

## Robustness of Surface-Mount Aluminum Electrolytic Capacitors When Subjected to Pb-Free Reflow

By N. Blattau<sup>1</sup>, J. Wright<sup>2</sup>, R. Schatz<sup>2</sup>, and C. Hillman<sup>1</sup>

### 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 was 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 was 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 of concern 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 (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, 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

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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.

Series	Capacitance (μF)	Tolerance	Voltage (VDC)	Size (h x d) (mm)	Rated Lifetime
NACETP <sup>1</sup> 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 <sup>2</sup> 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 <sup>3</sup> 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
NACTP <sup>4</sup> 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

<sup>1</sup>NACE is a general purpose capacitor rated from -40 to +85°C

<sup>2</sup>NACEW is a general purpose capacitor with a wider temperature range (-55 to +105°C)

<sup>3</sup>NACHL is an extended lifetime capacitor rated from -40 to +105°C

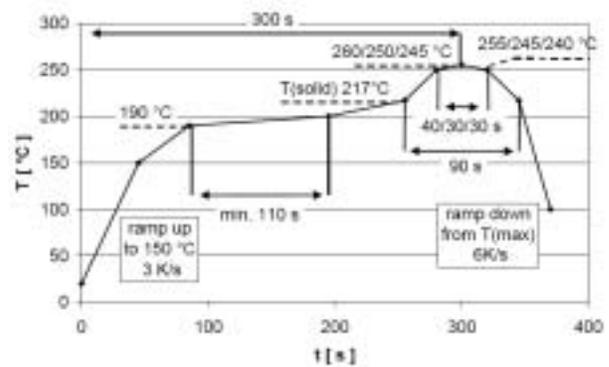
<sup>4</sup>NACT is a general purpose capacitor with an extended temperature range (-40 to +125°C)

**Table 1: Surface Mount Electrolytic Capacitors Subjected to Reflow Sensitivity Analysis**

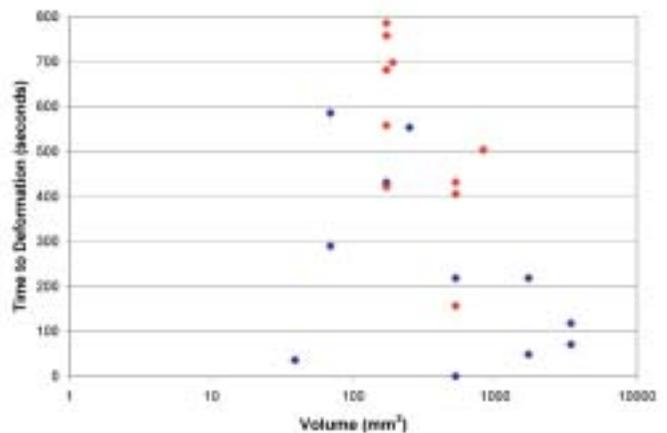
The time/temperature behavior was adjusted to ensure a preheat and ramp rate that was representative of a Pb-free reflow profile. The specific parameters chosen were based upon IPC/JEDEC J-STD-020C Moisture/Reflow Sensitivity

Classification for Non-hermetic Solid State surface-mount Devices (Figure 2). Capacitors were ramped up to a pre-heat 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.

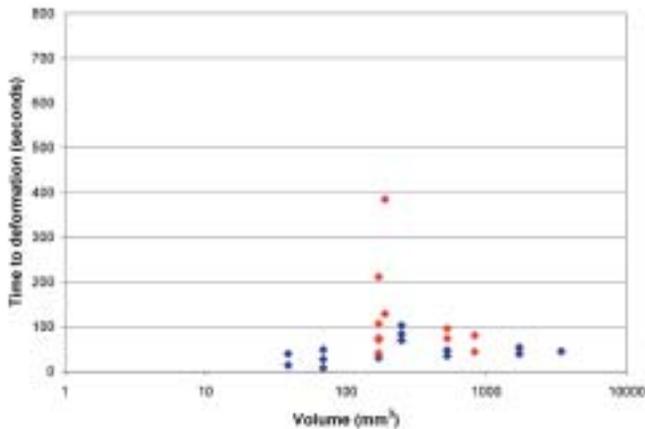
The peak temperatures chosen were 235°C and 260°C. These temperatures were based upon the minimum recommended reflow temperature for tin/silver/copper (SAC) solder alloys and the maximum expected peak temperature detailed by J-STD-020C.



**Figure 2: Pb-Free Reflow Profile Detailed in J-STD-020C**



**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.**

## Results

The results for time to deformation at 235°C and 260°C peak temperature are displayed in Figure 3 and Figure 4, respectively. One capacitor experienced deformation during the ramp up to the 235°C peak temperature, and is therefore not displayed in Figure 3.

## Discussion

Several trends were identified upon review of the preliminary results displayed in Figure 3 and Figure 4. 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 500mm<sup>3</sup>). 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  $\Delta T$ , 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 than 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 within the cylinder for a given temperature. The case resisting the pressure, the surface area, scales with dimensional unit squared. Since the pressure in the can that induces deformation scales with dimensional unit cubed, it can be seen how larger electrolytic capacitors could be more susceptible to 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.



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# SURFACE-MOUNT ELECTROLYTIC CAPACITORS

Sample Set	Part Number	Reflow Conditions		
		Benign	As per J-STD-020C	Severe
Volume < 350 mm <sup>3</sup>	NACE1R0M50V4X5 NACE220M63V6.3X8	235°C / 30 sec	250°C / 30 sec	260°C / 30 sec
			250°C / 40 sec	
Volume > 350 mm <sup>3</sup>	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

**Table 2: Experimental Design Selected for Assessing Long-Term Degradation**

## Long-Term Degradation

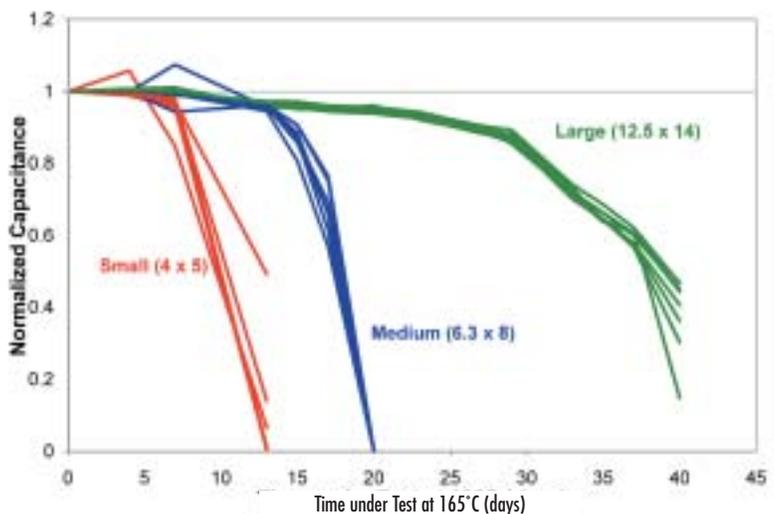
To assess the potential of degradation during exposure to Pb-free reflow conditions, a limited sample set of capacitors listed in Table 1 were subjected to a range of peak reflow temperatures and hold times. Due to the behaviors observed during the first set of experiments, the sample set was primarily 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.

## 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).



**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.**

## Results

Capacitors were periodically pulled from the environmental chamber for capacitance and equivalent series resistance (ESR) measurements. The results are displayed in Figure 5 and Figure 6.

## 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, as shown in Figure 7.

## Conclusion

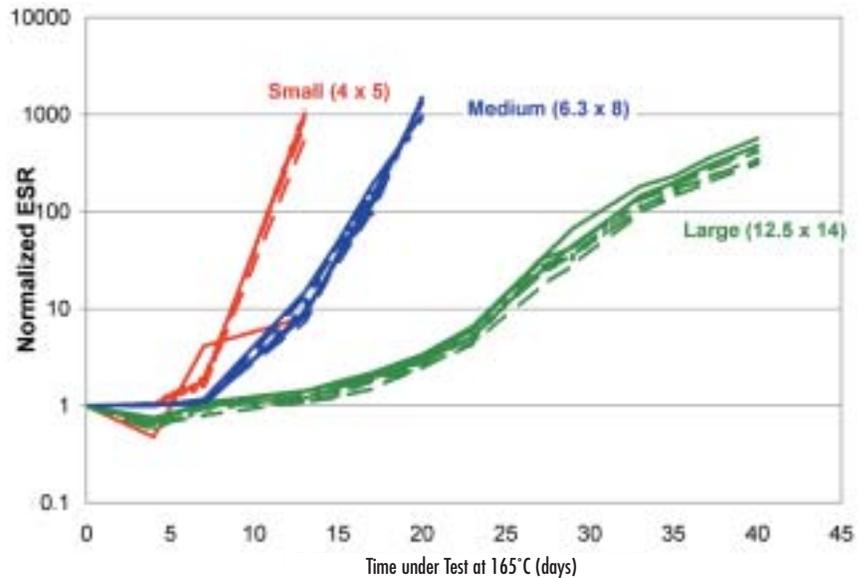
The potential for case distortion in V-chip capacitors during Pb-free reflow was found to be dependent primarily upon the volume of the capacitor, with small (less than 100 mm<sup>3</sup>) and large (greater than 1000mm<sup>3</sup>) showing the greatest degree of susceptibility. Capacitors with extended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

Exposure to a range of Pb-free reflow conditions and the

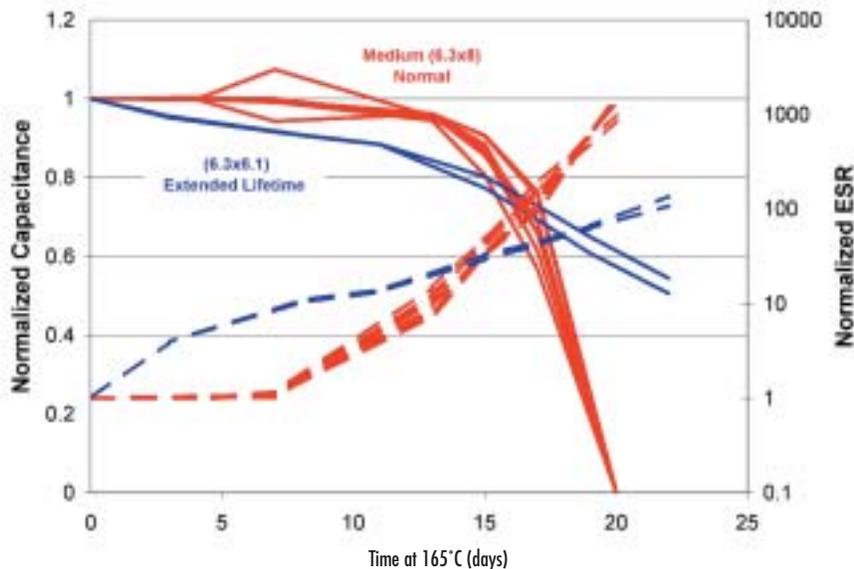
occurrence of case deformation seemed to have minimal influence on the reliability of the V-chip capacitors in environments designed to accelerate electrolyte evaporation, the most common root-cause for electrolytic capacitor failure in the field. □

<sup>1</sup>DfR Solutions, College Park, MD

<sup>2</sup>NIC Components, Melville, NY



**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**