THE COMBINED EFFECT OF ASSEMBLY PITCH AND DISTANCE TO NEUTRAL POINT ON SOLDER JOINT THERMAL CYCLING LIFE

APT4 Session: Thermo-Mechanical Reliability
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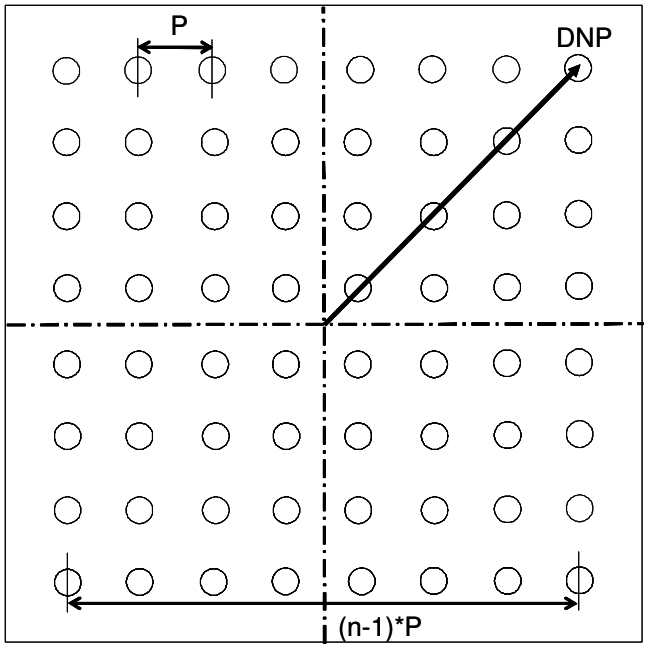
Outline

- **Problem: “Life vs. DNP*” trends**
- **“Pitch and DNP” model**
- **Supporting data** / model validation**
- **Conclusions**

*DNP = maximum Distance to Neutral Point at critical corner joint(s)

**References for all quoted datasets are in paper’s reference list

Problem: "Life vs. DNP" Trends



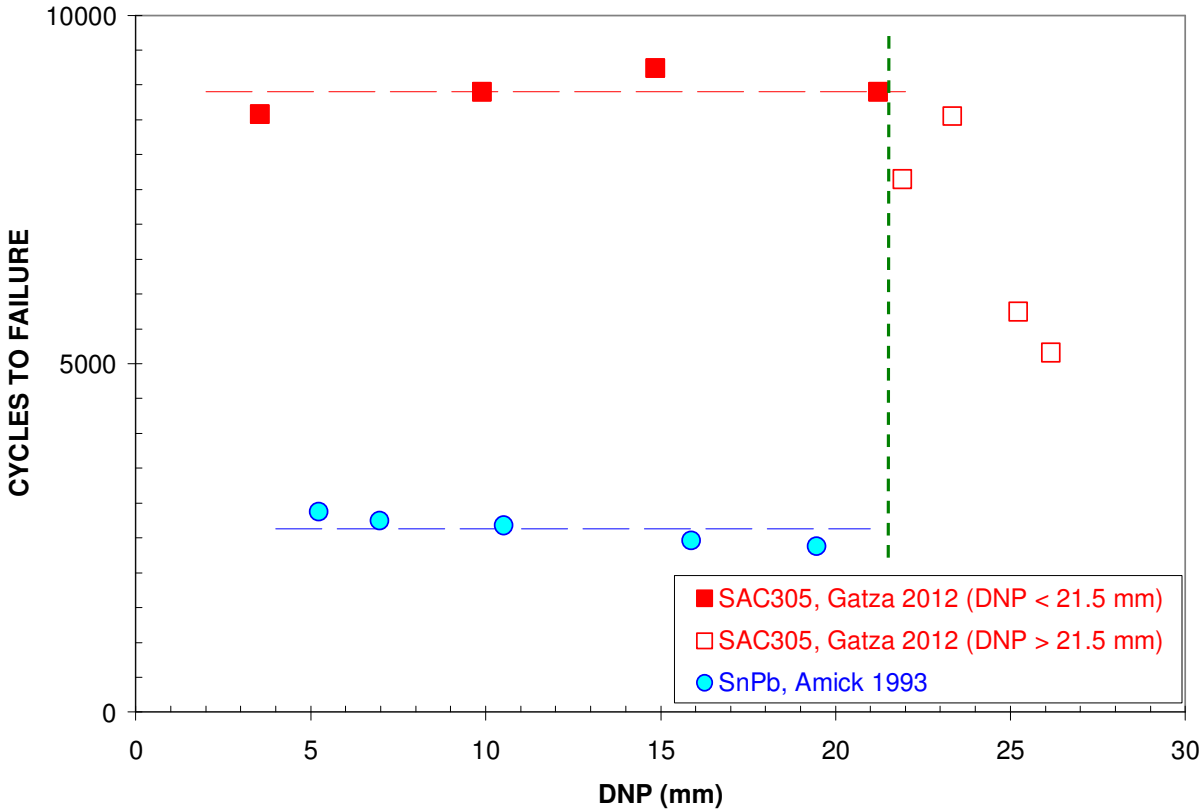
- In standard models, cycles to failure go as $1/DNP^m$
  - m ~ 1.9 to 3.2+
- Accelerated Thermal Cycling (ATC) shows different trends (next slides)

- Note: in n x n array, maximum DNP is:

$$DNP = (n-1) \cdot P / \sqrt{2}$$

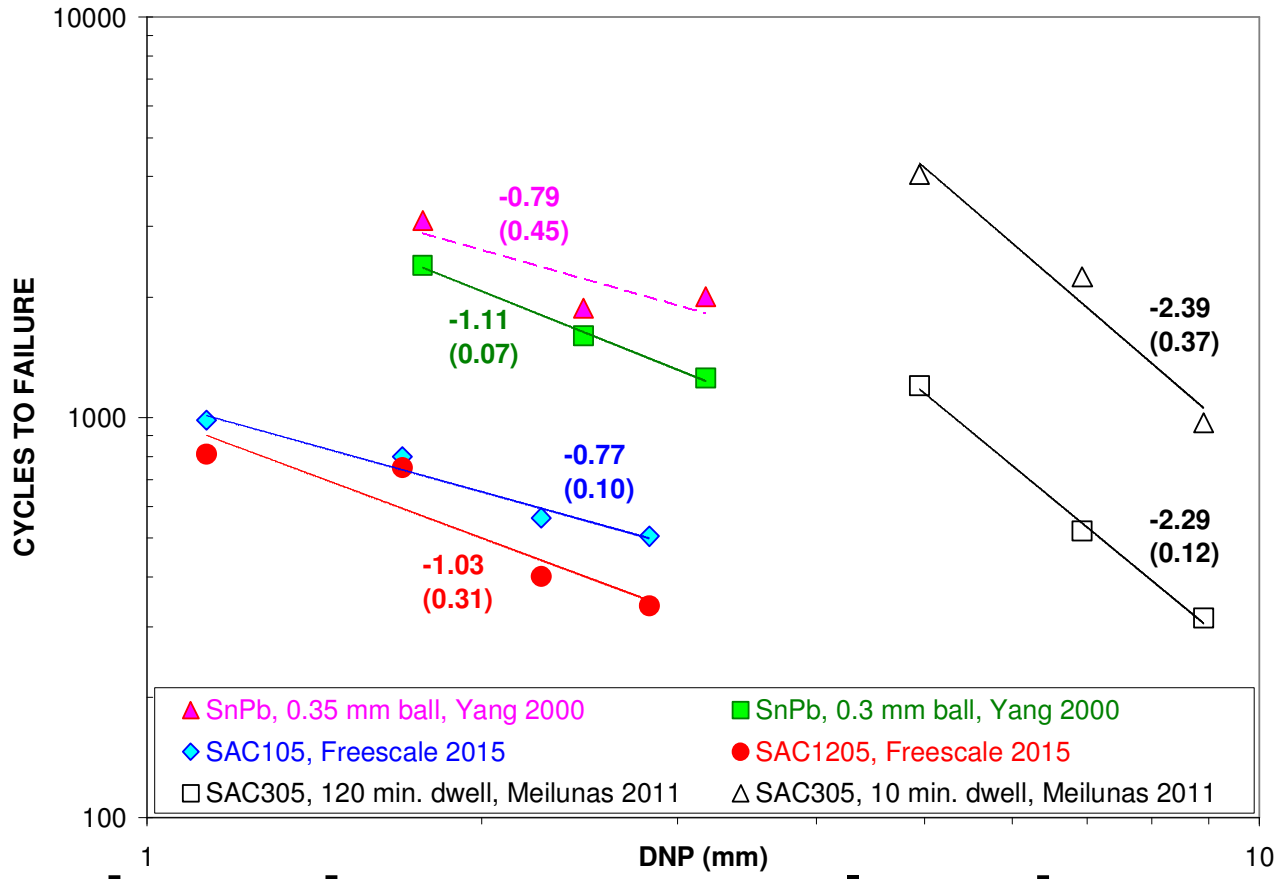
  - Chose Pitch (P) & DNP as independent variables

ATC Trend # 1



- **Little to no DNP effect when**
  - In-plane CTE mismatch is small (<≈ 2 ppm/ºC)
  - Local CTE mismatches dominate

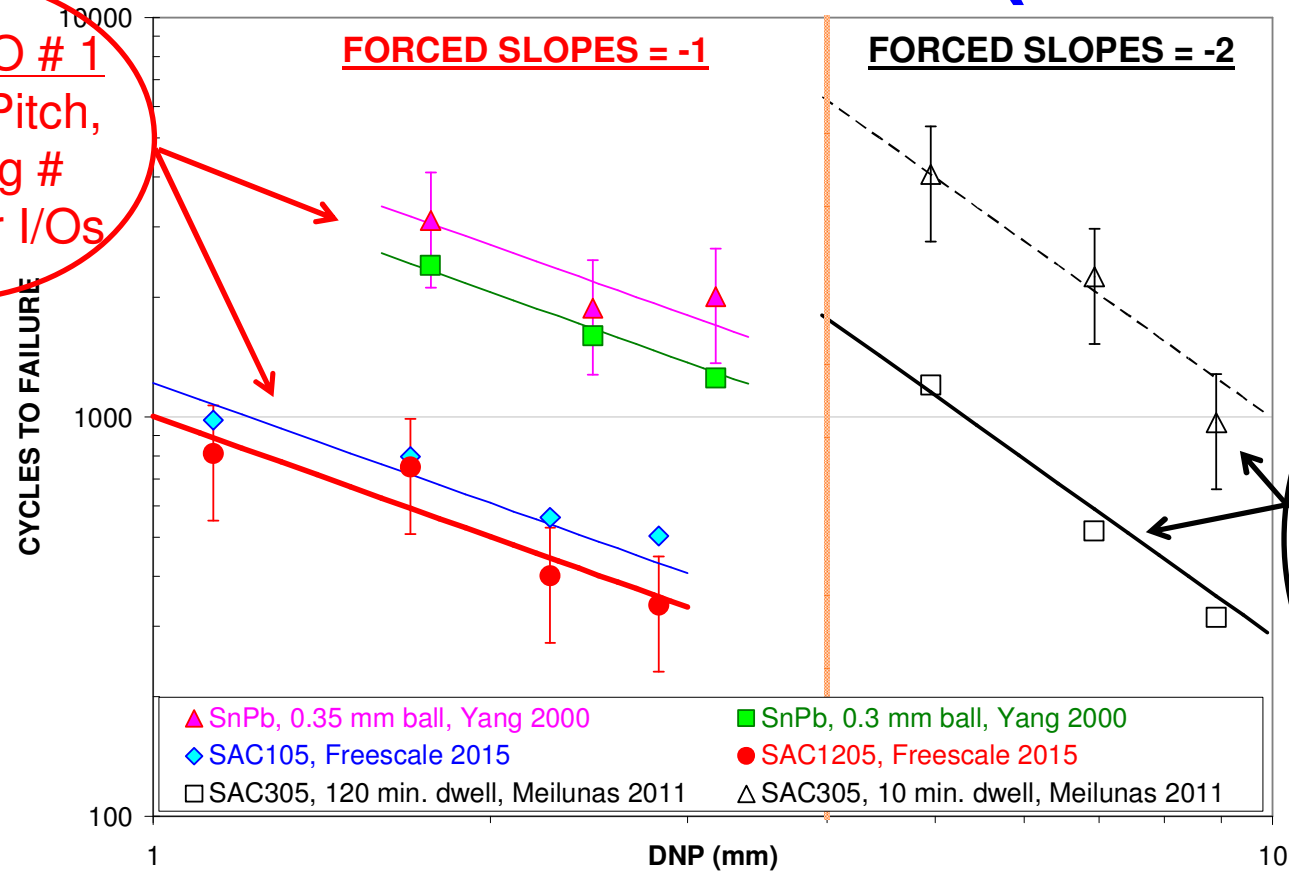
ATC Trends # 2 & 3



- **Test data shows power-law dependence with wide range of slopes: -2.39 to -0.77 & large standard deviations (as much as 0.45)**

ATC Trends # 2 & 3 (cont'd)

SCENARIO # 1
Constant Pitch, Increasing # of Rows or I/Os



SCENARIO #2
Constant I/Os, Increasing Pitch

- **Power-law trendlines, with forced slopes of -1 or -2, fit the data within error margins.**

Solution: "Pitch & DNP" Model

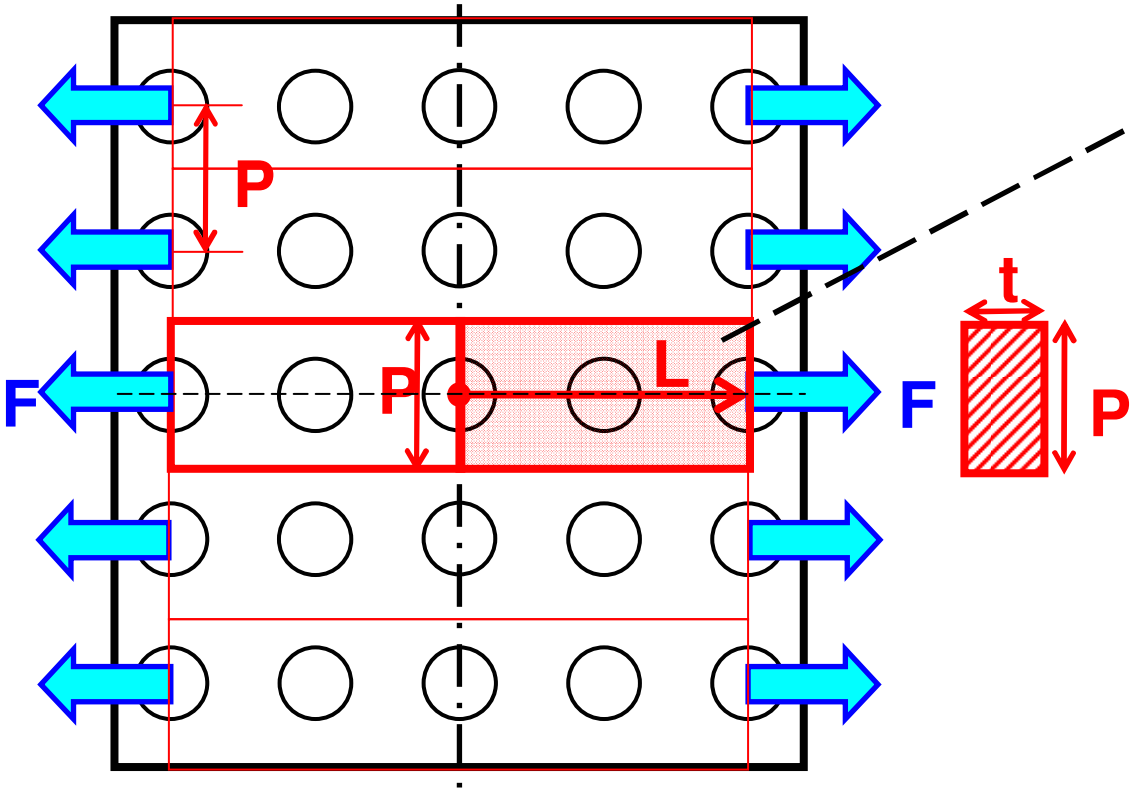
- From strain energy model (in paper), cycles-to-failure N_f go as:

$$N_f \sim 1 / (\text{Pitch} * \text{DNP})$$

  - Scenario # 1: if "Pitch" is fixed and I/Os increase by adding rows: $N_f \sim 1 / \text{DNP}$
  - Scenario # 2: if I/Os are constant but the pitch P increases, DNP increases as the pitch. Get: $N_f \sim 1 / \text{DNP}^2$ (or $1 / \text{Pitch}^2$)

- Model agrees with data in slide # 6

Why Does the Pitch Matter?



Pitch & DNP stiffness effect:

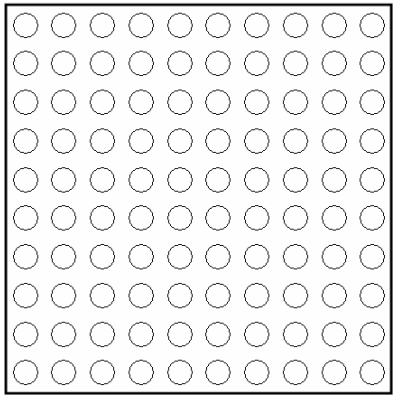
K ~ E*(P*t)/L

increases as the pitch and 1/DNP

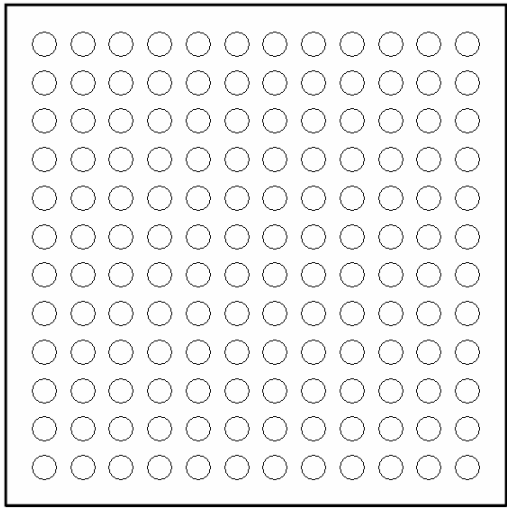
(E = Young's modulus)

- **Shear forces & moments act on half strips of width the pitch P and length L ("DNP")**
  - **Long & narrow strips (small P) are more flexible**

Application & Validation Example



10 x 10 array
(subscript “10”)



12 x 12 array (subscript “12”)
has two extra-rows; everything else is the same.

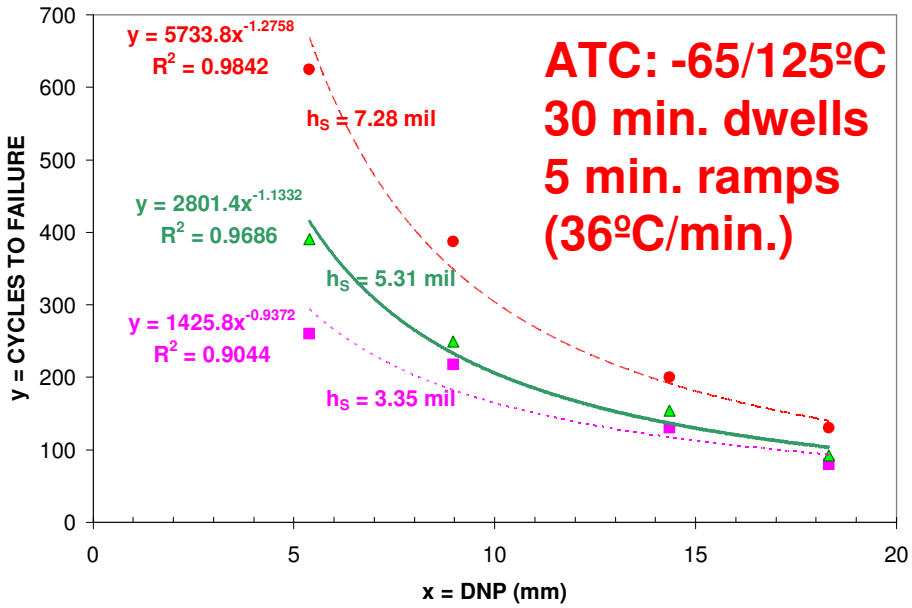
- **What is the ratio of solder joint lives for these two WLCSP assemblies?**
  - **Pitch is constant. Model predicts: r = $Life_{10}$ / $Life_{12}$ = DNP_{12} / DNP_{10} = (12-1)/(10-1) = 1.22**
  - **Test result: r = 1.2 (Kaysar Rahim, 2009)**

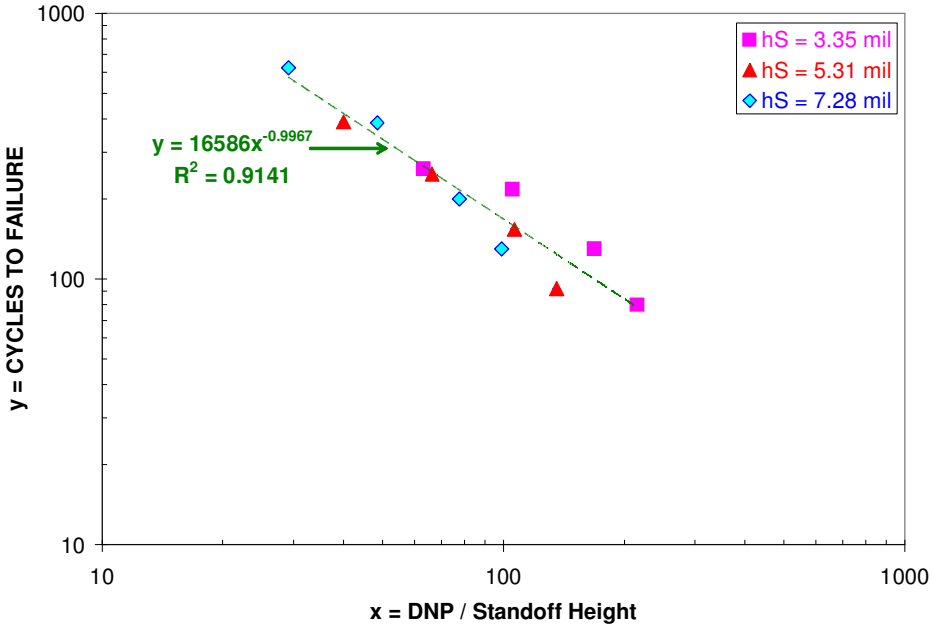
Stand-Off Height Effects

Strain Energy "Pitch & DNP" Model	Strain Range Model (assuming m ~ 2)
$N_f \propto \frac{1}{\left(P \cdot \frac{L}{h_S}\right) \cdot (\Delta\alpha \cdot \Delta T)^2}$	$N_f \propto \frac{1}{\left(\frac{L}{h_S} \cdot \Delta\alpha \cdot \Delta T\right)^2}$
For given pitch: N_f goes as $1/(L/h_S)$	N_f goes as $1/(L/h_S)^2$
For given pitch & DNP: N_f goes as h_S (see microSMD example in paper)	For given DNP: N_f goes as $(h_S)^2$ Supporting data?

Notations: $\Delta\alpha$ = Global CTE mismatch, ΔT = Temperature swing

DNP / h_S Effect: Supporting Data #1

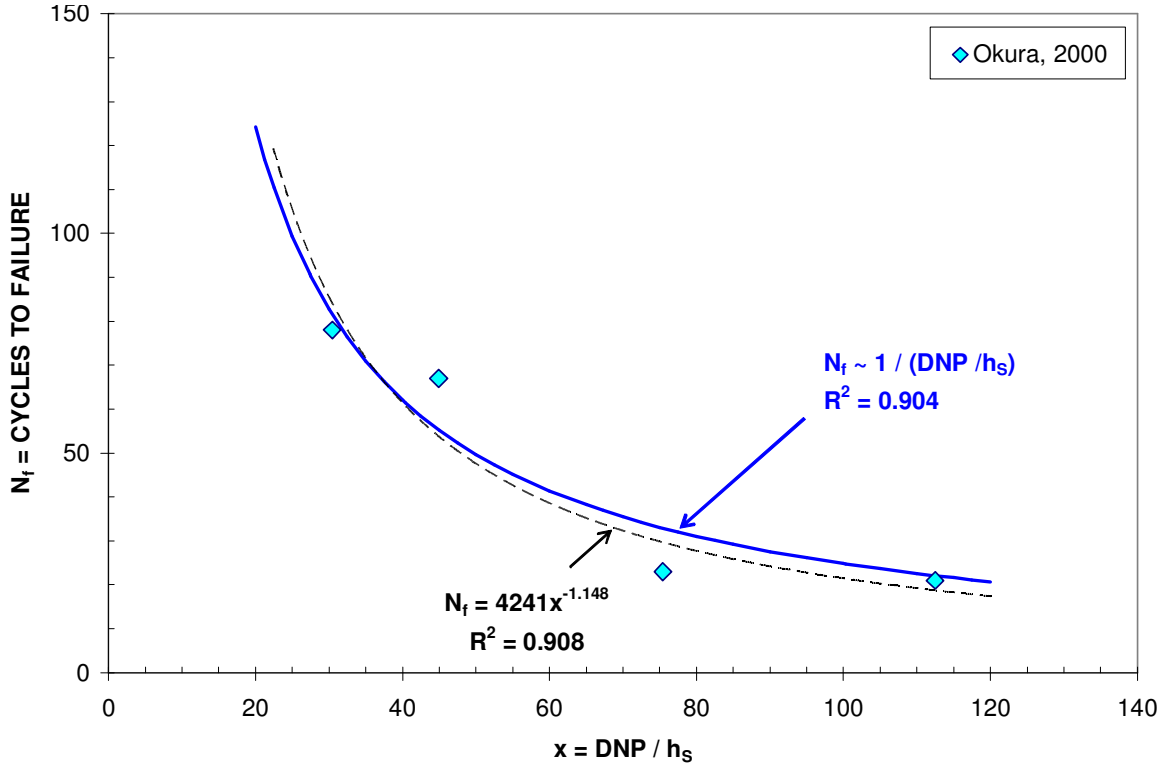




- **Itoh 1982, 50 mil pitch LCCCs (SnPb)**
  - **"N_f vs. DNP" data for three controlled stand-off heights**

- **"N_f vs. DNP/h_S" correlation gives slope of -0.997, close to -1 prediction**

DNP / h_S Effect: Supporting Data #2



- **Okura, 2000: SAC FCOB, no underfill**
  - **Data is for two chip sizes & two stand-off heights; constant, staggered pitch**

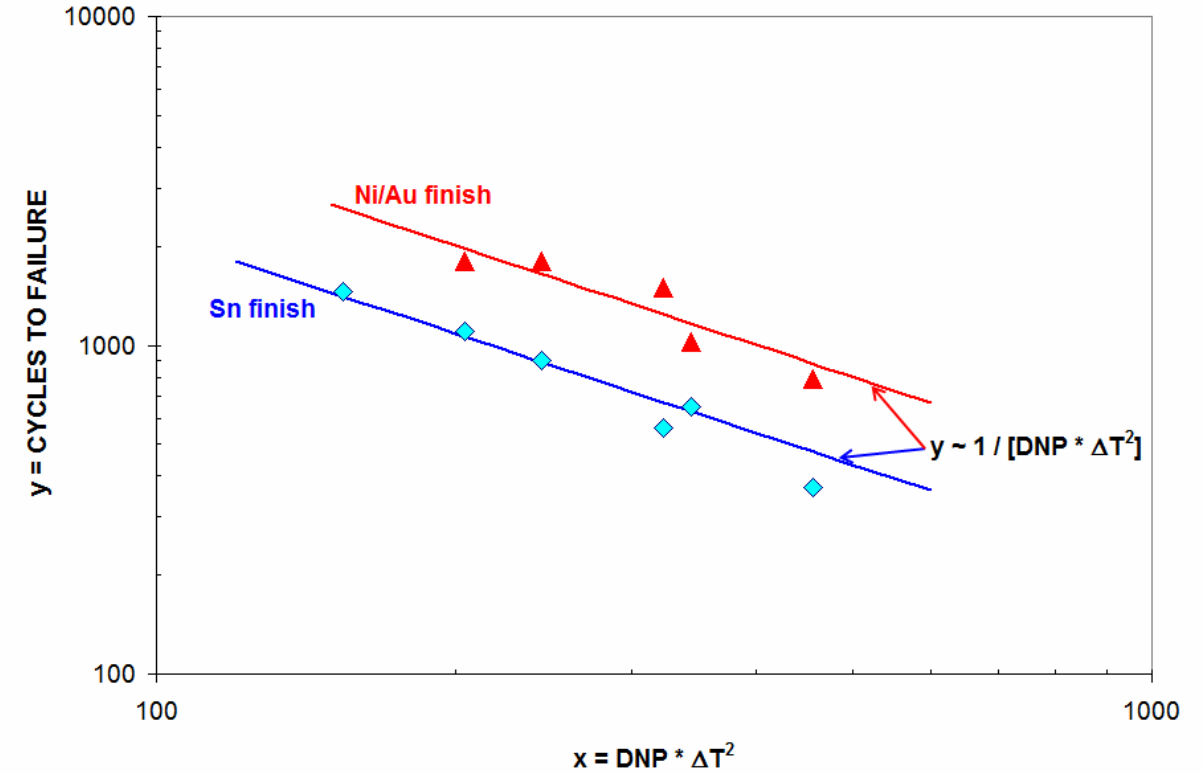
- **Model (solid blue line) captures the data as well as power-law trendline (dashed line)**
  - **Correlation coefficients R^2 's are similar**

Combined DNP & ΔT Effect

Strain Energy "Pitch & DNP" Model	Strain Range Model (assuming m ~ 2)
$N_f \propto \frac{1}{\left(P \cdot \frac{L}{h_S}\right) \cdot (\Delta\alpha \cdot \Delta T)^2}$	$N_f \propto \frac{1}{\left(\frac{L}{h_S} \cdot \Delta\alpha \cdot \Delta T\right)^2}$
For given pitch: N_f goes as $1/(L^*\Delta T^2)$	N_f goes as $1/(L^*\Delta T)^2$

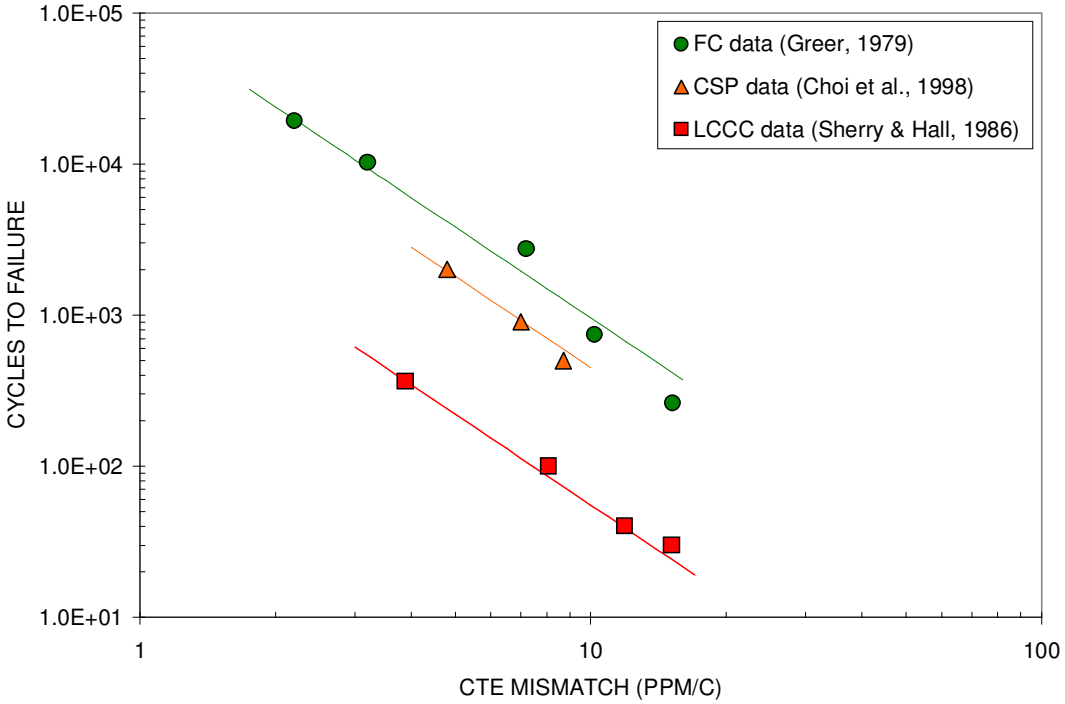
DNP NOT SQUARED **DNP SQUARED**

DNP * ΔT^2 Effect: Supporting Data



- **Roellig et al., 2007: SAC ceramic test vehicles**
  - **Components have: 4 corner joints + 1 center joint; constant width (pitch) and increasing span**
  - **Trendlines with -1 slopes follow the test data well**

CTE Mismatch Effect Is Squared



- **Trendlines with slopes of -2, as per "Pitch & DNP" model, follow test data well**
  - **"CTE mismatch" datasets are rare because CTEs are not measured routinely, let alone reported.**

Conclusions

- "Physics 101" works
  - Paper highlights the physics behind the pitch stiffness effect and its impact on solder joint life.
  - "Pitch & DNP" model is supported by over a dozen independent experiments
- "Trust but verify"
  - When considering life models that do not account for the pitch stiffness effect, validate said models prior to running simulations.
- Concurrent and all important pad size effect was not addressed in this paper.
  - To be continued…

Thank You!

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