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ESTIMATING THE LIFETIME OF ELECTROLYTIC CAPACITORS

M. Simard-Normandin and C. Banks
MuAnalysis Inc.
Ottawa, ON, Canada

Aluminum electrolytic capacitors of three different ratings are stressed using Telcordia standard's requirements to compare their expected lifetime to the manufacturer's datasheet value.

Keywords: Aluminum electrolytic capacitors reliability; MIL-STD-202 method 108; Telcordia GR-357-CORE.001; Lifetime predictions.

I. Introduction

Equipment manufacturers incorporate hundreds, if not thousands, of electronic components into a system. Each type of component must be chosen according to its match to electrical specifications and compatibility with the system materials and the intended operating environment. The overall lifetime of the system is dominated by the weakest component. For high reliability equipment, or equipment difficult or impossible to access for repairs, it is important to have good data on the expected lifetime of the weaker devices before committing to a build. Aluminum electrolytic capacitors in particular have earned a bad reputation for long term reliability. These devices, which cost only a few cents, have been known to leak, explode or become short-circuited, ruining expensive equipment and the reputation of the equipment manufacturer. It is therefore important to put effort into the characterization of the lifetime of such parts.

II. Device selection

A. Three Types of Capacitors

Three types of electrolytic capacitors were tested: 10V-680µF, 50V-22µF and 400V-22µF. Capacitors of these values are commonly used in inverter power supplies, either stand alone or built-in and incorporated into equipment. Forty two (42) capacitors of each type were included. The requirement of the Telcordia GR-357-CORE document is for thirty-eight (38) devices. A few spares were included. Each capacitor was assigned a unique ID and followed through the tests. The capacitors were stressed at their maximum rated voltage (10V, 50V or 400V) and their maximum rated temperature (105°C) for 2000 hours per MIL-STD-2002 Method 108 condition F.

B. Experimental Set-up

Capacitors of the same type were mounted on a test board with pogo plugs to allow easy removal for testing. A resistance was placed in series with each capacitor to limit the current in case of capacitor short circuit and to ensure that the proper voltage was maintained to the other capacitors on the board. The current drawn by each board was monitored to detect such occurrences.

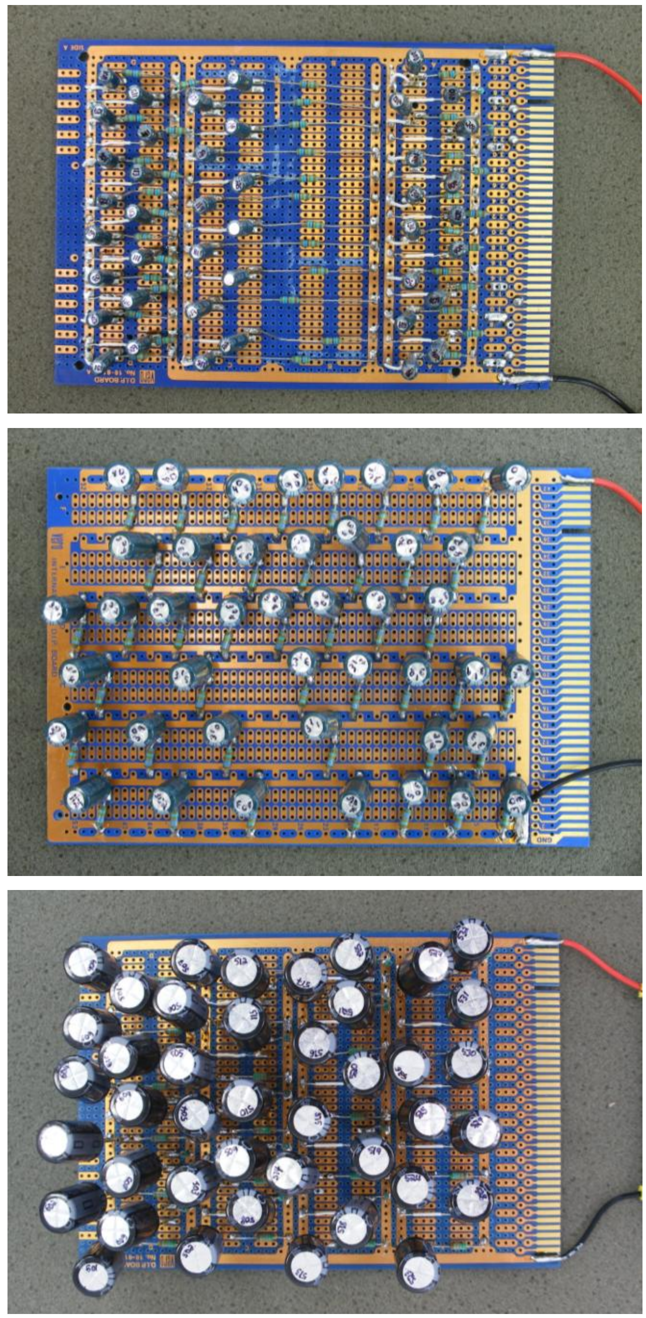


Figure 1. Capacitors mounted on their test boards. Top: 50V-22µF. Middle: 10V-680µF. Bottom: 400V-22µF

III. TEST RESULTS

Twelve sets of measurements were taken: at 0 hours, 2000 hours and 10 interruptions. The initial characterization of the capacitors was recorded before the test. These measurements included weight, capacitance (C), dissipation factor (D), quality factor (Q), equivalent series resistance (ESR), and current leakage. C, D, Q, and ESR were measured at these intervals during the testing period: 25 hours, 50 hours, 100 hours, 250 hours, 500 hours, 750 hours, 1000 hours, 1250 hours, 1500 hours, 1750 hours, and 2000 hours. A calibrated thermocouple was positioned in the oven next to the parts and checked periodically to ensure that the chamber was in the temperature range of the standard. Another thermocouple was placed next to it and connected to a data logger. Voltage and current were monitored during this process as well.

Within each group of 42 capacitors there were two date codes: a subgroup of 10 parts (a) and one of 32 parts (b).

In the Telcordia GR-357-CORE.001 standard for capacitors, the recommended sample size is 38. One failure in 38 is acceptable for a 10% Lot Tolerance Percent Defective (LTPD).

One capacitor from the 400V group failed initial tests. No other initial failures were observed.

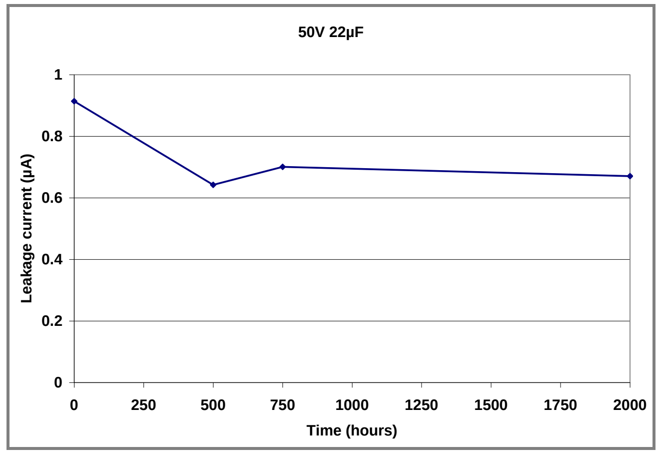
The weight of all capacitors decreased during the testing period, yet none of the vents showed any sign of opening and no body bulge was observed. (Table1)

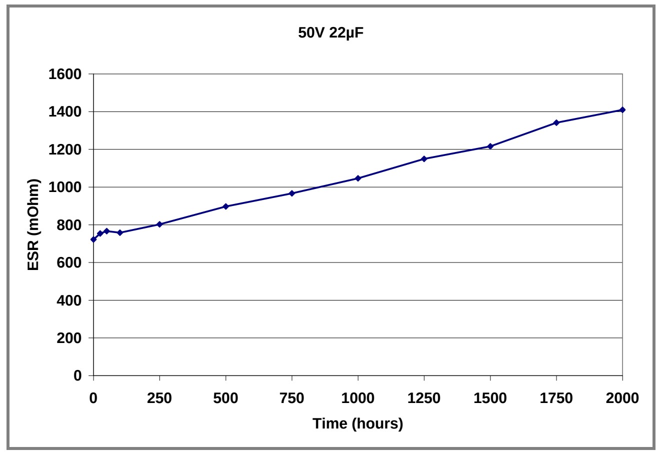
Table 1. Changes after 2000hrs.

Groups	**50V**	**10V**	**400V**
ΔC Failure criterion	25%	25%	20%
Average capacitance change	15%	6%	16%
Leakage current failure criterion	>3μA	>3μA	>100μA
Average leakage current	0.7μA	2μA	3μA
Average weight Percent change	-2.12%	-1.89%	-0.87%
Standard Deviation	0.15	0.18	0.08

A. 50V Capacitors

No failures were detected within the 50V capacitors after 2000 hours. The capacitance of all capacitors decreased and their ESR increased with time. Failure within this group is defined as a capacitance change exceeding 25% of the initial value, or leakage current above 3μA.





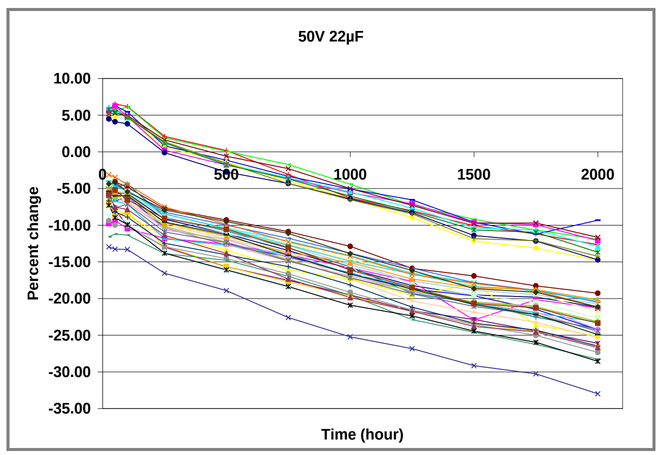


Figure 2. Changes in the 50V capacitors over 2000 hours. Top graph: Average leakage current. Middle graph: average increase of ESR. Bottom graph: Decrease of capacitance of each capacitor. There is a clear separation between the two date codes and there is one outlier.

Two capacitors in this group showed residue at the + pin after the tests.

B. 10V Capacitors

No failures were detected within the 10V capacitors after 2000 hours. The capacitance of all capacitors decreased over time. Failure within this group is defined as a capacitance change exceeding 25% of the initial value, or leakage current above 3μA.

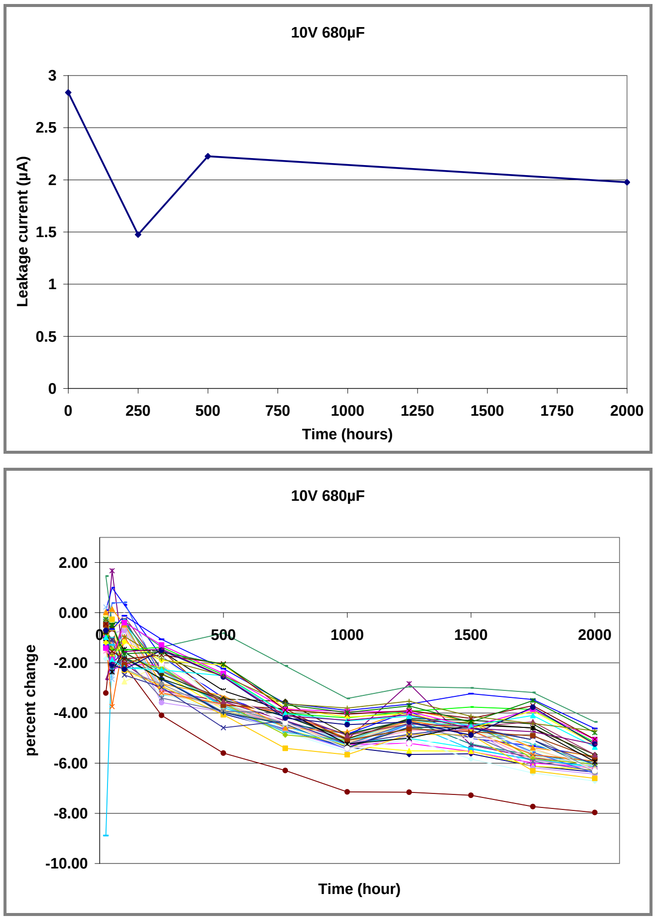


Figure 3. Changes in the 10V capacitors over 2000 hours. Top graph: average leakage current. Bottom graph: Decrease of capacitance of each capacitor. Within this group there is no clear separation between the two date codes, but there are two outliers.

Only one capacitor in this group showed residue at the + pin after the tests.

C. 400V Capacitors

One capacitor failed before the life test began. The capacitance of all 400V capacitors decreased and their ESR increased with time. Failure within this group is defined as a capacitance change exceeding 20% of the initial value, or leakage current above 100µA.

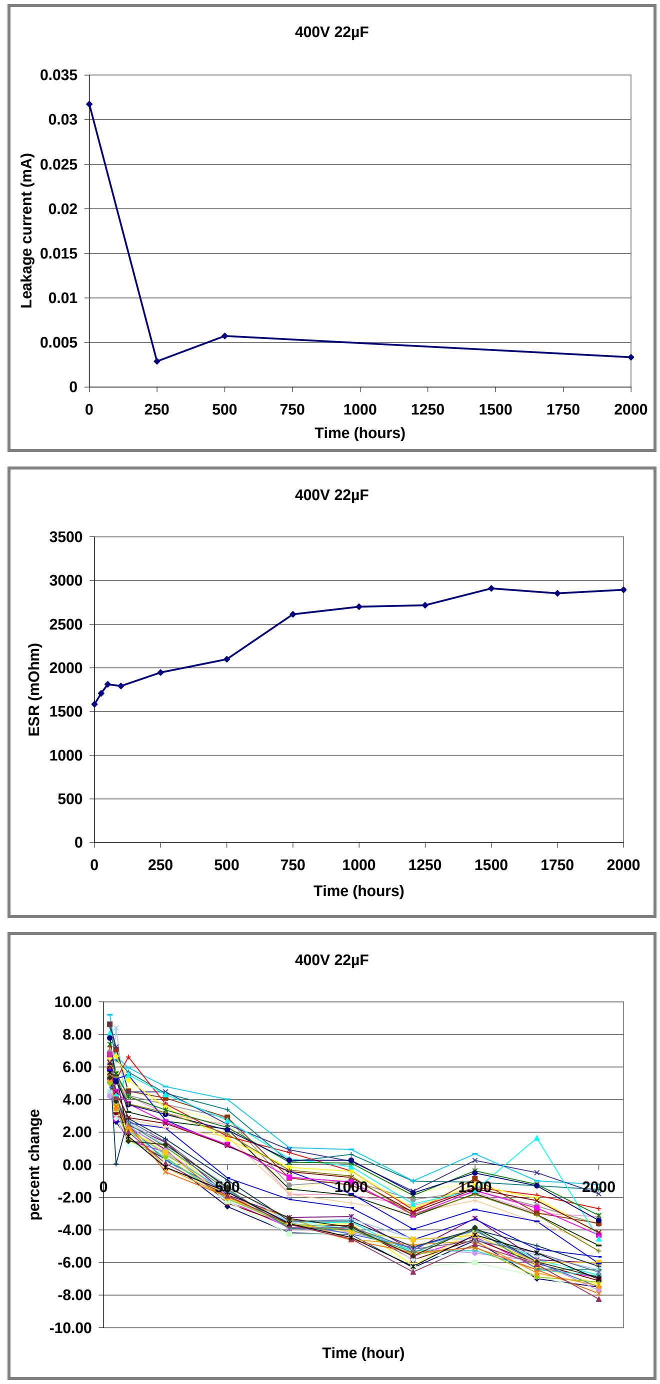


Figure 4. Changes in the 400V capacitors over 2000 hours. Top graph: Average leakage current. Middle graph: average increase of ESR. Bottom graph: Decrease of capacitance of each capacitor. There is a clear separation between the two date codes.

Eight capacitors in the group of thirty-two 400V capacitors show leakage at the + pin.

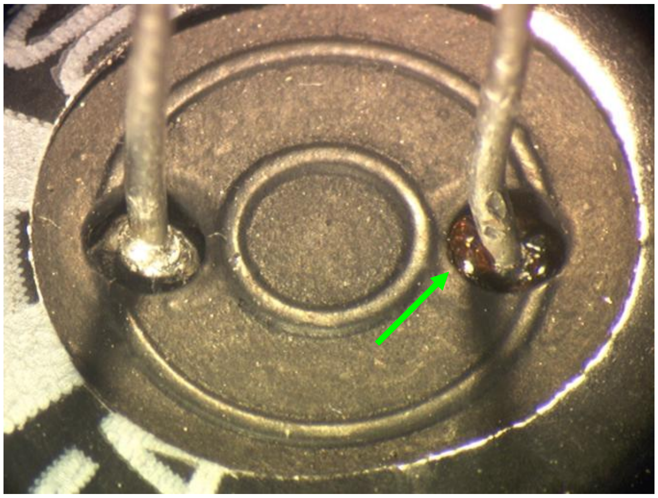


Figure 5. Capacitor 522 shows residue of electrolyte leakage (arrow).

IV. LIFETIME CALCULATIONS

The observed percentage change in capacitance versus time for all these capacitors is linear. The average curve was extrapolated using a linear regression and the expected Load Life calculated. Since there was always a jump between the 0 hour and the 24-hour capacitance value, the 24-hour value was used in place of the zero hour value. The capacitors do form when held under bias for some time. The data show that they were fully formed at 24 hours.

For the 50V capacitors the data follow the relation:

$$\Delta C = -9E\text{-}05 * t - 0.0071 \qquad (1)$$

Where C is the capacitance change in % and t is the time in hours. The Load Life for the 50V capacitors (25% change) is therefore expected at 2,700 hours. This is short of the datasheet value of 10,000 hours.

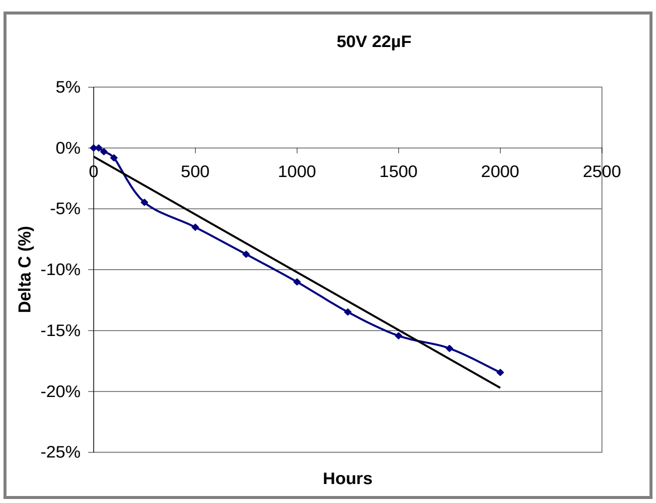


Figure 6. Percentage decrease of capacitance of the 50V capacitors and linear regression of equation 1.

For the 10V capacitors, the data follow the relation:

$$\Delta C = -2E\text{-}05 * t - 0.0046 \qquad (2)$$

Where C is the capacitance change in % and t is the time in hours. The Load Life for the 10V capacitors (25% change) is then expected at 12,270 hours, thus exceeding the datasheet value of 8,000 hours.

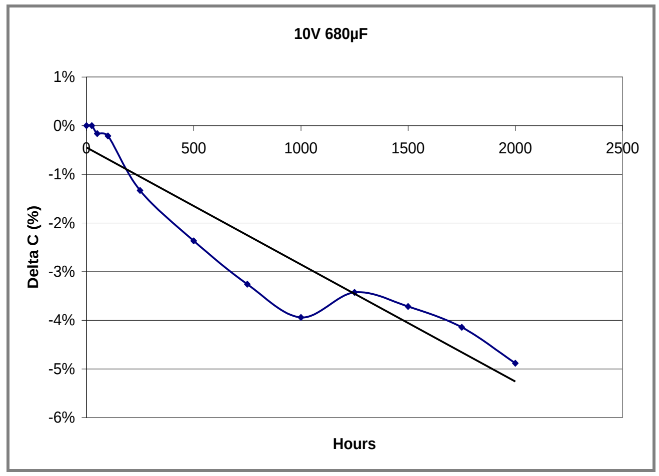


Figure 7. Percentage decrease of capacitance of the 10V capacitors and linear regression of equation 2.

For the 400V capacitors the data follow the relation:

$$\Delta C = -5E\text{-}05 * t - 0.0192 \qquad (3)$$

Where C is the capacitance change in % and t is the time in hours. Load Life for the 400V capacitors (20% change) is expected at 3,600 hours, short of the datasheet value of 10,000 hours.

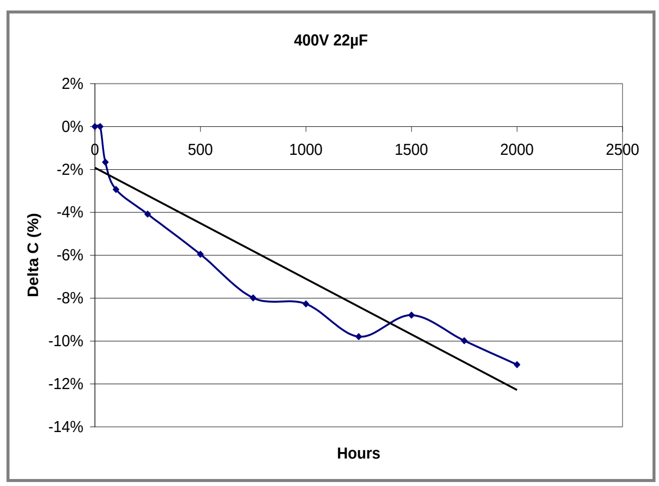


Figure 8. Percentage decrease of capacitance of the 10V capacitors and linear regression of equation 3.

Table 2. Load Life in hours for the capacitors.

Capacitors	Measured	Datasheet value
10V	12,270	8,000
50V	2,700	10,000
400V	3,600	10,000

Once the Load Life is known, the lifetime at a given operating condition can be calculated. The expected lifetime is related to the Load Life by the following expression [1]:

$$L_2=L_1\ (V_r/V_0)*\ 2^X \qquad (4)$$

Where :

$$X = (T_m-T_a)/10 \qquad (5)$$

And

L_2 is the projected life at the operating condition

L_1 is the Load Life rating

V_0 is the operating voltage of the application

V_r is the maximum voltage rating of the capacitor.

T_m is the maximum temperature rating of the capacitor.

T_a is the ambient temperature (including the self-heating caused by the ripple effect).

Using equations 4 and 5 above we can calculate predicted lifetime of the capacitors in different operational conditions. This is shown in Figure 9.

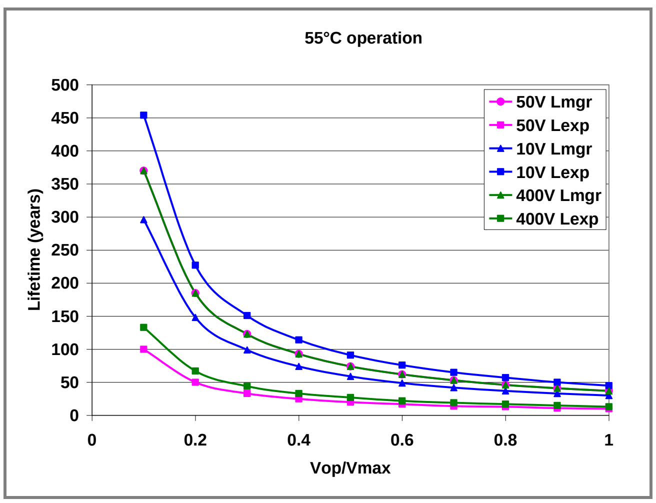


Figure 9. Experimentally predicted lifetime and manufacturer predicted lifetime of the three sets of capacitors if operated at 55°C at various voltages.

The life time decreases rapidly as the operating voltage increases. For the graph of Figure 9, an operating temperature of 55°C has been chosen as representative of the temperature inside equipment enclosures or chassis. Capacitors are typically chosen to have maximum rated voltages twice that of the intended operating voltage. Under such operating conditions all the capacitors in this study are expected to have lifetimes of a few decades. In other applications, replacement light bulbs for example, the temperature of operation can be much higher. In Figure 10, the expected lifetimes are shown versus temperature for devices operated at half the maximum rated voltage. For lifetimes exceeding 20 years, the ambient operating temperature of the capacitors needs to remain below 60°C in most cases. Inside the neck of several light bulbs the temperature is higher. Circuit tolerances therefore need to allow decreases in capacitance larger than 25%.

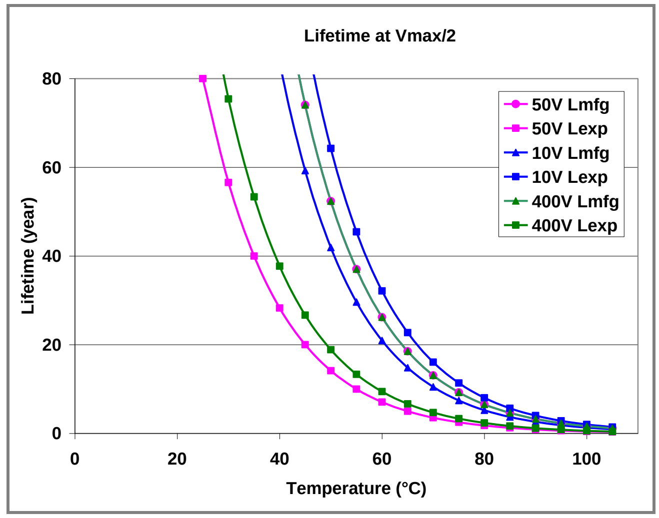


Figure 10. Experimentally predicted lifetime and manufacturer predicted lifetime of the three sets of capacitors if operated at Vmax/2 at various temperatures.

V. Dicussion and Conclusion

The test was done in accordance with the requirements specified in Telcordia gr357 core.001 MIL-STD-202 method 108 condition F and the parts passed the test.

- No failures up to 2000 hours in the 10V and 50V groups.
- Capacitor 602 failed before the start of the test. No additional failures have been observed in the 400V group at 2000 hours. Since one failure in 38 is acceptable, the capacitors passed the test.

The capacitance of all capacitors decreased over time and their ESR increased. The leakage current also decreased with time.

The weight of all capacitors decreased after 2000 hours. Vents were not opened and the bodies showed no bulges. Except for the large 400V group , where 8 out of 32 capacitors showed pin leakage, only a few other capacitors showed evidence of residue formation at the pins.

Although no failures were observed, the load life of two sets of capacitors fell short of the datasheet values. Nevetheless, lifetime predictions show reasonable expected lifetimes for all the capacitors in this study.

The effort needed to verify the lifetime of capacitors and qualify suppliers is enormous in terms of duration, chamber time, test set-up when compared to the cost of the capacitors themselves. Expensive equipment is tied up for over six months. Therefore these tests are rarely done. However we observe that in all three cases studied, the decrease of capacitance is very linear with time and shorter duration tests can be used effectively to weed out counterfeit devices or devices of poor quality.

REFERENCES:

[1] http://www.illinoiscapacitor.com/tech-center/life-calculators.aspx