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## **Accelerated Testing of Systems and Assemblies**

Accelerated testing is a powerful tool that can be effectively used in two very different ways: in a qualitative or in a quantitative manner. Qualitative accelerated testing is used primarily to identify failures and failure modes while quantitative accelerated testing is used to make predictions about a product's life characteristics (e.g., MTTF, B10 life, etc.) under normal use conditions. In accelerated testing the quantitative knowledge builds upon the qualitative knowledge. Using accelerated testing in a quantitative manner requires a Physics-of-Failure approach i.e., a comprehensive understanding and application of the specific failure mechanism involved and the relevant activating stress(es).

**The RAC is frequently asked the question, "How can I accurately estimate the reliability of a new system or assembly using an accelerated test?"**

It is sometimes suggested that a Highly Accelerated Life Test (HALT) might be used. Used as a qualitative tool i.e., to identify design or component weaknesses and manufacturing process problems, HALT testing can be very effective. The results of the tests are then used to increase the margin of strength of the design. However, HALT is not an effective quantitative tool i.e., to predict the life or reliability of the product. Correlation of this type of test data to actual use is extremely difficult, some of the failure modes exposed may not even occur in the normal operating or non-operating envelope.

**Unfortunately, there is no single magic analytical model that can accurately estimate the life of complex assemblies or systems. Each life analytical model describes physical change mechanisms associated with specific material characteristics.**

**Constructing an accurate quantitative accelerated test requires the following steps:**

1. Define the anticipated failure mechanisms in terms of the materials used in the product to be tested. Remembering, of course, that the majority of "electrical failures" are basically mechanical or chemical in nature.
2. Determine the environmental stresses to which the product will be exposed when operating and when not operating or stored.
3. Based on the failure mechanisms that are anticipated to limit the life of the product; choose a test, or combination of tests, that will accelerate that failure mechanism(s).
4. Relevant acceleration models that should be considered include:
  - Arrhenius Temperature Acceleration for temperature and chemical aging effects
  - Inverse Power Law for any given stress
  - Miner's Rule for linear accumulated fatigue damage
  - Coffin-Manson non-linear mechanical fatigue damage
  - Peck's Model for temperature and humidity combined effects
  - Eyring/Black/Kenney models for temperature and voltage acceleration

Table 1 describes each of these models, their relevant parameters and frequent applications of each.

## Accelerated Testing of Systems and Assemblies (Cont'd)

Table 1. Frequently Used Acceleration Models, Their Parameters and Applications

Model Name	Description/ Parameters	Application Examples	Model Equation
Arrhenius Acceleration Model	Life as a function of Temperature or Chemical Aging	Electrical Insulation and Dielectrics, Solid State and Semiconductors, Intermetallic Diffusion, Battery Cells, Lubricants & Greases, Plastics, Incandescent Lamp Filaments	$\text{Life} = A_0 e^{-\frac{E_a}{kT}}$ <p>where:            Life = median Life of a population            A<sub>0</sub> = scale factor determined by experiment            e = base of natural logarithms            E<sub>a</sub> = Activation Energy (Unique for each failure mechanism)            k = Boltzmann's constant = 8.62 x 10<sup>-5</sup> eV/K            T = Temperature (degrees Kelvin)</p>
Inverse Power Law	Life as a function of any given stress	Electrical Insulation and Dielectrics (Voltage Endurance), Ball & Roller Bearings, Incandescent Lamp Filaments, Flash Lamps	$\frac{\text{Life at normal stress}}{\text{Life at accelerated stress}} = \left( \frac{\text{Accelerated stress}}{\text{Normal stress}} \right)^N$ <p>where:            N = Acceleration factor</p>
Miner's Rule	Cumulative Linear Fatigue Damage as a function of Flexing	Metal Fatigue (Valid only up to the yield strength of the material.)	$CD = \sum_{i=1}^k \frac{C_{Si}}{N_i} \leq 1$ <p>where:            CD = Cumulative damage            C<sub>Si</sub> = Number of cycles applied @ stress S<sub>i</sub>            N<sub>i</sub> = number of cycles to failure under stress S<sub>i</sub> (determined from an S-N diagram for that specific material)            k = number of loads applied</p>
Coffin-Manson	Fatigue Life of Metals (Ductile Materials) due to Thermal Cycling and/or Thermal Shock	Solder Joints and other connections	$\text{Life} = \frac{A}{(\Delta T)^B}$ <p>where:            Life = Cycles to failure            A = scale factor determined by experiment            B = scale factor determined by experiment            ΔT = Temperature change</p>
Peck's	Life as a combined function of Temperature and Humidity	Epoxy packaging	$\tau = A_0 (RH)^{-2.7} \exp\left[\frac{0.79}{kT}\right]$ <p>where:            τ = median life (time-to-failure)            A<sub>0</sub> = scale factor determined by experiment            RH = Relative Humidity            k = Boltzmann's constant = 8.62 x 10<sup>-5</sup> eV/K            T = Temperature (degrees Kelvin)</p>

## Accelerated Testing of Systems and Assemblies (Cont'd)

Table 1. Frequently Used Acceleration Models, Their Parameters and Applications (Cont'd)

Model Name	Description/ Parameters	Application Examples	Model Equation
Peck's Power Law	Time to Failure as a function of Relative Humidity Voltage and Temperature	Corrosion	$TF = A_0 * RH^N * f(V) * \exp[E_a/kT]$ where: TF = Time-to-Failure A <sub>0</sub> = scale factor determined by experiment RH = Relative Humidity N = ~2.7 E <sub>a</sub> = 0.7-0.8 eV (appropriate for aluminum corrosion when chlorides are present) f(V) = an unknown function of applied voltage k = Boltzmann's constant = 8.62 x 10 <sup>-5</sup> eV/K T = Temperature (degrees Kelvin)
Eyring/Black/Kenney	Life as a function of Temperature and Voltage (or current density (Black))	Capacitors, Electromigration in Aluminum conductors	$\tau = \frac{A}{T} \exp\left[\frac{B}{kT}\right]$ where: τ = median life (Time-to-Failure) A = scale factor determined by experiment B = scale factor determined by experiment k = Boltzmann's constant = 8.62 x 10 <sup>-5</sup> eV/K T = Temperature (degrees Kelvin)
Eyring	Time to failure as a function of Current, Electric Field and Temperature	Hot Carrier Injection, Surface Inversion, Mechanical Stress	$TF = B(I_{sub})^N \exp(E_a/kT)$ where: TF = Time-to-Failure B = scale factor determined by experiment I <sub>sub</sub> = peak substrate current during stressing N = 2 to 4 E <sub>a</sub> = -0.1 eV to -0.2 eV (note the apparent activation energy is <b>negative</b> ) k = Boltzmann's constant = 8.62 x 10 <sup>-5</sup> eV/K T = Temperature (degrees Kelvin)
Thermo-mechanical Stress	Time to failure as a function of change in Temperature	Stress generated by differing thermal expansion rates	$TF = B_0 (T_0 - T)^{-n} \exp(E_a/kT)$ where: TF = Time-to-Failure B <sub>0</sub> = scale factor determined by experiment T <sub>0</sub> = stress free temperature for metal (approximate metal deposition temperature for aluminum) n = 2 - 3 E <sub>a</sub> = 0.5 - 0.6 eV for grain-boundary diffusion, ~ 1 eV for intra-grain diffusion k = Boltzmann's constant = 8.62 x 10 <sup>-5</sup> eV/K T = Temperature (degrees Kelvin)

Further information on this topic may be found in a series of excellent documents published by JEDEC Solid State Technology (Source references 1-4) <http://www.jedec.org/>. They deal in depth with the topic of accelerated testing based upon a Physics-of-Failure approach that addresses specific failure mechanisms in electronic components.

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## **Accelerated Testing of Systems and Assemblies (Cont'd)**

### **Source:**

- JEDEC JEP143 Solid State Reliability Assessment and Qualification Methodologies (November 2001).
- JEDEC JEP122B Failure Mechanisms and Models for Semiconductor Devices (August 2003).
- JEDEC JESD91A Method for Developing Acceleration Models for Electronic Component Failure Mechanisms (August 2003).
- JEDEC JEP148 Reliability Qualification of Semiconductor Devices Based on Physics of Failure Risk and Opportunity Assessment (April 2004).
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- Seager, J.D., A Method to Predict an Average Activation Energy for Subassemblies, IEEE, Transactions on Reliability, Vol. #37, No.5, 1988. *A search for a single test value, using a combination process to average the expected component activation energies.*
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- Vassiliou, P., Mettas, A., Understanding Accelerated Life-Testing Analysis, 2001 Reliability and Maintainability Symposium Tutorial. *A synopsis of problems and pitfalls of accelerated testing.*