A New Method for Testing Electrolytic Capacitors to Compare Life Expectancy

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Overview

- Aluminum Electrolytic Capacitors
  - Introduction
  - Construction
  - Failure Criteria
  - Ripple Current
  - Wear-Out

- Life Test
  - Traditional
    - Trends evident in data
  - Accelerated
    - Calculations
    - Traditional vs. Accelerated

- Accelerated Life Test
  - Conditions
  - Suppliers A & B
  - Suppliers C & D

- Conclusions
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Aluminum Electrolytic Capacitors – Introduction

Traditional life testing of Al ECaps indicates test lifetime can be slightly less than or 2-3x greater than datasheet lifetime.
Aluminum Electrolytic Capacitors – Construction

Different lead lengths distinguish the anode (long) and the cathode (short) leads.

The body consists of an Al can encased with a plastic sleeve.

CT scan showing the internal windings.

Internal construction of an Al ECap with equivalent circuit from Nippon Chemi-Con.
Aluminum Electrolytic Capacitors – Construction

A rubber bung seals the Al can.

Non-hermetic seal between bung and can allows for evaporation of electrolyte during operation.

CT scan showing the crimped seal between the can and the bung.

Smaller capacitors have etched vents at can top. These are designed so that in the event of a failure, leaking electrolyte is directed away from the PCB.
Aluminum Electrolytic Capacitors – Failure Criteria

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Acceptance Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacitance Change</td>
<td>Within +/- 20% of initial value</td>
</tr>
<tr>
<td>Dissipation Factor</td>
<td>Not more than 200% of the specified value</td>
</tr>
<tr>
<td>Leakage Current</td>
<td>Initial specific value or less</td>
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Failure criteria defined in manufacturer datasheets. Dissipation factor is proportional to equivalent series resistance (ESR), so >200% increase in ESR is classified as failed.

Increase in leakage current

Increase in dissipation factor (ESR);
Decrease in capacitance
Aluminum Electrolytic Capacitors – Failure Criteria

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<th>Criteria Details</th>
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Failure criteria defined in manufacturer datasheets. Dissipation factor is proportional to equivalent series resistance (ESR), so >200% increase in ESR is classified as failed.

- Increase in leakage current
- Increase in dissipation factor (ESR);
- Decrease in capacitance

Dissolution factor is proportional to equivalent series resistance (ESR), so >200% increase in ESR is classified as failed.
Aluminum Electrolytic Capacitors – Ripple Current

Lower Frequency

Lower frequencies allow the capacitor to fully charge and discharge.

Higher Frequency

Higher frequencies do not allow the capacitor to fully charge and discharge.

Larger amplitude and larger applied ripple currents induce greater internal temperature rise.
Aluminum Electrolytic Capacitors – Wear-Out

Apply ripple and bias

Heating of the capacitor from applied ripple current causes evaporation of the electrolyte.

Internal pressure increase from electrolyte evaporation facilitates electrolyte egress between the rubber bung and Al case.
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Life Test – Traditional (& Accelerated: Rate of Weight Loss)

Apply rated ripple and bias at rated temperature.

Oven and ripple current heating causes electrolyte evaporation.

Turn off electricity and cool to room temperature.

Did ESR have a >200% increase from the initial value?

Measure ESR

Electrical characterization

Weight: 1.432 g
Life Test – Trends in Traditional Data

Linear throughout entire test lifetime of an Al ECap population.

Exponential behavior that is relatively constant until approach time to failure.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Impact on Rate of Weight Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient temperature</td>
<td>↑</td>
</tr>
<tr>
<td>Applied ripple current</td>
<td>↑</td>
</tr>
<tr>
<td>Heat dissipation</td>
<td>↑</td>
</tr>
<tr>
<td>Crimp between bung and can</td>
<td>↑</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>Impact on Critical Weight Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrolyte stability</td>
<td>↑</td>
</tr>
<tr>
<td>Initial ESR measurement</td>
<td>↓</td>
</tr>
</tbody>
</table>
Life Test—Accelerated: Critical Weight Loss

1. Puncture a hole in the capacitor.
2. Oven heating causes electrolyte evaporation.
3. Turn off heat and cool to room temperature.

Did ESR have a >200% increase from the initial value?

No. Continue testing.

Yes. Testing is complete.

Measure ESR

Electrical characterization

Weight: 1.432 g
1. Critical weight loss at 200% increase in ESR is calculated using the ESR-Weight Loss curve

2. Rate of weight loss is extrapolated to the critical weight loss and the corresponding time is recorded as the accelerated test lifetime
Life Test – Accelerated Wear-Out Failure Mode

Accelerated test

Dried out, off white paper indicative of electrolyte evaporation.

Grey paper indicative of electrolyte saturation.

As-received
Life Test – Traditional vs. Accelerated

### Applied Test Conditions*

<table>
<thead>
<tr>
<th></th>
<th>Traditional (T)</th>
<th>Accelerated (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ripple Current (I)</td>
<td>$I_T = I_R$</td>
<td>$0 &lt; I_A \leq I_R$</td>
</tr>
<tr>
<td>Bias Voltage (V)</td>
<td>$V_T = V_R$</td>
<td>$0 &lt; V_A \leq V_R$</td>
</tr>
<tr>
<td>Temperature (T)</td>
<td>$T_T = T_R$</td>
<td>$T_A = T_R$</td>
</tr>
</tbody>
</table>

*Datasheet rating (R). All ripple applied at 120 Hz.
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- Conclusions
The accelerated test approached was used to compare the behavior of the following two pairs of Al ECaps.

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Capacitance (μF)</th>
<th>Size (mm)</th>
<th>Rated Lifetime (hrs)</th>
<th>Voltage (V)</th>
<th>Test Voltage (V)</th>
<th>Rated Ripple Current (mA RMS)</th>
<th>Test Ripple Current* (mA RMS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>68</td>
<td>18 x 31.5</td>
<td>10,000</td>
<td>450</td>
<td>225</td>
<td>1575</td>
<td>300</td>
</tr>
<tr>
<td>B</td>
<td>68</td>
<td>18 x 40</td>
<td>&gt;15,000</td>
<td>450</td>
<td>225</td>
<td>1517</td>
<td>300</td>
</tr>
<tr>
<td>C</td>
<td>2.2</td>
<td>10 x 20</td>
<td>10,175</td>
<td>450</td>
<td>225</td>
<td>43</td>
<td>20</td>
</tr>
<tr>
<td>D</td>
<td>2.2</td>
<td>10 x 20</td>
<td>5,000</td>
<td>450</td>
<td>225</td>
<td>29</td>
<td>15</td>
</tr>
</tbody>
</table>

* Ripple applied at 120 Hz.
Accelerated Life Test – Suppliers A & B Rate of Weight Loss

450 V, 68 μF

- Supplier A\(_{\text{Rate of Weight Loss}} \approx \frac{1}{2} \) Supplier B\(_{\text{Rate of Weight Loss}}\)
- Supplier A capacitors have a better seal between the can and bung
Accelerated Life Test – Suppliers A & B Critical Weight Loss

450 V, 68 μF

- Supplier A Critical Weight Loss ≈ Supplier B Critical Weight Loss
- Chemical stability of Supplier A and Supplier B electrolyte is comparable
Accelerated life test results indicate that the Supplier A Al ECap is more reliable than Supplier B

- This is opposite of what the datasheet lifetimes suggest
Accelerated Life Test – Suppliers C & D Rate of Weight Loss

450 V, 2.2 μF

- Supplier C rate of weight loss ≈ 2 Supplier D rate of weight loss
- Supplier C capacitors have a worse seal between the Al can and bung
Supplier C\textsubscript{Critical Weight Loss} \approx 2.5\ Supplier D\textsubscript{Critical Weight Loss}

Supplier C capacitors have a more chemically stable electrolyte
# Accelerated Life Test – Suppliers C & D Comparison

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Minimum Accelerated Lifetime (hours)</th>
<th>Maximum Accelerated Lifetime (hours)</th>
<th>Datasheet Lifetime (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>12,010</td>
<td>17,170</td>
<td>10,175</td>
</tr>
<tr>
<td>D</td>
<td>7,910</td>
<td>11,160</td>
<td>5,000</td>
</tr>
</tbody>
</table>

- Accelerated life test results indicate that the Supplier C Al ECap is more reliable than Supplier D
- This supports what the datasheet lifetimes suggest
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The Al ECap accelerated life test approach is an effective way to compare the reliability of the same capacitors from different manufacturers under applied test conditions.

Test results indicated that datasheet lifetime values can be inaccurate when compared to the reliability test results.

### Conclusions

<table>
<thead>
<tr>
<th>Al ECap 1</th>
<th>Traditional test time</th>
<th>Accelerated test time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al ECap 2</td>
<td>Traditional test time</td>
<td>Accelerated test time</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al ECap 3</td>
<td>Traditional test time</td>
<td>Accelerated test time</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Time (hours)
Many thanks to Steph, who is the primary author, for letting me present her findings. Our appreciation as well goes to our collaborators, LED Roadway, for allowing us to publish the findings of this study.