A Pseudo-Stress, Pseudo-Strain Methodology to Predict Lead-Free Solder Joint Reliability

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Outline

- Issues being addressed
- Pseudo-stresses & strains: definitions & properties
- Application Examples
  - Comparison of measured and simulated SAC305 hysteresis loops
  - Correlations of ATC test data; dwell time effect (SAC105, 305 & 405)
  - SAC to SAC life predictions
- Conclusions

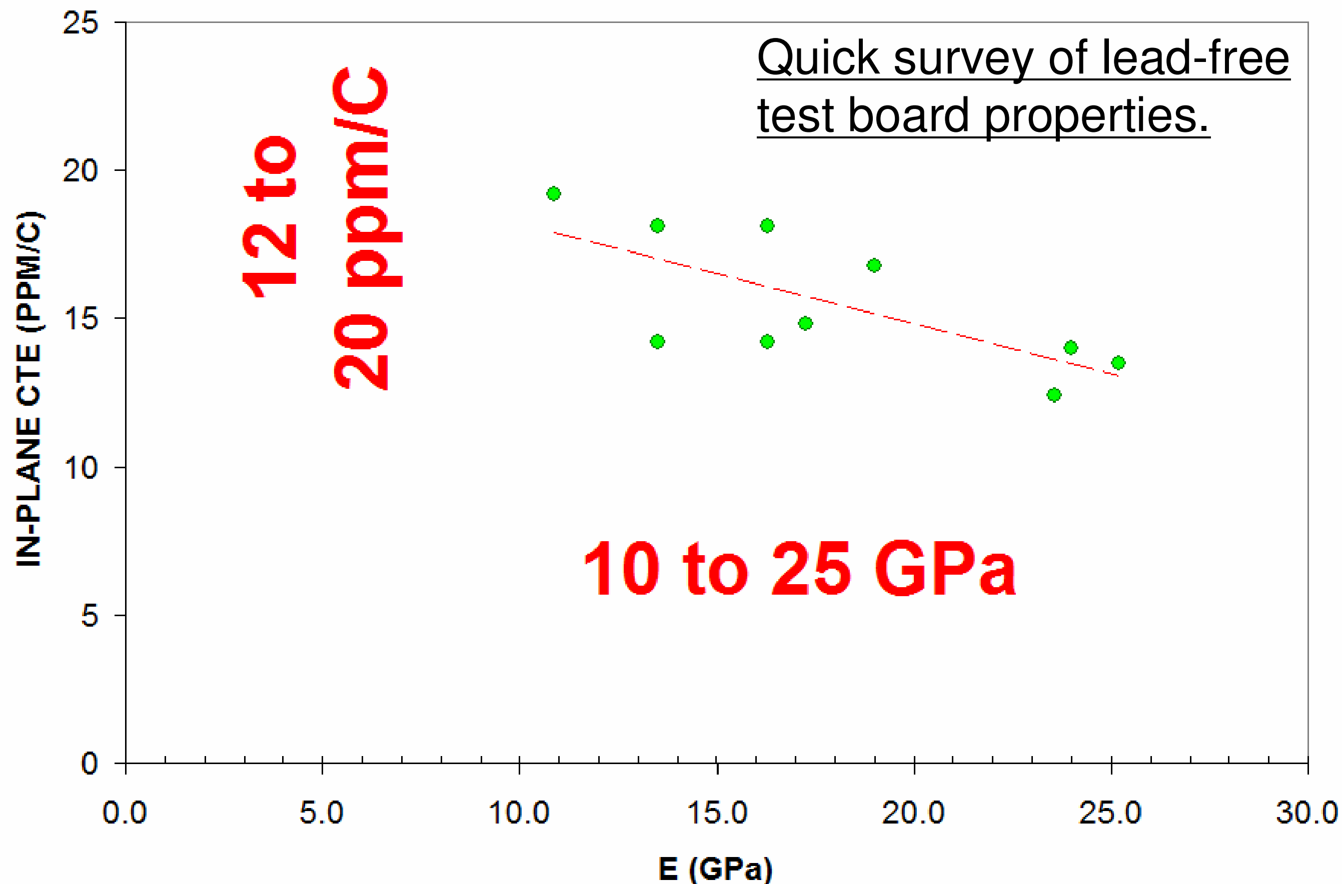
What is “pseudo”?

- Synonyms:
  - Bogus, deceitful, fake, false, phony, sham…
- In this paper:
  - “Pseudo” refers to transformed quantities (stresses, strains, strain energy) with a purpose.
    - Pseudo-quantities are denoted with a star * super-script.

Issues Being Addressed

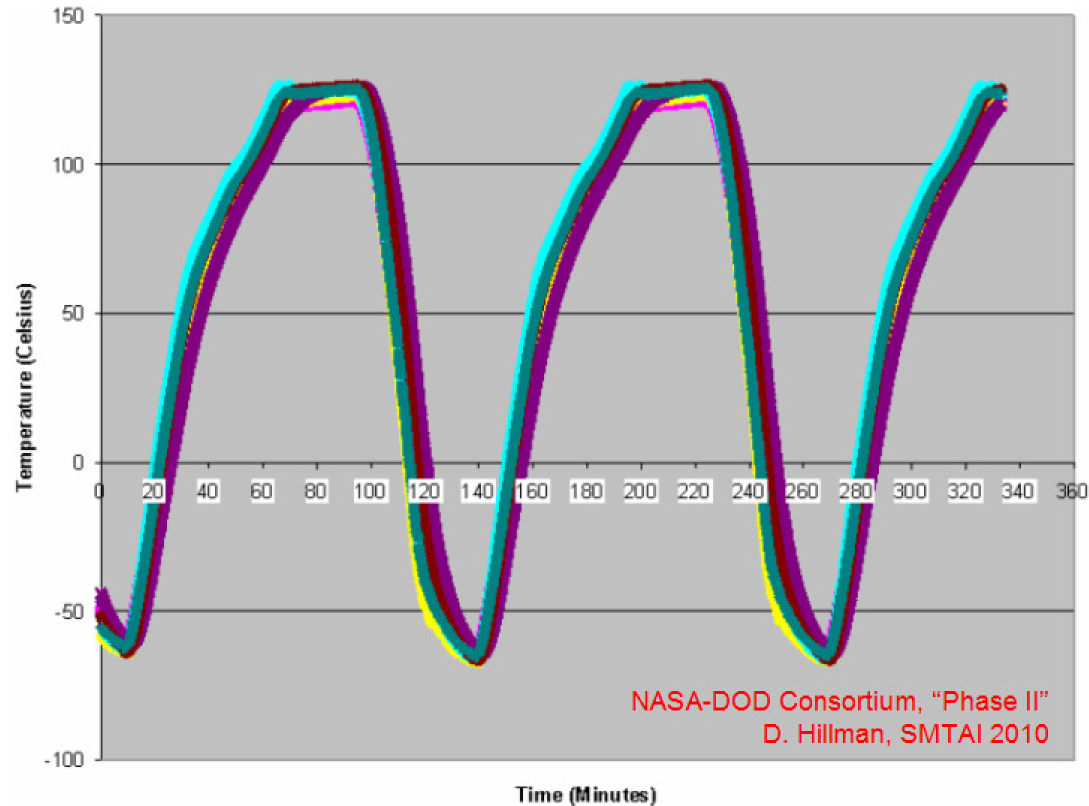
- How do we correlate test results and/or make solder joint (SJ) field life predictions when:
  - Little to no package and/or board information is available (CTEs, board moduli…)?
  - SAC solder joints have intermediate Ag content other than 1, 3 or 4% Ag (wt.)?

Modeling Challenges (1)



- **Package and board properties (e.g. CTEs and moduli) vary over a wide range and cannot be guessed at.**

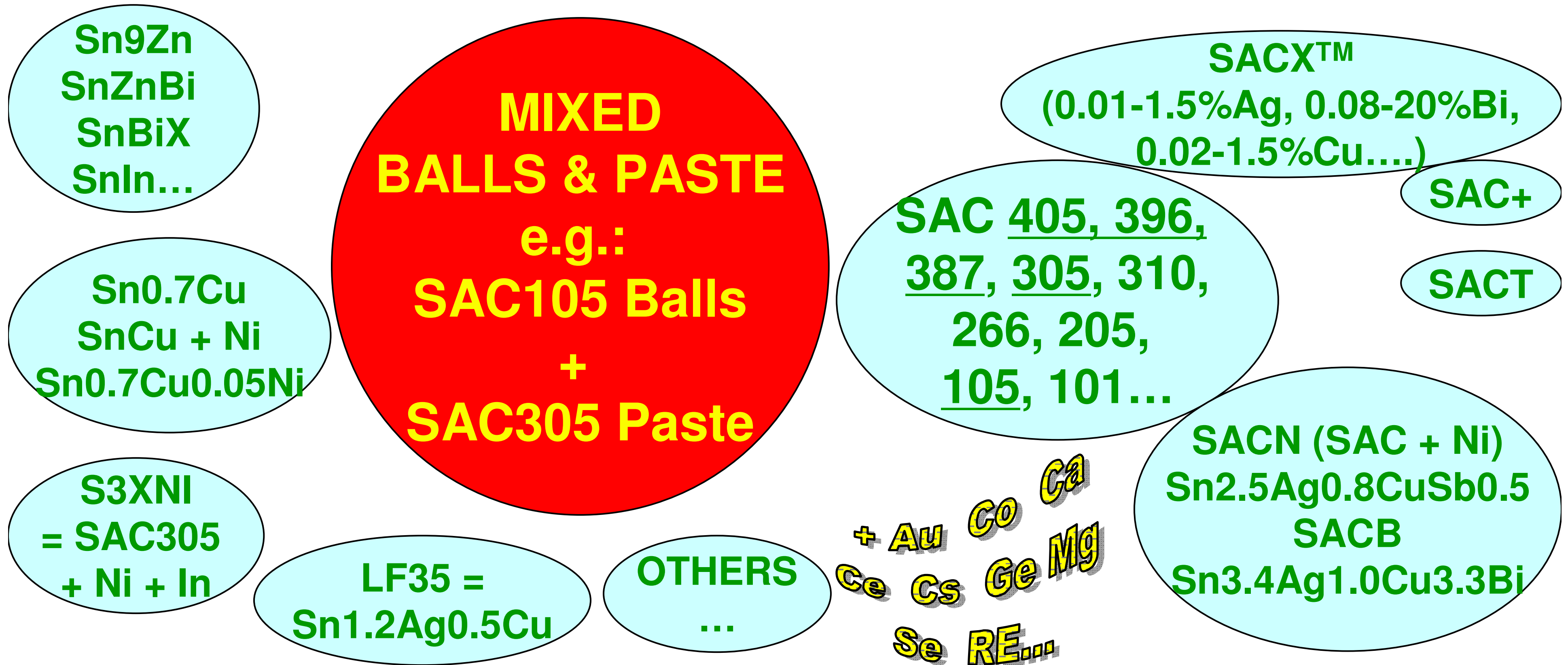
Modeling Challenges (2)



Graph, courtesy of David Hillman, Rockwell International

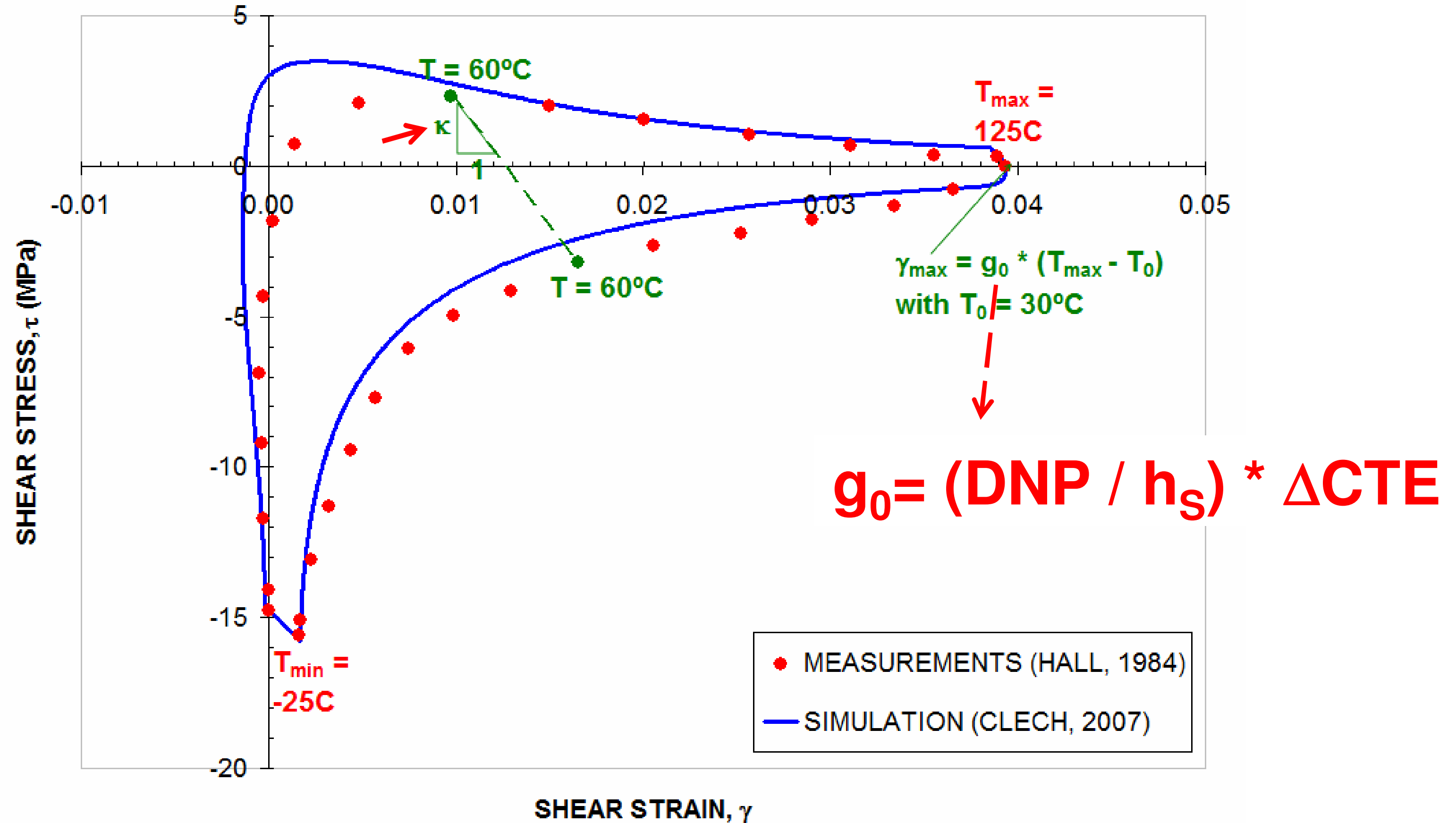
- **On-board profiles are not all symmetrical**
  - **Ramp rates vary too.**

Modeling Challenges (3)



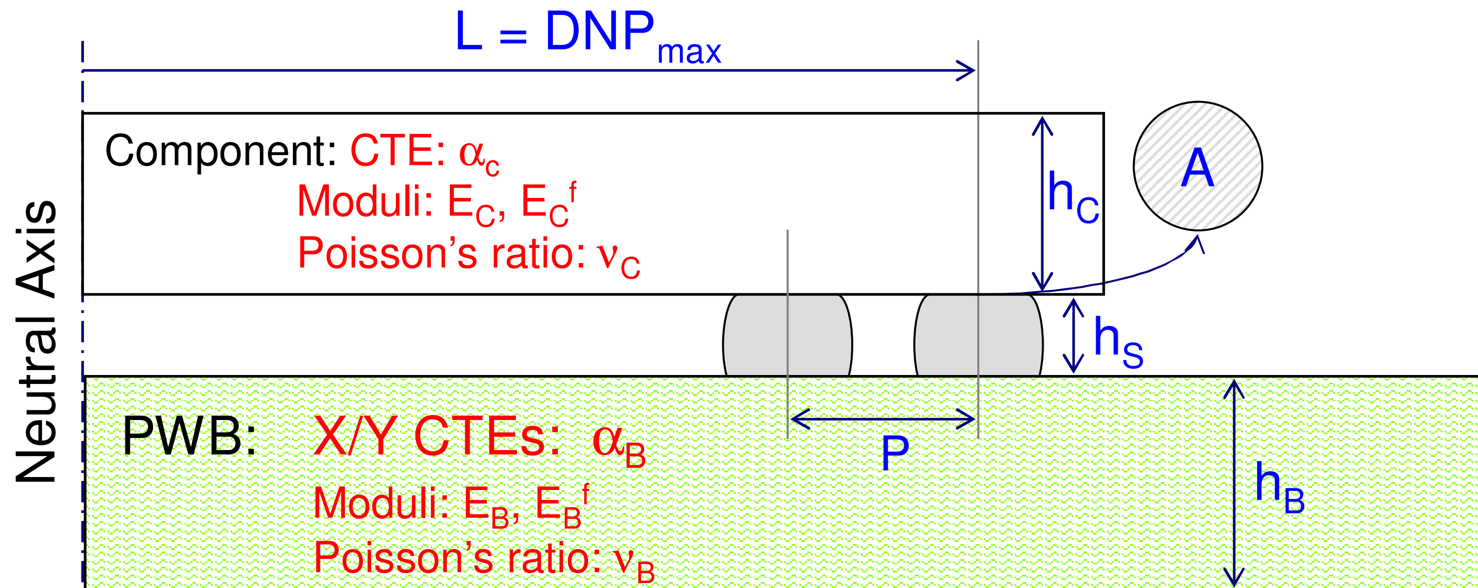
- **An infinite number of possible solder joint alloy and mixed alloy compositions.**
  - **Testing them all thoroughly, as was done with SnPb, is not economically feasible.**

SJ Life Depends on Strain Energy



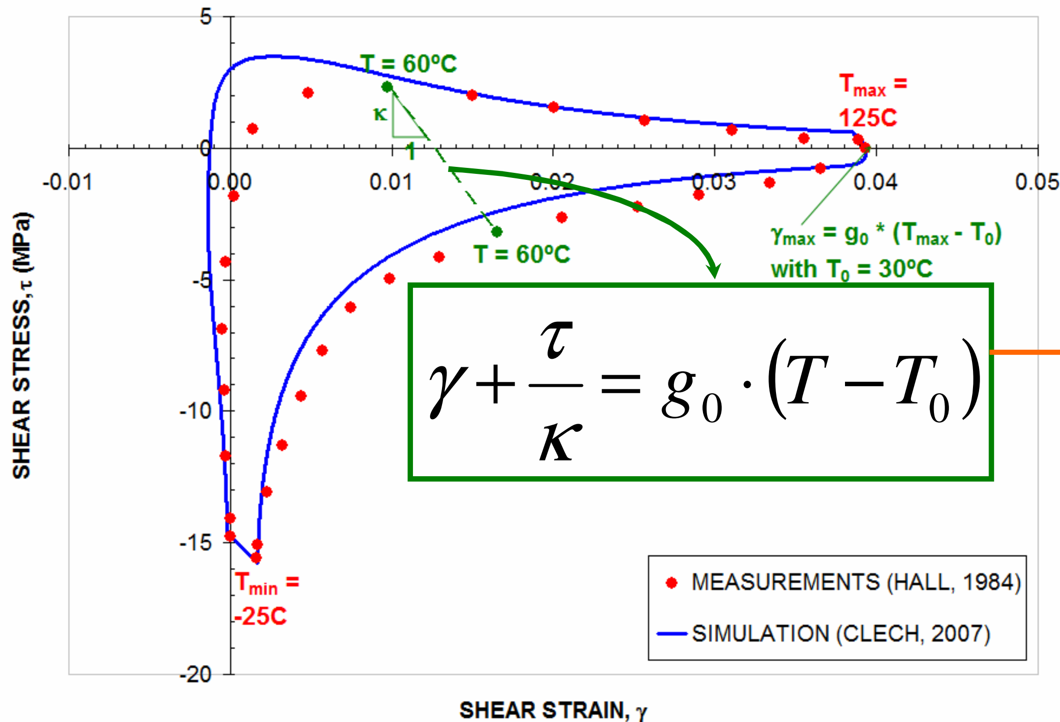
- Loop shape and area depend on:
  - "CTE mismatch" or strain parameter g_0
  - Assembly stiffness parameter κ

Pseudo-Stresses/Strains: Why?



- **The parameters κ and g_0 may not be readily available.**
  - **They depend on 14+ design parameters and material properties.**
  - **Pseudo-approach: Get rid of them.**

Pseudo-Stress/Strain Definitions



$$\gamma + \frac{\tau}{\kappa} = g_0 \cdot (T - T_0)$$

Divide by g_0 and get:

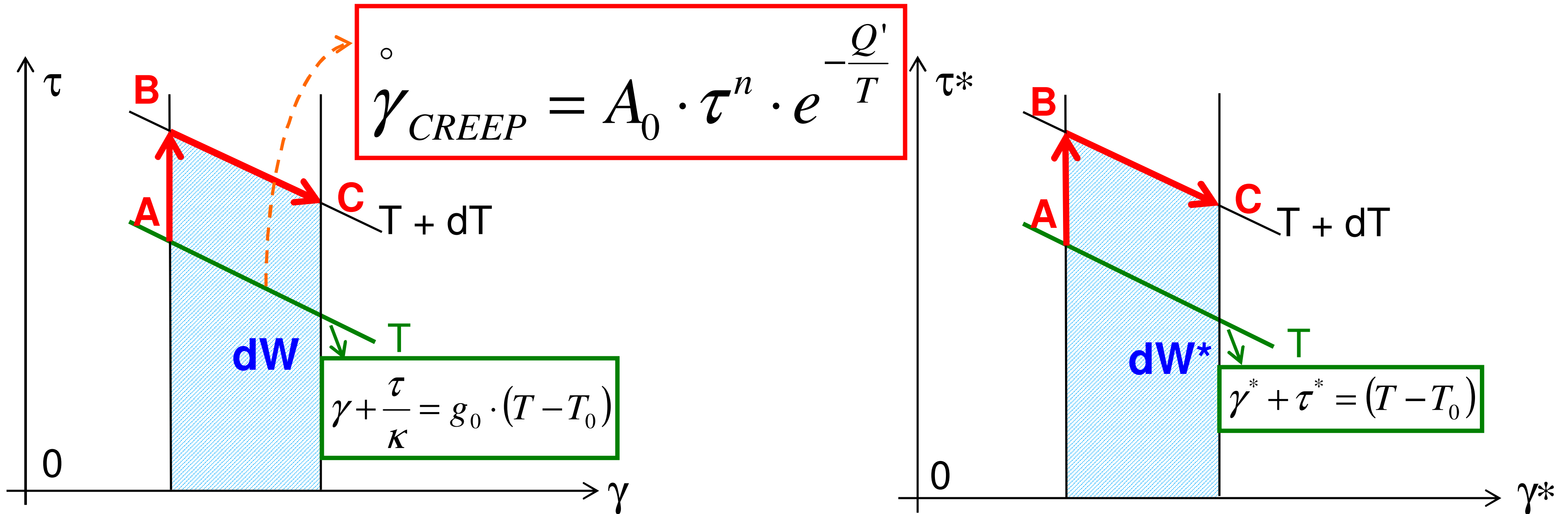
$$\gamma^* + \tau^* = T - T_0$$

$$\gamma^* \equiv \frac{\gamma}{g_0} = \text{Pseudo-Strain}$$

$$\tau^* \equiv \frac{\tau}{\kappa \cdot g_0} = \text{Pseudo-Stress}$$

- **Pseudo-stresses/strains remove κ and g_0 from isothermal stress reduction line equation. γ^* & τ^* have units of temperature.**

Creep & Pseudo-Strain Energy



- **Pseudo-strain energy, W*, depends solely on assembly coefficient "c":**

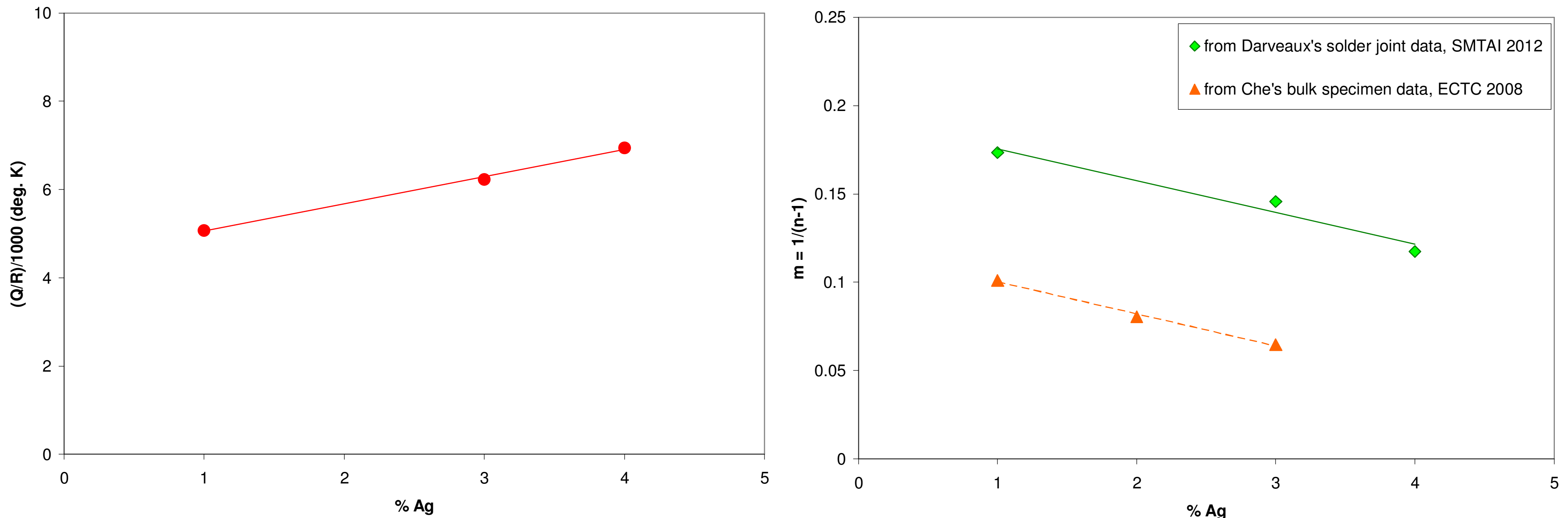
$$c \equiv A_1 / \left(\kappa^{1+m} \cdot g_0\right)$$

where m = 1 / (n-1),

$$A_1 \equiv \left[(n-1)A_0\right]^{-m}$$

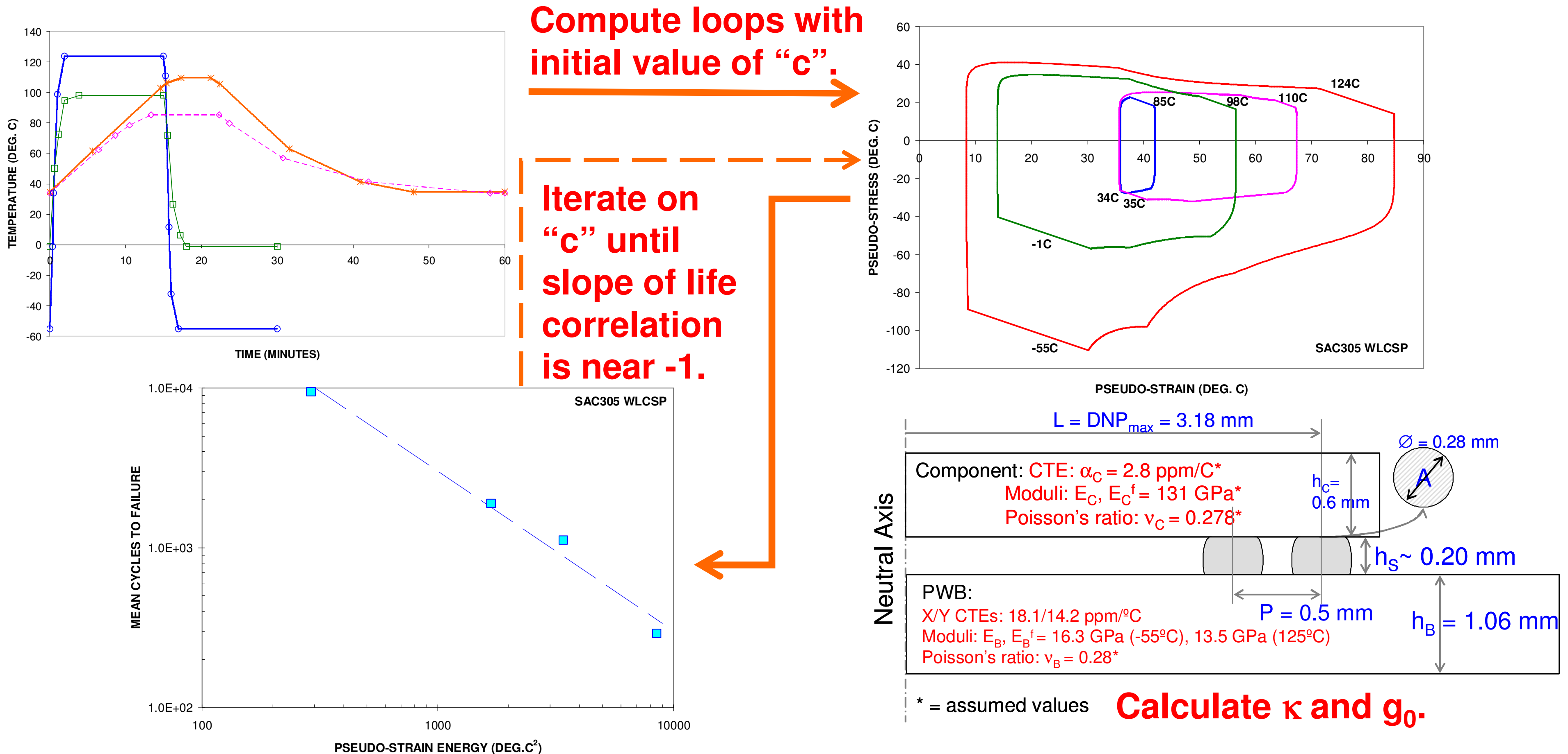
= solder constant

Creep Parameters vs. %Ag



- **For most assemblies, solder joint shear strain rates in ATC are less than $5x10^{-3}$/s.**
- **Based on Darveaux et al.'s SMTAI 2012 SAC creep data at strain rates < $5x10^{-3}$/s:**
  - **Activation energy and m = 1/(n-1) are linear with Ag content in range 1 to 4%.**

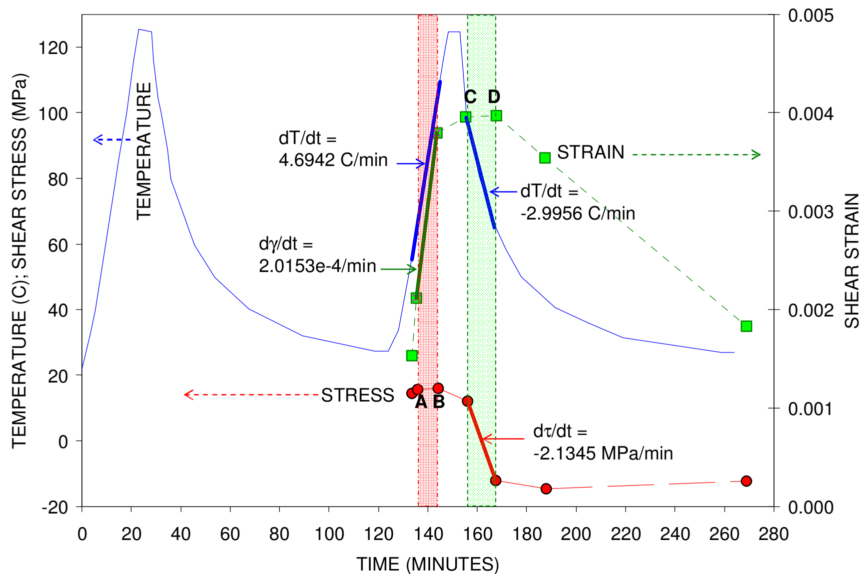
Ex. # 1: SAC305 Data Correlation

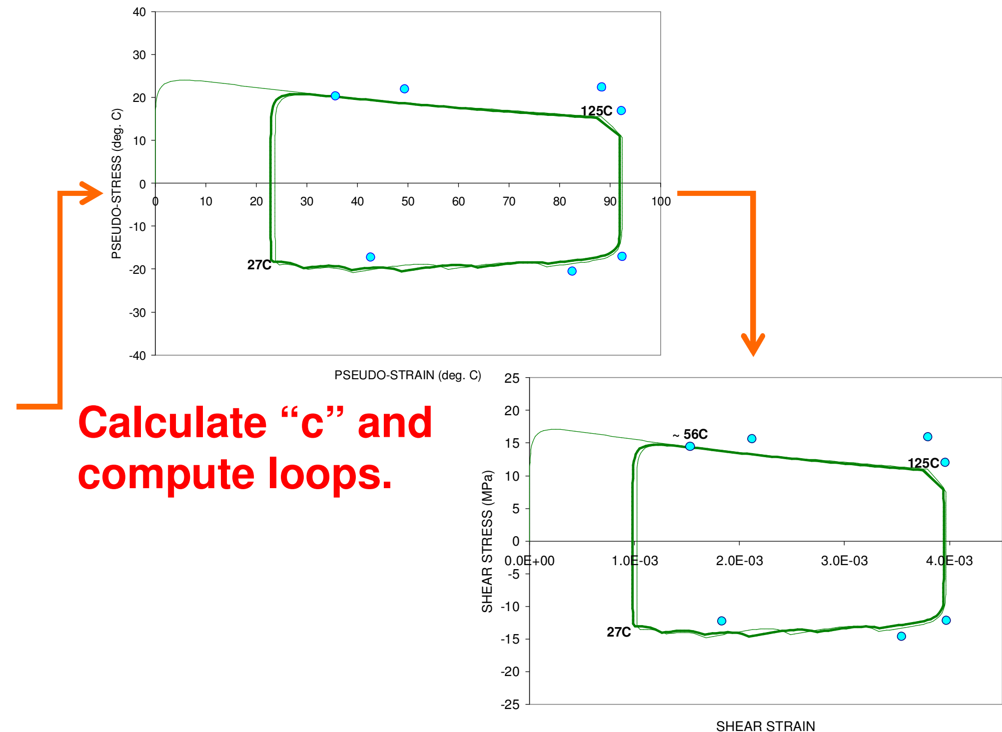


- **Use Darveaux et al. (SMTAI 2009) WLCSP solder joint reliability data to get creep constant A_1 for non-aged SAC305 solder.**

Ex. # 2: SAC305 Hysteresis Loop

Get κ and g_0 from stress/strain history

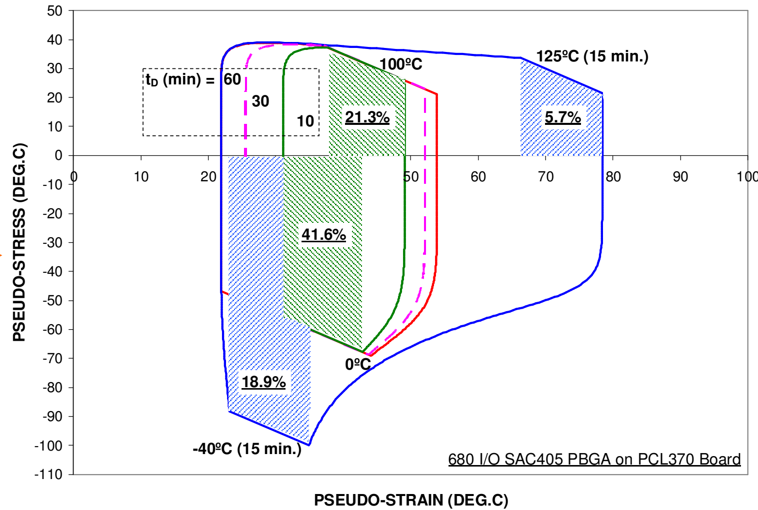




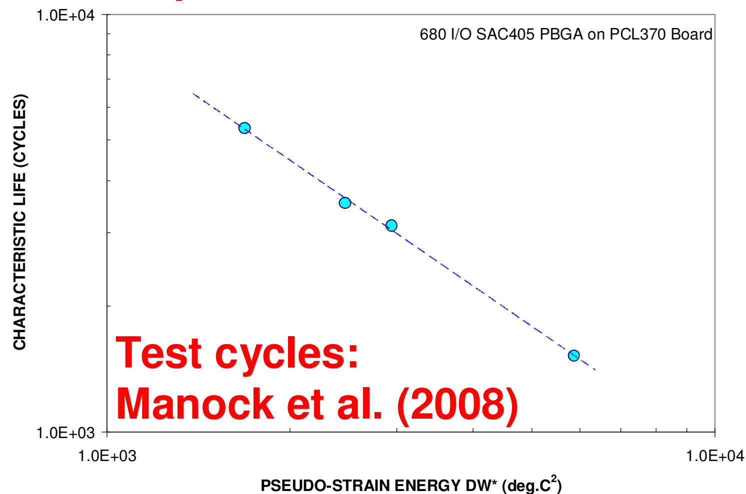
- FC-BGA DSC strain data by Shirazi, 2011
  - Using A_1 from Ex. # 1, compute "**c**" and pseudo-hysteresis loop. NO CALIBRATION.
  - Agreement between measurements and simulation validates creep model.

Ex. # 3: SAC405 Dwell Time Effect

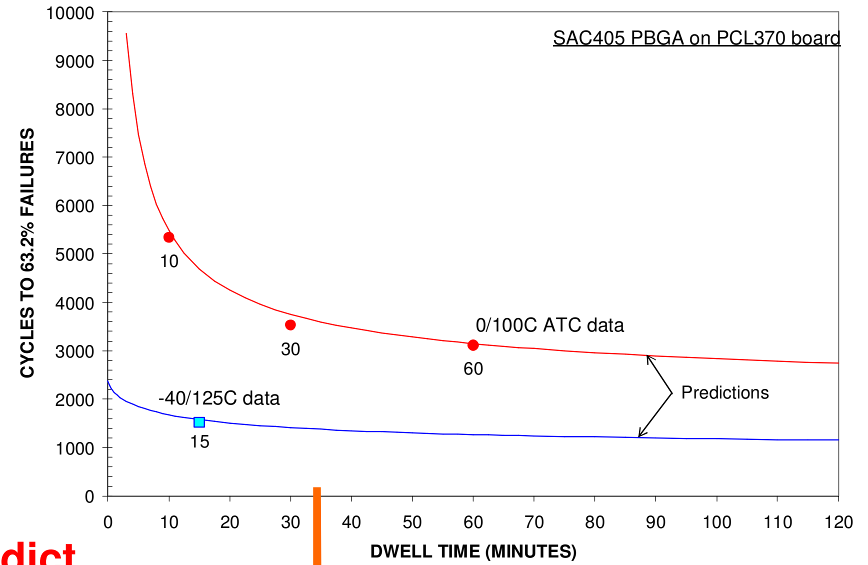
Start with guessed value of “c” and generate loops for 4 ATC profiles

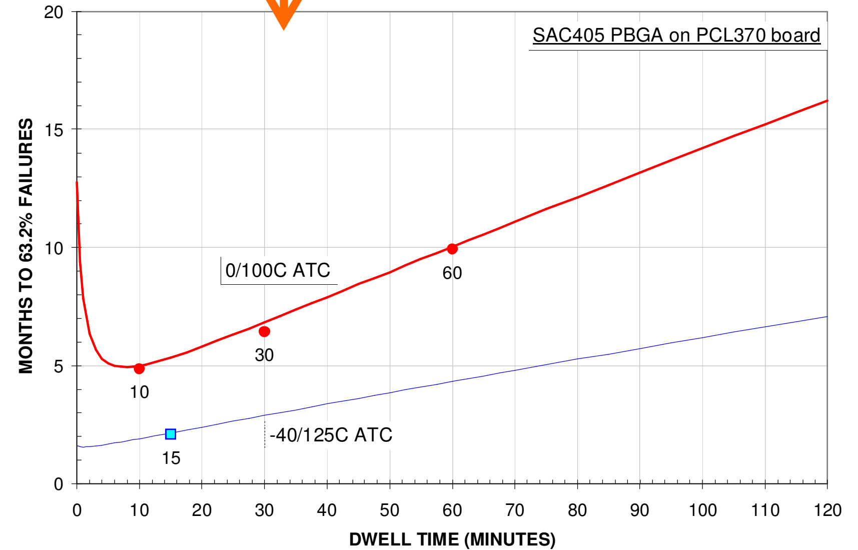


Iterate on “c” to get life correlation with a slope of -1.



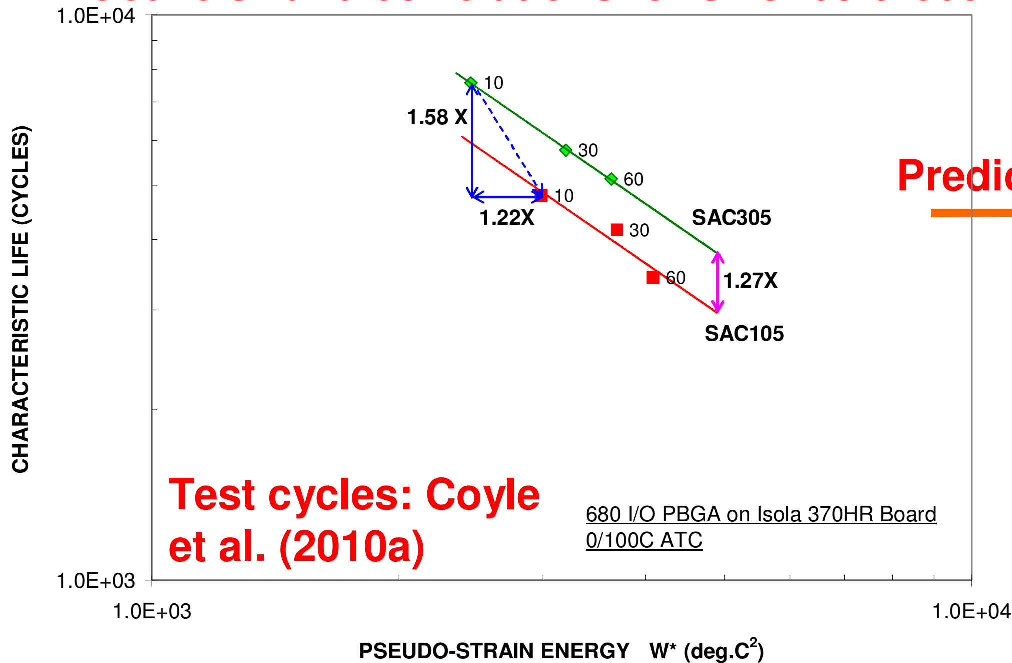
Predict



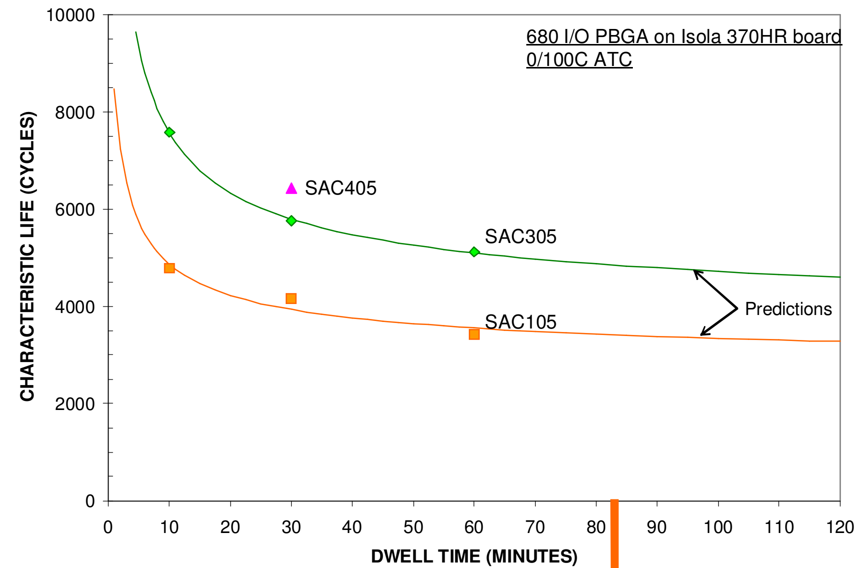


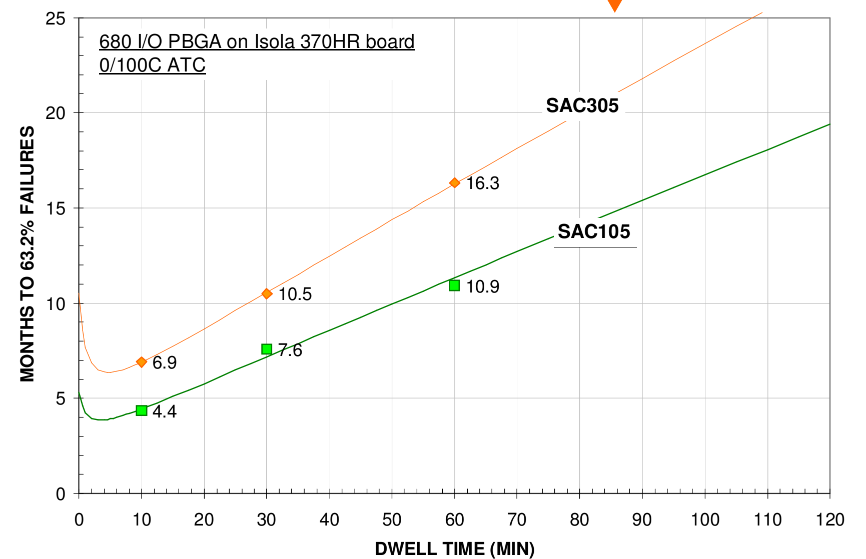
Ex. # 4: SAC105/305 Dwell Effect

Get "c's" and correlations for SAC105 & 305



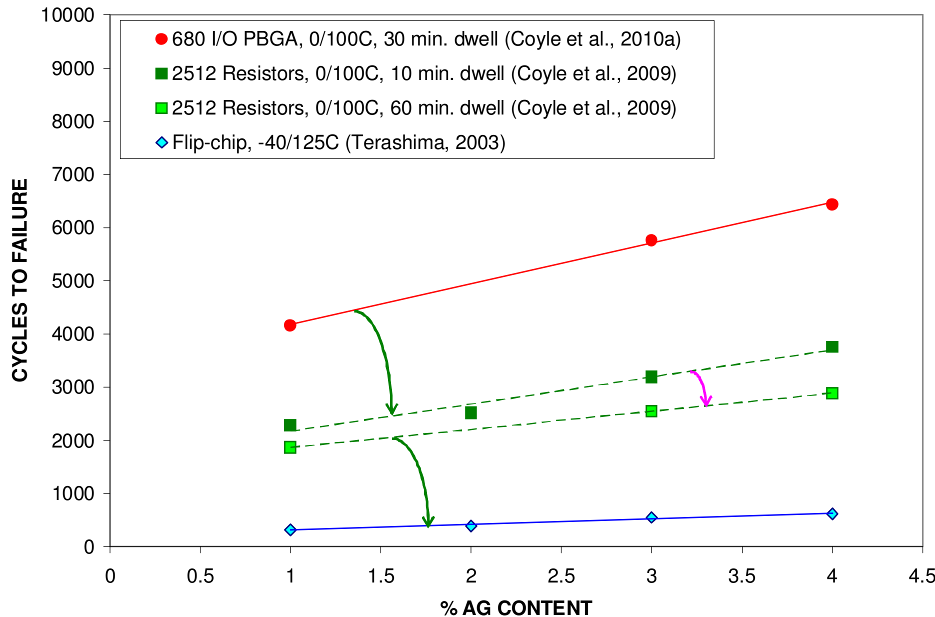
Predict

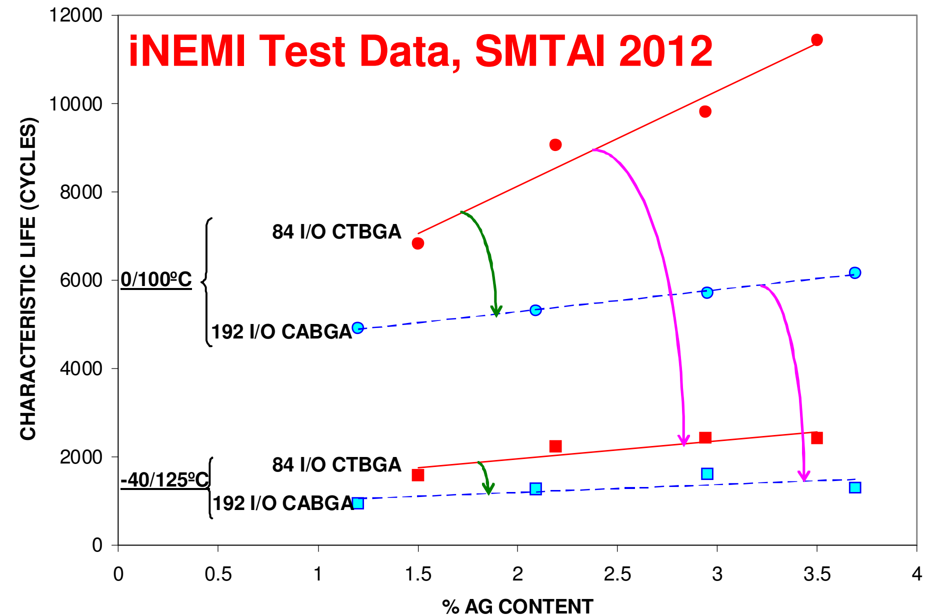




- In a given ATC test, SAC105 & 305 joints are subject to different strain energies or stress/strain cycles.

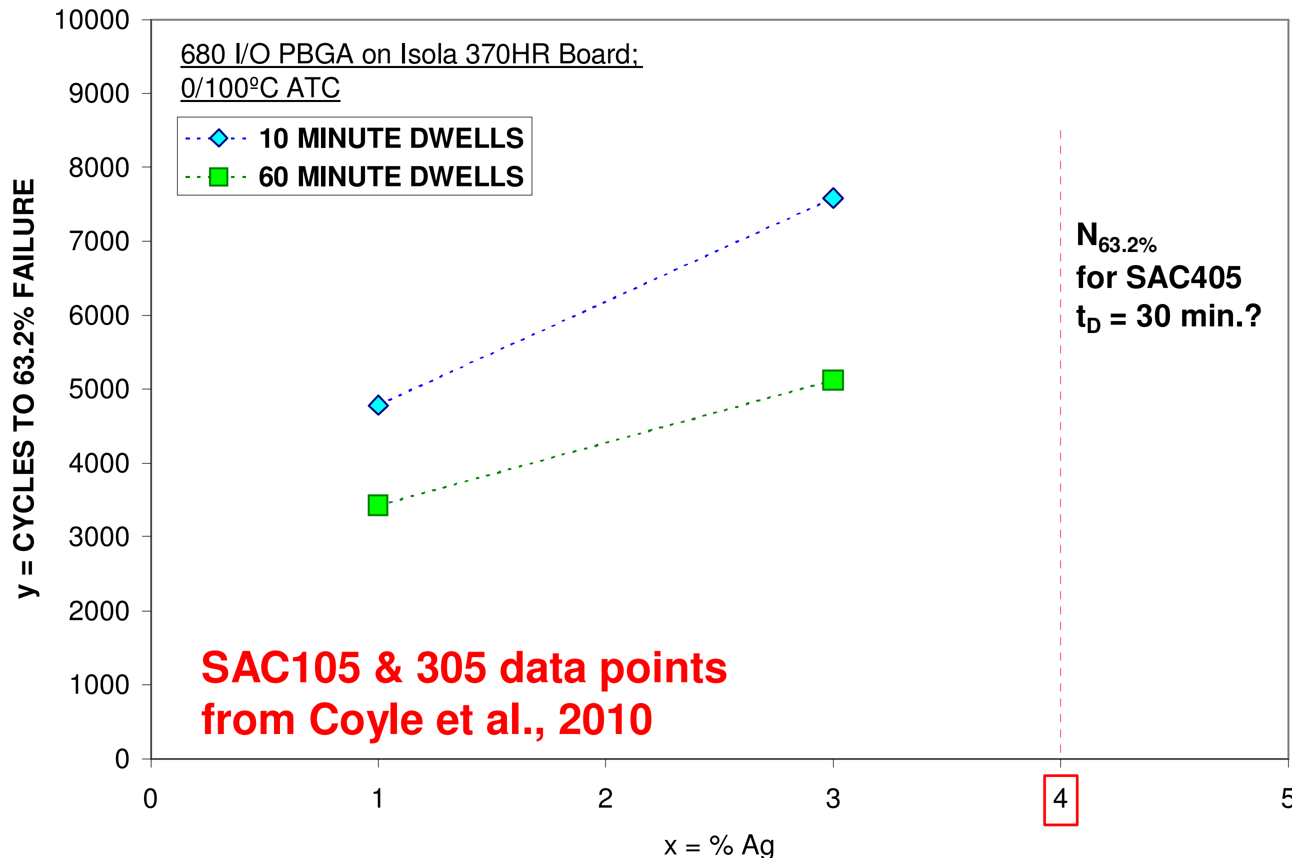
Effect of Ag Contents on SAC Life





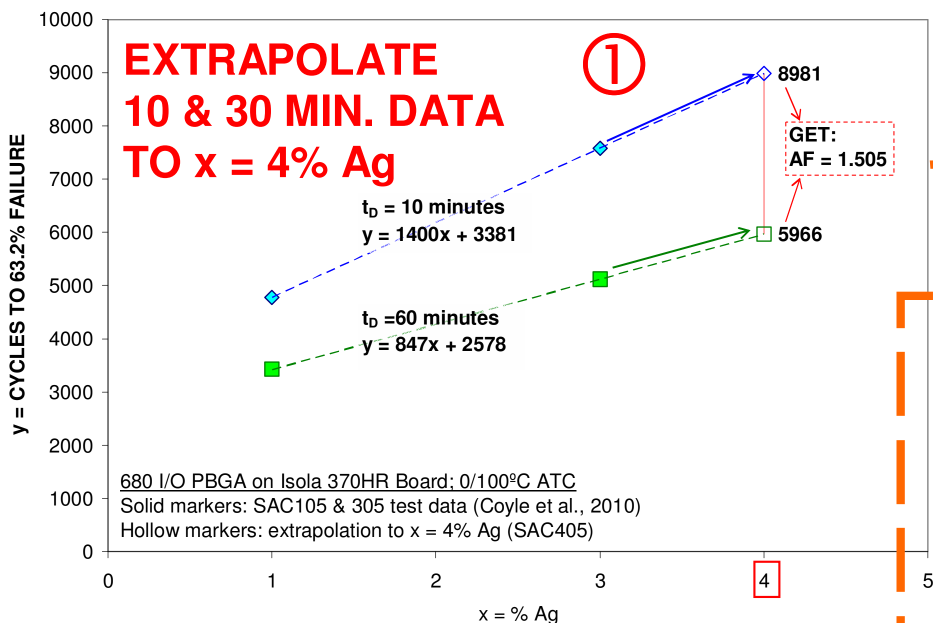
- **Survey shows linear trend in range 1-4% Ag**
  - **Slopes decrease under harsher conditions (pink arrows) or with an increase in thermal expansion mismatch (green arrows).**
  - **In other words, differences between SAC alloys increase under lower "stress".**

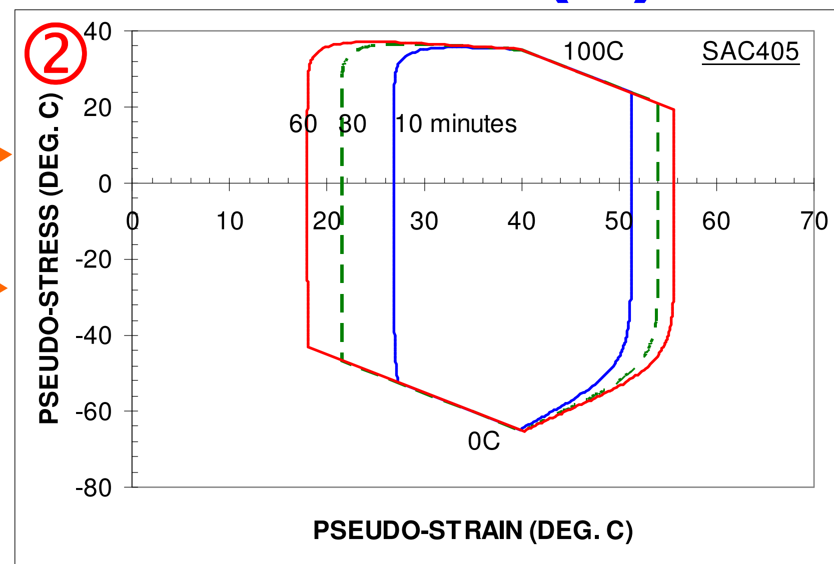
SAC to SAC Life Prediction (1)



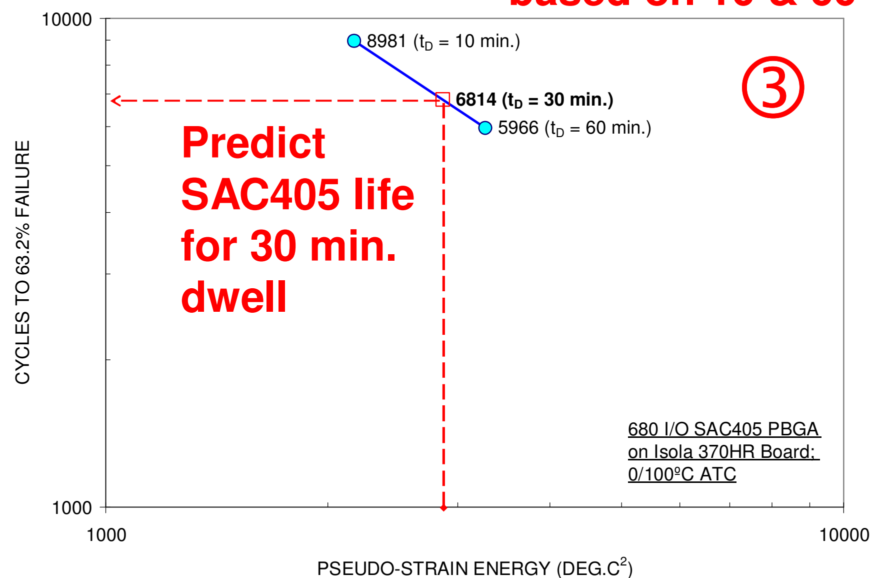
- Predict SAC405 PBGA life in ATC: 0/100ºC, 30 minute dwells, based on characteristic lives for SAC105 and SAC305 PBGAs in ATC with 10 and 60 minute dwells.

SAC to SAC Life Prediction (2)



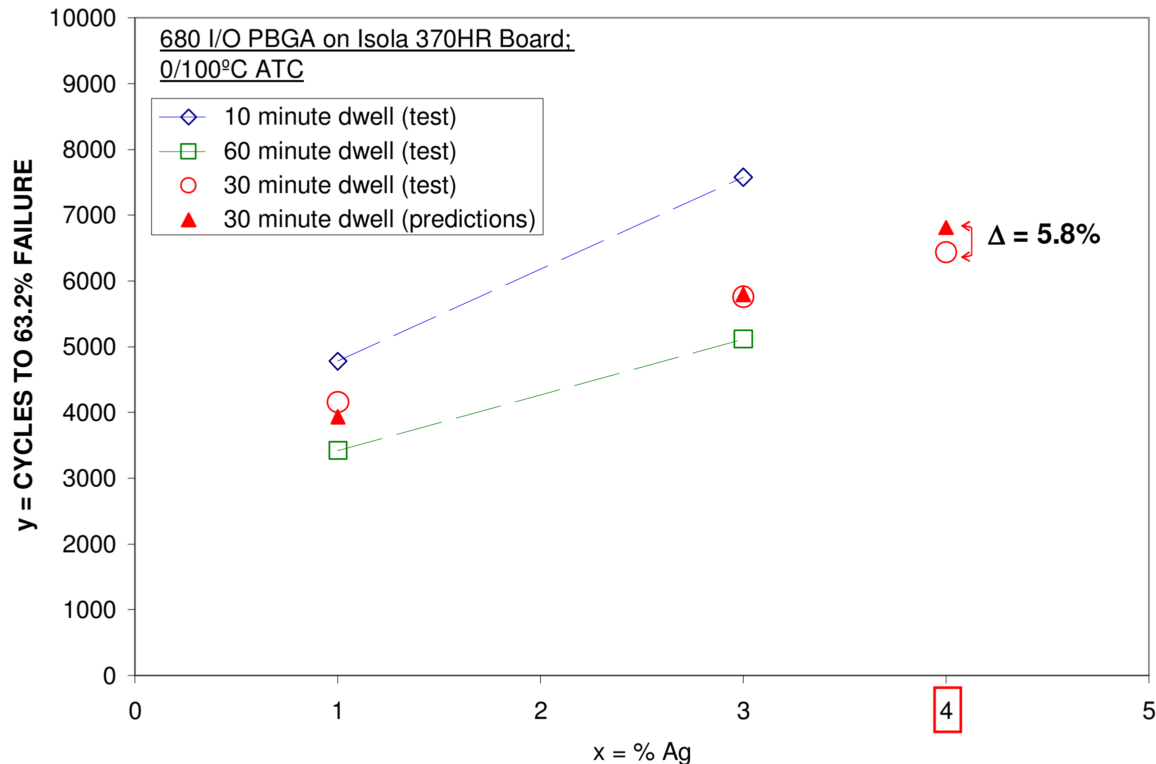


Iterate on "c" to get SAC405 life correlation based on 10 & 60 min. dwell data



- In last iteration, use 30 min. dwell pseudo-loop strain energy to predict life

SAC to SAC Life Prediction (3)



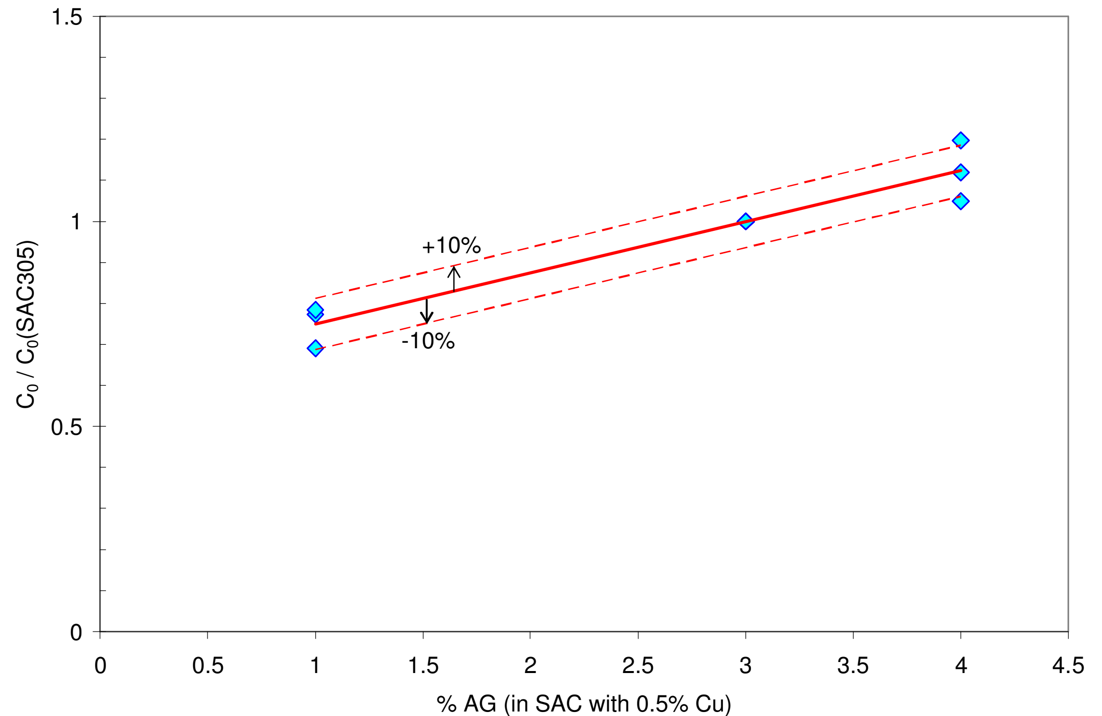
- **Predicted SAC405 PBGA life (0/100ºC, 30 min. dwell) is within 5.8% of measured life.**
  - **Prediction also lines up with SAC105 & SAC305, 30 min. dwell test data which was not used in making SAC405 life prediction.**

Fatigue Constant C_0 vs. %Ag

Characteristic life

$$\frac{\alpha}{A} = \frac{C_0}{\Delta W} = \frac{C_0}{\kappa \cdot g_0^2 \cdot \Delta W^*}$$

Solder joint load bearing area (or crack area)



- **Normalized solder fatigue constant C_0 (relative to SAC305) follows linear trend with Ag content in range 1 to 4%.**

Conclusions

- **The pseudo-hysteresis loop approach helps correlate ATC test data when:**
  - **Test vehicle parameters are not readily available.**
  - **Temperature profiles deviate from regular, trapezoid profiles.**
- **Creep and fatigue constants of the model follow linear trends vs. % Ag content in range 1 to 4%**
  - **This allows to predict solder joint life for mixed SAC assemblies with final alloy composition other than SAC105, 305 or 405.**

Gracias!

Pregundas?