Robustness of Surface Mount Aluminum Electrolytic Capacitors When Subjected to Lead Free Reflow

C. Wiest[1], N. Blattau[2], J. Wright[3], R. Schatz[3], and C. Hillman[2]
1 – University of Maryland, College Park, MD
2 – DfR Solutions, College Park, MD
3 – NIC Components, Melville, NY

Abstract
In addition to a change in materials, the movement to Pb-free will also result in significantly higher temperatures during surface mount assembly. Initial attempts at surface mount reflow have noted the initiation of case deformation aluminum liquid electrolytic capacitors in a surface mount configuration (V-chip). Of special concern is not only the visually observable change in component dimensions, but the possibility of damaged capacitors escaping into the field and inducing widespread field returns. To assess this issue, a wide range of V-chip capacitors were subjected to two series of experiments. In the first set, capacitors of various size and electrolyte formulation were exposed to a modified reflow condition, where the peak temperature was maintained until deformation of the aluminum housing was observed. Based on time to deformation determined in this experiment and the reflow parameters defined in J-STD-020C, a more limited population of V-chip capacitors were exposed to simulated reflow conditions and then subjected to highly accelerated life tests. Results suggest that the strongest predictor of deformation is the volume of the capacitor, with the smallest and largest case sizes having the potential to deform during reasonable Pb-free reflow conditions. When exposed to elevated temperature conditions designed to accelerate electrolyte evaporation, V-chip capacitors showed limited differentiation in time to failure as a function of reflow conditions or the presence or absence of case deformation.

Introduction

The transition to Pb-free manufacturing, to ensure compliance with RoHS legislation, has resulted in substantial concern over the possibility of unknown reliability issues in product released to customers. One particular area identified has been the observation of bulged or deformed surface mount aluminum liquid electrolyte capacitors (aka, V-chip) subjected to temperatures recommended for Pb-free reflow (see Figure 1). Initial reports have simply been limited to observation, with little to no quantitative information available on process guidelines or degradation in capacitor performance.

The purpose of this investigation was to provide the industry with an initial accounting of the susceptibility of V-chip capacitors to case deformation and assess the potential for potential reliability issues after exposure to Pb-free reflow conditions.

Figure 1: Aluminum liquid electrolytic capacitor, on the left-hand side, that has experienced case distortion after an extended time at Pb-free reflow temperatures

Sample Population

Ranges of electrolytic capacitor part types were selected to investigate the influence of electrolyte formulation, capacitor dimensions, and rated voltage. A listing of the various capacitors used in this investigation is provided in Table 1. All capacitors were subjected to an initial inspection to identify any potential anomalies or defects. No anomalies were identified.

Reflow Sensitivity

Reflow sensitivity level (RSL) describes the potential for surface mount aluminum liquid electrolytic capacitors to experience deformation or degradation when exposed to elevated reflow temperatures for extended periods of time. To assess reflow sensitivity, the capacitors were subjected to a modified Pb-free reflow profile.

Experimental Procedure

Three capacitors of the same part type were placed in a reflow simulation chamber. The temperature in the chamber was regulated using a K-type thermocouple, which was attached with Kapton tape to one of the capacitors on the top of its aluminum housing.

Table 1: Surface mount electrolytic capacitors subjected to reflow sensitivity analysis

Series	Capacitance (µF)	Tolerance	Voltage (VDC)	Size (h x d) (mm)	Rated Lifetime
NACETP[1]PT	10	20%	16	3X5.5	2000 hrs at 85°C
NACE	1	20%	50	4X5.5	2000 hrs at 85°C
NACE	10	20%	50	6.3X5.5	2000 hrs at 85°C
NACEWTP[2]PT	100	20%	16	6.3X5.5	1000 hrs at 105°C
NACEW	1000	20%	6.3	6.3X5.5	1000 hrs at 105°C
NACHLTP[3]PT	33	20%	25	6.3X6.1	5000 hrs at 105°C
NACE	22	20%	63	6.3X8	2000 hrs at 85°C
NACE	220	20%	35	8X10.5	2000 hrs at 85°C
NACTTP[4]PT	47	20%	35	8X10.5	1500 hrs at 125°C
NACT	220	20%	25	10X10.5	1500 hrs at 125°C
NACE	330	20%	50	12.5X14	2000 hrs at 85°C
NACE	3300	20%	16	16X17	2000 hrs at 85°C

The time/temperature behavior was adjusted to ensure a preheat and ramp rate that was representative of a Pb-free reflow profile. The specific parameters chosen were based upon IPC/JEDEC J-STD-020C Moisture/Reflow Sensitivity Classification for Non-hermetic Solid State Surface Mount Devices (see Figure 1). Capacitors were ramped up to a preheat temperature of 190°C at a rate of 3°C/sec. This temperature was maintained for 120 seconds and increased to the peak temperature at a rate of 3°C/sec. The capacitors were then held at the peak temperature until physical deformation of the aluminum housing was observed.

[1] NACE is a general purpose capacitor rated from -40 to +85°C
[2] NACEW is a general purpose capacitor with a wider temperature range (-55 to +105°C)
[3] NACHL is an extended lifetime capacitor rated from -40 to +105°C
[4] NACT is a general purpose capacitor with an extended temperature range (-40 to +125°C)

The peak temperatures chosen were 235°C and 260°C. These temperatures were based upon the minimum recommended reflow temperature for tin/silver/copper (SAC) solder alloys and the maximum expected peak temperature detailed by J-STD-020C.

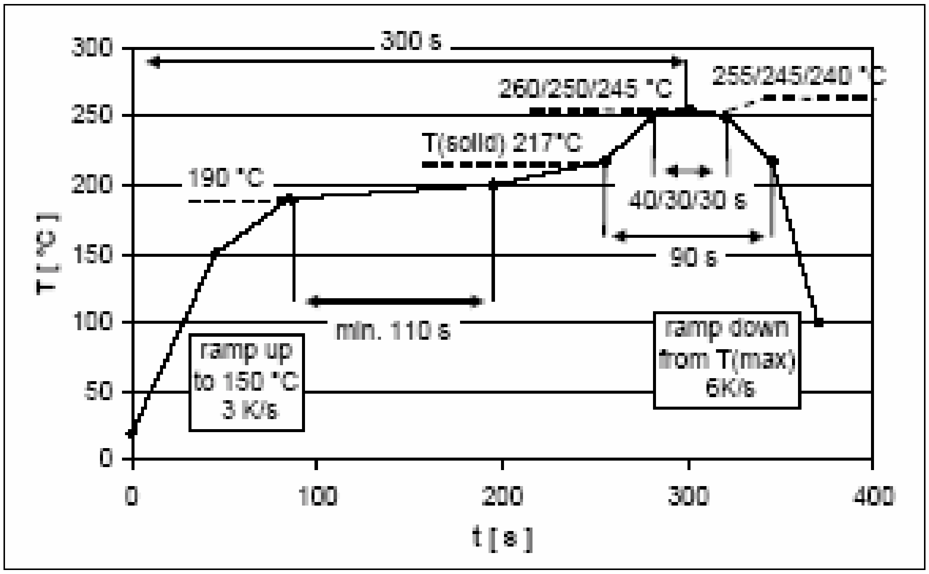


Figure 2: Pb-free reflow profile detailed in J-STD-020C

Results

The results are for time to deformation at 235°C and 260°C peak temperature. One capacitor experienced deformation during the ramp up to the 235°C peak temperature.

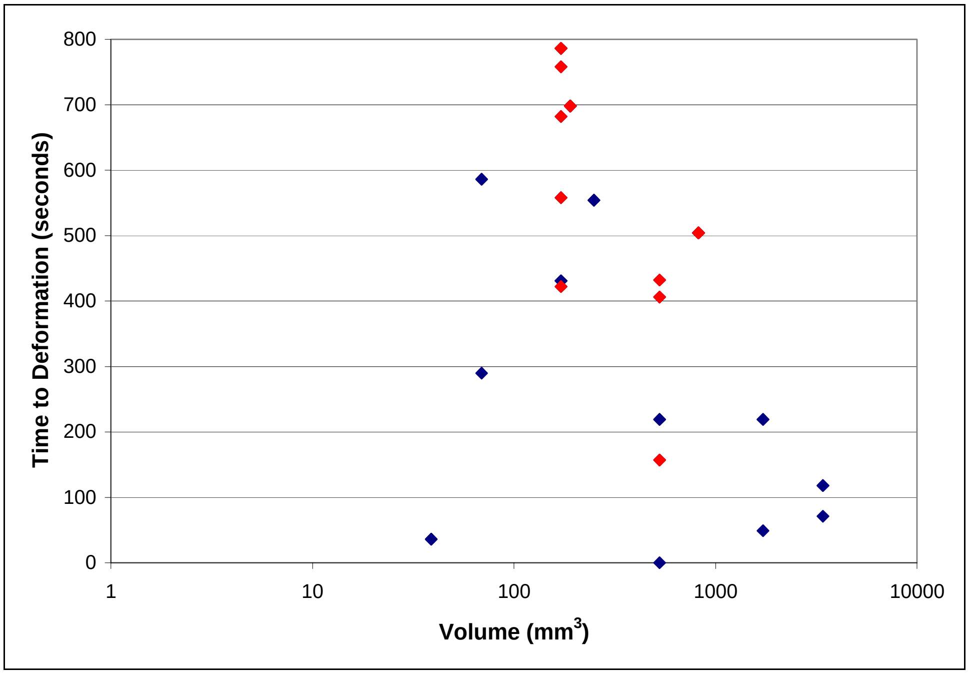


Figure 3: Time to deformation as a function of capacitor volume at 235°C peak reflow temperature. The diamonds in red are indicative of extended temperature or extended life capacitors.

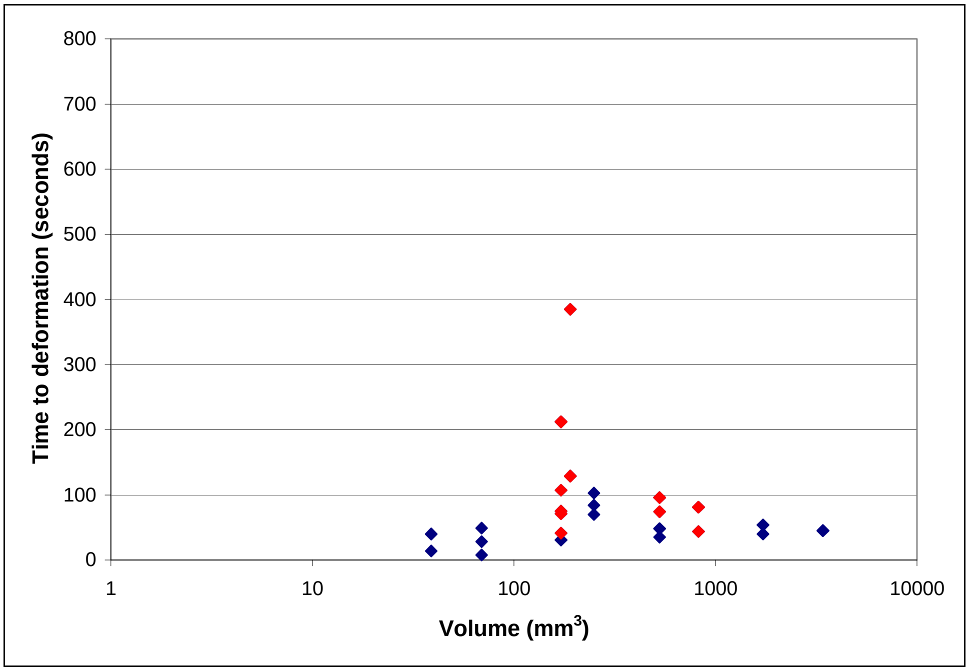


Figure 4: Time to deformation as a function of capacitor volume at 260°C peak reflow temperature. The diamonds in red are indicative of extended temperature or extended life capacitors.

Discussion

Several trends were identified upon review of the preliminary results. The time to deformation seemed to be strongly dependent upon the volume of the capacitor, with the maximum time to deformation observed to occur at moderate volumes (100 to 500 mm^3). The smallest and largest capacitors seemed to be most prone to deformation, with the smallest capacitors at 235°C and several more capacitors at 260°C experiencing deformation before the 40 second hold time defined in J-STD-020C. This may suggest that the smallest and largest surface mount aluminum liquid electrolytic capacitors could experience deformation in more severe Pb-free reflow conditions.

The dependency on volume is expected based upon the steps involved in case deformation. The first step is introducing a sufficient amount of energy into the system to raise the temperature beyond the boiling point of the electrolyte. The temperature on the outside of the capacitor, where the thermocouple was placed, can be considered the energy flowing into the system. The heat capacity of the electrolyte, which relates energy introduced into the system to a ΔT, is dependent upon the moles of electrolyte present in the system. Therefore, for a given outside temperature, the smaller capacitors will equilibrate with the ambient conditions more rapidly then larger capacitors.

As the boiling point is reached, the vapor pressure will increase rapidly. The larger the volume of liquid present, the larger the pressure is within the cylinder for a given temperature. The case resisting the pressure, the surface area, scales with dimensional unit squared. Since the pressure on the can inducing deformation scales with dimensional unit cubed, it can be seen how a more benign time/temperature environment within the larger electrolytic capacitors would induce earlier deformation.

In general, extended temperature or extended lifetime capacitors displayed a less severe sensitivity to reflow conditions, with all extended temperature/lifetime capacitors having a time to deformation exceeding 40 seconds.

While deformation behavior as a function of reflow temperature and capacitor volume was demonstrated, of greater concern is the possibility that capacitors that did not experience deformation may have experienced some degree of unobservable damage or degradation that would result in a limited lifetime.

Long-Term Degradation

To assess the potential of degradation during exposure to Pb-free reflow conditions, a limited sample set of capacitors listed in Table 1 were subjected to a range of peak reflow temperatures and hold times. Due to the behaviors observed during the first set of experiments, the sample set was primarily based on volume, with an extended lifetime part also selected for comparison purposes. The experimental design is detailed in Table 2. Three capacitors from each part number were exposed to each reflow condition.

Table 2: Experimental design selected for assessing long-term degradation

Sample Set	Part Number	Reflow Conditions		
		Benign	As per J-STD-020C	Severe
Volume < 350 mm^3	NACE1R0M50V4X5 NACE220M63V6.3X8	235°C / 30 sec	250°C / 30 sec	260°C 30 sec
			250°C / 40 sec	
Volume > 350 mm^3	NACE331M50V12.5X14	235°C / 30 sec	245°C / 30 sec	260°C 30 sec
			245°C / 40 sec	
Extended Lifetime	NACHL330M25V6.3X6.1	N/A	N/A	260°C 20 sec

Experimental Procedure

After exposure to the reflow conditions detailed in Table 2, the capacitors were subjected to accelerated test conditions. The accelerated test conditions used to assess degradation behavior were based on previous experiments performed on electrolytic capacitors, which determined that testing to industry specifications would be insufficient to assess long-term reliability. The test temperature was selected to ensure capacitor failure within a reasonable time period without inducing inappropriate failure modes. In addition, since damage to the seal during reflow was the primary concern, a high temperature was desirable to ensure that evaporation of the electrolyte was the mechanism that induced capacitor failure.

Given these requirements, the test conditions were set at 25 VDC at 165°C. The applied voltage helped ensure maintenance of the dielectric without inducing dielectric breakdown. The elevated temperature, while above industry and company specifications, was significantly below the boiling point of the liquid electrolyte (180°C to 200°C).

Results

Capacitors were periodically pulled from the environmental chamber for capacitance and equivalent series resistance (ESR) measurements. The results are displayed in Figure 4 and Figure 5.

Discussion

The results show that within normal variations, the reflow exposure conditions had no influence on long-term degradation behavior. This observation was found to be true even when the capacitor was observed to have experienced case deformation after Pb-free reflow simulation. The primary influence on time to failure under accelerated test conditions was determined to be capacitor volume. Extended lifetime capacitors were found to have similar degradation behavior to the general-purpose capacitors.

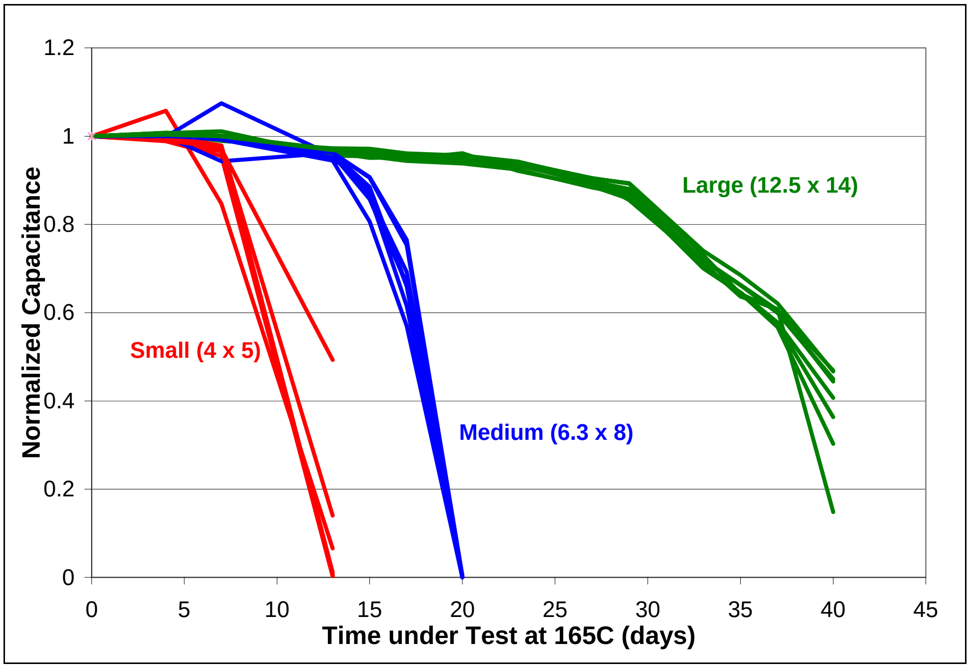


Figure 5: Change in normalized capacitance as a function of time under test. Changes in degradation behavior by volume (small, medium, large) can be observed.

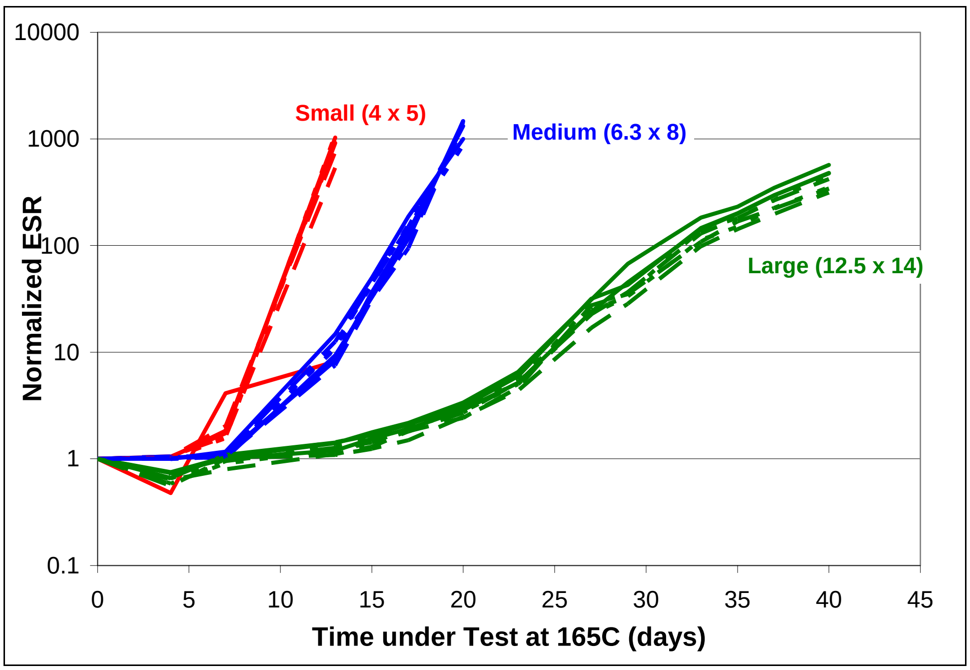


Figure 6: Change in Normalized Equivalent Series Resistance (ESR) as a Function of Time Under Test. Changes in degradation behavior by volume (small, medium, large) can be observed.

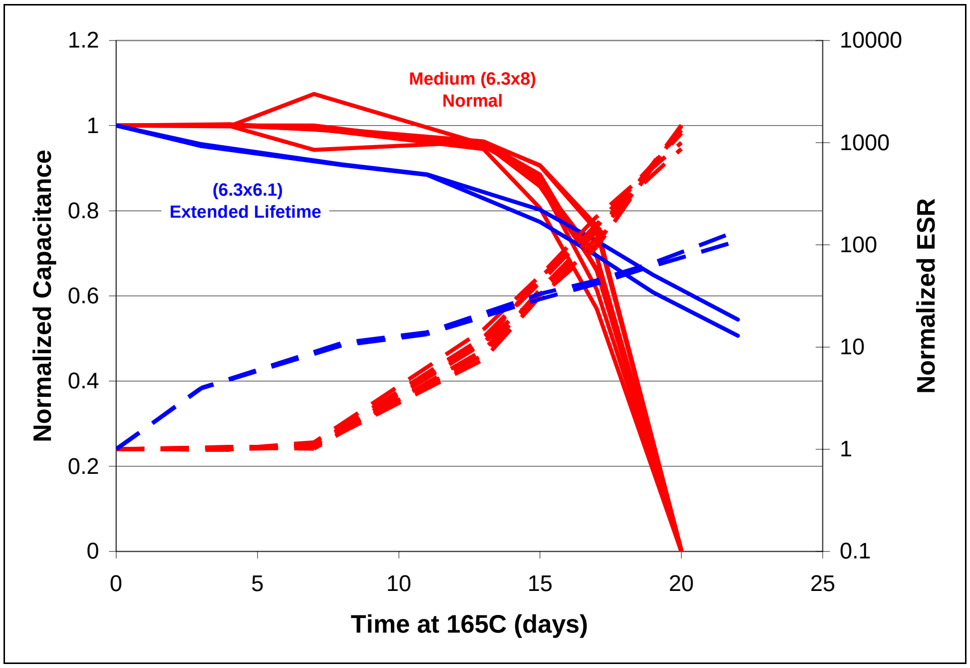


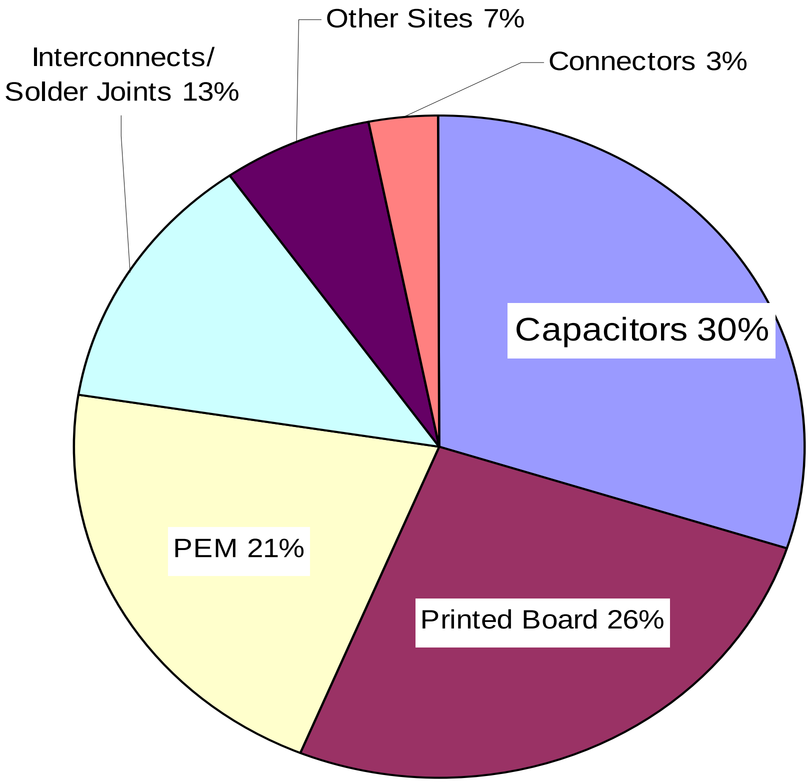
Figure 7: Comparison of Degradation Behavior of General Purpose and Extended Lifetime Capacitors

Conclusion

The potential for case distortion in V-chip capacitors during Pb-free reflow was found to primarily be dependent upon the volume of the capacitor, with small, less than 100 mm^3, and large, greater than 1000 mm^3, showing the greatest degree of susceptibility. Capacitors with extended temperature or extended lifetime capacitors in general showed more robust behavior.

Exposure to a range of Pb-free reflow conditions and the occurrence of case deformation seemed to have minimal influence of the reliability of the V-chip capacitors in environments designed to accelerate electrolyte evaporation, the most common root-cause for electrolytic capacitor failure in the field.

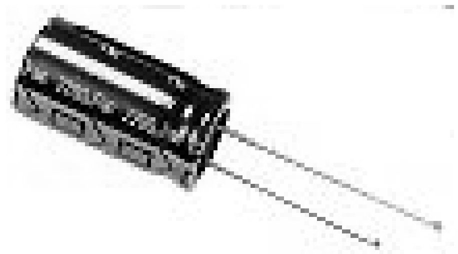
What are the Biggest Headaches in Electronics Reliability?



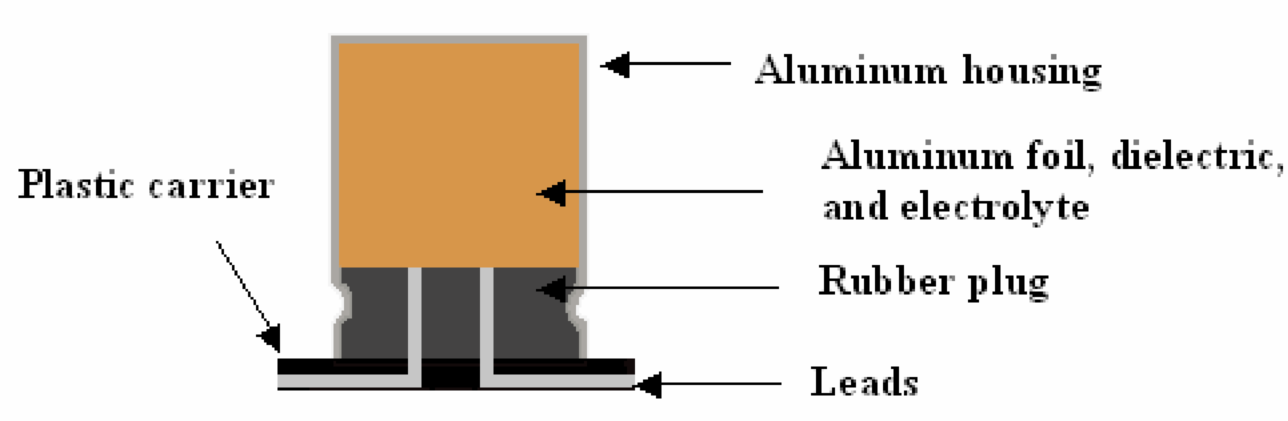
Survey of failure analyses

- Capacitors and printed board issues accounted for over 50% of these failures
- Will Pb-free reflow profiles change this
- Electrolytic capacitors are sensitive to elevated reflow soldering temperatures

Electrolytic Capacitor (V-Chip Packaging)



Thru-hole electrolytic capacitors are not suitable for SMT and are not designed to handle reflow temperatures



SMT V-Chip is an adaptation of electrolytic capacitors to surface mount technology specifically designed to handle the high temperatures. Can they withstand the higher temperatures associated with SAC alloy Pb-free reflow?

Reflow Sensitivity Analysis

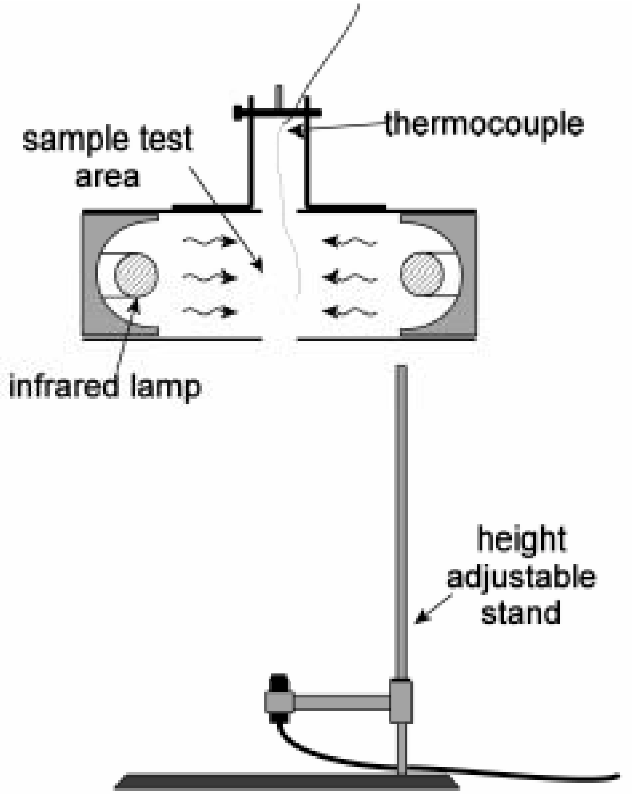
Simulated Reflow

Pb-free SnPb

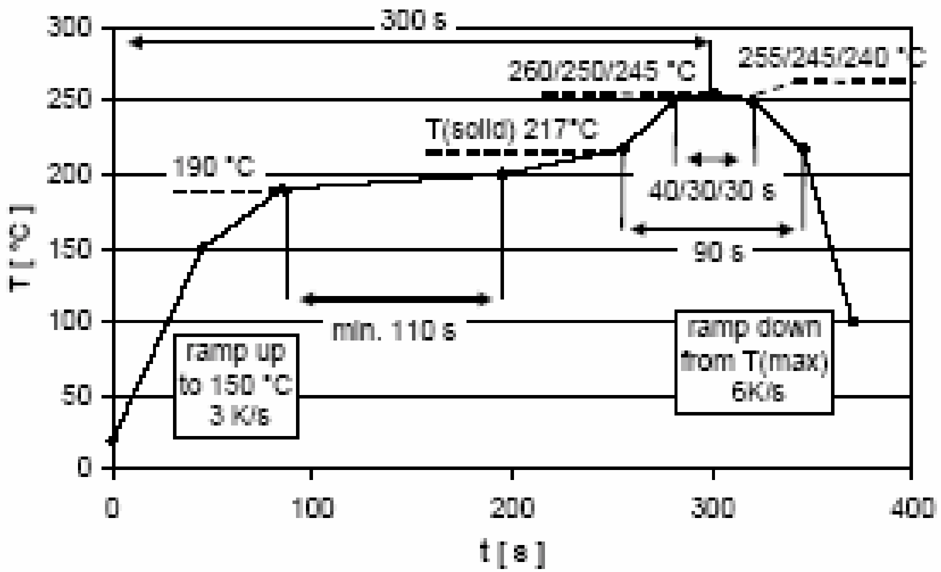
- Concern over the possibility of unknown reliability issues associated with Pb-free reflow profiles
- Observation of deformed electrolytic capacitors

1.) Do deformed capacitors represent a reliability issue?
2.) Is there the possibility of latent defects?

Test Setup



Infrared source and Omega temperature controller programmed to duplicate ramps of reflow profile



Temperature feedback from thermocouple mounted to specimen

Pb-free reflow simulation based upon J-STD-020C

Sample Population

NIC V-Chip Capacitors	Rating
• NACE100M16V3X5.5	2000 hrs at 85^{o}C
• NACE1R0M50V4x5	2000 hrs at 85^{o}C
• NACE100M50V6.3X5.5	2000 hrs at 85^{o}C
• NACEW101M16V6.3X5.5	1000 hrs at 105^{o}C
• NACEW102M6.3V6.3X5.5	1000 hrs at 105^{o}C
• NACHL330M25V6.3X6.1	5000 hrs at 105^{o}C
• NACE220M63V6.3X8	2000 hrs at 85^{o}C
• NACE221M35V8X10.5	2000 hrs at 85^{o}C
• NACT470M35V8X10.5	1500 hrs at 125^{o}C

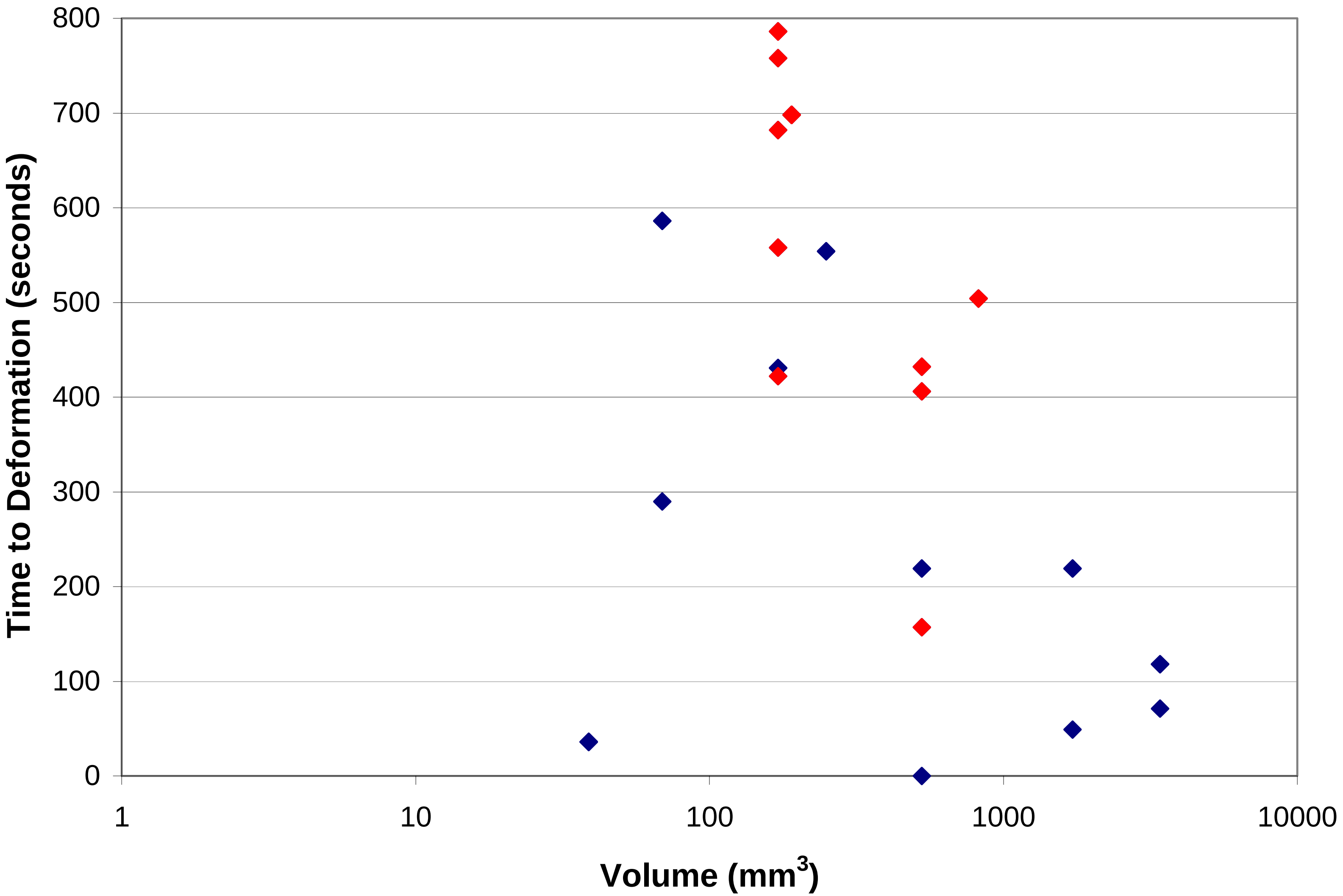
Case Volume

Size	Diameter	Height	Volume
3X5.5	3	5.5	39
4X5.5	4	5.5	69
6.3X5.5	6.3	5.5	171
6.3X5.5	6.3	5.5	171
6.3X5.5	6.3	5.5	171
6.3X6.1	6.3	6.1	190
6.3X8	6.3	8	249
8X10.5	8	10.5	528
8X10.5	8	10.5	528
10X10.5	10	10.5	824
12.5X14	12.5	14	1717
16X17	16	17	3416

Time to deformation measured at two temperatures

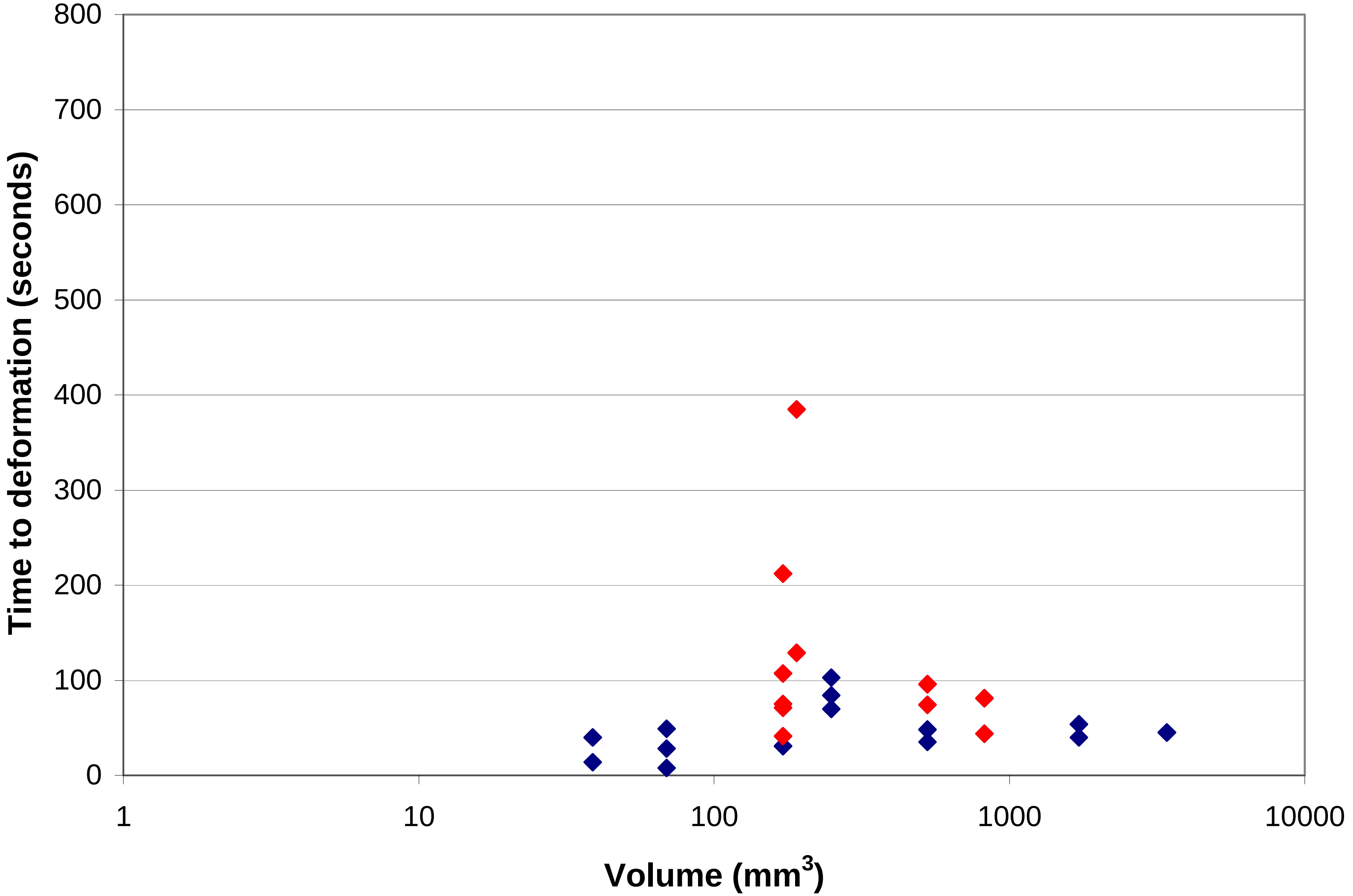
- 235ºC
- 260ºC

Time to Deformation



Time to deformation at 235ºC

Time to Deformation



Time to deformation at 260ºC

Reflow Sensitivity Results

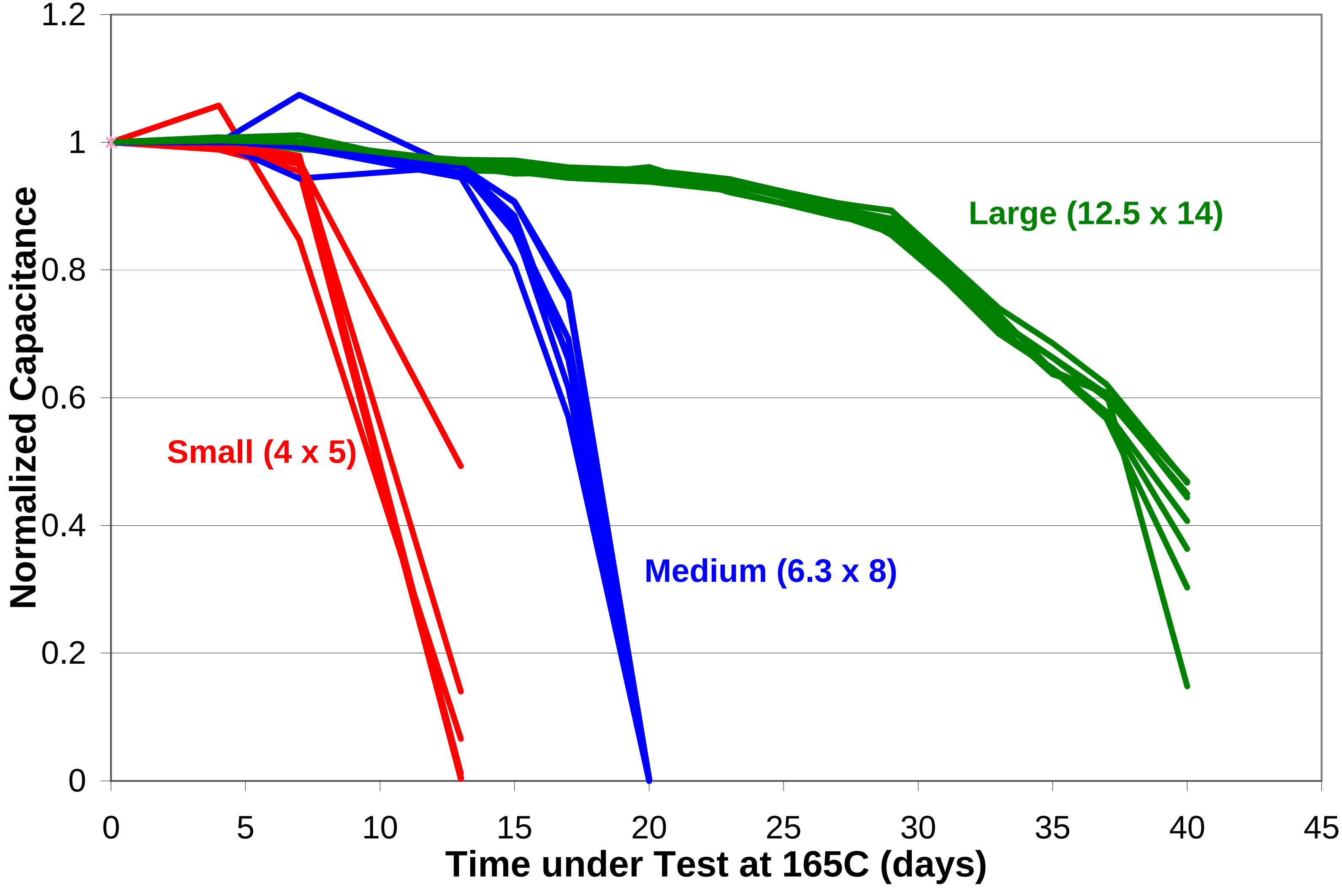
- Time to deformation strongly dependent on capacitor volume
- Smallest and largest more susceptible to deformation
- Moderate volume capacitors
  - 100 – 500 mm^3
  - More robust
- Some capacitors experienced deformation before the 40 second hold time defined in J-STD-020C

Long-Term Degradation

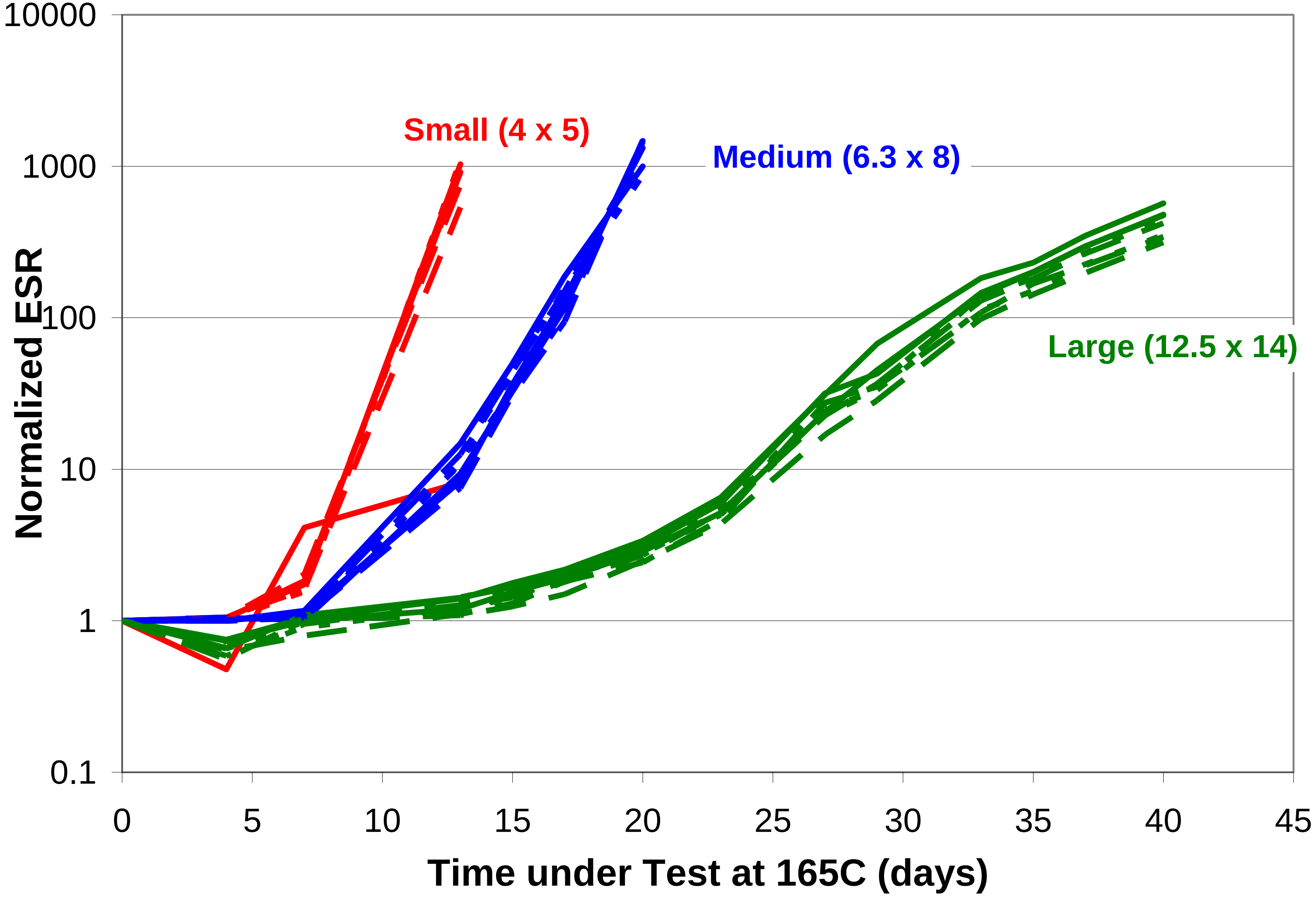
<table>
<tr><th rowspan="2">Sample Set</th><th rowspan="2">Part Number</th><th colspan="3">Reflow Conditions</th></tr>
<tr><th>Benign</th><th>J-STD-020C</th><th>Severe</th></tr>
<tr><td rowspan="2">Volume
< 350 mm^3</td><td rowspan="2">NACE1R0M50
V4x5
NACE220M63V
6.3X8</td><td rowspan="2">235ºC / 30 sec</td><td>250ºC / 30 sec</td><td rowspan="2">260ºC / 30 sec</td></tr>
<tr><td>250ºC / 40 sec</td></tr>
<tr><td rowspan="2">Volume
> 350 mm^3</td><td rowspan="2">NACE331M50V
12.5X14</td><td rowspan="2">235ºC / 30 sec</td><td>245ºC / 30 sec</td><td rowspan="2">260ºC / 30 sec</td></tr>
<tr><td>245ºC / 40 sec</td></tr>
<tr><td>Extended
Lifetime
(NACHL)</td><td>NACHL330M25
V6.3X6.1</td><td>N/A</td><td>N/A</td><td>260ºC / 20 sec</td></tr>
</table>

Test conditions set at 165ºC at 25 VDS

Capacitance

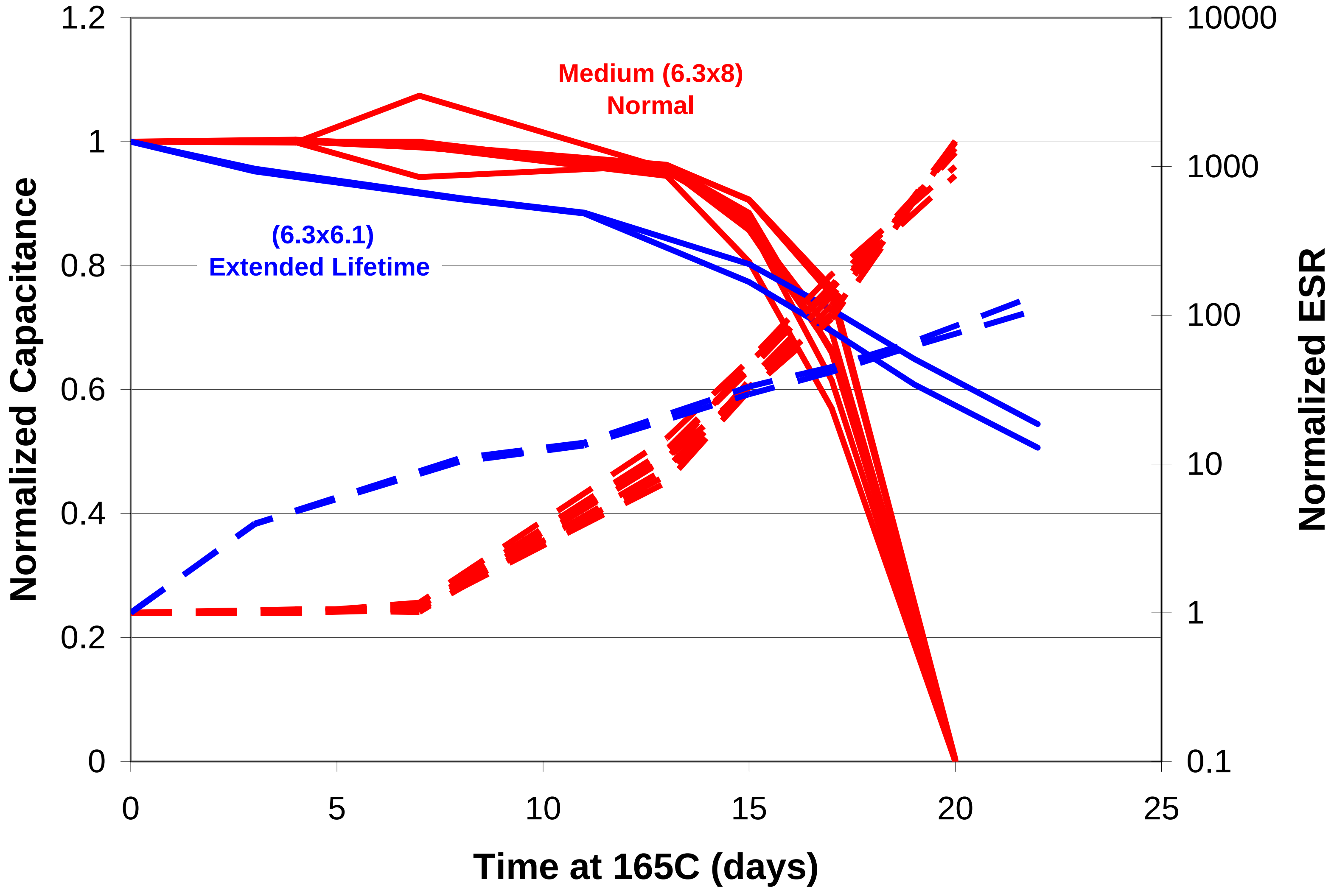


ESR



10000
1000
100
10
1
0.1
Normalized ESR
0
5
10
15
20
25
30
35
40
45
Time under Test at 165C (days)
Small (4 x 5)
Medium (6.3 x 8)
Large (12.5 x 14)

Extended Lifetime Capacitors



Conclusions

- Case distortion mainly dependent on the volume of the capacitor
  - Small capacitors <100 mm^3 and large capacitors >1000 mm^3 susceptible to case distortion
  - Medium capacitors, less susceptible
- Case distortion did not influence capacitor life
  - No evidence of latency in any sample
- Extended temperature or extended lifetime capacitors are more robust