Reliability of Low-Voltage Tantalum Polymer Capacitors

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Abstract

This paper briefly reviews earlier work which first assessed the reliability of 6V tantalum polymer capacitors. A physics-based acceleration formula that better models the interaction of voltage and temperature stress is presented and discussed. New observations are made about the original test data in light of the physics-based acceleration model as well as new testing done on 6V capacitors since the original paper was presented. Then the focus is shifted to accelerated lifetesting of 4V and 2.5V tantalum polymer capacitors.

Accelerated lifetest data for 4V and 2.5V capacitors are presented and are compared and contrasted with the 6V data. Similarities and differences in the behavior of the lower-voltage devices with respect to each other and the 6V devices are discussed. The physical bases of these similarities and differences are explored, and conclusions are reached regarding the expected long-term reliability of low-voltage tantalum polymer capacitors.

Introduction

The data from accelerated lifetesting of 6V tantalum polymer capacitors were first published one year ago.[1] It was found that the times-to-failure of the test samples were tightly distributed and could be accurately predicted for given stress levels of voltage and temperature. While the tight distribution of failures suggests the presence of distinct wear-out mechanisms, it also suggests that device lifetime can be accurately predicted, not only at accelerated conditions, but also at more normal operating conditions. For 100µF, 6V tantalum polymer capacitors in an EIA 3528-21 case, the test data suggest typical capacitor lifetimes approaching 1,000 years at rated voltage and 85°C.

The accelerated testing strategy and acceleration models employed in this initial assessment of reliability of tantalum polymer capacitors were borrowed from accelerated testing work done on multilayer ceramic capacitors by various researchers. In summary, the testing strategy is to apply much higher than normal stress (voltage and temperature) of various intensities to capacitors, and then precisely record the times-to-failure of devices in representative test samples. Failure is defined as blowing a 1 ampere fuse in a low-impedance lifetest circuit, and all test samples are drawn from one large, randomized population of capacitors. The relative times-to-failure observed at the various stress levels are compared with each other, and are then fitted to mathematical models for voltage and temperature acceleration so that times-to-failure at voltages and temperatures lower than those used in the investigation can be extrapolated.

It was found that typical times-to-failure were shorter when the voltage stress was raised or when the test temperature was increased. Also it was found that the relative time-distribution of these failures (the shape of a percentile plot of failures versus time) was not altered as the voltage and temperature were changed over a wide range. This behavior was interpreted to mean that no new failure mechanisms were being activated at any of the stress conditions employed in the investigation.

Finally it was found that if the times-to-failure of the various test samples were plotted on a common graph, the individual plots were uniformly spaced as the stress level (voltage or temperature) was changed. This boosted confidence that the data could be fit to appropriate mathematical models for voltage and temperature acceleration.

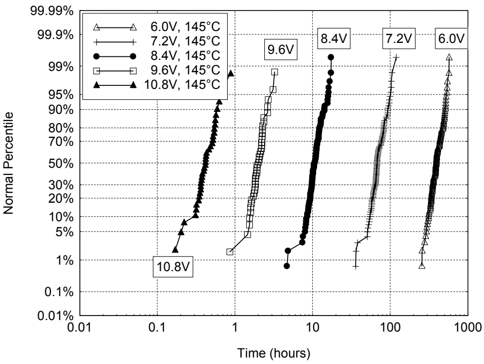

Figure 1. Lognormal Plot of Failure Percentile versus Time-To-Failure at 6.0V, 7.2V, 8.4V, 9.6V, and 10.8V for Tests Performed at 145°C on 100µF, 6V Tantalum Polymer Capacitors.

Figure 1 contains representative time-to-failure data from the original investigation that were recorded at various test voltages at a constant temperature of 145°C for 100µF tantalum polymer capacitors rated at 6V. These data clearly demonstrate (1) shorter lifetimes at higher voltages, (2) similarly shaped failure distributions, and (3) uniform, predictable spacing as the voltage is changed.

Figure 2 contains representative time-to-failure data from the original investigation that were recorded at various test temperatures at a constant voltage of 10.8V for capacitors rated at 6V. These data clearly demonstrate (1) shorter lifetimes at higher temperatures, (2) similarly shaped failure distributions, and (3) uniform, predictable spacing.

For each of the test samples subjected to a specific combination of voltage and temperature, a single statistic was assigned to quantify the relative performance of the samples at the specific cumulative stress level. Since the times-to-failure were found to be log-normally distributed in time, the chosen statistic was median life, denoted as t_{50}, which is the time when 50% of the test samples have failed. These t_{50} statistics were fit to the same empirical voltage acceleration model and Arrhenius temperature acceleration model that have been successfully used to describe the reliability of ceramic capacitors.[2,3]

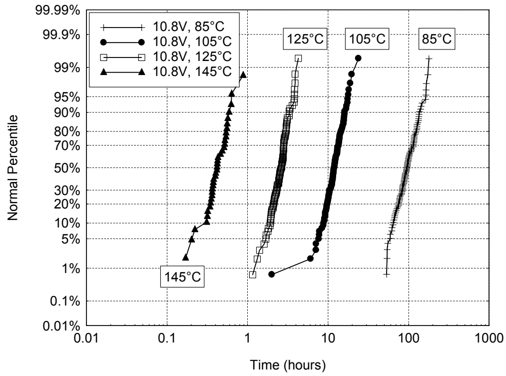

Figure 2. Lognormal Plot of Failure Percentile versus Time-To-Failure at 85°C, 105°C, 125°C, and 145°C for Tests Performed at 10.8V on 100µF, 6V Tantalum Polymer Capacitors.

The empirical voltage acceleration model employed in the initial investigation is the power law relationship given by Equation 1, where η is an empirically-derived exponent.

$$A = \frac{t_1}{t_2} = \left(\frac{V_2}{V_1}\right)^{\eta} \qquad (1)$$

For the 100µF, 6V tantalum polymer capacitors tested in the original investigation, it was found that the t_{50} times fit the empirical model of Equation 1 well at each temperature, but that the value of η was different at each temperature. Specifically, it was found that η=19 at 85°C, η=16.5 at 105°C, η=14.5 at 125°C, η=12.5 at 145°C and η=10.5 at 165°C. It is clear from these results that the voltage acceleration process is temperature dependent. Moreover, the temperature dependence likely fits some mathematical model, but that model was not identified during the investigation.

In Figure 3, the t_{50} times appear on a log-log plot that produces straight lines from the model of Equation 1. The log-log plot provides graphical means to discover the value of η at each temperature (the slope of the line), and to extrapolate t_{50} times at voltages outside the original range of test voltages.

Two data points in Figure 3 that correspond to (1) rated voltage at 145°C and (2) 1.2 times rated voltage at 125°C fell below the lines fit to the other data points at those temperatures. It was subsequently determined (and verified by means of independent testing of similarly processed capacitors) that these samples saw a different, harsher reflow profile during board mounting than did the other test samples. The correct data points (based on additional testing) are marked on the graph with the letter X.

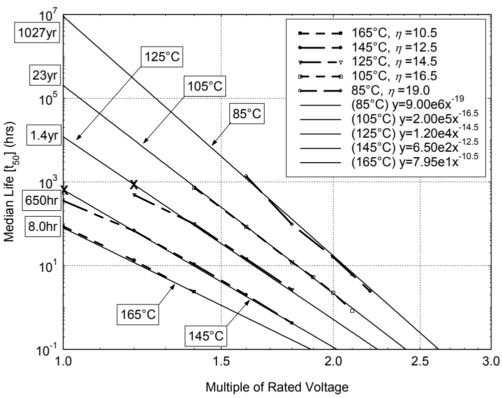

Figure 3. Plot of Median Life versus Test Voltage at 85°C, 105°C, 125°C, 145°C, and 165°C on Log-Log Scale for 100μF, 6V Tantalum Polymer Capacitors.

The Arrhenius temperature acceleration model employed in the initial investigation is given by Equation 2, where E_a is an empirically derived activation energy, k is Boltzmann's constant, and T is absolute temperature in Kelvins.

$$A = \frac{t_1}{t_2} = e^{\left[\frac{E_a}{k}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)\right]} \qquad (2)$$

For the 100μF, 6V tantalum polymer capacitors tested in the investigation, it was found that the t_{50} times fit the empirical model of Equation 2 well at each voltage, but that the value of E_a was different at each voltage (in cases where there were sufficient data to independently identify E_a). Specifically, it was found that E_a=1.75eV at 1.0V_r, E_a=1.55eV at 1.2V_r, E_a=1.40eV at 1.4V_r, E_a=1.25eV at 1.6V_r, and E_a=1.10eV at 1.8V_r. It is clear from these results that the temperature acceleration process is voltage dependent. Moreover, the voltage dependence likely fits some mathematical model, but that model was also not identified during the investigation.

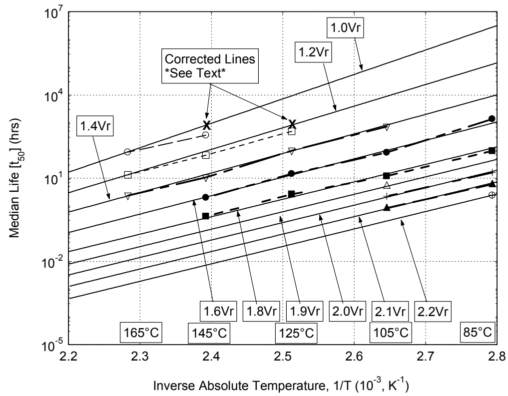

Figure 4. Plot of Median Life versus Inverse Absolute Temperature at 1.0Vr, 1.2Vr, 1.4Vr, 1.6Vr, 1.8Vr, 1.9Vr, 2.0Vr, 2.1Vr, and 2.2Vr on Semi-Log Scale for 100μF, 6V Tantalum Polymer Capacitors.

In Figure 4, the t_{50} times of the investigation appear on a semi-log plot that produces straight lines from the Arrhenius temperature acceleration model of Equation 2. The semi-log plot provides graphical means to discover the value of E_a at each voltage (the slope of the line), and to extrapolate t_{50} times at temperatures outside the original range of test temperatures.

Note that the value of E_a at 1.8V_r was originally reported as 1.25eV, but inspection of the graph of Figure 4 clearly shows smaller slope at 1.8V_r than at 1.6V_r. Also, the two data points in Figure 4 corresponding to 1.0V_r at 145°C and 1.2V_r at 125°C, are the same two data points that were corrected in Figure 3 because of a testing error. The corrected data points are marked on the graph of Figure 4 with the letter X.

In summary, the data of the original investigation clearly demonstrate (1) shorter lifetimes at higher voltages and higher temperatures, (2) similarly shaped failure distributions at the various stress levels, and (3) uniform, predictable spacing as the stress is changed. Moreover the t_{50} times (median life of the test sample) can be successfully fit to the empirical voltage acceleration formula of Equation 1 or to the Arrhenius temperature acceleration formula of Equation 2. The models can then be used to successfully extrapolate device performance at voltages and temperatures outside the range of the experimental data. One such extrapolation can be made from the top-most curve of Figure 3 where one observes that the curve predicts median life greater than 1000 years at $1.0V_r$ and 85°C. However, interaction is clearly evident between the voltage stress and the temperature stress, but this interaction was only identified, but not modeled in the original investigation. In the next section, a physics-based model is identified that better accommodates the voltage-temperature interaction that clearly exists in the test data. The data of the original investigation are fit to this new model, and the quality of the fit is discussed.

Physics-Based Model

During the question and answer session following presentation of the original work, and during subsequent private communications, Dr. Yuri Pozdeev-Freeman of Vishay-Sprague suggested that the voltage and temperature acceleration data might better fit a physics-based model that he and his colleagues developed and published at his previous place of employment in Russia. He reported successful correlation of accelerated test data of low-voltage MnO_2 tantalum capacitors with this model. He further identified oxygen-ion migration in the anodic oxide as the dominant degradation mechanism.

The physics-based model is given in Equation 3.

$$t = t_0 e^{\left[\frac{(W-\alpha U)}{kT}\right]} \qquad (3)$$

In Equation 3, W represents the activation energy of the migration of oxygen ions, αU represents reduction of this energy by the action of the electric field in the dielectric, t is the time to failure, t_0 is an empirically derived constant, k is Boltzmann's constant, and T is the absolute temperature in Kelvins. Dr. Freeman further explained that during testing of conventional MnO_2-based tantalum capacitors, it was found that W=1.8+/-0.1eV and αU=0.4+/-0.04eV at U=rated voltage.

The instant appeal of the physics-based model is the seamless integration of both the voltage and temperature stress factors into one equation and the explicit interdependence of these two kinds of stress. The data of the original investigation are fit to the physics-based model of Equation 3 and appear in Figure 5.

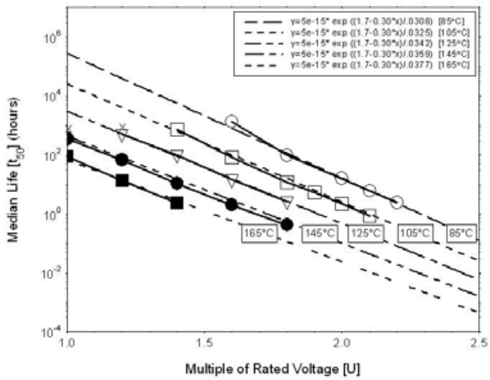

Figure 5. Plot of Median Life versus Test Voltage at 85°C, 105°C, 125°C, 145°C, and 165°C on Semi-Log Scale for 100μF, 6V Tantalum Polymer Capacitors to Evaluate Fit of Original Test Data to Physics-Based Model.

The fit of the accelerated test data to the physics-based model is quite good. The interaction between the voltage stress and temperature stress is successfully captured by the model. Moreover, the value of W was found to be 1.7eV and the value of αU was found to be 0.3eV at rated voltage. Such good agreement of the test data with the physics-based model, and with the values of W and αU suggested by Dr. Freeman, almost certainly indicates that the primary degradation mechanism at work in these capacitors is oxygen-ion migration in the dielectric.

But the accelerated test data do not fit the model perfectly, and this imperfection-of-fit deserves some attention. Specifically, there is curvature in every line of Figure 5 that connects the voltage data points associated with a fixed temperature. Actual reliability performance always improves more as the voltage is lowered than is suggested by the model. Even when the corrected data points at

$1.0V_r$ @ 145°C and $1.2V_r$ @ 125°C are ignored, only the line at 125°C appears to be straight on the semi-log graph that allows linear plotting of Equation 3. But ignoring these corrections does make these lines have different shape than the lines at the other temperatures, a strong indication of the need to correct some kind of error in the original data.

Because the physics-based model of Equation 3 so elegantly fits the experimental data with respect to the interaction of voltage and temperature, much effort has been expended to establish whether the curvature of the lines of Figure 5 simply represents systematic experimental error, or whether the curvature indicates one or more factors that are unaccounted-for in the model.

A follow-up experiment was carefully designed to explore this issue. Additional capacitors were randomly selected from the same population of capacitors that was used to correct the erroneous two data points in Figures 3 through 5. These samples were mounted on 20- piece test cards, all during the same afternoon. After the surface-mounting process, the test cards were again randomized and five 20-piece cards were chosen for four 100-piece test samples. These test samples were installed in fixturing in a single high-performance test chamber. This chamber has proven-good thermal distribution and airflow. Moreover, the

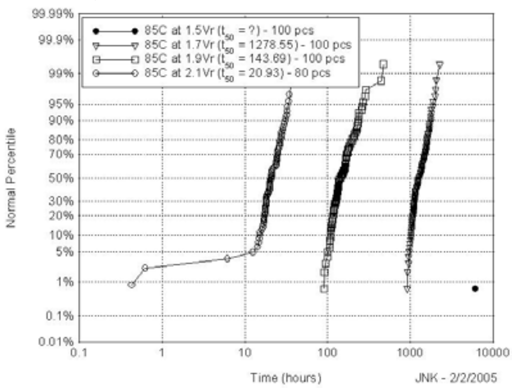

Figure 6. Lognormal Plot of Failure Percentile versus Time-To-Failure at $1.5V_r$, $1.7V_r$, $1.9V_r$, and $2.1V_r$ for Model Validation Test Performed on 100µF, 6V Tantalum Polymer Capacitors at 85°C.

cards were installed in the oven fixturing such that the order of installation was one card from each sample followed by one card from the next sample, etc., until all cards from the four 100-piece samples were evenly distributed over the test space in the oven. All power supplies, fixturing, and wiring were made as similar for each of the test samples as was practicable. The only deliberate difference was the voltage settings of the power supplies which were set to $1.5V_r$, $1.7V_r$, $1.9V_r$, and $2.1V_r$. The oven was set to 85°C.

The range of voltages was shifted to somewhat lower voltages than were used for the original investigation. The objective was to strongly emphasize any deviation of the resulting measured data from either the empirical voltage acceleration model of Equation 1 or the physics-based model of Equation 3. Such deviations appear to be most strongly pronounced at lower voltages. Also there was a desire to do testing closer to rated voltage since the real aim of the investigation was to validate one or both of the models as providing believable prediction of lifetime at the maximum rated conditions of the capacitors. This objective motivated the choice of 85°C as the test temperature since the voltage rating of these capacitors is reduced at temperatures above 85°C.

All time-to-failure data from this experiment available at the time of writing appear in Figure 6. There are a few early failures in the $2.1V_r$ sample, but otherwise the data are very uniform with each failure distribution having similar shape. Only one failure has occurred in the $1.5V_r$ sample. It is too early to know for sure whether this is an early failure or the first true wear-out failure from the $1.5V_r$ sample.

Even with all the care and attention that this experiment received, one mistake was made. The capacitors on one of the test cards randomly assigned to the $2.1V_r$ sample were mounted with reverse polarity. These capacitors overloaded the power supply upon application of voltage and prevented starting of the $2.1V_r$ test. This card of capacitors was electrically disconnected from the test system and the test was re-started, albeit with only 80 capacitors instead of 100. It is fully expected that the time-to-failure data generated from the 80 remaining capacitors are valid.

Figure 7 contains the t_{50} data from the follow-up experiment. The t_{50} data are fit to the empirical power-law model of Equation 1 and plotted on log-log scales. The available t_{50} data and a line fit to the power-law model appear in the figure, and the fit to the power-law model of Equation 1 is clearly very good. The final test regarding the quality of fit will be when the t_{50} data point is available at $1.5V_r$. Unfortunately, the model projects that this data point will not be available until roughly 13,000 hours after the start of the test. As of the time of writing, the test has been running for roughly 6,200 hours, or roughly half the necessary time. The first failure occurred after 6,168 hours for the capacitors being tested at $1.5V_r$, so simply by observing the shape of the other time-to-failure curves, the t_{50} point is not likely to be reached any time before 10,000 hours at the very least. It is more likely that the actual t_{50} time will occur very close to the time predicted by the power-law model.

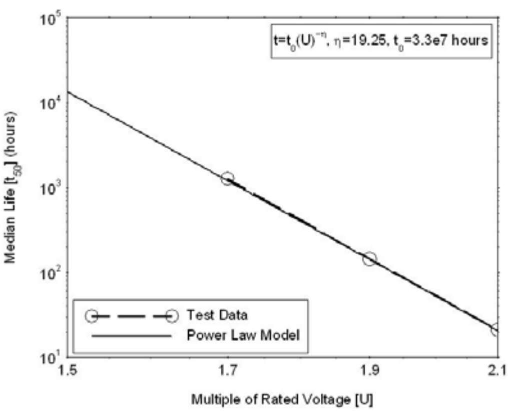

Figure 7. Plot of Median Life versus Multiple of Rated Voltage at 85°C on Log-Log Scale to Check the Validity of the Power-Law Model for 100µF, 6V Tantalum Polymer Capacitors.

In contrast, Figure 8 contains the t_{50} data fit to the physics-based model of Equation 3 and plotted on semi-log scales. The fit is not as good as is seen in Figure 7. The t_{50} point at $1.7V_r$ is already high and it is now clear that the t_{50} point at $1.5V_r$ will also be high since only the first failure has occurred at 6,168 hours and the model predicts that t_{50} should occur at 7,300 hours. Based on the shape of the other time-to-failure curves, the actual t_{50} time will be in excess of 10,000 hours which is much higher than the value predicted by the model.

So while the physics-based model does an excellent job of combining the voltage and temperature stresses into a single elegant form, the voltage acceleration data simply fit the empirical power-law model better, at least at constant temperature. The reason why this distinction is important is that the empirical model predicts twice the life at $1.5V_r$ than does the physics-based model, and approximately 35 times the life at $1.0V_r$. Since the models will be used to predict lifetest performance at $1.0V_r$ and 85°C as well as life at customer application conditions (which are typically less stressful than these), the choice of model can significantly affect the accuracy of the prediction.

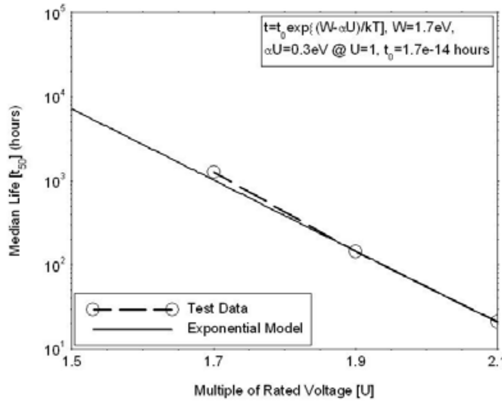

Figure 8. Plot of Median Life versus Multiple of Rated Voltage at 85°C on Semi-Log Scale to Check the Validity of the Physics-Based Model for 100µF, 6V Tantalum Polymer Capacitors.

This minor discrepancy is not a good reason to dismiss the physics-based model. The physics-based model is certainly a better *kind* of model. Rather, reasons should be sought to explain why the data do not fit it as precisely as desired. One obvious explanation is that there is another failure mechanism at work and that this additional mechanism has different activation energy and voltage sensitivity than does the oxygen-ion migration mechanism. Indeed, the values of W and αU that were observed for these capacitors are at the edge or slightly out of the range suggested by

Dr. Freeman. This may be an indicator that an additional degradation mechanism is at work.

The idea of two failure mechanisms that have the mathematical form of the physics-based model is explored graphically in Figure 9. It is demonstrated in Figure 9 that the desired curvature needed to match the test data to the physics-based model can be achieved by introducing a second degradation mechanism having W=2.5eV and αU=0.45eV at $U=V_r$. These values of W and αU are consistent with a degradation mechanism that has proportionately less negative impact on predicted life at lower (versus higher) voltages and temperatures than does the oxygen-ion migration mechanism.

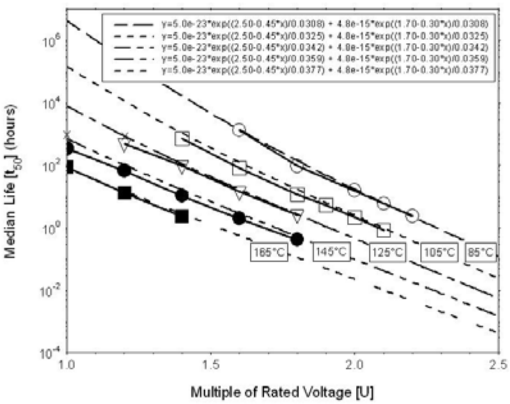

Figure 9. Plot of Median Life versus Multiple of Rated Voltage at 85°C on Semi-Log Scale for Exploration of the Physics-Based Model with Two Failure Mechanisms for 100µF, 6V Tantalum Polymer Capacitors.

At this time, the most likely candidate for this second degradation mechanism is field-driven crystallization of the normally amorphous oxide dielectric. There are plans to test this hypothesis in the future.

Accelerated Testing of 4V and 2.5V Capacitors

Progress has also been made in characterizing the voltage acceleration behavior of capacitors with rated voltages other than 6V. Specifically, accelerated lifetests have been conducted on 4V and 2.5V capacitors at 85°C.

The 4V capacitors were 1000µF devices having EIA 7343 footprint and 4.3 mm nominal height. These capacitors also were ultra-low ESR devices built with multiple-anode construction.

After some preliminary scouting tests, it was determined that test voltages between 9.8V and 11.0V at 85°C would generate times-to-failure between 1 hour and 100 hours (a desirable time range for accelerated testing). Randomly selected 100-piece samples were tested at 9.8V, 10.2V, 10.6V, and 11.0V and 85°C. The time-to-failure data of this testing appear in Figure 10. For these capacitors, there were a few early out-of-population failures, but the rest of the capacitors failed with predictable statistical distributions of times-to-failure.

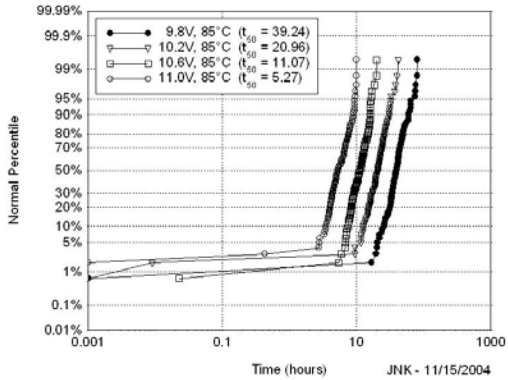

Figure 10. *Lognormal Plot of Failure Percentile versus Time-To-Failure at 2.45V_r, 2.55V_r, 2.65V_r, and 2.75V_r for 1000µF, 4V, Multiple-Anode Tantalum Polymer Capacitors Tested at 85°C.*

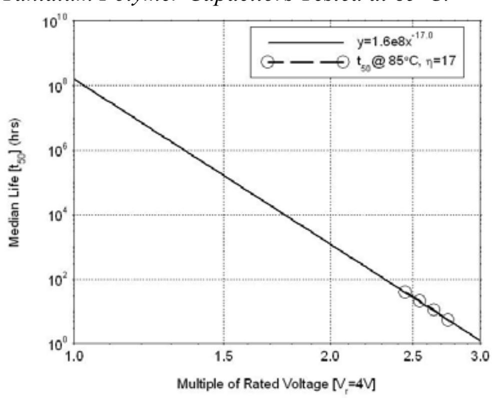

Figure 11. Plot of Median Life versus Multiple of Rated Voltage at 85°C on Log-Log Scale for

1000µF, 4V, Multiple-Anode Tantalum Polymer Capacitors Tested at 85°C.

The t_{50} times-to-failure were plotted on a log-log-scaled graph along with a straight line representing the best fit to the power-law acceleration equation. These data appear in Figure 11. In contrast to the 6V capacitors discussed previously, the voltage ratio exponent of the 4V capacitors at 85°C is η=17 which is lower than η~19 for the 6V devices.

It is speculated that there is a fundamental difference in the behavior of very-low-voltage tantalum polymer capacitors because the "air oxide" generated as the anodes are exposed to the atmosphere after high-temperature sintering makes up a higher percentage of the total thickness of the dielectric. Perhaps oxygen diffusion is somehow interrupted at the boundary between the air oxide and the anodic oxide in these low-voltage capacitors. Or perhaps the electric field is distributed non-proportionately between the air oxide and the anodic oxide in a fashion that deemphasizes the electric field's influence on oxygen-ion diffusion rates in one of the two kinds of oxide. This topic is certainly worthy of additional research.

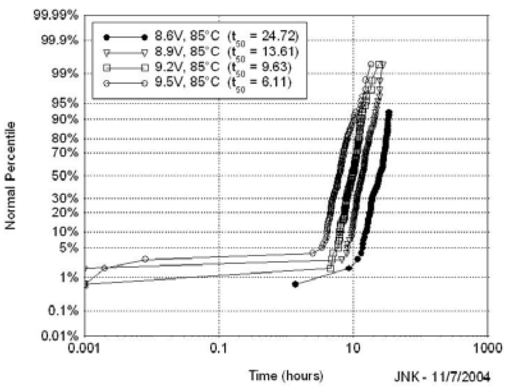

Figure 12. *Lognormal Plot of Failure Percentile versus Time-To-Failure at 3.44V_r, 3.56V_r, 3.68V_r, and 3.80V_r for 680µF, 2.5V, Multiple-Anode Tantalum Polymer Capacitors Tested at 85°C.*

Regardless of the mechanisms at work, the practical result is that these capacitors are capable of very high reliability. The data of Figure 11 predict the median life of these capacitors at rated voltage and 85°C to be 160 million hours or roughly 18,000 years. Given the shape of the times-to-failure distributions in Figure 10, normal wear-out would start at about 7,000 years, a very long life. Finally, the small percentage of freak failures at the low end of the distribution could easily be removed from the population by means of a very short exposure to 9.8V at 85°C prior to final screening. This voltage exposure would not consume any meaningful fraction of the life expectancy of the surviving capacitors.

680µF, 2.5V capacitors were also investigated. These capacitors have EIA 7343 footprint and 4.0 mm maximum height. These capacitors are also ultra-low ESR devices built with multiple-anode construction.

After preliminary scouting, it was determined that test voltages between 8.6V and 9.5V at 85°C would generate times-to-failure between 1 hour and 100 hours. Randomly selected 100-piece samples were tested at 8.6V, 8.9V, 9.2V, and 9.5V and 85°C. The time-to-failure data of this testing appear in Figure 12. For these devices, there also were some early out-of-population failures, but the rest of the capacitors failed with predictable statistical distributions of times-to-failure.

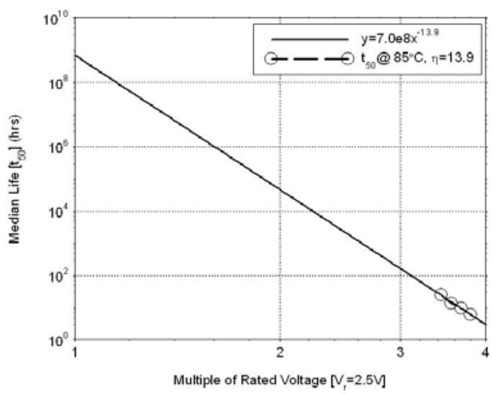

Figure 13. Plot of Median Life versus Multiple of Rated Voltage at 85°C on Log-Log Scale for 680µF, 2.5V, Multiple-Anode Tantalum Polymer Capacitors Tested at 85°C.

The t_{50} times-to-failure were plotted on a log-log-scaled graph along with a straight line representing the best fit to the power-law acceleration equation. These data appear in Figure 13. The voltage ratio exponent of these 2.5V capacitors is η=13.9, which is even lower than that seen for the 4V parts (η=17), and very much lower than that seen for the 6V devices (η~19) when all were tested at 85°C.

It is interesting to observe that the voltage ratio exponent of the 4V capacitors (η=17) falls close to the geometric mean (16.3) of the exponent for the 2.5V capacitors (η=13.9) and the exponent for the 6V parts (η ~19). Of course any true relationship would depend more directly on the oxide formation voltage than it would depend on rated voltage. But some relationship surely exists between the acceleration exponent and the capacitor's dielectric thickness. This relationship is worthy of further investigation.

Like the 4V tantalum polymer capacitors, the 2.5V tantalum polymer capacitors are capable of very high reliability. The data of Figure 13 predict the median life of these capacitors at rated voltage and 85°C to be 700 million hours or roughly 80,000 years. Given the shape of the times-to-failure distributions in Figure 12, normal wear-out should start at about 25,000 years, an exceptionally long time. Finally, the small percentage of freak failures at the low end of the distribution could easily be removed from the population by means of a very short exposure to 9.5V at 85°C prior to final screening.

Summary and Conclusions

Low-voltage tantalum polymer capacitors are especially well suited for accelerated testing. Their times-to-failure are generally tightly distributed and there are very few early or "freak" failures.

The very first systematic reliability investigation of these capacitors was published one year ago. This work investigated the performance of 100µF, 6V, EIA 3528-21 case size capacitors. These capacitors were found to have expected median life in excess of 1000 years in spite of having such high capacitance and rated voltage in such a small case volume.

The highlights of this initial investigation are reviewed in this paper to set the stage for discussion of subsequent follow-up work done over the last year. The empirical voltage and temperature acceleration formulas employed in the original investigation are reviewed, and interaction between these originally-assumed-independent stress factors is discussed.

A different, physics-based model is described that is based on the oxygen-ion-diffusion degradation mechanism. This model elegantly combines both the voltage and temperature stress factors and suggests the nature of the interaction between these stresses. The data of the original investigation are found to fit this model quite well, but a small discrepancy exists between the model and laboratory observations.

Carefully designed follow-up investigations on additional capacitors of the same description and manufacturing process are described. These tests were performed to determine whether the small discrepancy between the physics-based model and the experimental data was real or simply systematic testing error.

There is now sufficient evidence that the discrepancy is real. An effort has been made to identify the reason for the discrepancy. It is suspected that a second degradation mechanism other than oxygen-ion diffusion is at work, but this mechanism has different voltage and temperature sensitivity. Graphical construction of hypothetical combinations of degradation mechanisms having the mathematical form of the physics-based model demonstrates that modeling two simultaneous mechanisms can account for the observed discrepancies quite well. A possible suspect for the second mechanism is electric-field-driven crystallization of the tantalum oxide dielectric.

Finally, testing performed on 4V and 2.5V tantalum polymer capacitors is discussed. Two significant findings are made. First, the exponent of the empirical voltage acceleration formula was lowest for the 2.5V capacitors (η=13.9) and slightly higher for the 4V capacitors (η=17). Both of these values are lower than that found for the 6V capacitors (η~19). Second, the expected median life of the 2.5V capacitors was better than that of the 4V capacitors, and both of these lower-voltage parts had better expected median life than did the 6V capacitors. This leads to the suggestion that there could be a physical link between the observed acceleration exponent and the ultimate reliability of tantalum polymer capacitors. This link should be further explored.

In conclusion, not only has accelerated testing provided an effective means to assess the expected reliability of tantalum polymer capacitors, but also it has provided a window through which the fundamental workings of tantalum capacitors can be explored. It was found in this work that the expected life of low-voltage tantalum polymer capacitors is generally excellent, with reliability greater than that required for almost all applications. But important questions still remain regarding the specific degradation mechanisms at work in these capacitors, and future effort should be focused on answering these questions.

References

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