Design for Reliability (DfR) Considerations in the Application of Lead-Free Solders

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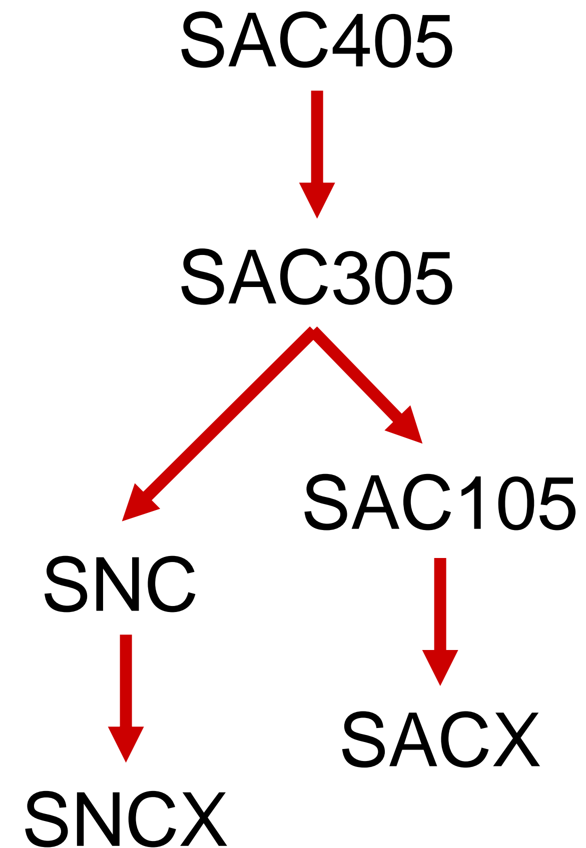
Design for Reliability (DfR)

- Design for Reliability (DfR) is a process of using the knowledge of how things fail to ensure reliability during the design phase
  - Does not include testing
- DfR for Lead-Free Solders
  - How do lead-free solders ‘fail’?
  - What are the biggest concerns of the electronics marketplace?

Divergence in Solder Selection

?? SnAg SnAgCu ~~SnCu~~

- Considerations include
  - PRICE!
  - Insufficient performance
  - Newly identified failure mechanisms
- Market still unsteady; proliferation and evolution of material sets
- Solder seeing the fastest increase in market share?
  - Tin-Nickel-Copper (SNC)

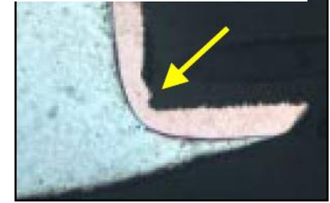


Copper Dissolution

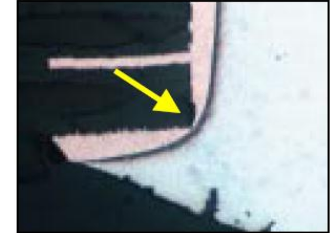
- The reduction or elimination of surface copper conductors due to repeated exposure to Sn-based solders
- Significant concern for industries that perform rework
  - Pretty much everyone
- Contact time is the major driver
  - Some indications of a 25 second limit
- Already having a detrimental effect
  - Major OEM unable to repair ball grid arrays (BGAs)

S. Zweigart, Solectron

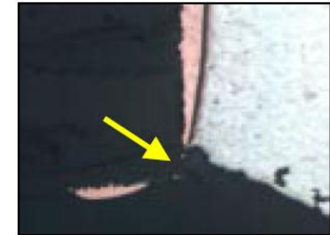
Dwell time: 20.1 sec

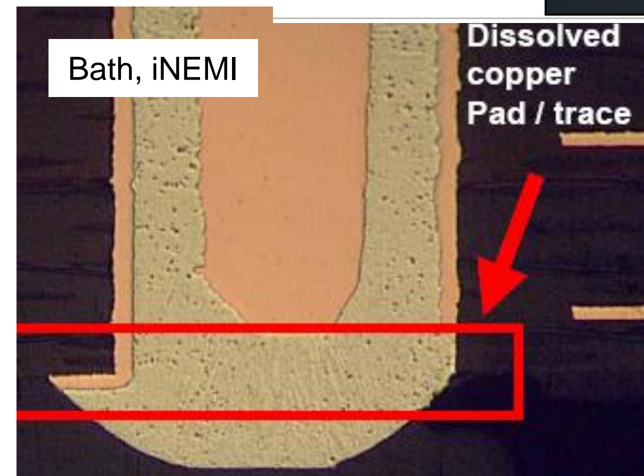


Dwell time: 22.4 sec



Dwell time: 35.6 sec





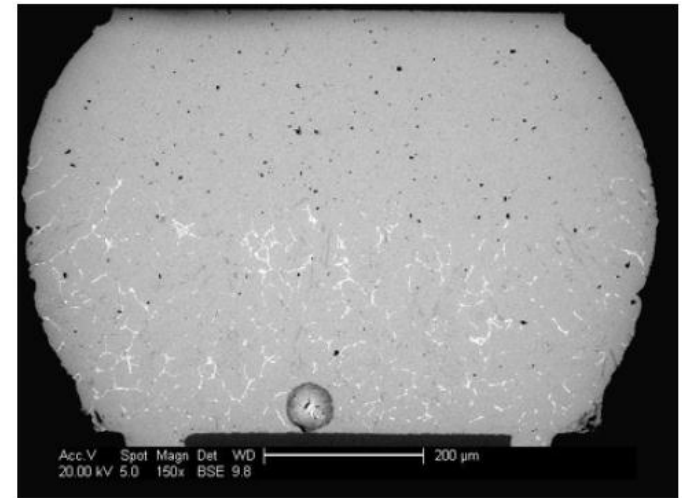
Copper Dissolution Solution

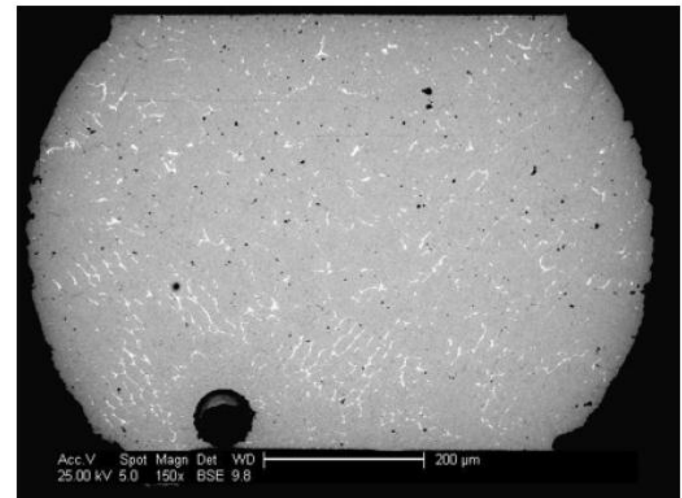
- Some early indications that SNC can decrease dissolution rates
- Reduced diffusion rate through Sn-Ni-Cu intermetallics

EROSION OF COPPER WIRE AT 250C
CROSS SECTION AREA (%)
IMMERSION TIME (MINUTES)
Sn-37Pb
Sn-0.65Cu-0.05Ni
Sn-0.65Cu
Sn-3.0Ag-0.5Cu
Sn-3.0Ag-0.5Cu+100ppmP

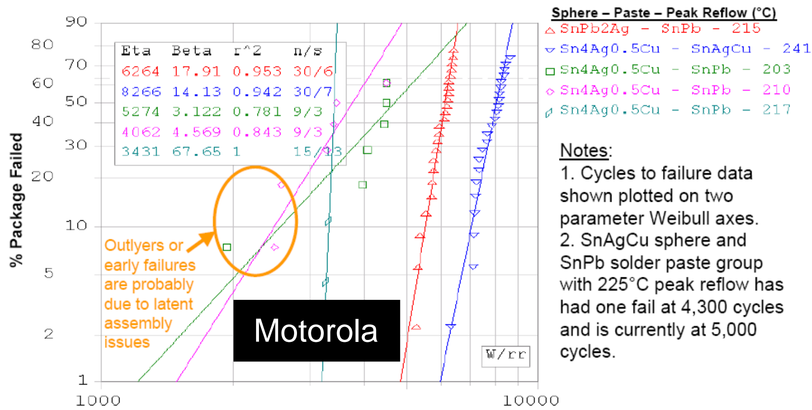
Mixed Solder

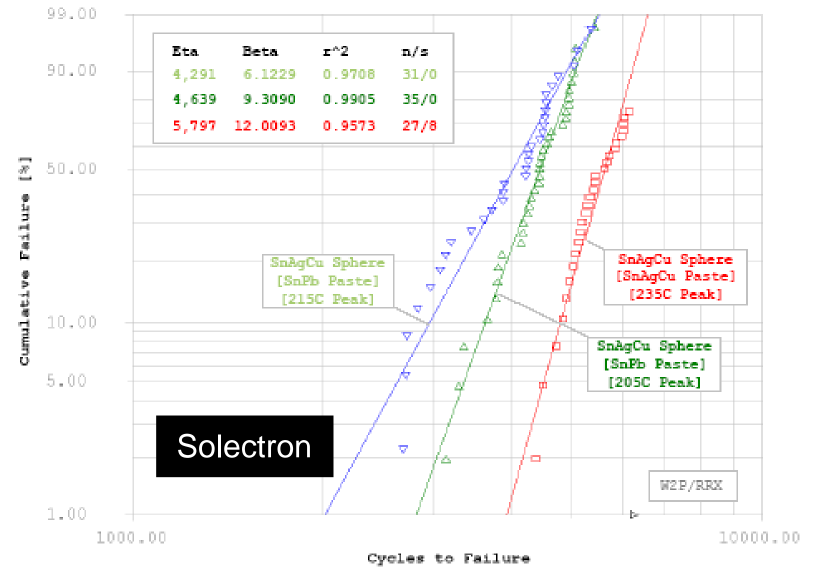
- Primary reference to Pb-free BGAs assembled using eutectic solder paste
  - Some concern with high-Pb ceramic BGA on a Pb-free board
  - Increasing concern with SAC/SNC systems
- Studies identified melt temperature of solder ball as critical parameter (SAC305: 217C)
  - Ensures ball collapse and intermixing
  - Larger volume of SnPb paste may induce greater mixing

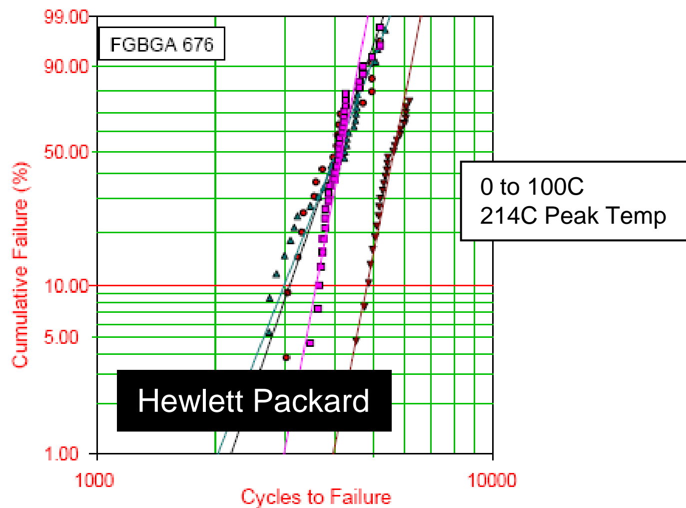




388 PBGA, 1 mm pitch, 27x27mm body, (-40 to 125C)

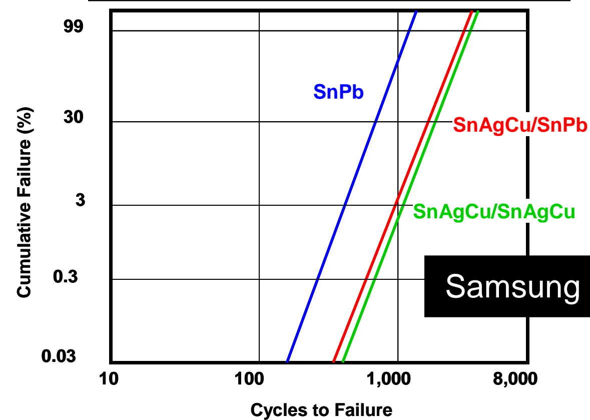






	β	N63	N1
SAC/SAC 10 min.	12.0	5797	3950
SAC/SAC 60 min.	12.6	4280	2970
SAC/SnPb 10 min.	6.12	4290	2040
SAC/SnPb 60 min.	6.92	4244	2200

48 FBGA, 230C Reflow, (-40 to 125C)

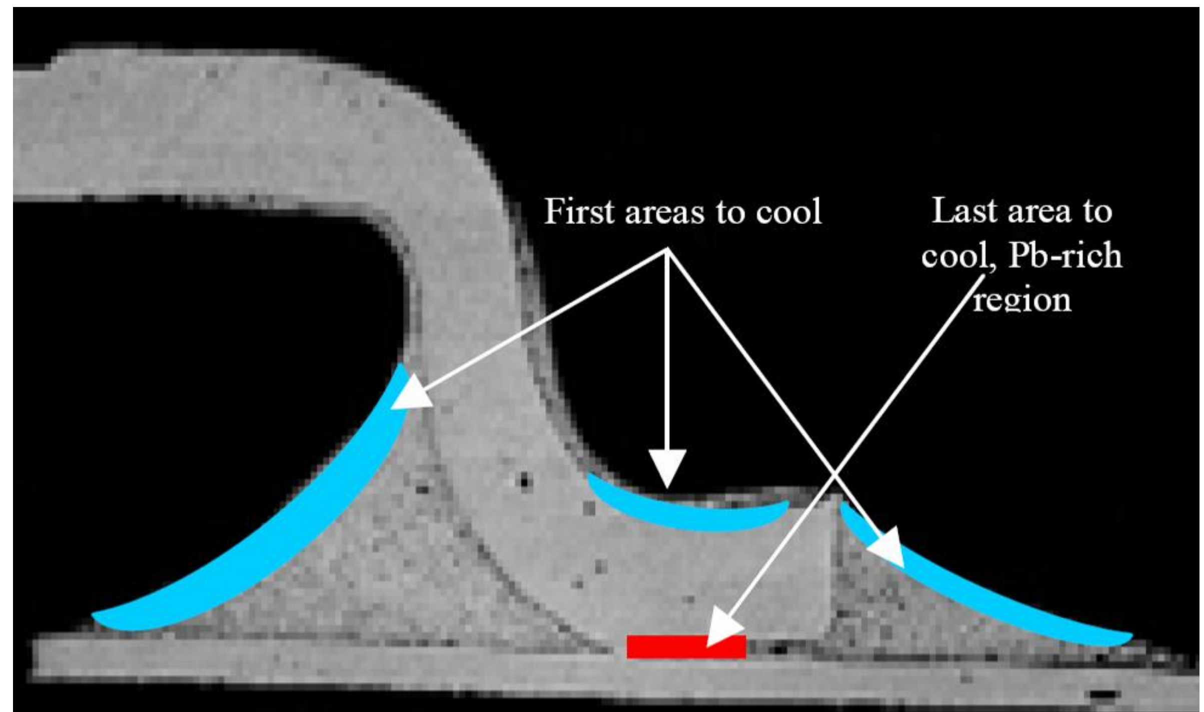


Mixed Assembly (cont.)

- Extensive testing demonstrates similar reliability to SAC system during temperature cycling
  - No data on vibration and mechanical shock performance
- More issues with finer pitch parts due to increased placement issues and lack of self alignment
  - 0.5mm > 0.8mm > 1 to 1.27mm
- Some organizations claiming lower reflow temperature (~210C)
  - Due to formation of SnPbAg phase (melt temperature of 179C)

The Other Mixed

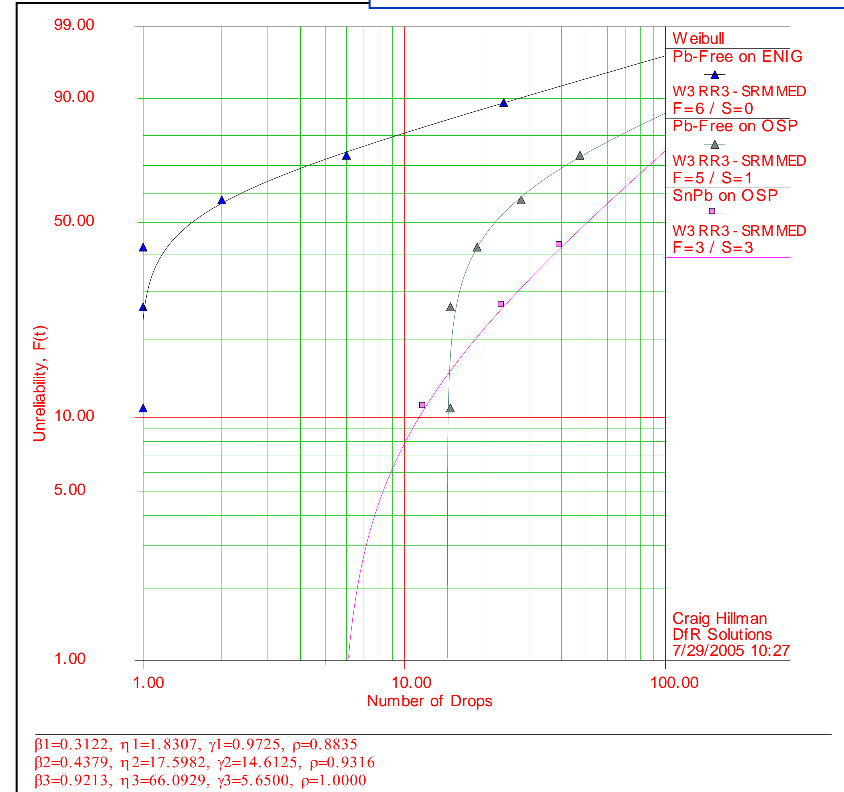
- SnPb-Plated Components in SAC Assembly

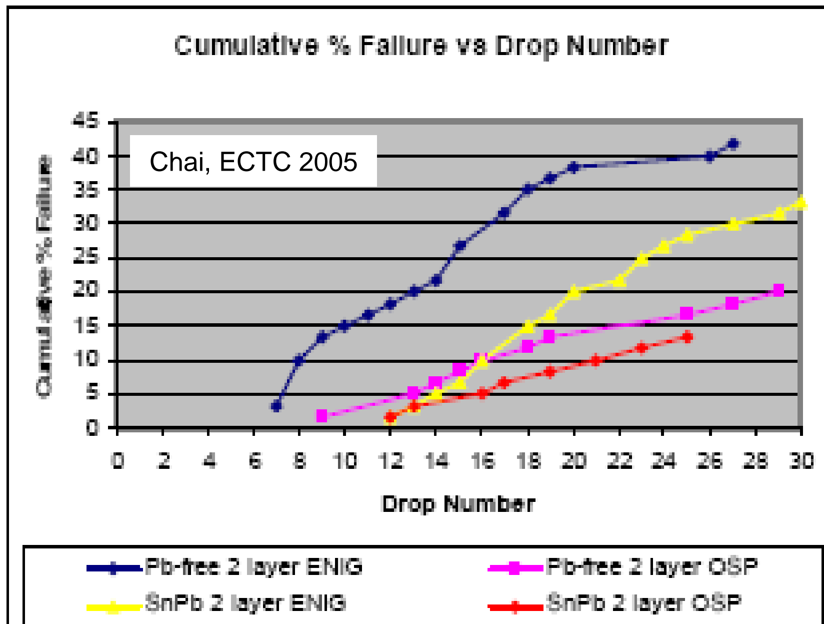


Mechanical Shock

- SAC slightly less robust than SnPb
  - Not always consistent
- Crossover into board failure
  - Very strain-rate dependent
- Plating is an important driver
  - SnNi vs. SnCu intermetallics

35x35mm, 312 I/O BGA

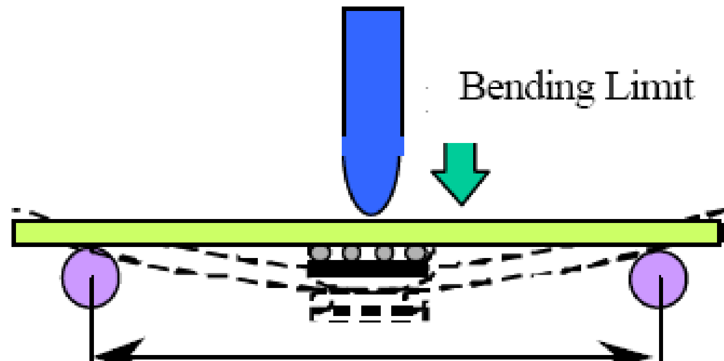




PQFP (28x28mm, 208 I/O)	Failures	
Pb-Free on ENIG	2/6	44/50, 45/50
Pb-Free on OSP	2/6	16/50, 29/50
SnPb on OSP	0/6	--

Chong, ECTC 2005

Mechanical Stress Testing



35x35mm, 388 I/O BGA; 0.76 mm/min			
Paste	**Solder Ball**	**Average Fracture Load (N)**	**Std Dev (N)**
SnPb	SnPb	692	93
Sn4.0Ag0.5Cu	SnPb	656	102
	Sn4.0Ag0.5Cu	935	190

Roubaud, HP
APEX 2001

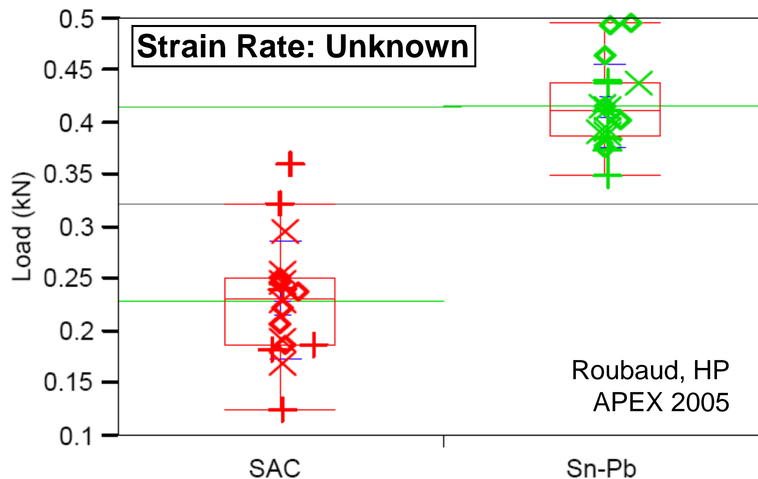
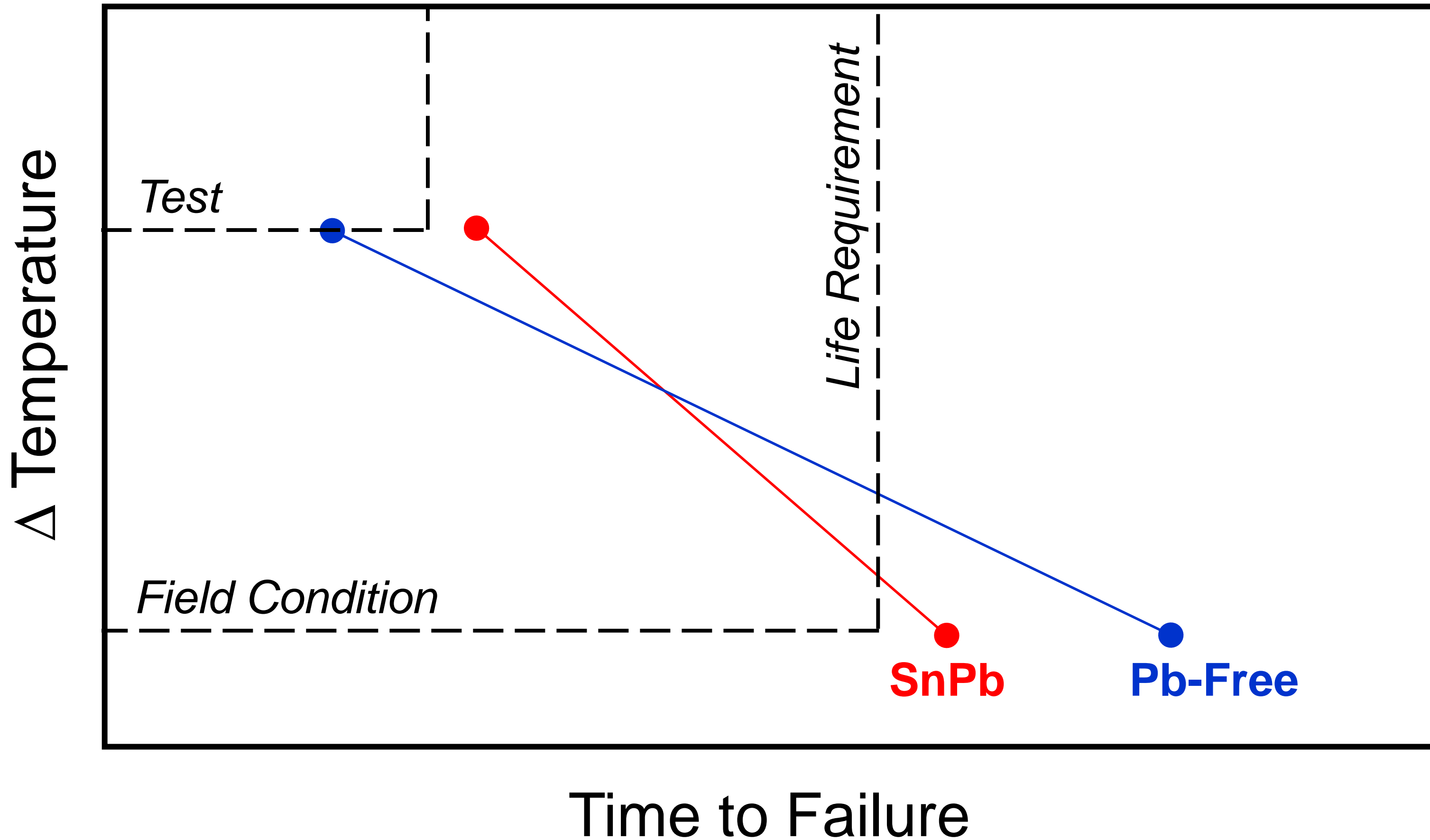


Table 4. Board displacements until solder joint open failure as a function of joint material combination.

Solder ball	SnPb	SnAgCu	SnAgCu
Solder paste	SnPb	SnAgCu	SnPb
Avg.	0.808	0.740	0.783
Max.	0.898	0.854	0.960
Min.	0.669	0.617	0.630

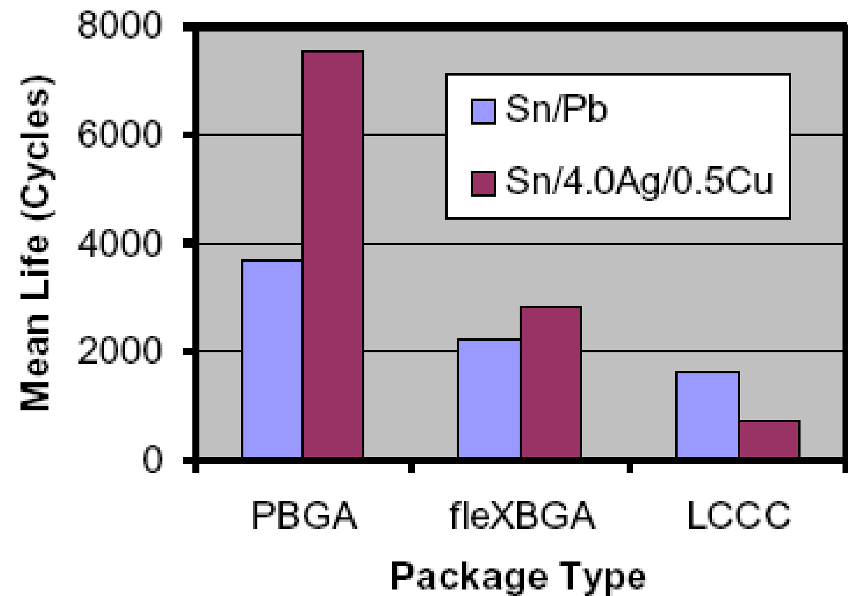
Speed: 5mm/min (or 2.5mm/min)

When is Failure not a Failure?

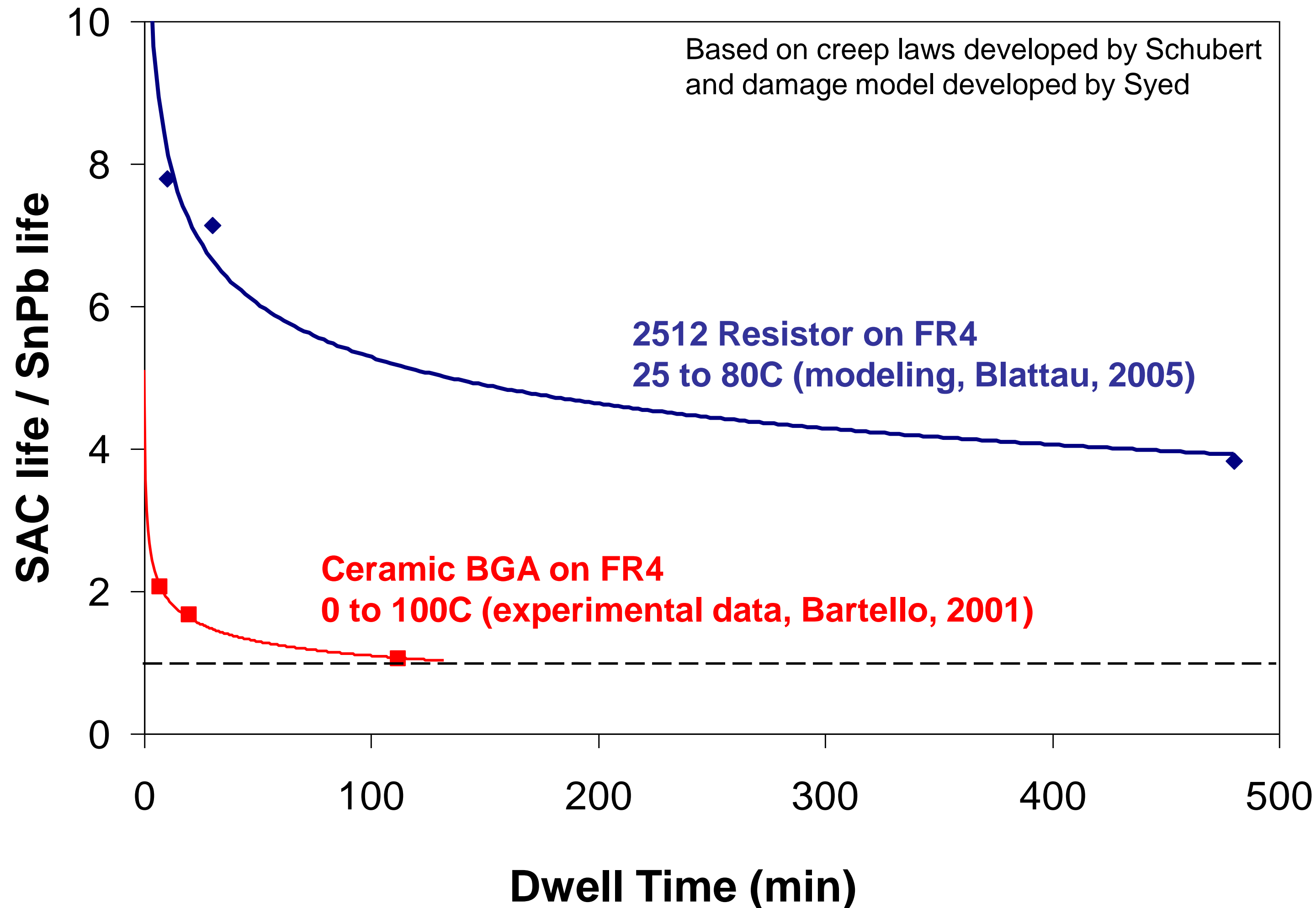


SnPb vs. SAC

- Where does SnPb outperform Pb-free?
  - Depends
- Leadless, ceramic components
  - Leadless ceramic chip carriers (crystals, oscillators, resistor networks, etc.)
  - SMT resistors
  - Ceramic BGAs
- Severe temperature cycles
  - -40 to 125°C
  - -55 to 125°C



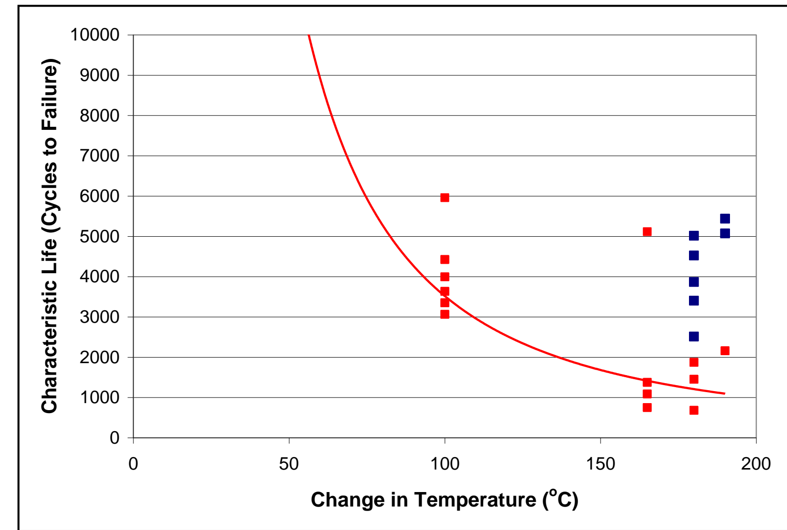
Effect of Dwell Time on Reliability

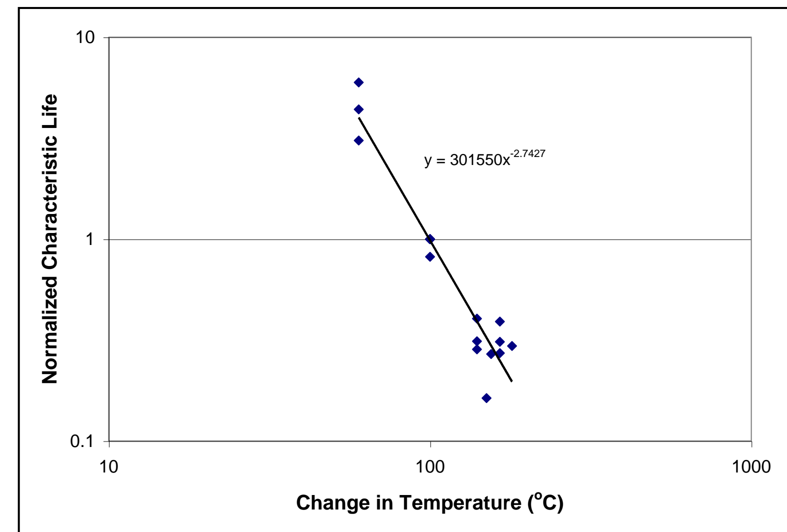


Visual concept courtesy of J.P. Clech

Epidemiology Study on SnAgCu Solder

- Data gathering (>100 articles)
  - Time to failure data for Pb-free solder under a variety of standard test conditions
  - Two parameter Weibull parameters (characteristic life, shape parameter)
- Focused on:
  - BGA (area array devices – CSP, PBGA, CBGA)
  - Packages with Alloy42 leadframe (TSOPs)
  - Leadless chip resistors, 2512 and 1206



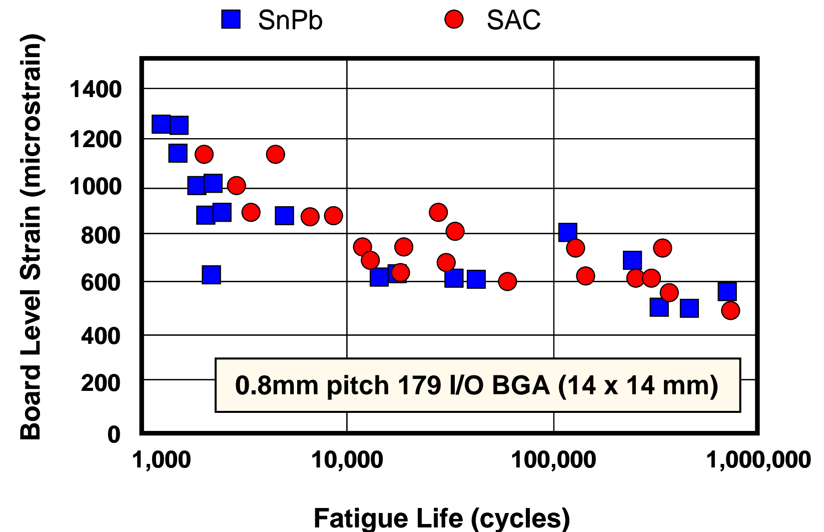


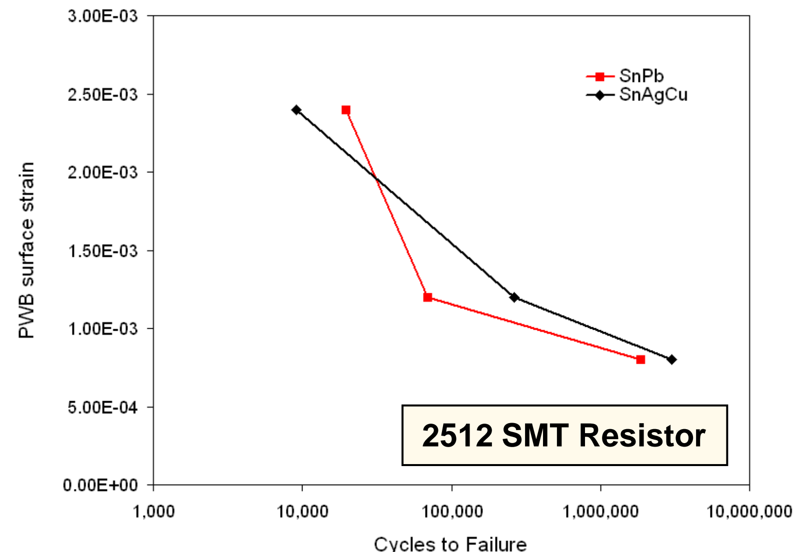
Epidemiology Study (Findings)

- 2512 Resistors and TSOPs with Alloy42 leadframes have limited lifetimes
  - 500 cycles of -40 to 125C
  - 1500 cycles of 0C to 100C
- Power law dependence seems to be package dependent
  - Leadless and stiff leaded components: -1.5 exponent
  - Area array components: -2.7 exponent
- Long dwells up to 8 hours would be expected to reduce lifetime between 40 and 60%
- Once long dwell and differences in shape parameters are taken into account, there is likely to be ***minimal statistical difference*** between SAC and SnPb in most operating environments

Vibration / Mechanical Cycling

- Findings
  - High strain: SAC worse
  - Low strain: SAC better
- Missing datapoint
  - Leaded devices
  - Failure is in lead, not solder
  - Solder transfers stresses
- What does this mean?
  - Problems with vibration and SnPb → Problems with vibration and SAC
  - No problems now? No problems later





Summary

- The reality of Pb-free reliability is all about materials
  - Design is minimally affected
- Field issues have been predicted
  - Laws of physics have not changed
- Qualify and control!
  - Defect-free product tends to be a reliable product, regardless of SnPb / SAC/ SN100C