



Use Condition Based Reliability Evaluation of New Semiconductor Technologies

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Abstract: The use conditions methodology offers a reliability evaluation methodology based on the use conditions a component is expected to encounter in its market applications. Package/assembly technologies are utilized throughout this white paper as examples for clarity. However, the concepts are directly applicable to silicon and product technologies. The use condition methodology is based on an understanding of the end user conditions expected to be encountered by the technology. Based on this understanding, detailed process steps are described for the supplier to establish the reliability stress program and evaluate all encountered failure mechanisms. Three major end use segments were developed as examples for this paper: Indoor, Mobile, and Other. An understanding of the failure mechanisms, acceleration models, and their relation to the component's application is included in the qualification procedure. Compared to stress-based methods, this approach requires more knowledge about the physics of failure mechanisms and about the anticipated use of the component.

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EXECUTIVE SUMMARY

Increased package performance expectations, new packaging materials and market segmentation are key trends in today's semiconductor industry. The SEMATECH Reliability Technology Advisory Board (RTAB) has developed a reliability test methodology to keep pace with these market trends. The RTAB's Use Conditions Methodology offers a reliability evaluation methodology based on the use conditions a component is expected to encounter in its market applications. Reliability test methods have typically been based on prescribed stress test conditions. For new advanced technologies focusing on specific market segments, these prescribed stresses may produce false failures or not accelerate valid failures because the stress conditions do not closely correlate to the actual use environment. The Use Condition Methodology provides for selecting stress conditions based on knowledge of the components usage environment. An understanding of the failure mechanisms, acceleration models and their relation to the component's application is included in the qualification procedure. Compared to stress-based methods, this approach requires more knowledge about the physics of failure mechanisms and about the anticipated use of the component. It also requires the producers to derive the stress conditions for reliability evaluation, rather than following a prescribed table of stress conditions in a specification. Industry adoption of this approach is needed to help bring advanced performance technologies to market.

INTRODUCTION

This White Paper describes a process for using "use conditions" as the basis for validating the reliability of semiconductor technologies. Package/Assembly technologies are utilized throughout the White Paper as examples for clarity, however the concepts are directly applicable to Silicon and Product technologies.

The process is based on an understanding of the end user conditions expected to be encountered by the technology. Based on this understanding of the application, the supplier establishes the reliability stress program and evaluates all encountered failure mechanisms. There are 3 major use conditions or end use segments; Indoor, Mobile and Other. Each segment encompasses a range of conditions. The supplier and customer are expected to work together to refine the conditions within the ranges based on the specifics of the application.

SCOPE

This White Paper applies the process to new package or assembly technologies. Silicon and product technologies can also utilize the approach. Modifications and extensions of existing technologies can benefit from this method if the use conditions for the existing technology are known.

REFERENCE DOCUMENTS

EIA/JEDEC:

EIA/JEP122	"Failure Mechanisms and Models for Silicon Semiconductor Devices"
EIA/JEP131	"Process Failure Modes and Effects Analysis (FMEA)"
JESD22-A113	"Preconditioning of Plastic Surface Mount Devices Prior to Reliability Testing"

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RTAB Paper on Acceleration Factors, Models & Reliability Statistics (August 1999)
"Use Conditions Based Reliability Evaluation - An Example Applied to BGA Packages"

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PROCEDURE

Figure 1 depicts the process flow for “Use” condition certification. The following paragraphs describe each step in the flow.

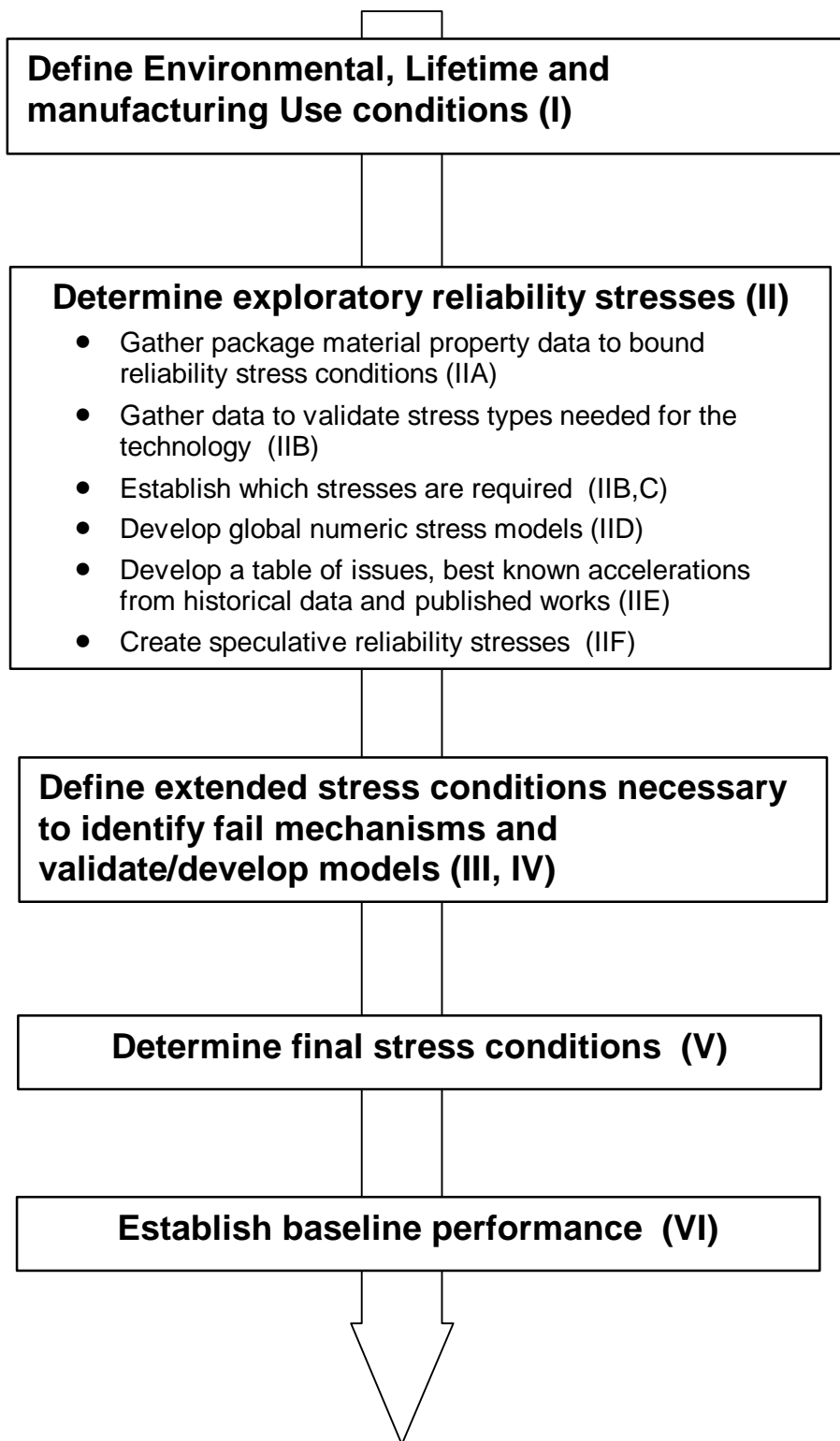


Figure 1
Use Condition Reliability Validation

I. Definition of Environmental, Lifetime, and Manufacturing Conditions:

This is one of the most critical steps in the process as it provides the basis for all follow on activities. Decisions made at this point will be utilized at all future steps. Determining the target market segment establishes the use environment and lifetime appropriate for the technology. There may be significant overlap as products may be sold into more than one market, necessitating a testing envelope that encompasses all of the relevant markets (environment/lifetime). The major market segments are:

- Indoor: PC/ Desktop, Server, Workstation, Consumer
- Consumer Portable: Notebook PCs, PDAs, Cel Phones, etc.
- Other: Automotive, Telecom switching, Unattended outside, etc.

Table 1 - Examples of Major Market Segment Environmental Ranges

MAJOR MARKET SEGMENT	OP LIFE	POWER ON (Hrs / week)	CYCLES / DAY	MOISTURE @ Low Power	OP TEMP (ambient in enclosure)	STORAGE TEMP
INDOOR	5 – 10 yrs	60 – 168	Env. Cycle: 1-2 Power Cyc: 2-4	30°-36°C @ 85-92%RH	0° to 40°C	-40° to 50°C
CONSUMER PORTABLE	5 – 10 yrs	60 – 168	Env. Cycle: 2-4 Power Cyc: 4-6	30°-36°C @ 85-92%RH	-18° to 55°C	-40° to 55°C
OTHER	7 – 25 yrs	20 – 168	Env. Cycle: 2-4 Power Cyc: 2-10	30°-36°C @ 85-92%RH	-55° to 125°C	-40° to 55°C

The condition ranges in Table 1 are meant to be used as guides. Determination of exact conditions may require discussion between the supplier and individual customers.

The expectation is that Table 1 will encompass the vast majority of specific conditions in each segment. The methodology described here can and should be applied to conditions outside Table 1, assuming supplier and customer agree. In addition to the conditions in Table 1, it is important to understand the manufacturing and shipping environments (Hot/Cold, Humidity, Vibration, Shock, etc.) the component will see prior to use. An example of this is the use of Preconditioning, per JEDEC A113, prior to certain environmental stresses on surface mount devices.

As each market segment can have various failure rate requirements, the cumulative failure rate goals at end-of-life need to be defined. Existing supplier goals are recommended as a benchmark for this requirement.

II. Determination of Exploratory Reliability Stresses:

The goal of this step is to establish a set of initial exploratory reliability stresses for collecting failure mechanism data. Since this and the following steps may require modeling and data interpretation, it may be helpful to form a team of content experts including Quality/Reliability Engineering, Materials Engineering, Design, Numeric Model Experts, and Silicon Reliability Engineers (if the package technology could have an interaction with the silicon technology). FMEA is a useful procedure to help accomplish this step. EIA/JEDEC publication EIA/JEP131 "Process Failure Modes and Effects Analysis (FMEA)" is a good reference for this procedure.

This step is divided into a number of activities.

IIA). Bound the reliability stress conditions so that they aren't set beyond the physical capability of the assembly materials, as this may result in false or artifactual failures. These physical limits may put upper and/or lower limits on the stress. This material property data will also be used in establishing global numeric stress – strain models in step IID. . Typical material property data needed includes:

- CTE
- Modulus as a function of temperature
- Elongation as a function of temperature
- Creep propertiesGlass transition temperature

IIB). Determine which stresses are required to accelerate each of the market segment environments using the data gathered in steps I and IIA. The most commonly used stresses are:

- Temperature cycling (air to air cyclic stress)

- Thermal shock (liquid to liquid cyclic stress that can be more severe than temperature cycling. It has very fast ramp rates and shorter cycle times than temperature cycle.)
- Temperature, Humidity and Bias (THB)
- 85 °C/85% RH (non-condensing and run at atmospheric pressure)
- Highly Accelerated Stress Test (HAST) combines high temperature with humidity (typically 85% RH) in a non-condensing atmosphere (requires a pressure vessel)
- Pressure Cooker (PCT) - unbiased with conditions of 121 °C/100% RH (requires a pressure vessel)
- Power cycling
- Shock
- Vibration
- Preconditioning

IIC). Determine if there are new requirements or uses that may require a new stress type. Two examples of this are “mated pair” testing where the component may need to be tested in a socket because the stress state changes due to socket/component interaction and preconditioning which simulates moisture uptake and high temperature solder reflow as seen during customer (OEM) manufacturing.

IID). Develop global, numeric stress models for the package. These models should be used to determine if there are any high stress areas in the package which might require special attention and evaluation. The areas identified should be evaluated pre & post environmental stress testing to determine if there is a potential reliability impact on devices that might not be found with standard electrical tests. Evaluations could consist of visual, cross-sections, CSAM, etc., in addition to electrical test.

IIE). Determine all known and possible issues and failure modes that may impact the technology. Use knowledge from existing similar technologies as a source of possible mechanisms and failure types. If there are analogies from prior history then use those available acceleration models and values as the starting point. Perform a literature search to determine possible mechanisms and acceleration values that may be unique to the new technology or material set. For mechanisms with no precedents, select a conservative acceleration factor for planning purposes until data are available. Develop a table of issues and “best known” accelerations. Appendix A contains a table and description of some commonly used acceleration models. For a more complete discussion see the SEMATECH RTAB Paper “Acceleration Factors, Models & Reliability Statistics” and EIA/JEP122 “Failure Mechanisms and Models for Silicon Semiconductor Devices”.

IIF). Use standard models with the acceleration factors, environmental conditions, material property data, and lifetime requirements to develop a set of exploratory reliability stresses. These exploratory reliability stresses will be used until adequate data are available for recalculating acceleration factors. As noted in IIA, ensure hot and cold temperature extremes of the stress do not exceed the physical capability of the material set in the package. Other factors to consider when setting exploratory conditions:

- Test socket compatibility with test conditions
- In situ monitoring of DUT's
- Whether a guardband is to be built into the exploratory (and/or final) reliability stress conditions for the technology
- How the stressing needs to be accomplished:
 - Stand alone component
 - Surface mounted to a board
 - In a socket
 - With heatsink attached
 - Any combinations above
- Conditions that yield the fastest throughput time and are compatible with the package material set.

III. Determine Extended Stress Conditions

Define extended stress conditions as part of the stress model development. These are derived from the estimated acceleration factors and represent conditions that simulate extremely long lifetimes in a highly accelerated fashion. Extended stress conditions are used to define technology margins, determine acceleration factors, and identify all failure mechanisms. Subsequent failure model development will determine the relevant mechanisms. Extended stress data can also be used for the mechanism modeling activities. Sequential and/or step stressing can also be used to determine margins and failure mechanisms, but data from such stressing is often very difficult to interpret. Use of sequential stressing should be approached with care and failure mechanisms validated with individual stresses

where possible. Knowledge of the expected use conditions and the relationship of the sequential stress to these use conditions is also critical.

IV. Apply Data to Models

Following completion of experiments using exploratory and extended stress conditions, prepare Pareto charts of the failure mechanisms and apply existing models to those mechanisms already understood. Check existing models and mechanisms for differences from predictions and determine if the technology follows a new acceleration curve. Compare package failure mechanisms and locations to model predictions. Analyze discrepancies between models and data and use this information to close gaps in the models. These models will be required for making extrapolations to different form factors or to other technologies as noted in step II, and thus, need to be accurate. Recalculate acceleration factors and develop models for extrapolation to other stresses and/or environments. Determine which mechanisms don't meet lifetime expectations. Mechanisms not meeting the lifetimes need to be studied and plans for resolution developed.

V. Determine Final Reliability Stress Conditions

Based on use conditions, lifetime required and the data generated in step IV, calculate the final reliability stress conditions and durations. Subsequent testing and technology goals will be based on these stresses. Select conditions that give the fastest throughput time but that are still compatible with the materials to maximize the number of data turns available for data collection. Also consider factors such as test socket compatibility with the test conditions and possible *in situ* monitoring of DUT's.

Appendix B Figures I and II are examples of how data from step IV were used to determine the final reliability stress and durations for a new package technology. To illustrate the use of the graphs in Appendix B Figures I and II, it is helpful to step through the process of constructing them. In this exercise, we will use Appendix B Figure I, (Temperature – Humidity – Bias) as the example.

Step 1. Determine the appropriate use condition. In this case we selected a lifetime use of 62,000 hours or 7 years at a use temperature of 30°C and a use relative humidity of 85%.

Step 2. Identify the possible relevant failure mechanisms and accelerations based on previously collected data. For this example, we'll consider 2 mechanisms; metal migration at 1.4ev and corrosion at 0.75ev.

Step 3. Apply the appropriate model. This will determine the minimum stressing needed to meet the use condition over the expected lifetime. Since, in this example, RH is constant at 85% for both the stress and the use condition, the Arrhenius model is appropriate.

Step 4. Generate the graph with axes of stress condition and duration based on the selected lifetime and use condition by iterative calculations using various stress temperatures / activation energies and solving for stress time.

Step 5. Apply appropriate accelerations and stress temperatures to determine the target stress time for 1 lifetime duration.

Application Examples:

The Temp/humidity/bias example (Appendix B, I) is a graph of stress temperature (T_{stress}) versus the equivalent time in stress (t_{equiv}). The graph is plotted using the Arrhenius model shown for several different activation energies. The use condition temperature (T_{use}) is 30°C and lifetime (t_{use}) is 62K hours. The equivalent time is the time required to stress the parts at a given stress temperature to achieve the same results as operating the parts at 30°C for 62K hours. For example; a failure mechanism has an activation energy (E_a) of 0.75 ev and we wish to stress parts at 120°C to determine if they meet our 62K hours lifetime requirement. From the graph we see that the equivalent time at 120°C is approximately 80-90 hours. If we use these numbers in the equation shown the equivalent time is 85 hours.

As another example; during development using exploratory and extended stresses two failure mechanisms were found. The mechanisms had activation energies of 1.4 ev and 0.75 ev and the data fit an Arrhenius model. No relative humidity factor is used since all data was taken at 85% RH, with the assumption that the "use" requirement (t_{use}) is 62K hours at 30°C and 85% RH. From the graph it can be seen that 50 hours at 130 °C would be equivalent to the 62K hour life for the failure mechanism with $E_a = 0.75$ ev. For the mechanism with E_a of 1.4 ev any failure after less than an hour of stress could be discounted since about 6 minutes at 130 °C would be equivalent to the 62K hours requirement.

Appendix B Figure II is an example using Thermal Cycling Application. It follows the same logic as the previous example but the data is plotted using the Coffin-Manson acceleration model shown instead of the Arrhenius model. The results of the exploratory and extended stresses found several failure mechanisms with Coffin-Manson exponents (n) ranging from 1.25 to 5. Looking at the graph of equivalent cycles (t_{equiv}) versus the ΔT it can be seen that for the slowest mechanism (n = 1.25) several conditions of TC (ΔT_{stress}) could give the equivalent of the 1500 cycles at $\Delta T_{\text{use}} = 40^\circ\text{C}$ “use” requirement. Again the equivalent cycles required for the higher CM exponents can be determined.

VI. Establish Baseline Performance

Establish the technology’s baseline performance using the final reliability stress conditions and durations. Stress sample sizes need to be consistent with the end of life failure rate expectations. Failure mechanisms may occur during reliability stressing that are irrelevant due to large acceleration factors and need to be discounted (invalidated) when making failure rate calculations. Utilize the data from step III to assist these decisions. Irrelevant failure modes need to be documented thoroughly in any case, as they may need to be explained in the final documentation. Changes to the technology (materials, processes) need to be compared to the existing baseline. Deviations from the baseline need to be validated against the model for impact to lifetime predictions. Field data should be utilized to help support and/or refine models.

DATA COLLECTION

Reliability stress data can be collected as binomial data sets or variables data that look at a measured variable of the device under test. Both types of data can be collected either at discrete intervals (hours or cycle counts) or continuously during the stress. Continuous variables data are the most useful types of data because their trends can be extrapolated against time to estimate failure times well in advance of reaching the failure criterion. Thus, variables data should be used wherever possible. Examples include;

Binomial data types (attribute or pass/fail):

- Shorts (inputs or outputs to any power supply)
- Opens (any pin disconnected from proper logic element)
- Functionality (digital logic conforms to truth table or Behavioral Model & analog responds to specification)

Variables (parametric) data types (measured or continuous):

- Electrical leakage
- V_{OL} , V_{IH} , source current, sink current, threshold voltage, etc.
- Temperature
- Moisture weight gain/loss
- Percent delamination
- Crack length, density, count
- Solder joint or wire bond strength
- Capacitance
- Resistance
- Inductance
- Simultaneous switching noise voltage or “ground bounce”
- Ring Oscillator frequency
- Material property changes
- Warpage & Co-planarity
- Void density/count

TECHNOLOGY EXTENSIONS

Changes that extend the existing technology to encompass new factors such as package form factor (size), die size or fab technologies may all be extensions. There are two ways to certify extensions - 1) collect additional data or 2) extrapolate from existing models.

Collecting additional data requires that units of the appropriate form factor be built and submitted for reliability stressing. However, it is not essential that all stresses be applied. Conduct an assessment to evaluate the changes being made and the possible risks to the base technology. Utilize the learning from the base technology evaluation. Consider reconvening the team of experts identified in Step II. Only apply those stresses where the assessment suggests there is an increase in risk. Typically, changes in form factors require thermomechanical stressing only as

the change in die or package size might change the package stresses. Changes in package materials or process changes may require moisture stressing as well as thermomechanical stresses.

DATA

The following data would be expected in the supplier's internal report to document the outcome of the reliability evaluation:

- Certified technology description
- Performance to final reliability stress conditions
- Use condition assumptions
- Extrapolated (or actual) lifetime margins against use conditions
- Performance to final reliability stress conditions
- Sample sizes
- Detailed mechanism assessments and models with extrapolations to technology limits
- Acceleration factors with model coefficients
- Model and key model parameters determined from data
- Summary of all failure mechanisms, both relevant and censored with rationale.
- Durations for lifetime endpoints
- Failure rate goals

The type and amount of data provided by the supplier is left to the discretion of the supplier.

APPLICATION EXAMPLE

An example of the application of this methodology can be found in the "Use Conditions Based Reliability Evaluation - An Example Applied to BGA Packages" White paper on the SEMATECH Web Site.

APPENDIX A - MODELS AND MECHANISMS

Acceleration Models

Table 2 is a list and description of commonly used acceleration models. Other sources for this type of information are EIA/JEDEC document EIA/JEP122 "Failure Mechanisms and Models for Silicon Semiconductor Devices", Sematech RTAB document on Acceleration Factors, Models & Reliability Statistics, Symposium Proceedings, and internal company historical data.

TEMPERATURE/HUMIDITY MECHANISMS

Peck's model is typically used but there are several other models that have demonstrated success at modeling the impact of RH on failure mechanisms. Other models should be considered when calculating lifetimes. When making the calculations be sure that only the failure mechanism of interest is used when plotting failure rates (that is, don't mix opens failures for package vias with shorts failures for copper migration, they need to be modeled independently). Data need to be collected for a minimum of two different temperatures (at constant RH) or four conditions if RH modeling is being performed (2x2 "box" in T-RH space is absolute minimum).

The failure rate data are plotted $1/T$ (Kelvin) vs. log time, the slope of which is the activation energy for the mechanism. The offset in the curves when multiple RH's are used is the effect due to RH. These data can then be used in the model to calculate the expected time to failure at the target use condition temperature and humidity.

Alternatively plotted data can be extrapolated and estimates made graphically which has the advantage that discontinuities in the data (e. g., two slopes) become readily apparent. Discontinuities would suggest that there is a new mechanism, possibly due to changes in the material properties. This can result in inaccurate lifetime assessments but can also be utilized to collect data on this mechanism even more rapidly. In this situation caution is urged.

TEMPERATURE ACTIVATED MECHANISMS

Typically these require only an Arrhenius model. When making the calculations be sure that only the failure mechanism of interest is used when plotting failure rates (that is, don't mix opens failures with shorts failures, they need to be modeled independently).

Data need to be collected at least at a minimum of two different temperatures and preferably more. The failure rate data are plotted $1/T$ (Kelvin) vs. log time, the slope of which is the activation energy for the mechanism. These data can then be used in the model to calculate the expected time to failure at the target use condition temperature and humidity.

Alternatively the plotted data can be extrapolated and estimates made graphically which has the advantage that discontinuities in the data (two slopes e.g.) become readily apparent. Discontinuities would suggest that there is a new mechanism possibly due to changes in the material properties. This can result in inaccurate lifetime assessments but can also be utilized to collect data on this mechanism even more rapidly. In this situation caution is urged.

TEMPERATURE/VOLTAGE MECHANISMS

These typically follow an Eyring model for which the total acceleration factor is the product of a voltage acceleration factor and the Arrhenius temperature acceleration factor. There are numerous models describing voltage/temperature mechanisms. This one (Eyring) is generic and specific mechanisms need to be handled separately. Similar to the THB models (Peck's e.g. is an Eyring derived model) they are analyzed similarly.

Data need to be collected at least at a minimum of two different temperatures (at constant voltage) or four conditions if voltage modeling is being performed (2x2 "box" in Temperature-Voltage space is absolute minimum). The failure rate data are plotted $1/T$ (Kelvin) vs. log time, the slope of which is the activation energy for the mechanism. The offset in the curves when multiple voltages are used is the effect due to voltage. These data can then be used in the model to calculate the expected time to failure at the target use condition temperature and voltage.

Alternatively the plotted data can be extrapolated and estimates made graphically which has the advantage that discontinuities in the data (two slopes e.g.) become readily apparent. Discontinuities would suggest that there is a new mechanism. This can result in inaccurate lifetime assessments but can also be utilized to collect data on this mechanism even more rapidly. In this situation caution is urged.

THERMOMECHANICAL MECHANISMS

Typically these failures are modeled using a Coffin-Manson relationship. There are some key assumptions that go into the success of this type of model, specifically, that the materials under consideration behave more or less linearly over the test range of interest. Thermal cycling and temperature shock are treated the same, except for solder fatigue for which the material relaxation times are affected by ramp rates and dwell times.

Data need to be collected over at least three temperature ranges, two of which have the same ΔT and at least one which is larger. This is required so that the model can be calibrated relative to the neutral temperature of the package. The neutral temperature is the temperature where the package stresses go to zero and is generally in the range of the mold compound, die attach or epoxy underfill cure temperatures. This assumption needs to be validated with Moiré warpage data on completely processed packages.

Temperature cycling data may be impacted by the dwell times at both the highest and lowest temperatures in the cycle. This is especially true when dealing with creep type mechanisms (solder joints e.g.). Therefore, it is necessary to include stress legs that have dwell times of ≥ 10 minutes ($\cong 2$ cycles per hour). These data need to be analyzed with the short dwell legs to determine the impact of dwell on performance.

Failure rate curves as a function of cycle counts and stress condition need to be developed for each of the thermomechanical failure modes. The slope of Log-log plots of the mean time to failure for each of the conditions is the Coffin-Manson coefficient for that mechanism.

If the data don't appear to be well behaved (multiple slopes or offsets, indicating multiple populations) then the data need to be re-analyzed using other models. One way is to modify the Coffin-Manson model by using the neutral temperature (T_{neu}) to calculate ΔT instead of the hot side of the temperature cycle for all of the stress conditions. This is likely to be true when the mechanism of interest doesn't exhibit significant stress relaxation during the stress cycle (brittle materials e.g.). Solders are likely to experience stress relaxation and will likely model using the stress ΔT . This is not a hard and fast rule and both analyses should be performed.

An example of the use of neutral temperature is shown in Figure III of Appendix B. When data from the different temperature cycle conditions were plotted using cum % fail versus log cycles, it was noted that two legs with the same ΔT_{stress} had different failure rates. This did not fit the normally used Coffin-Manson equation. If we calculate ΔT using the neutral (stress free) temperature instead of the high temperature side of the TC chamber we find we are able to determine a Coffin-Manson exponent that predicts the data. In this case the neutral temperature was assumed to be 170°C (the cure temperature of the mold compound) which gives ΔT_{neu} of 235, 210, and 170 vs. ΔT_{stress} of 215, 125, and 125 for the three TC conditions used.

TABLE 2 - SOME COMMONLY USED ASSEMBLY/PACKAGE ACCELERATION MODELS

Mechanism	Model	Assumptions
Temperature, Humidity mechanisms	<p>Peck's</p> $TF = A_0 * RH^{-N} * \exp[E_a/kT]$ <p>AF (ratio of TF values, use/stress)</p> $AF = (RH_{Stress}/RH_{use})^{-N} * \exp[(E_a/k)(1/T_{use} - 1/T_{stress})]$ <p>When calculating AF variables that remain constant from Stress 1 to Stress 2 will drop out of the equation.</p>	<ul style="list-style-type: none"> • AF = acceleration factor • TF = time to failure, • A₀ = arbitrary scale factor • V = Bias voltage • RH = Relative Humidity as % • N = an experimentally determined constant • E_a = activation energy for the mechanism (0.75 is conservative) • k = Boltzmann's constant = 8.625*10⁻⁵ eV/°K, • T = Temperature in °Kelvin. There are other models used for THB mechanisms which should be checked for fit to the data
Thermal Effects	<p>Arrhenius</p> $TF = A_0 * \exp[E_a/kT]$ <p>AF (ratio of TF values, use/stress)</p> $AF = \text{Exp}[(E_a/k)(1/T_{use} - 1/T_{stress})]$	<ul style="list-style-type: none"> • AF = acceleration factor • TF = time to failure, • A₀ = arbitrary scale factor • E_a = activation energy for the mechanism (0.75 is conservative) • k = Boltzmann's constant = 8.625*10⁻⁵ eV/°K, • T = Temperature in °Kelvin,
Thermo-mechanical mechanisms	<p>Coffin-Manson</p> $N_f = C_0 * (\Delta T)^{-n}$ <p>AF (ratio of N_f values per stress cycle, stress/use)</p> $AF = N_{use}/N_{stress} = (\Delta T_{stress}/\Delta T_{use})^n$	<ul style="list-style-type: none"> • AF = acceleration factor • N_f = Number of cycles to failure, • C₀ = a material dependent constant, • ΔT = entire temperature cycle-range for the device, • n = empirically determined constant. • Assumes that the stress and use ranges remain in the elastic regime for the materials • The Norris Landzberg modification to this model takes into account the stress test cycling rate
Creep	$TF = B_0 (T_0 - T)^{-n} \exp(E_a/kT)$ <p>AF (ratio of TF values, use/stress) = ((T₀ - T_{accel})/(T₀ - T_{use}))⁻ⁿ exp ([E_a/k](1/T_{accel} - 1/T_{use}))</p>	<ul style="list-style-type: none"> • AF = acceleration factor • TF = time to failure, • B₀ = process dependent constant, • T = temperature in °Kelvin, • T₀ = stress free temperature for metal (~ metal deposition temperature for aluminum) • n = 2 - 3, (n usually ~5 if creep, thus implies T < T_m/2) • E_a = activation energy = 0.5 - 0.6eV for grain-boundary diffusion, ~ 1 eV for intra-grain, • k = Boltzmann's constant = 8.625 10⁻⁵ eV/°K

Physical Models

Once an acceleration model is established the data needs to be checked against physical models for failure mechanisms. That is, the calculated activation energies or Coffin-Manson coefficients need to make physical sense relative to the mechanism they describe. Corrosion, for example, may be expected to be in the 0.5 to 1.0 eV and bulk diffusion in the 1.1 eV ranges

Table 3 gives some typical ranges of activation energies and exponents for physical mechanisms (for reference only). These ranges are based on historical data and published literature and are dependent on the physical properties of the material sets and the manufacturing processes being used. New technologies must have accelerations calculated for each mechanism or data indicating acceptable substitution from a prior technology. Acceleration values that appear to be outliers when compared to existing data need to be carefully analyzed to insure that there aren't competing mechanisms or a change in the physical properties of a material that significantly changes the slope of the acceleration curve. Modeling to the physical models should take precedence over polynomial curve fits as the former more closely links to the physical mechanism.

TABLE 3 - TYPICAL VALUES FOR SOME COMMON FAILURE MECHANISMS

	Ea (activation energy ranges in electron volts)	Other Coefficients
Peck's	0.75-1.5 eV (Dependent on the materials used for each package type)	N = 2-12 (dependent on the materials used for each package)
Arrhenius	0.3-0.6 Electrolytic corrosion 0.5-0.9 Electromigration in Al 0.6-1.0 Corrosion in THB 0.9-1.8 Metal Migration 0.9-1.5 Diffusion	na
Coffin-Manson	Na	n = 3-10 brittle materials 1.2-2.5 ductile materials 1-2 hard metals
Creep	0.5-1.0 eV	N = 2-3 for solder

NON ACCELERATED STRESSES

Power Cycling

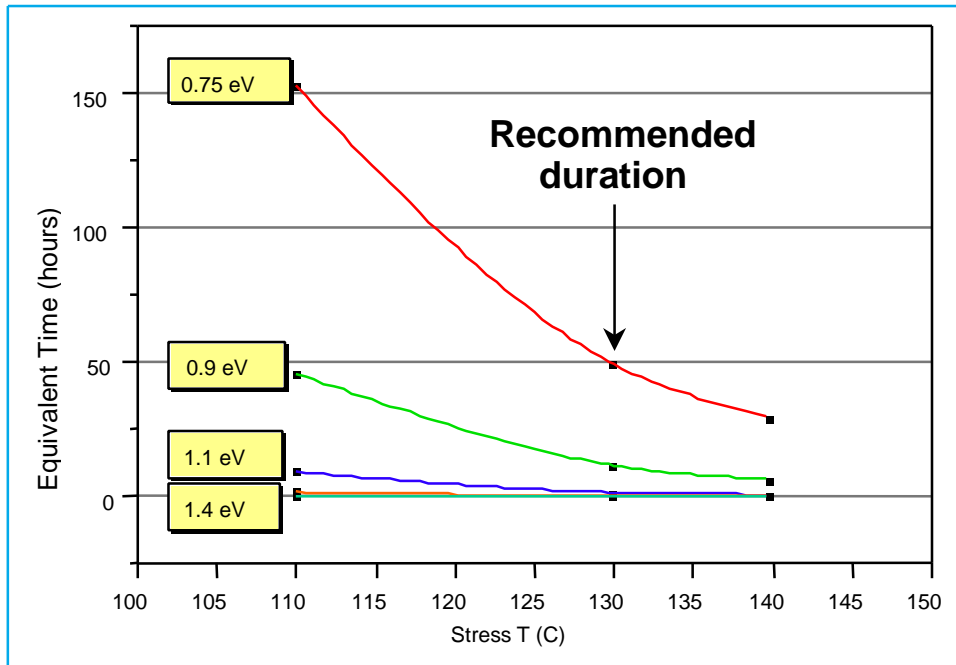
Power Cycling is simply on/off testing of the part and should be considered when evaluating packages that are expected to dissipate high power. In this test the unit is cycled from room temperature up to the junction temperature specified for the particular technology with the thermal solution in place. Establish the upper temperature that a unit will experience in the actual use environment with all thermal solutions attached. Establish the ramp rate that a unit may experience during on/off cycles in use. Establish the dwell time at peak temperature. Cycle the unit until fail or until the expected end of life for the product. Temperature and continuity are monitored continuously during the test. Changes in temperature indicate degradation of thermal impedance (failure of the thermal solution), continuity failures indicate failure of the component or module. Linear extrapolations of temperature sensor data should be used to predict thermal solution lifetimes.

Shock and Vibration

Shock and vibration testing are considered non-accelerated tests of the mechanical integrity of the package and/or assembly. The conditions used should simulate the actual expected use conditions. Units need to be fixtured similar to the actual use condition. Following establishment of the acceleration limits (in terms of g's of acceleration), units are tested to that limit as the minimum. Ideally, testing should also be performed in increasing increments beyond the g limit expectation until failure of the assembly, thus establishing the upper limit for the technology.

Figure I

Temp. - Humidity - Bias Application Example:



Use Arrhenius since
RH constant at 85%

$$t_{\text{equiv}} = t_{\text{use}} \cdot e^{\left[\frac{E_a}{k} \left(\frac{1}{T_{\text{stress}}} - \frac{1}{T_{\text{use}}} \right) \right]}$$

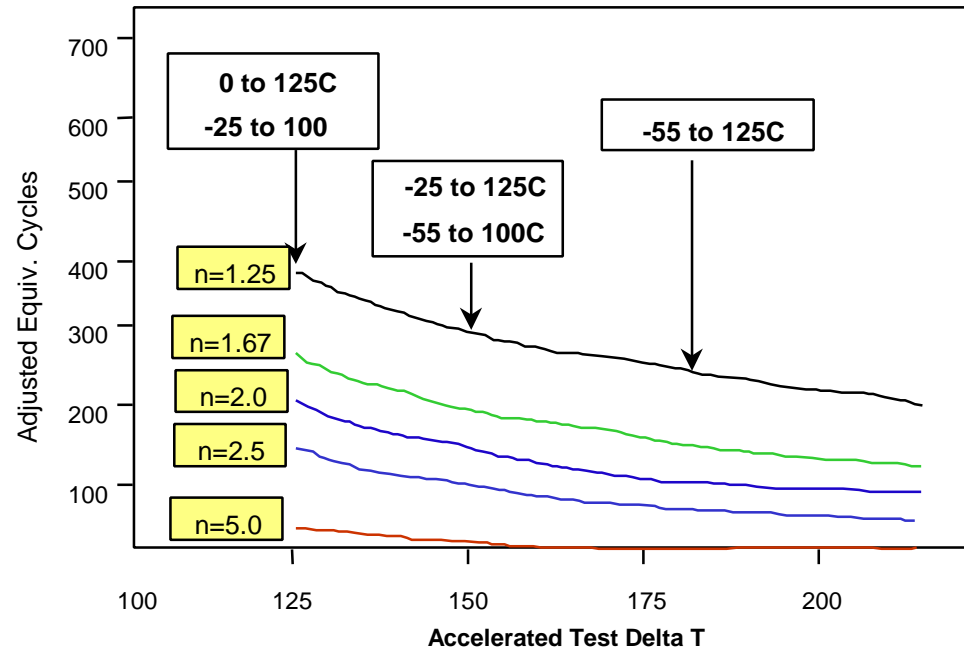
Use Conditions

$t_{\text{use}} = 62,000$ hrs.
 $T_{\text{use}} = 30\text{C}$
RH = 85%

Activation Energies

Mechanism #1: = 0.75 eV
Mechanism #2: = 0.9 eV
Mechanism #3: = 1.1 eV
Mechanism #4: = 1.4 eV

Figure II Thermal Cycling Application Example:



Coffin-Manson
Model
(Power Law)

$$t_{equiv} = t_{use} \cdot \left[\frac{\Delta T_{use}}{\Delta T_{stress}} \right]^n$$

Use Conditions

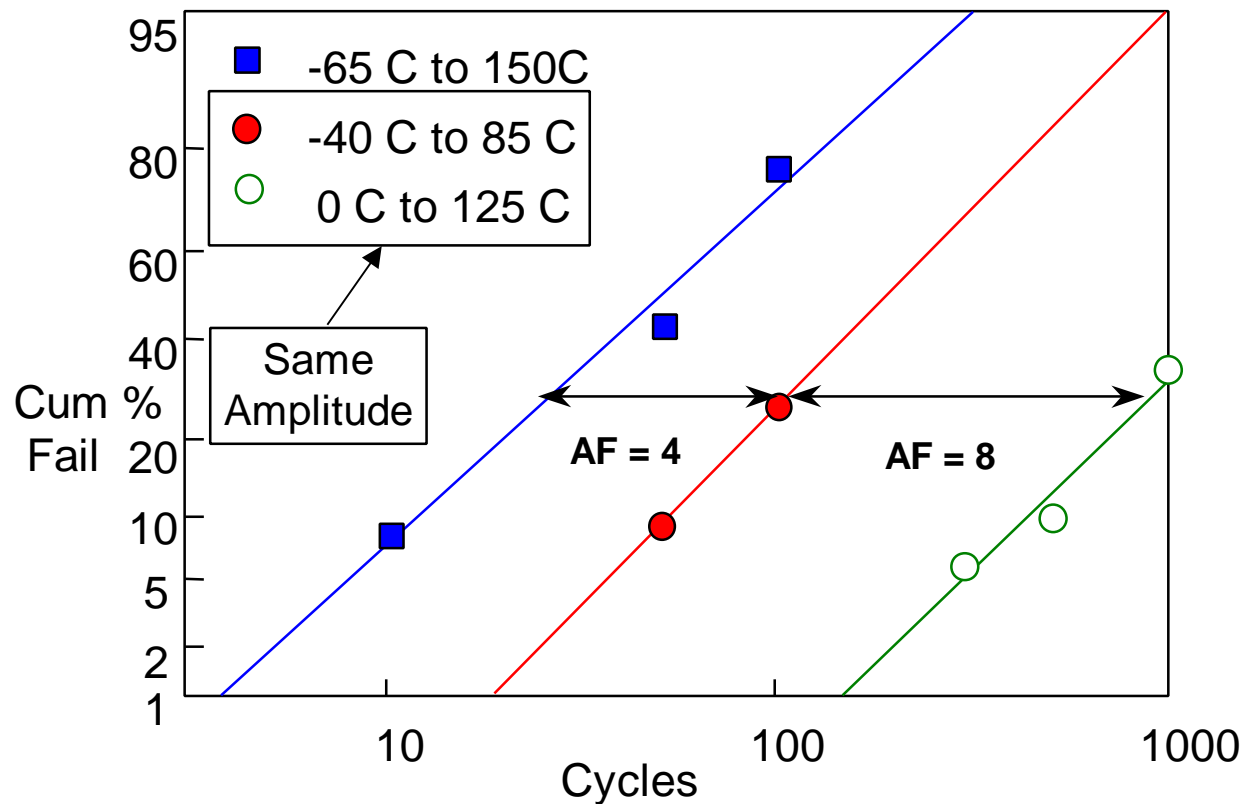
$t_{use} = 1500$ cycles
Mean $\Delta T = 40^{\circ}\text{C}$

Coffin Manson exponents

Mechanism #1: $n = 1.25$
Mechanism #2: $n = 1.67$
Mechanism #3: $n = 2.0$
Mechanism #4: $n = 2.5$
Mechanism #5: $n = 5.0$

Figure III Thin Film Cracking in Plastic Package

- Coffin-Manson formula with $\Delta T =$ maximum difference from **neutral stress** temperature (mold cure).
- For TC, the *low* temperature has the main effect in plastic packages.



$$AF = \left[\frac{\Delta T_{\text{Stress}}}{\Delta T_{\text{Use}}} \right]^n$$

$$n = \frac{\text{Ln}(AF)}{\text{Ln} \left(\frac{\Delta T_s}{\Delta T_{\text{Use}}} \right)}$$

Best Fit

$$n = 11$$

$$T_{\text{neu}} = 170 \text{ C}$$

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