ACCELERATION FACTORS & THERMAL CYCLING TEST EFFICICIENCY FOR LEAD-FREE SN-AG-CU ASSEMBLIES

by Jean-Paul Clech, EPSI Inc.
Montclair, NJ, USA

http://www.jpclech.com

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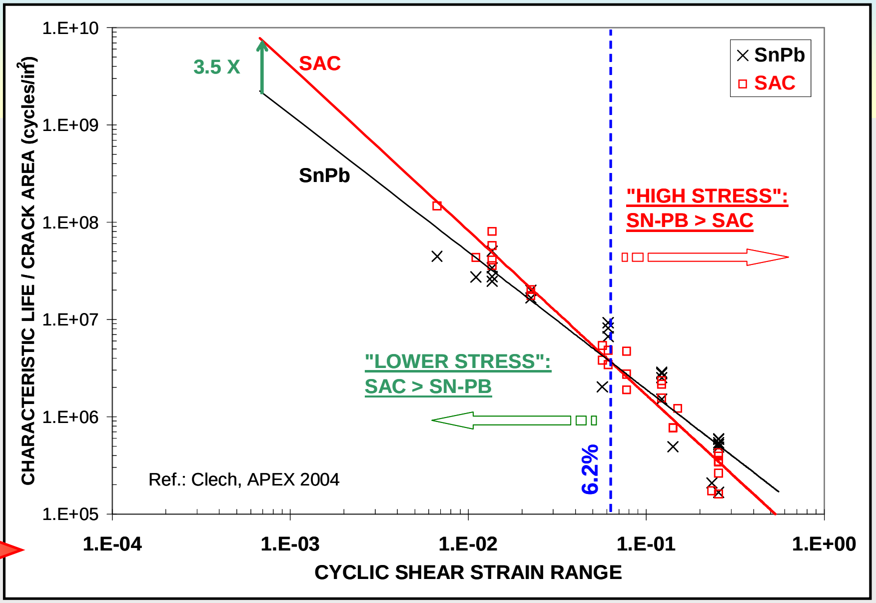
TOPICS

- **How effective are standard Accelerated Thermal Cycling (ATC) tests for SAC assemblies?**
  - Dwell time effects: short vs. long
  - Ramp rate effects: slow vs. fast
  - Mean temperature effects: high vs. low
- **How to extrapolate test results?**
  - SAC reliability models, Acceleration Factors (AFs)
  - Life predictions, AF examples
- **Conclusions**

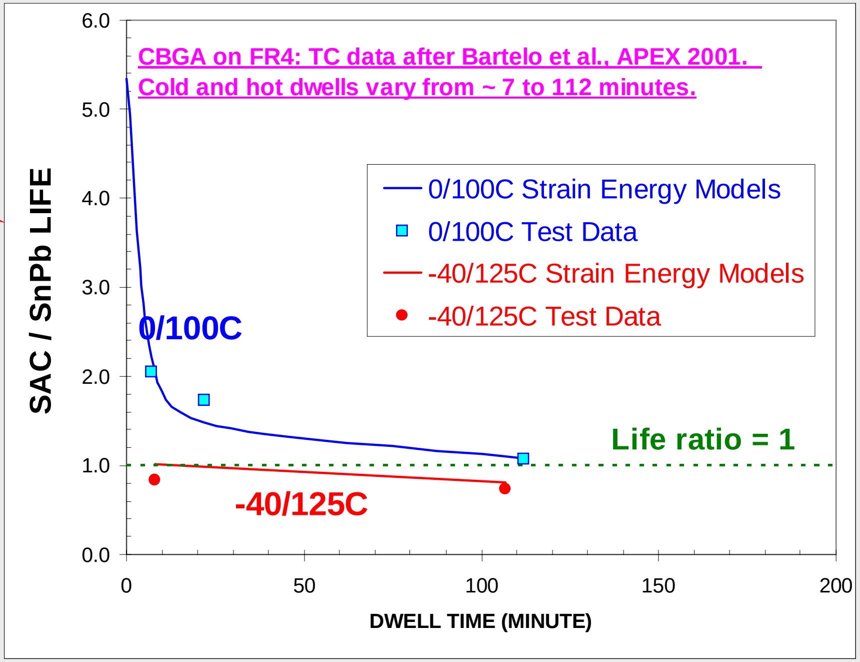
NOTE: SAC data in this paper is for lead-free solders with 3.8-4.0%wt. Ag, 0.5-0.7%wt. Cu.

CONTEXT

- **Whether favorable or not, SAC to SnPb comparison under ATC conditions may not hold under field conditions due to cyclic shear strain levels and dwell time effects.**

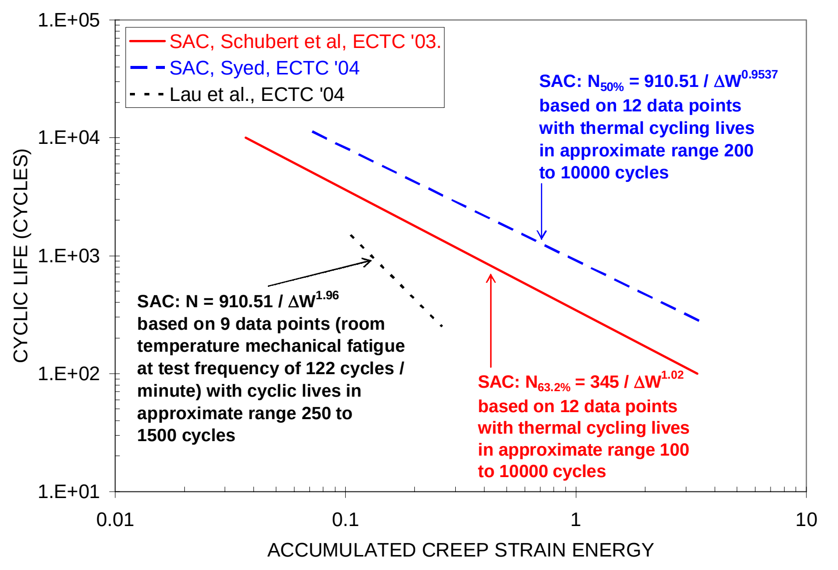


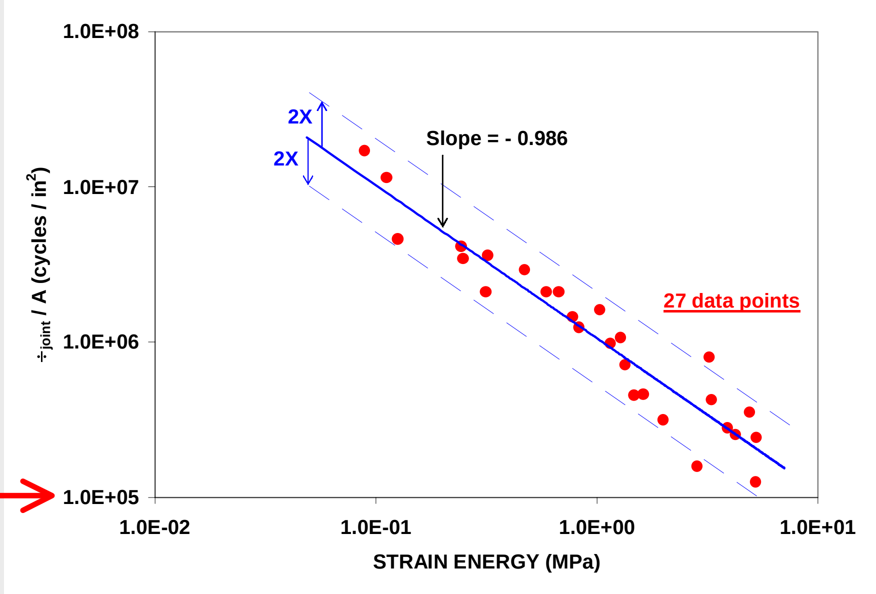
- **Important question is not whether SAC is better or worse than SnPb under ATC conditions, but whether field reliability requirements are met for SAC assemblies.**



SAC RELIABILITY MODELS

- **At least 12 reliability models have been developed for SAC solders (see first 11 references in paper).**
  - Various approaches: from algebraic to 3D finite-element models.
  - VALIDATE WITH INDEPENDENT TEST CASES PRIOR TO USE.
- **Under thermal cycling conditions, strain energy based models give a life to strain energy relationship with slope near -1.**
  - Slope is -2 in isothermal mechanical cycling



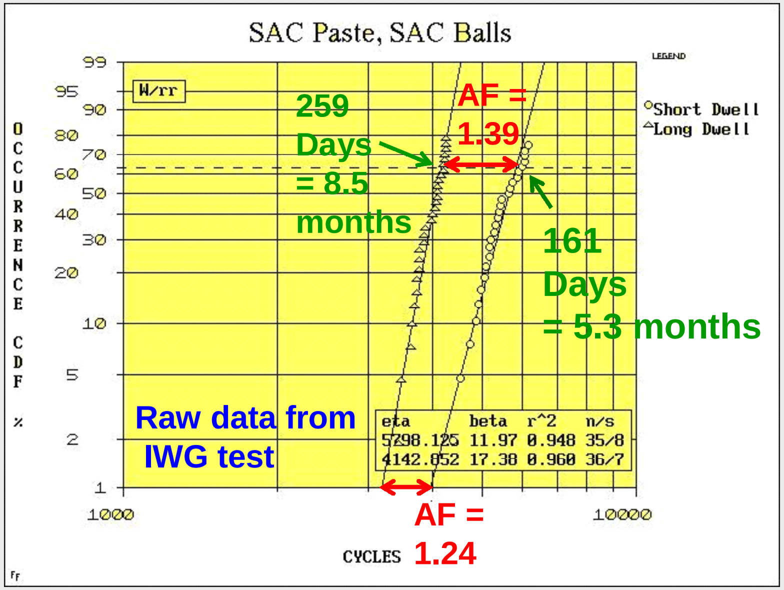


1D strain energy model used in this paper

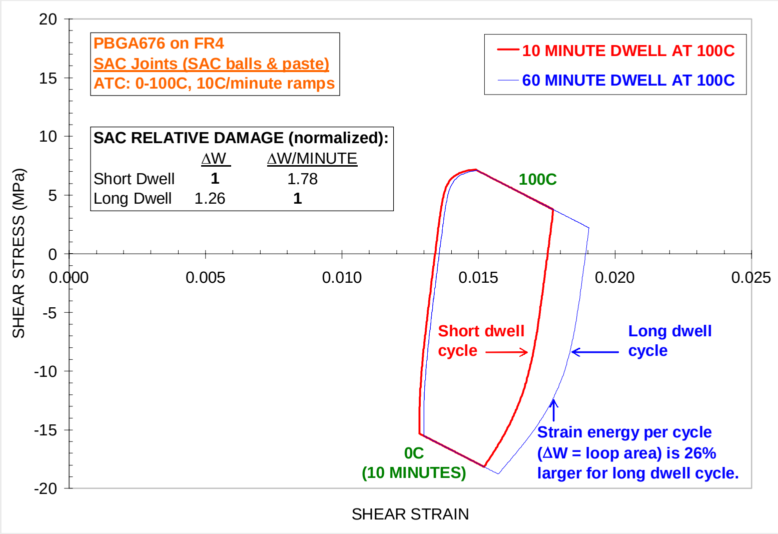
ATC DWELL TIME EFFECTS (1)

- **IWG (Industry Working Group) test:**
  - 0/100C, 10C/min., 10 min. cold dwell
  - Hot dwell: 10 or 60 min.

EXPERIMENTAL:
2P WEIBULL: AF = 1.24 to 1.39
3P WEIBULL: AF = 1.288



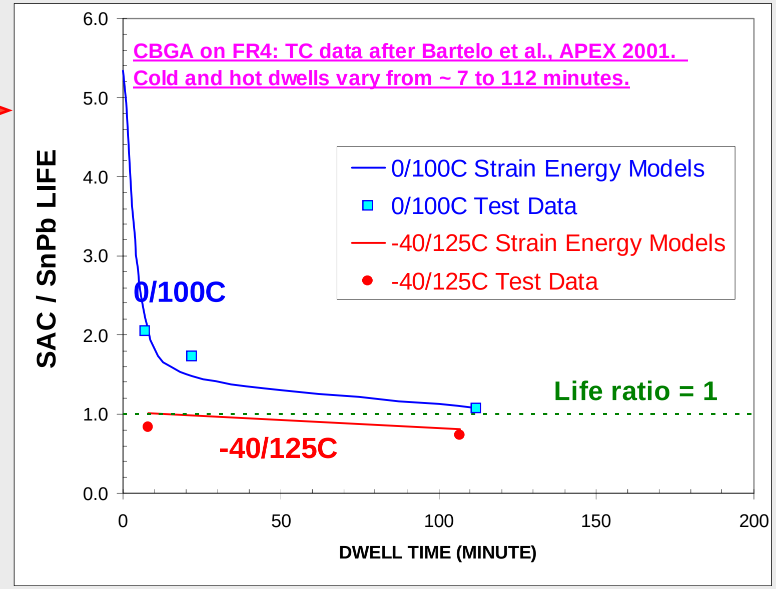
1D STRAIN ENERGY MODEL: AF = 1.26

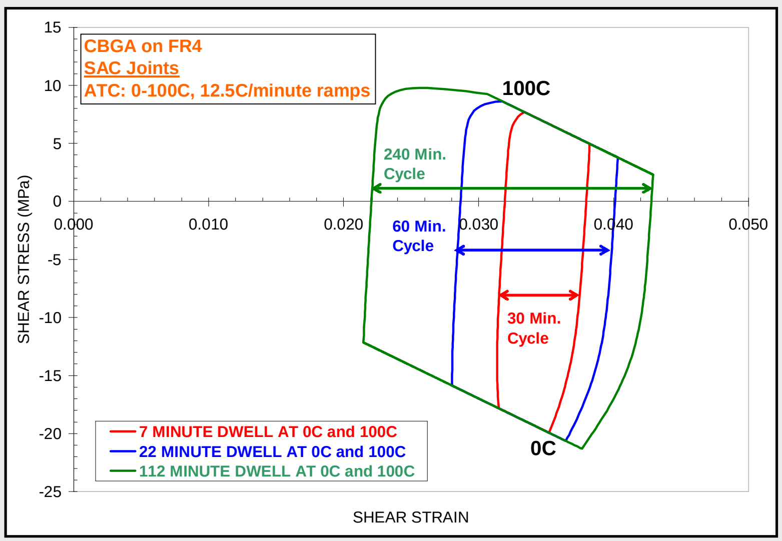


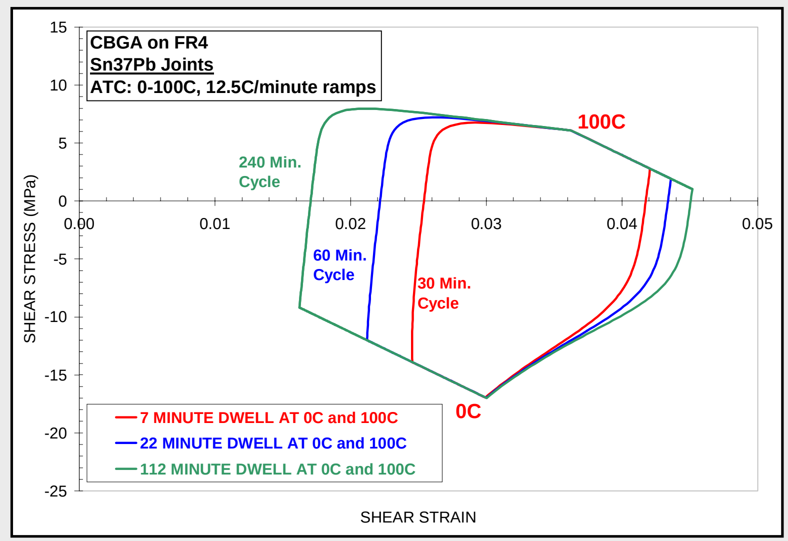
- **Results are consistent:**
  - Same failure modes (Bath et al., SMTAI'05).
  - AFs are in very good agreement.
    - Model correlates results of both tests
  - Long dwell test is 1.78 X less efficient

ATC DWELL TIME EFFECTS (2)

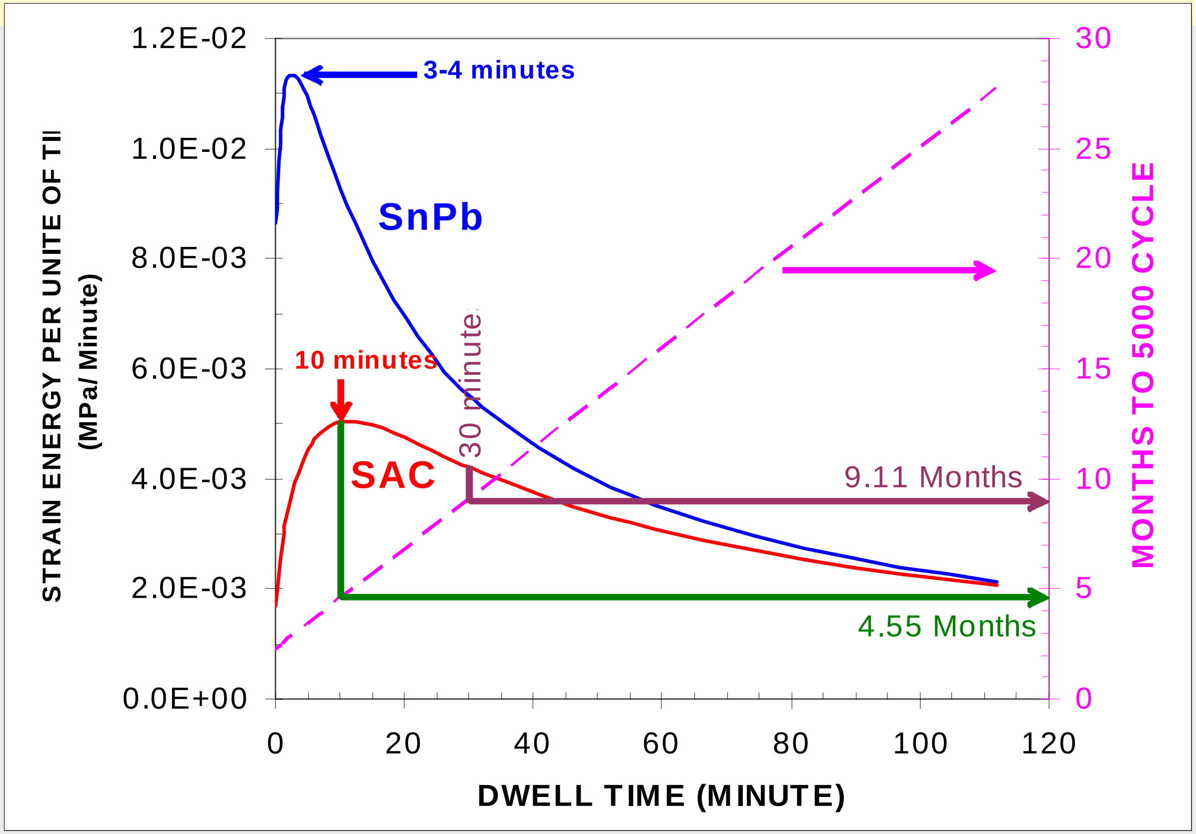
- **Bartelo et al. data (Apex 2001)**
- **Strain energy model suggests that life ratio decreases as dwell times increase because SAC joints experience higher stresses than SnPb joints.**
  - SAC loops widen at a faster rate than SnPb loops.





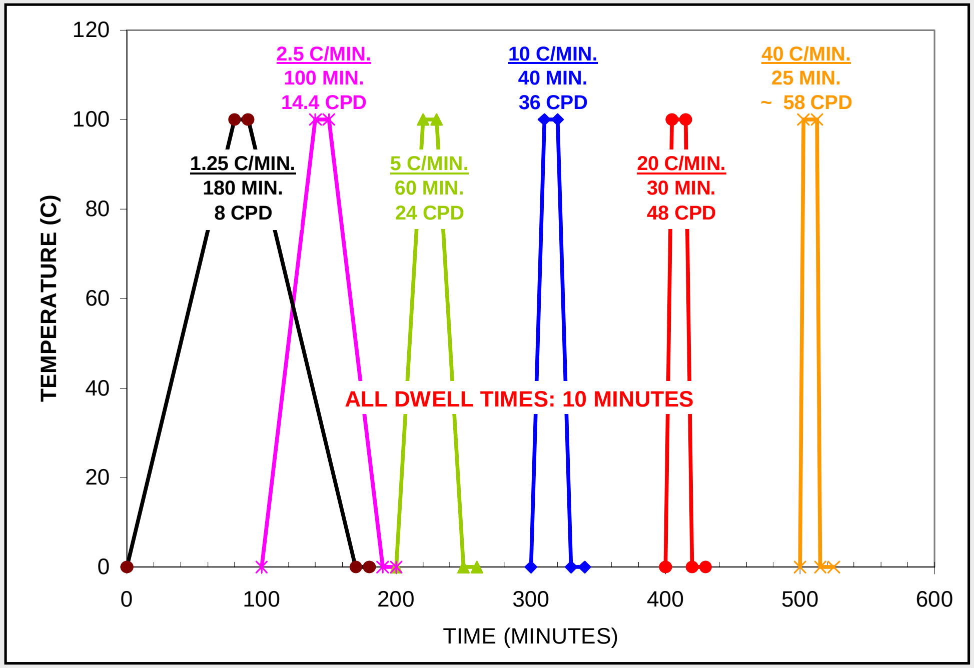


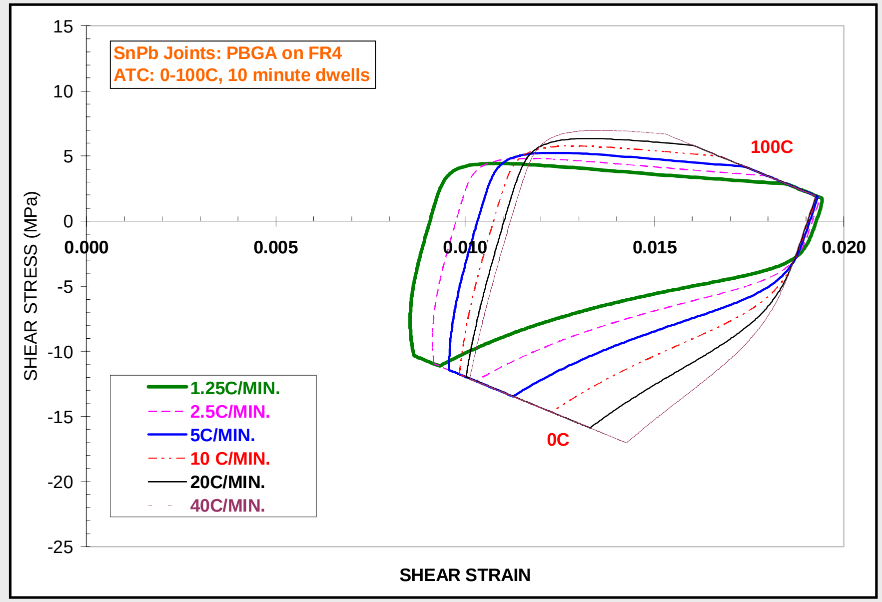
EFFECT OF DWELL TIME ON TEST EFFICIENCY

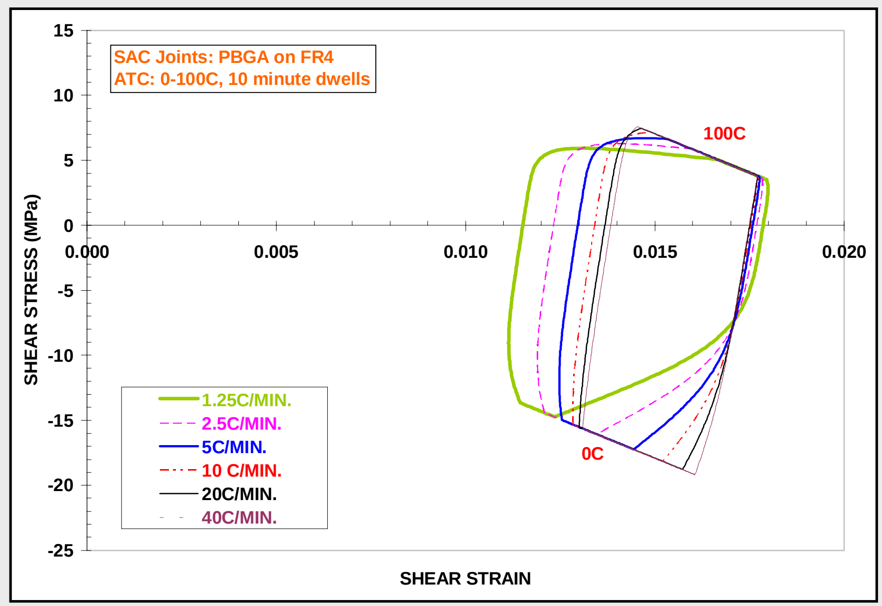


- **Simulations are for CBGA assemblies and equal dwell times at 0 C and 100 C (~ 10 C/min. ramps)**
- **Maximum test efficiency (strain energy per minute) is at dwell times of:**
  - 3-4 minutes for SnPb; 10 minutes (3 times as much) for SAC

RAMP RATE EFFECTS (1)

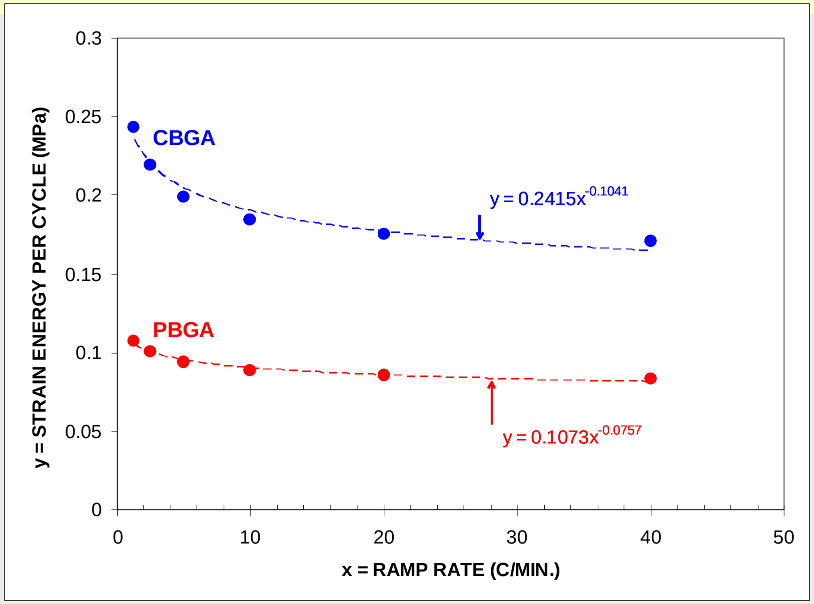


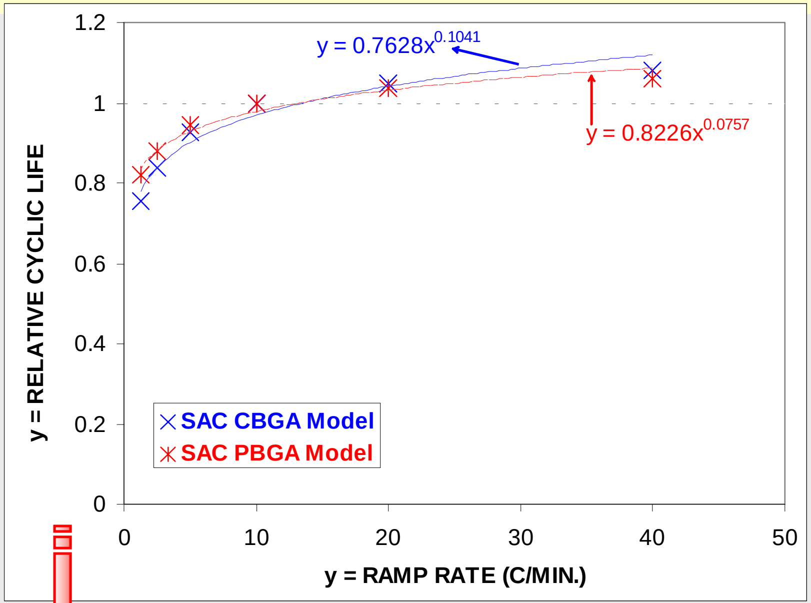


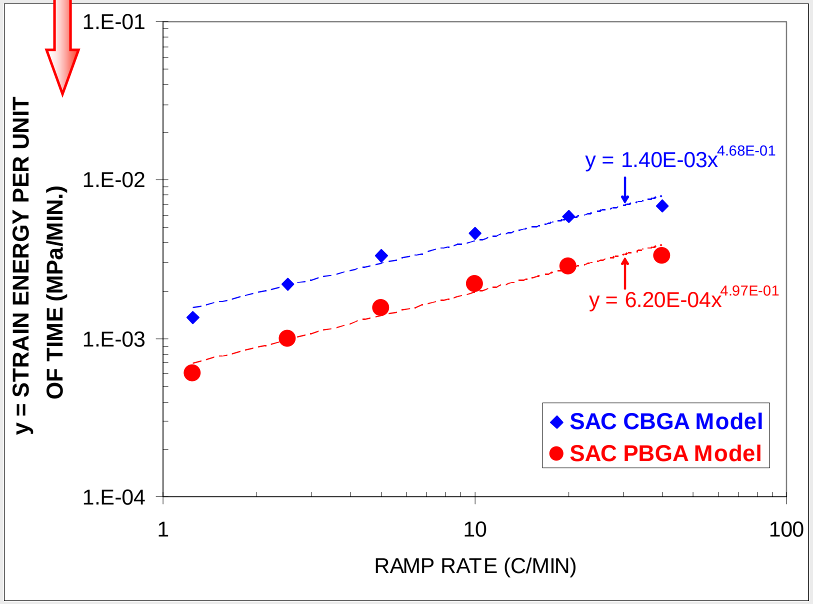


- **Hysteresis loop simulations for SAC and SnPb PBGA & CBGA assemblies.**
- **Rates: 1.25 to 40C/min.**

RAMP RATE EFFECTS (2)

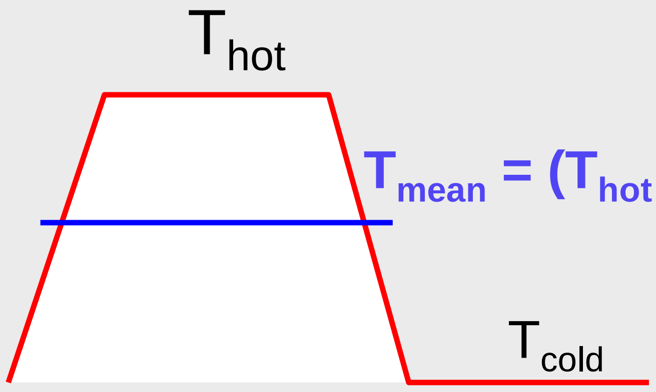




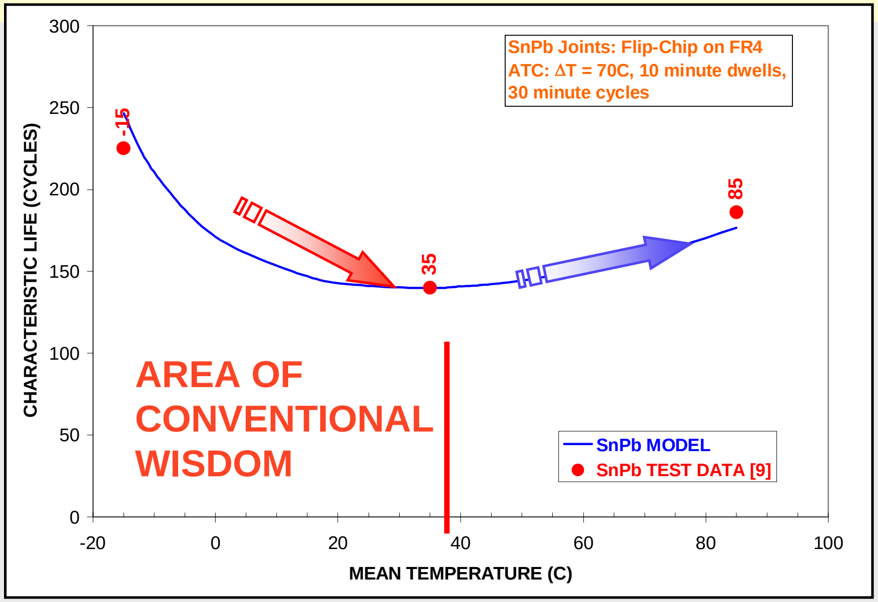


- **For SAC assemblies, STRAIN ENERGY PER CYCLE increases with slower ramp rates.**
  - In agreement with ATC results of Dusek et al. (SMTAI'04).
  - However, dependence remains weak (power law exponent ~ 0.1).
- **In terms of DAMAGE PER UNIT OF TIME, faster ramps increase test efficiency.**

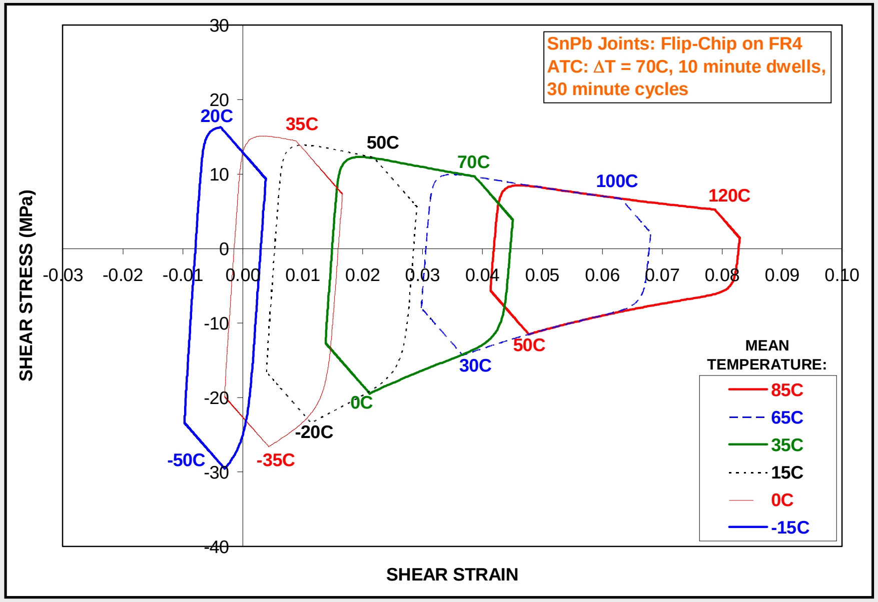
MEAN TEMPERATURE EFFECTS: SnPb



$T_{mean} = (T_{hot} + T_{cold}) / 2$

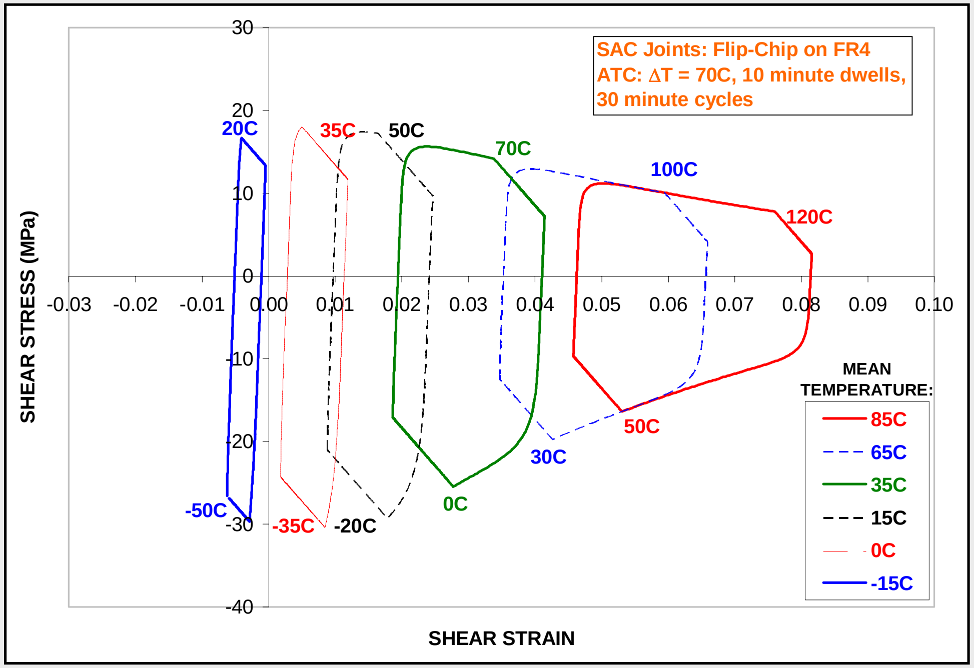


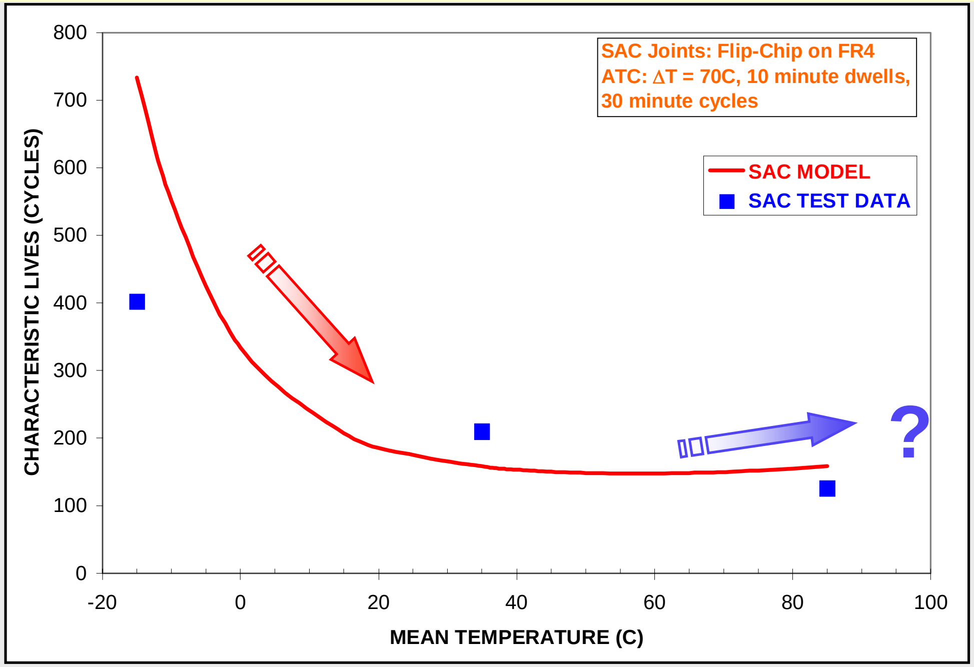
SnPb flip-chip (no underfill) test data from Schubert et al., 2003



- As T_{mean} increases, from -15C to 35C in shown example, life decreases.
- Then, life increases again due to faster decrease in stress range and corresponding decrease in cyclic strain energy.
- Supported by additional test data (Hall, 1986; Yoon, 2005) quoted in paper.

MEAN TEMPERATURE EFFECTS: SAC

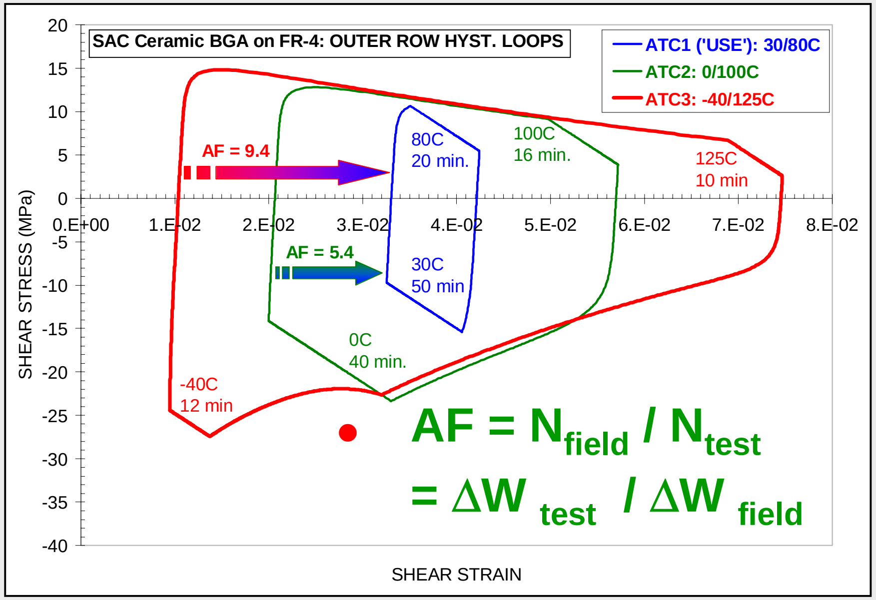


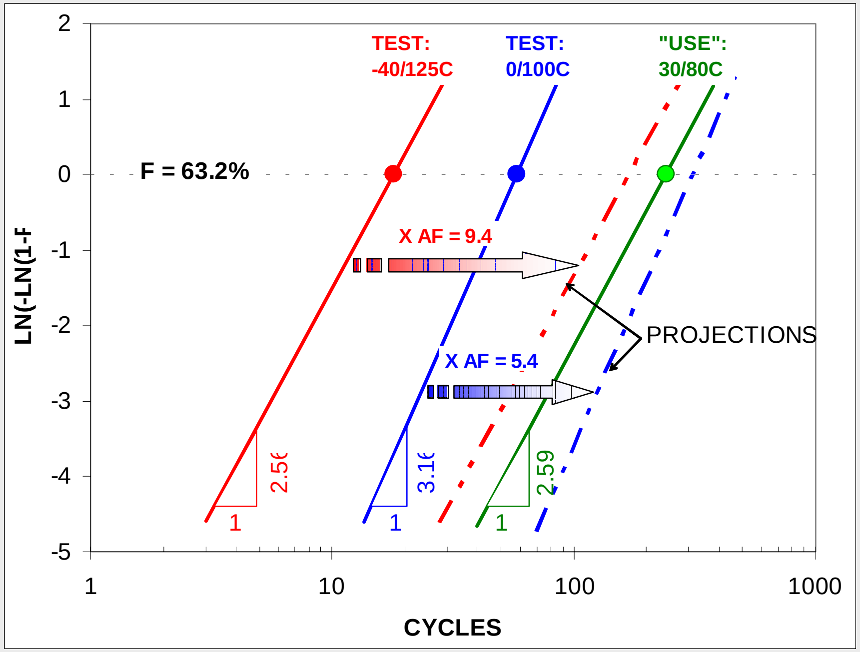


SAC flip-chip (no underfill) test data from Schubert et al., 2003

- For SAC flip-chip assembly of interest, model predicts that life vs. mean temperature increases for T_{mean} > ~ 60C.
- Not enough data to validate or disprove model prediction.
  - Neighboring data points are for T_{mean} = 35C and 85C
- Further investigations are needed to assess mean temperature effect for SAC assemblies.

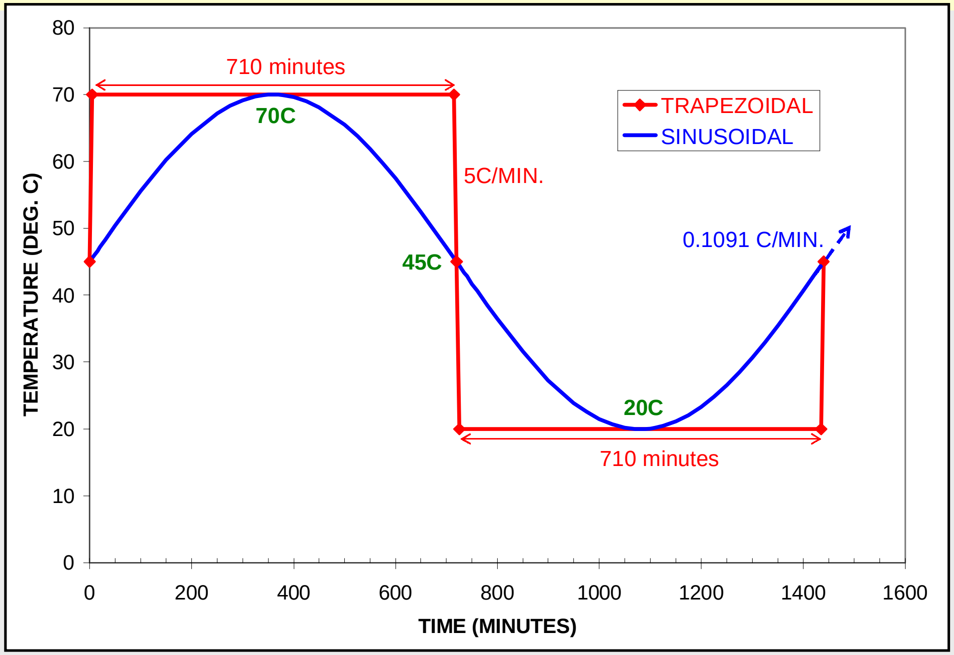
ACCELERATION FACTORS: VALIDATION EXAMPLE





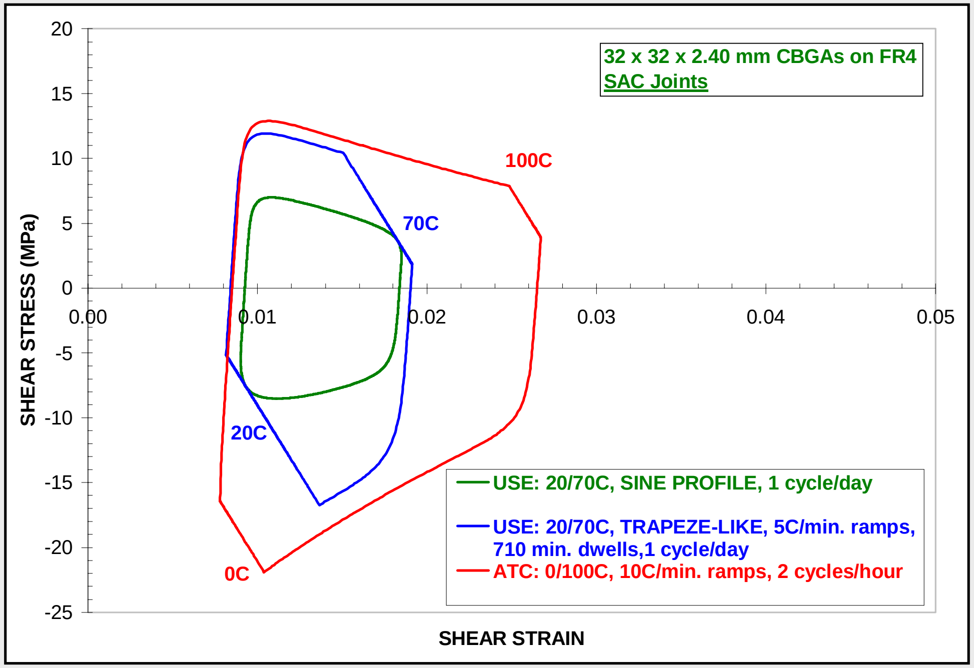
- Thermal cycling data for ceramic BGAs on FR-4:
  - ATC1: 30/80C = "USE CONDITION"
  - ATC2: 0/100C; ATC3: -40/125C = "TEST CONDITIONS"
    - Experimental data (characteristic lives) from Salmela et al., 2005
- Life projections from ATC 2 & 3 are within 30% of ATC1 measured life.

APPLICATION EXAMPLE: SAC CBGA



- **Problem:**
  - A SAC CBGA (32 mm x 32 mm) assembly has a cyclic life $N_{1\%}$ = 946 cycles in ATC (0/100C, 10 C/min. ramps, 10 min. dwells).
  - What is the expected field life under diurnal thermal cycling between 20C and 70C at a frequency of 1 cycle per day (1 CPD)? YEARS TO 1% FIELD FAILURES?
  - Consider trapezoidal and sine-like temperature profile.

APPLICATION EXAMPLE: SAC CBGA



- **$AF = N_{field} / N_{test}$**

  $= \Delta W_{test} / \Delta W_{field}$

- **“Sine” profile loop area is 1.8 x smaller than that of “Trapeze” profile**

$N_{1\%}$ (ATC) (Cycles)	946	
$N_{1\%}$ (Use) = $N_{1\%}$ (Test) * AF (cycles)	1949	"Trapeze-Like" Profile: AF = 2.06
	3538	"Sine" Profile: AF = 3.74
Years to 1% Failure in Use = $N_{1\%}$ (Use) / 365.25 Cycles/Year	**5.34**	"Trapeze-Like" Profile
	9.69	"Sine" Profile

Conclusions

- **At least a dozen models have been developed since 2003 for SAC reliability assessment under thermal cycling conditions.**
  - Numerous datasets are available in the literature for model validation prior to use.
- **Strain-energy models allow for the correlation of SAC failure data across a wide range of test conditions.**
  - AFs are derived from the ratio of hysteresis loop areas.
  - Loops are obtained by classical stress analysis (1D model here) or finite element analysis: ask your stress analyst or a consultant.
- **Standard ATC tests appear adequate for reliability testing of SAC assemblies**
  - Increased ramp rates and optimized dwell times provide opportunities to reduce test duration and to improve test efficiency.

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THANK YOU FOR YOUR ATTENTION

QUESTIONS OR COMMENTS?