EIA-469 that allows margins as small as 25 um and delamination up to 20% of the interface area.
- ❑ Some manufacturers have stricter requirements for margins for automotive than for MIL capacitors.

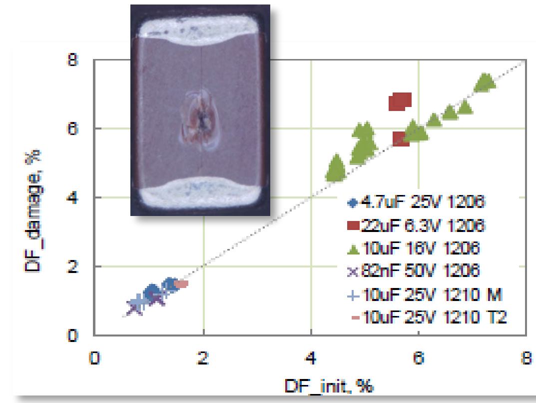


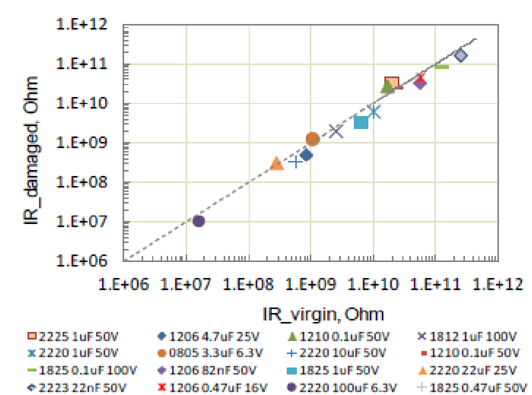
✓ Increasing the size of margins might reduce risks of cracking failures.

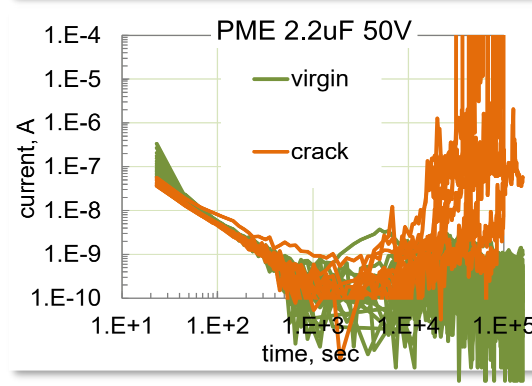
Screening: Electrical Measurements

- IR measurements require 2 min electrification but occur much faster in practice.
- Capacitance is the least sensitive characteristic to cracking.
- Cracking in MLCCs results in a relatively minor, ~15%, increase in DF.
- Efficiency of IR measurements to reveal cracks is low and increasing temperature or voltage during testing does not help.
- Increasing the time of electrification can rise the value of IR tests.

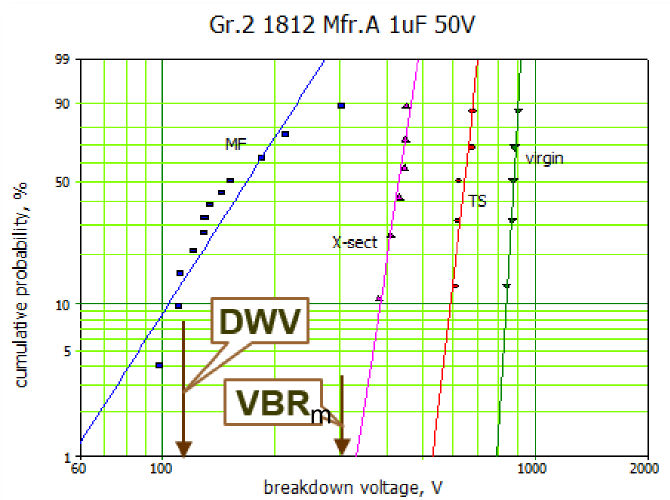
> ✓ Measurements of application leakage currents (currents at ≥ 1000 sec) instead of IR are much more effective in revealing cracks.

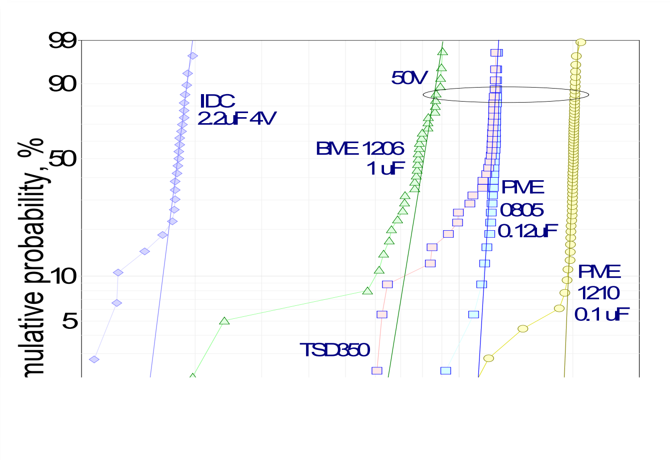






Screening: DWV and VBR



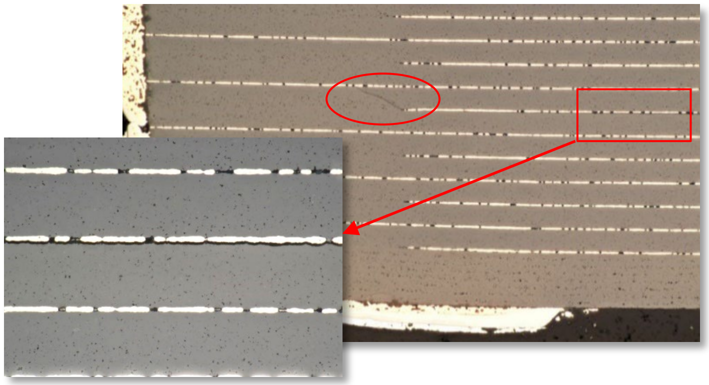


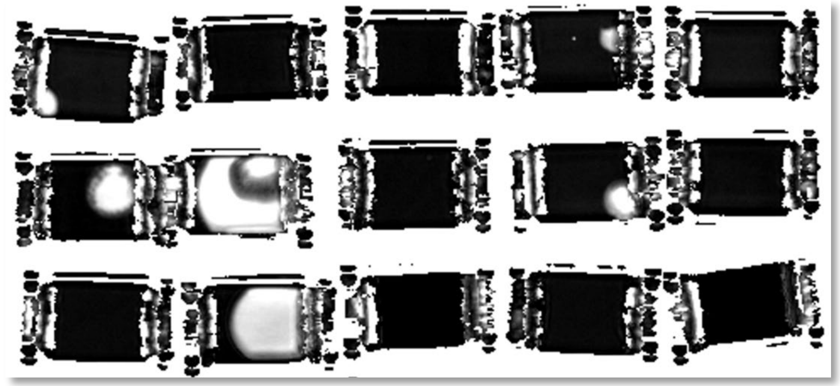
- DWV test requires 2.5VR.
- Only ~20% of parts with gross defects failed DWV test.
- 19 out of 30 (63%) lots of MLCCs damaged by X-sect and TS had the probability of DWV test failure of less than 1%.
- VBR is 10X to 100X times greater than VR.
- Distributions of VBR are typically bimodal with low-voltage tails indicating defects.
- Only M32535 requires VBR_m testing at 6VR.

✓ The effectiveness of the existing DWV testing is low.
✓ Distributions of VBR reflect quality of the lot.
✓ Critical values DWV for screening should be determined based on VBR distributions

$$VBR_{cr} = 0.5 \times \left(VBR_{avr} - 2 \times \sigma \right)$$

Ultrasonic Inspection





- ❑ Cracks are often associated with delamination that in many cases can be effectively screened out by ultrasonic examinations.
- ❑ Ultrasonic technique is not used for CDR capacitors.

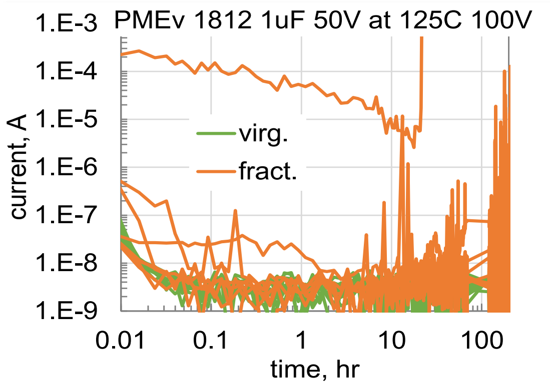
Test	M123	M55681	M49470	M32535
Ultrasonic	Pre termin. 100%; In-process 100%;	-	Chips (T only)	Scrn. (T, ≥ 0805); In-process, pre-term.; Qual (T, ≥ 0805, 254 pcs)

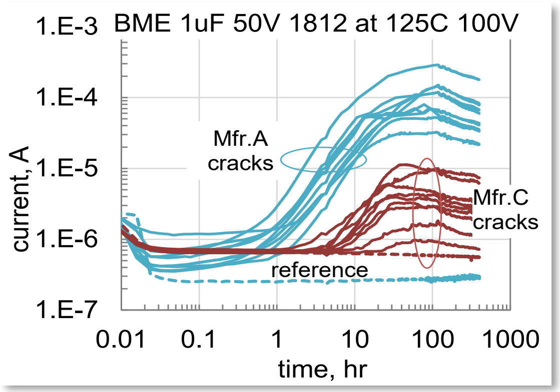
- ✓ Several cases of system-level failures were caused by cracks/delamination in PME MLCCs manufactured per M55681 or similar SCD specifications.
- ✓ Failures of CDR capacitors might have been prevented by a better S&Q tests (combination of ultrasonic inspection and soldering stresses).

Monitoring Currents During BI

- Failures during BI are determined by post test EM (assuming V applied).
- Capacitors with cracks might not fail short circuit during BI.
- Degradation of PME and BME capacitors with cracks is different but can be revealed by monitoring currents.
- All BI conditions are similar but CDR MLCCs have relaxed requirements.

Test	M123	M55681	M49470	M32535
Burn-In (voltage conditioning?)	20c TS, 2VR 168 - 264hr 125C	2VR T_{max} 100hr	20c TS, 2VR 125C 168 -264hr (T) 96hr (B)	20c TS, 2VR 168 - 264hr 125C





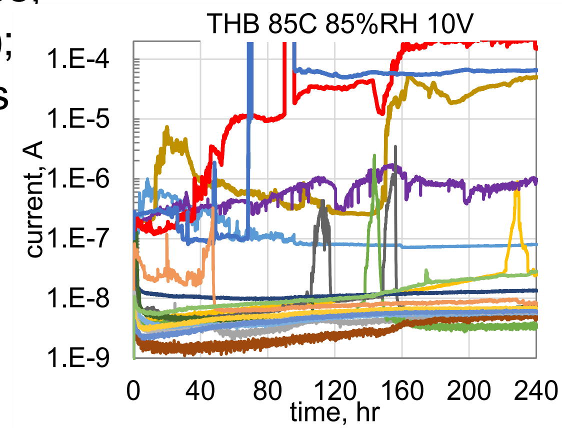
✓ Monitoring leakage currents during BI is useful to reveal capacitors with defects.

Three types of Humidity Testing

I. HSSLV test was developed to detect cracks in MLCCs
- was a key element of LVF risk reduction strategy since 1980s;
- is not required for MIL-grade parts since 2010 (NESC 2009);
- not used in M32535 because BME capacitors are much less susceptible to LVF compared to PME.

II. Moisture resistance test per MIL-STD-202 TM106 evaluates resistance to wetting, allows up to 10% failures, and is not suitable for space components.

III. THB at 85C, 85% RH, and VR can be more effective for BME capacitors.

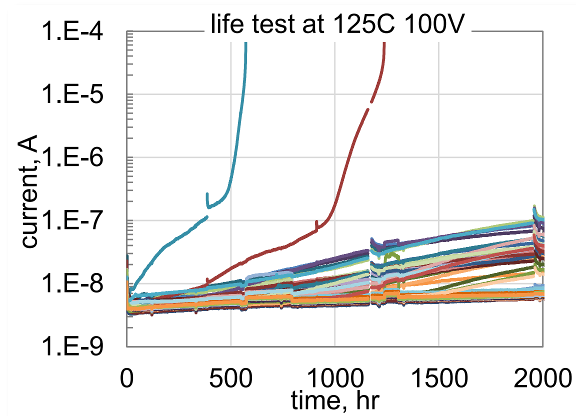


Test	M123 (HR)	M55681	M49470	M32535
HSSLV per M123	Qual 12(0) Gr.B 12(0)	Qual 12(0) Gr.C 12(0)	Qual (T) 6(0) Gr.B 6(0)	-
MR per M202, TM106	Qual 12(1) Gr.B 12(1)	Qual 9(1) Gr.C 12(0)	Qual 12(1) Gr.B 12(1)	-
THB (85/85/VR) per M32535	-	-	-	Gr.B 12(0) 96hr Qual 22(0) 1000hr

- ✓ Monitoring leakage currents during THB increases the efficiency of tests.
- ✓ Monitoring at RC after 160hr/85C/85% RH might be a viable option.

TC and Life Test

- Mounting before qualification testing:
  - M123 does not specify mounting requirements.
  - M55681 does not have mounting requirements for life or HSSLV testing.
  - M49470: mounting is at the discretion of the manufacturer.



Two defective parts were revealed by monitoring leakage currents after soldering onto PWB and 10 TC.

All specifications require testing at 125C and 2VR

Test	M123	M55681	M49470	M32535
TC and Life	Qual 123(1): 100 TC, 4000hr. Gr.B 25(0): 100 TC, 1000hr.	Qual 25(1): 2000hr.	Qual 24(1): 100 TC, 4000hr (T), 1000hr (B) Gr.B 12(1): 100 TC (T), 1000hr.	Qual 123(1): 100TC 4000hr (T), 5TC 1000hr (M) Gr.B 1000hr: 32(0) 100 TC (T), 16(0) 5TC (M).

- ✓ CDR capacitors have the weakest life test requirements.
- ✓ Qualification tests should be carried out using parts soldered onto PWBs.
- ✓ Instead of warning about risks of LT failures caused by soldering, acceptable soldering conditions should be specified (e.g per J-STD-020).
- ✓ Monitoring currents during LT facilitates detection of defective samples.

Resistance to Soldering Heat

- RSH tests should simulate the worst case of specified soldering conditions and verify robustness of MLCCs against soldering stresses.
- MIL-STD-202 TM210 has 8 versions of the test. Only two, and at relaxed requirements are used:
  - solder dip at T_{max} = 230C (M123 only);
  - infrared/convection reflow for at T_{max} = 235C.
- From 9 to 22 samples are used for RSH testing (30 pcs in AEC-Q200)
- Post test: visual examination, IR, C, DF (in some cases, one sample can fail).
- Commercial parts are tested at much higher temperatures (260C).
- Soldering iron test that simulates manual soldering is not used.

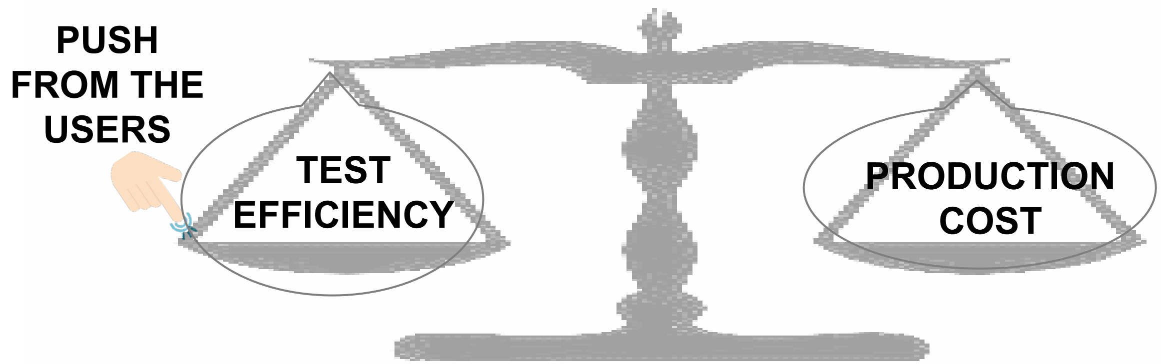
✓ Conditions for RSH tests should be strengthen.

✓ A terminal solder dip test can be used to select parts robust to manual soldering that is often used in production of space cards.

Conclusion

- Procedures for screening and qualification in military specifications can be improved to better reveal propensity of MLCCs to cracking and failures. In particular:
  - Qualification tests should be carried out using capacitors soldered onto test boards.
  - Measurements of IR, burn-in, humidity and life tests should be carried out by monitoring leakage currents.

Are Changes in MIL Specs Viable?



The volume of MLCCs in space systems is negligible compared to MIL industry ∴ low leverage with MLCC manufacturers.

- Combined efforts from hi-rel users are necessary to change MIL specs.
  - Users' consensus is difficult to reach.
  - Introduction of new procedures can increase cost and delivery time.
  - Changes might take years for implementation.
- A viable option: upscreen MIL parts according to NASA SCDs or DLA DWGs.
  - Additional S&Q tests are easier for a relatively small group of parts.
  - Manufacturers might be interested in cooperation with NASA for the benefits of success stories.
- Experience in development of SCDs and cooperation with manufacturers might facilitate implementation of non-MIL components by selecting, derating, and upscreening automotive grade capacitors.