AIA-AMC-GEIA Lead-free Electronics in Aerospace Project
Meeting #15
Baltimore, MD
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CALCE Pb-free Research Activities

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Formed 1987

ISO 9001:2000
Certified, 1999

What is CALCE?

http://www.calce.umd.edu

Center for Advanced Life Cycle Engineering (founded 1987) is dedicated to providing a knowledge and resource base to support the development and sustainment of competitive electronic components, products and systems.

Center Organization

16 research faculty
5 technical staff
60+ PhD candidates
30+ MS candidates
11 visiting scholars

Education
- MS and PhD EPS program
- International visitors
- Web seminars
- Short courses for industry

EPS Consortium
- 40-45 companies
- Pre-competitive research
- Risk assessment, management, and mitigation for electronics

PHM Consortium
- Pre-competitive research
- Research in fundamental methodologies to develop and implement prognostics and health management systems.

CALCE
Center for Advanced Life Cycle Engineering

Research Contracts
- Larger programs

Reliability simulator (KIM, Korea)
Remaining life assessment (Air Force)
Tin whisker mitigation (Navy, TMTI)
Part obsolescence (NSF, NAVSEA)
Design refresh planning (Army CECOM, DML)

Lab Services
- Small jobs
- Fee-for-service
- Proprietary work
- Use of CALCE Tools & Methods
- Turnkey capabilities
- “Fire-fighting”

Long-term Pb-free Reliability Studies
- Aging
- PWB Finish
- Mixed Solder

FY07 CALCE Pb-Free Research

C07-07	Solder Joint Reliability of Reworked/Repaired SMT Assemblies
C07-01	Reliability of Pb-free and Reballed PBGAs in SnPb Assembly Process
C07-04	Solder Joint Reliability of Solder Dipped (SAC/SnPb) Leaded SMT Packages in a SnPb Assembly Process
C07-03	Effect of Long Dwell on Thermal Cycling Fatigue Damage for Pb-Free Solders (Continuation of C06-03)
C07-06	Effect of Temperature Cycle on the Durability Pb-free Interconnects (Sn96.5Ag3.0Cu0.5 and SnCuNi) (continuation C06-06)
C07-48	Characterization and Reliability Assessment of Lead-Free Solder Alloys in High Temperature Applications
C07-02	Accelerated Qualification of SAC Assembly: Combined Temperature Cycling & Vibration (Continuation of C06-02)
C07-05	Tin Whisker Growth and Risk Assessment Update
C07-08	Characterization of Tin Pest Formation in Pb-free Solder Joints
C07-27	Characterization of PCB Laminate Materials Properties after Lead-free Reflow Cycles
C07-47	Acceleration factors in electrochemical migration

FY08 CALCE EPSC Lead-Free and Mixed Solder Research Proposals

P08-P1 Lead Free Synthesis

P08-O5* Effect of Temperature Cycle on the Durability Pb-free Interconnects (Sn96.5Ag3.0Cu0.5 and SnCuNi) (Continued from C07-06)

P08-O6 Vibration Fatigue Life of Pb-free Interconnects (Sn96.5Ag3.0Cu0.5 and SnCuNi)

P08-O7 Thermal Aging Effect on Reliability of Pb-free Interconnects (Sn96.5Ag3.0Cu0.5 and SnCuNi)

P08-A2 Effect of Cyclic Damage Accumulation on Accelerated Qualification of SAC Assembly (Continuation of C07-02)

P08-A3 Effect of Cyclic Fatigue Damage Accumulation on Properties of SAC Solders

P08-H3 Characterization of Work Hardening Behavior of Pb-Free Solder and its Effect on Assembly Reliability

P08-H6 Reliability Assessment of Underfilled Packages Subjected to Pb-Free Solder Reflow Profile

P08-SM1 Shorting Propensity of Tin Whiskers

P08-BS1 Characterization of Halogen-free PCB Laminate Materials

P08-Z1 Mitigation Measures for Electrochemical Migration on Lead-Free Assemblies with Low-Profile Components

Reprocessing/Rework/Mixed Solder

P08-O1* Reliability of Pb-free and Reballed PBGAs in SnPb Assembly Process (Continued from C07-01)

P08-O2* Solder Joint Reliability of Solder Dipped (SAC/SnPb) and SnBi Leaded SMT Packages in a SnPb Assembly Process (Continued from C07-04)

P08-O3* Solder Joint Reliability of Reworked/Repaired SMT Assemblies (Continue C07-07)

CALCE Consortia Meetings

- CALCE EPSC Fall Technical Review and Project Kickoff Meetings October 16-18
  - Review over thirty research projects
  - Industrial Advisory Board Meeting
  - Kick-off FY08 Research Program
- CALCE PHMC Fall Meeting, October 18th
  - Review status of current research efforts
  - Discuss future research activities

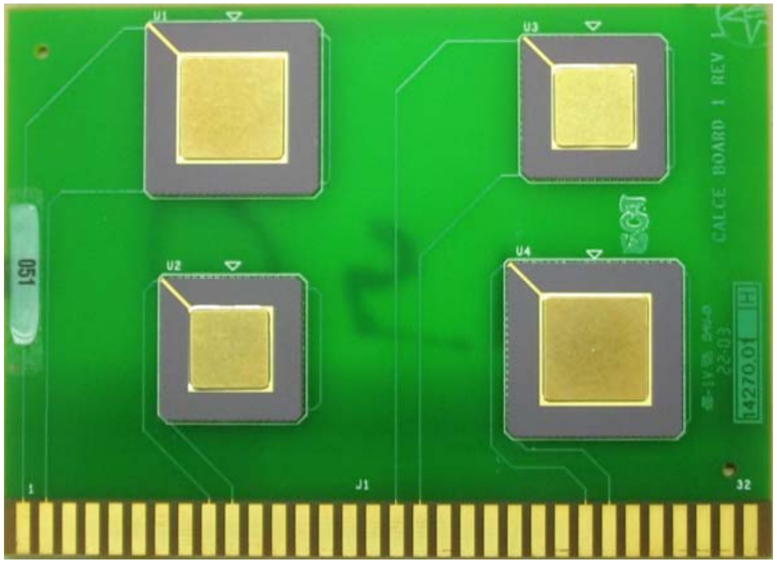
CALCE to hold a Rework/Repair and Part Reprocessing Symposium

Presentations by individuals from Benchmark, Boeing, Celestica, Rockwell Collins, NAVY-BMP, Raytheon, SAIC, San Jose State University, Six Sigma, University of Missouri-Rolla, University of Maryland-CALCE, and Wight Patterson Air Force Base

Challenges-General Pb-free Electronics

- No exact drop-in replacement for Pb-based materials/components.
- Solder alloy selection may vary based on application.
- Replacements likely to see wide adoption include
  - SnAgCu – Reflow
  - SnAgCu or SnCu or SnCuNi – Wave
  - SnAgCu or SnAg - Rework
- Changes in component finishes, die attach materials, solders joints
  - Higher processing temperatures (pop-corning, board warpage, delamination)
  - Compatibility with Pb-free processing (mixed technology)
  - Indirect failure mechanisms (tin whiskers, creep corrosion)
  - Solder joint reliability (durability, intermetallic growth)

CALCE Pb-free Solder Temperature Cycling Reliability Testing



Packages Under Test

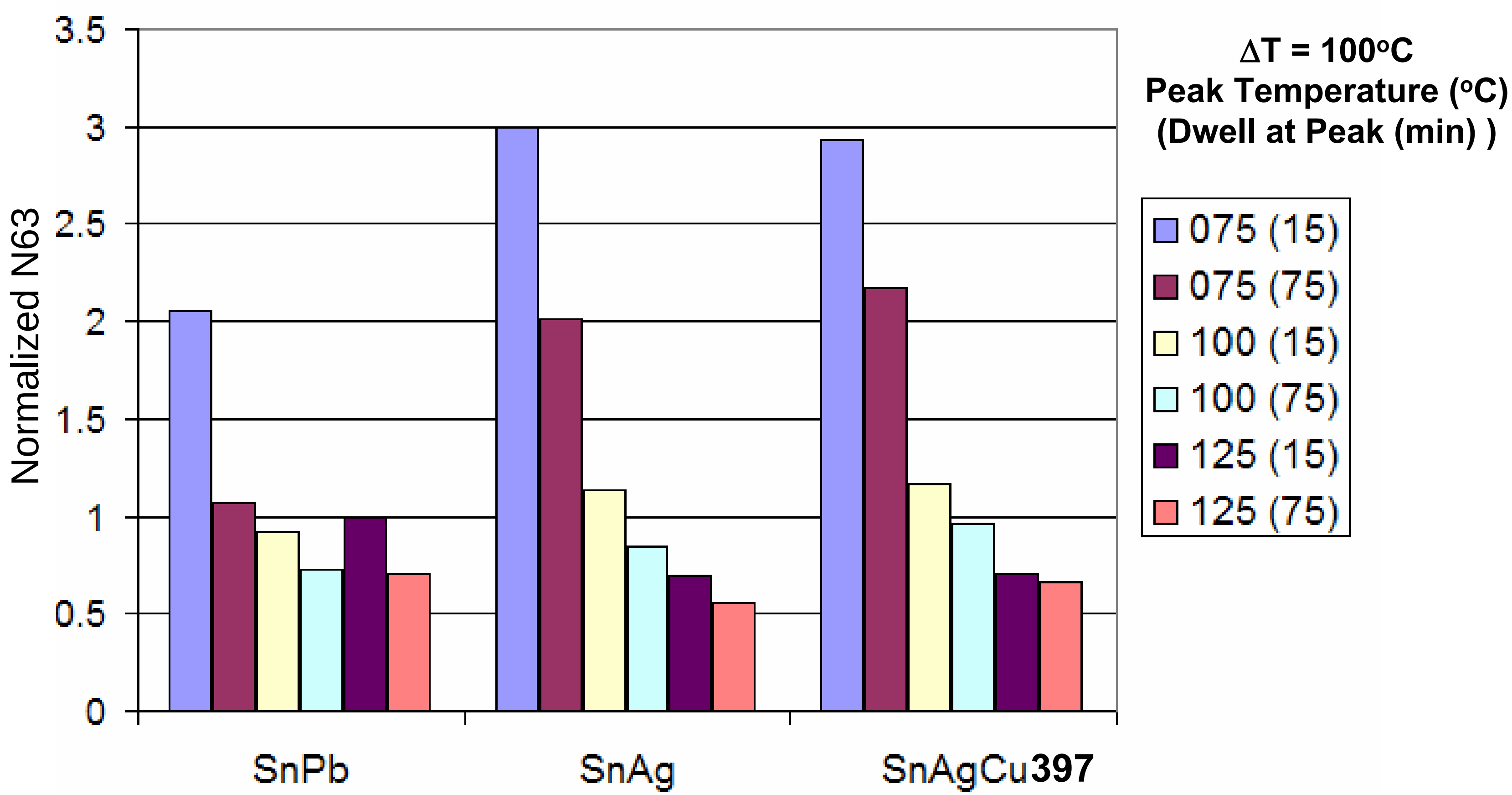
- 68-pin LCCC: 24mm × 24mm
- 84-pin LCCC: 30mm × 30mm
- PCB Board: 130 x 93 x 2.5 mm, FR4

- **Solders Completed**
  - Indium SMQ 230 Sn95.4/Ag3.9/Cu0.7
  - Indium SMQ 230 Sn96.5/Ag3.5
  - Indium SMQ 92J Sn63/Pb37
- **Solder Under Test**
  - Aim SN100C Sn/Cu/Ni(.5) w/254 flux
  - Aim SAC 305 w/254 flux
  - Indium SMQ92J Sn61.5/Pb 36.5/Ag2

Test details

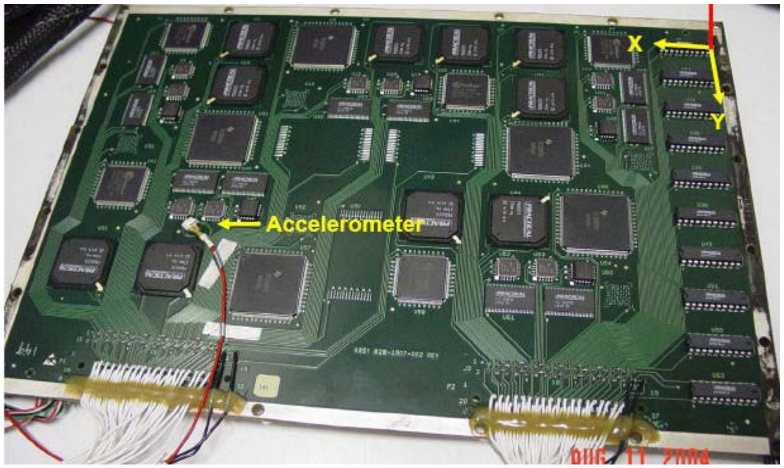
- 16 samples in each test condition
- Resistance of each chip is monitored by a data logger.
- Temperature is recorded at the center of each card.
- Test continues until 100 % failure occurs.
- Cross sectioning was performed on failed test specimens to verify a solder interconnect failure.

Comparison of Time to Failure (68 IO Package)

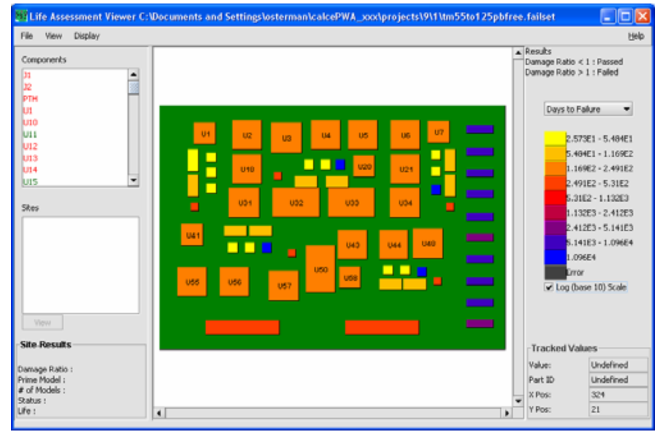


For the Pb-free solders, increasing the average cyclic temperature showed a decrease in time to failure. As can be seen in the above chart, the behavior of the SnPb solder at the 100 and 125°C peak temperature shows non-monotonically decreasing behavior.

Comparison with Stain Range Simulation Model

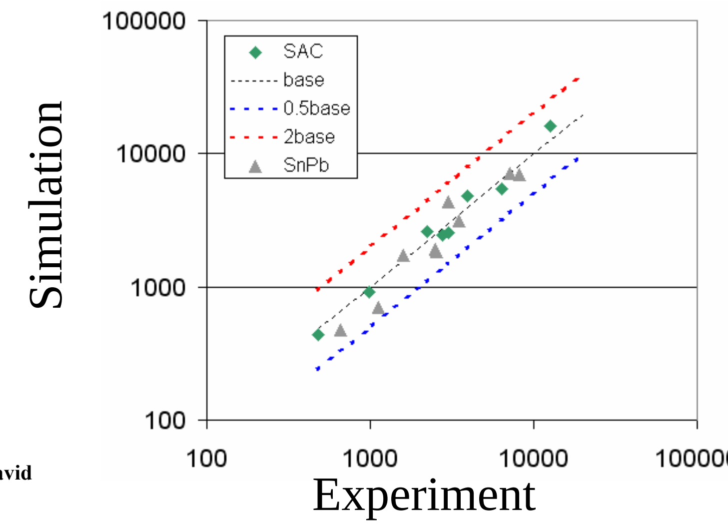


Test Board



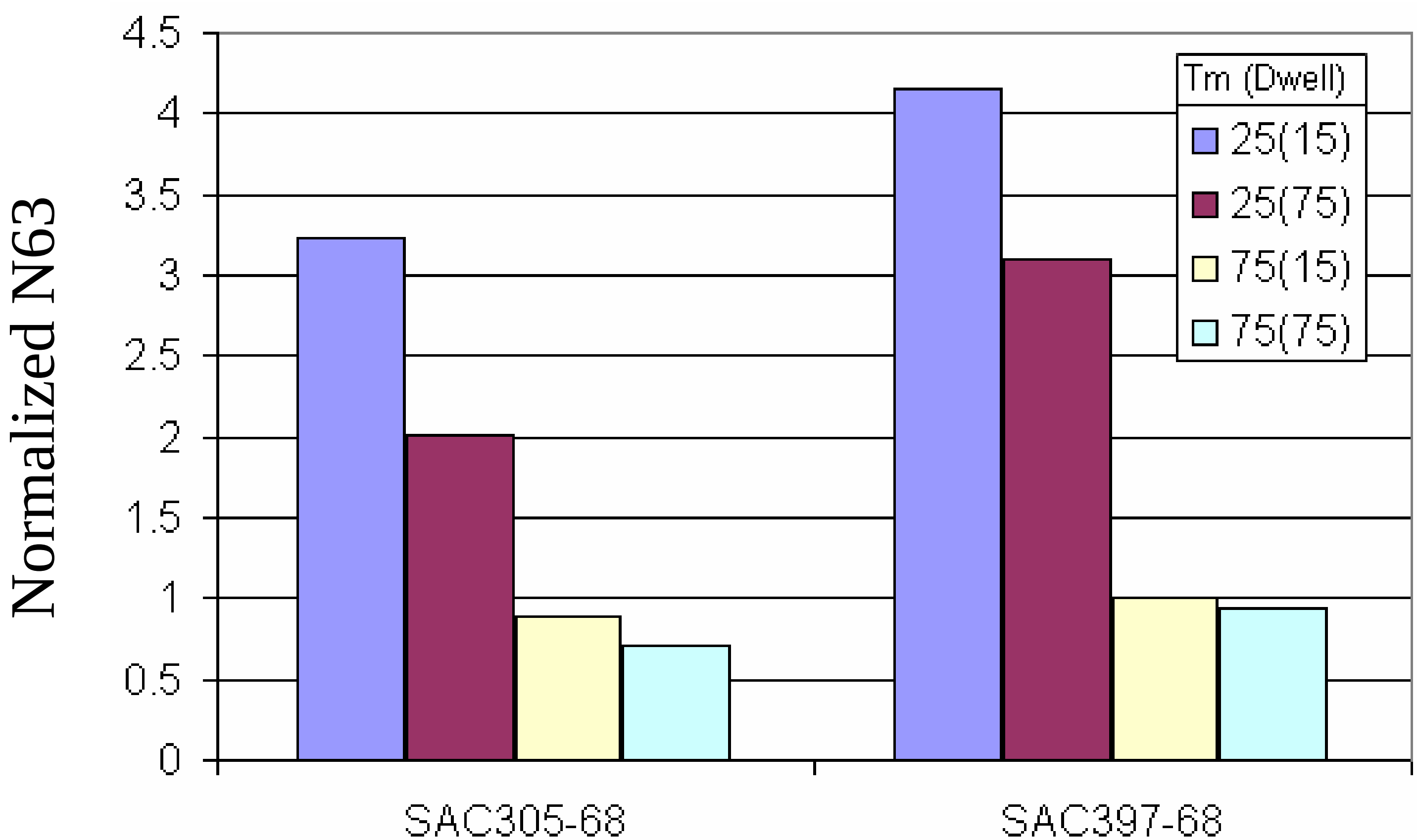
Simulation based reliability assessment with calcePWA

2 mm thick board contained PBGA, TSOP, TQFP, CLCC packages. The simulation model is based on testing conducted under the JGPP/JCAA Pb-free Solder Test Program. Test assemblies were subjected to a -55 to 125°C temperature cycle and a -20 to 80°C cycle condition



•JCAA/JG-PP No-Lead Solder Project:-55°C to +125°C Thermal Cycle Testing Final Report, David Hillman and Ross Wilcoxon, March 15, 2006

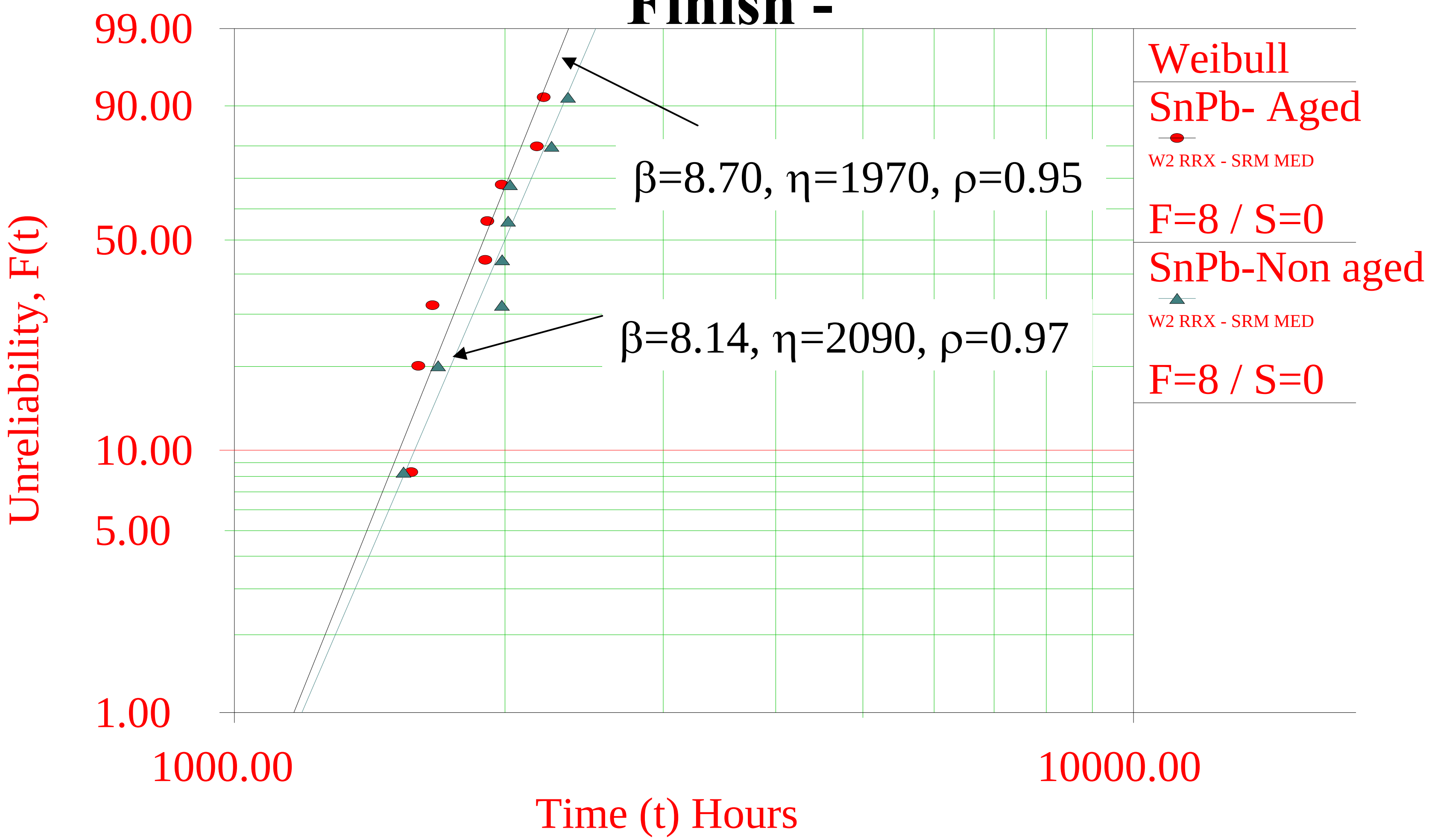
SAC305 versus SAC397



ΔT=100°C
Mean Temp
(dwell time)

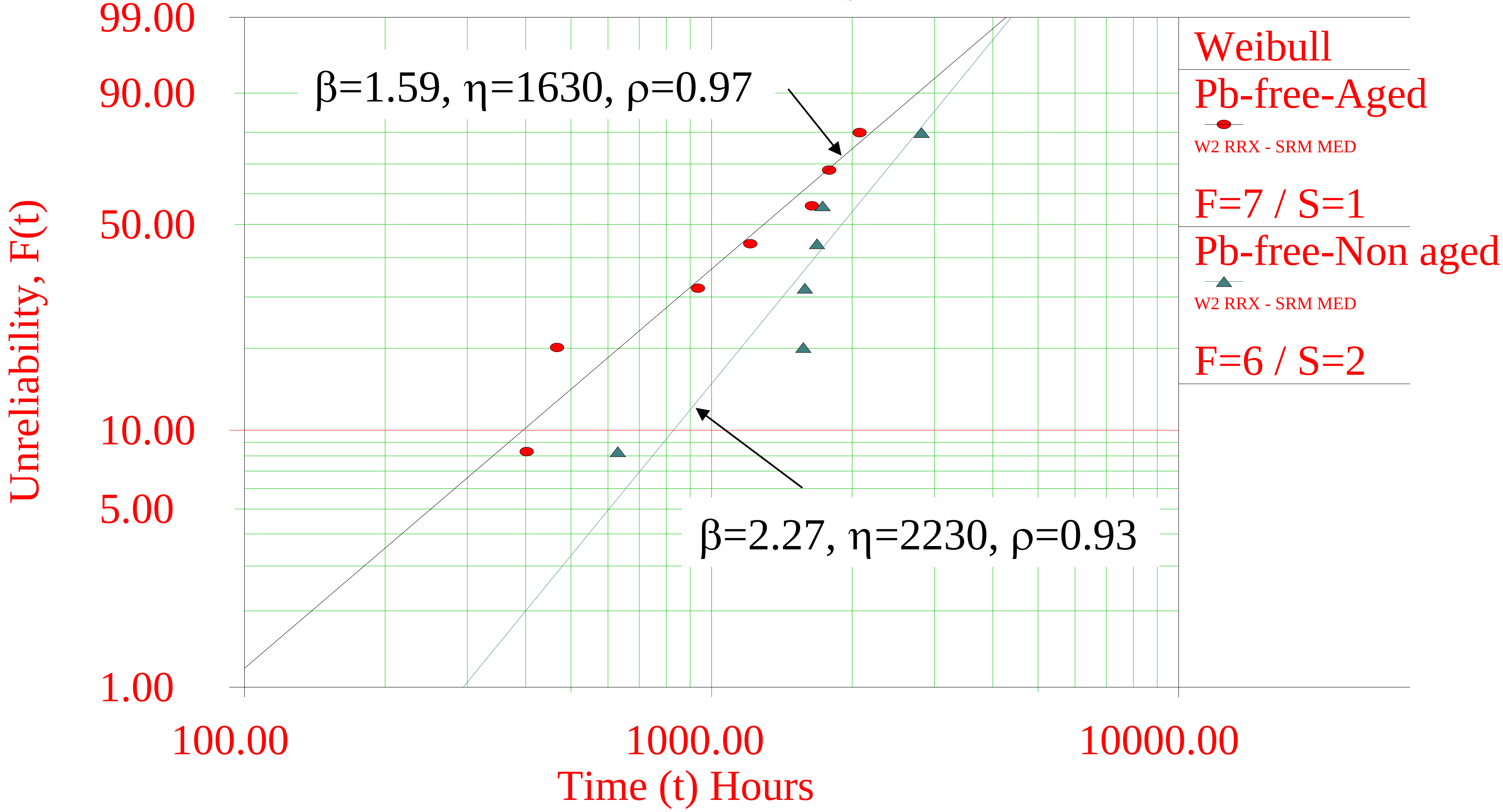
With the exception of 75(15), SAC 305 is slightly less reliability than SAC 397 under temperature cycle loads.

SnPb Solder Joint Durability
- BGA(Sn37Pb) – Sn37Pb Solder – HASL Pad Finish -



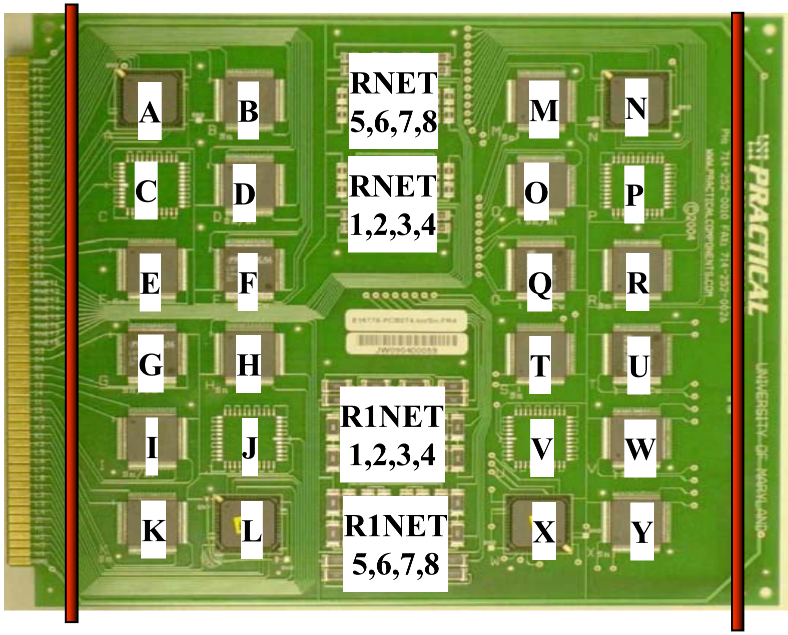
Under a -40 to 125^{o}C 1 hr cycle with 15 minute dwells, a decrease in life of 5% was observed between aged (350hr/125^{o}C) and non aged assemblies.

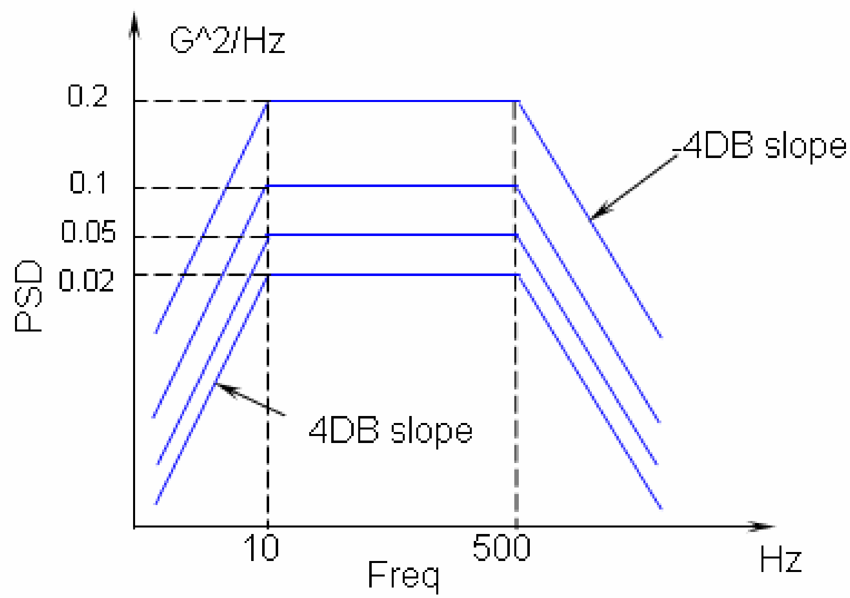
Pb-free Solder Joint Durability
- BGA (Sn3.0Ag0.5Cu) – Sn3.0Ag0.5Cu Solder – ImSn Pad Finish



Under a -40 to 125oC 1 hr cycle with 15 minute dwells, a decrease in life of 25% was observed between aged (350hr/125oC) and non aged assemblies.

Random Vibration Tests



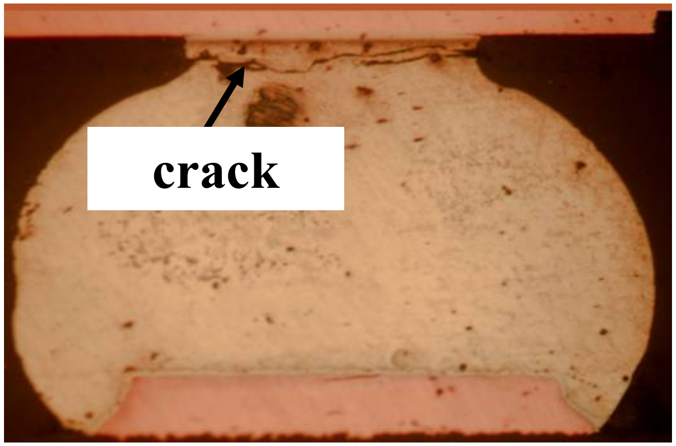


Thermally aged (100 hr/125°C and 350hr/125°C) conventional tin-lead assemblies (SnPb solder/HASL board finish) and lead-free (SAC305 solder/OSP board finish) were subjected to a random vibration stress step tests.

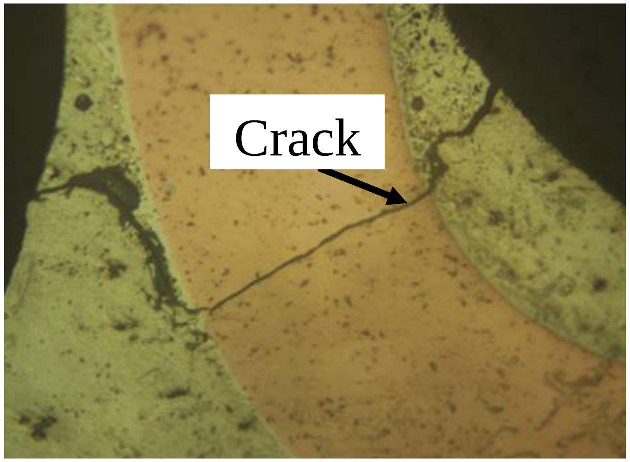
Step Stress Test Applied
0.02 G^2/Hz – 6 hrs
0.05 G^2/Hz – 6 hrs
0.1 G^2/Hz – 6 hrs
0.2 G^2/Hz – 18 hrs

Failure Analysis

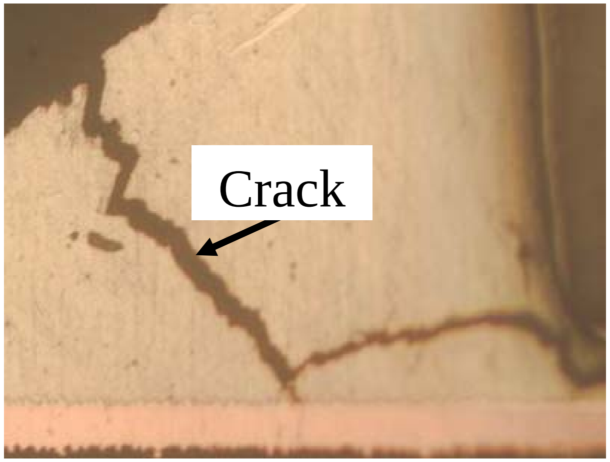
- Destructive failure analysis was carried out for selected components to confirm that the failure mode and sites are related to solder interconnect failure.
- No failures have been found at the traces in the PWB.
- The identified failures include the following:



Crack in neck of BGA joint



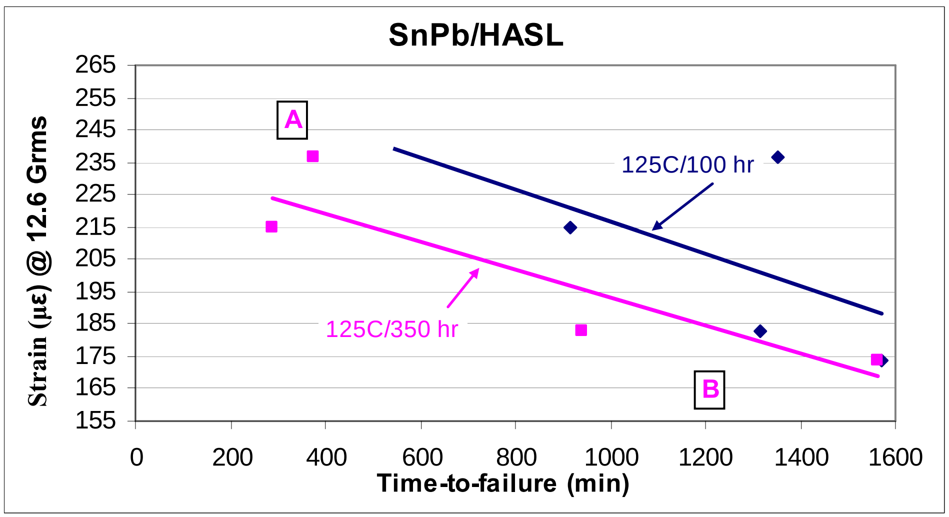
Crack in QFP gull wing solder joint and lead

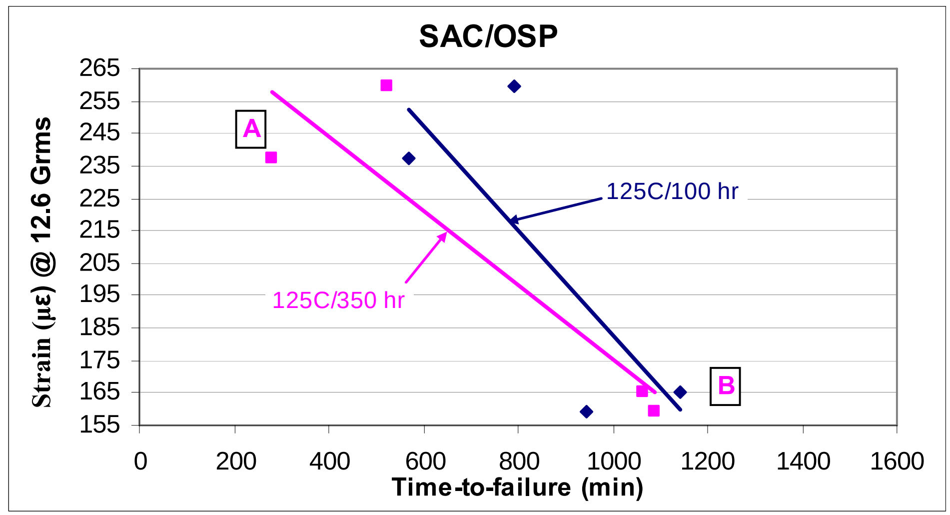


Crack in fillet of LCR solder joint

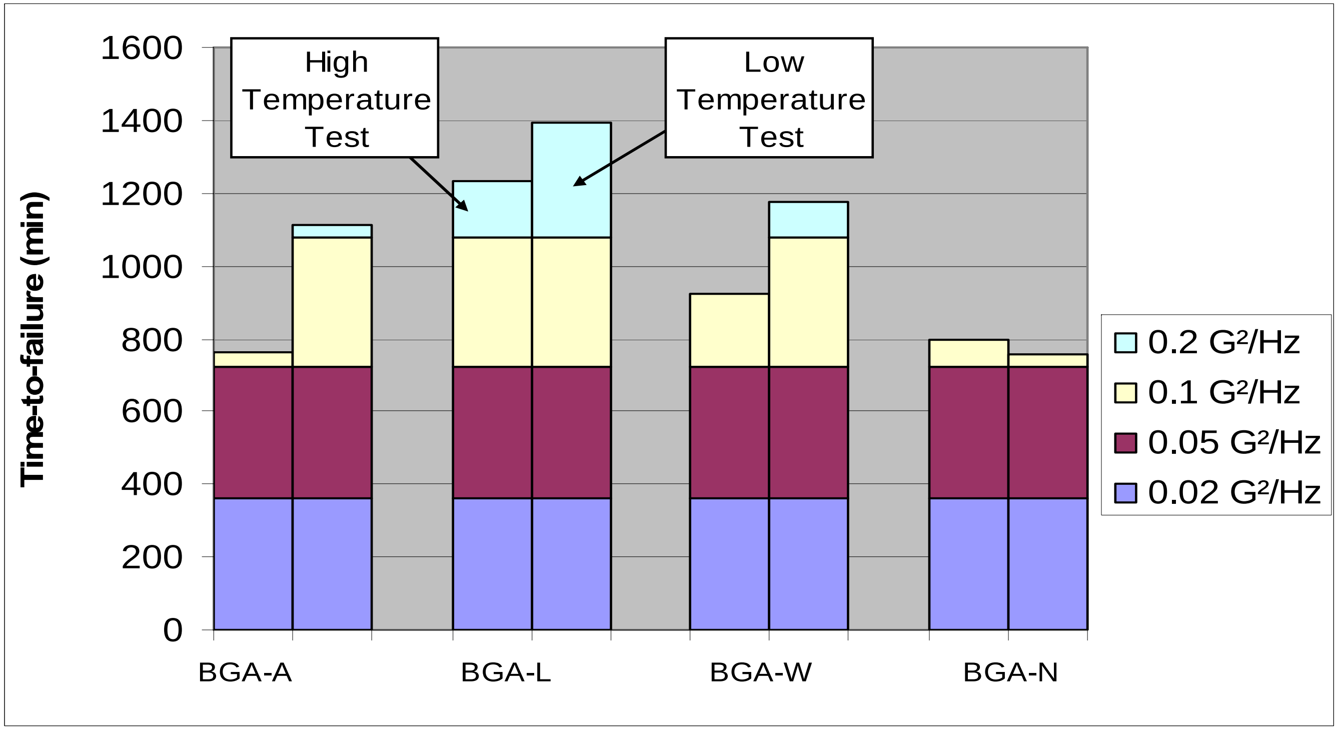
Isothermal Aging Effect

- Pre-aging decreased vibration durability of both SnPb & SAC assemblies. SnPb assemblies appear to be more sensitive to pre-aging duration than SAC assemblies.
- The slope of the fatigue pseudo-curves appear to be independent of aging time for SnPb assemblies, but the slope decreases with aging time in SAC assemblies.





Ambient Temperature Effect



There are four BGA components in each board:

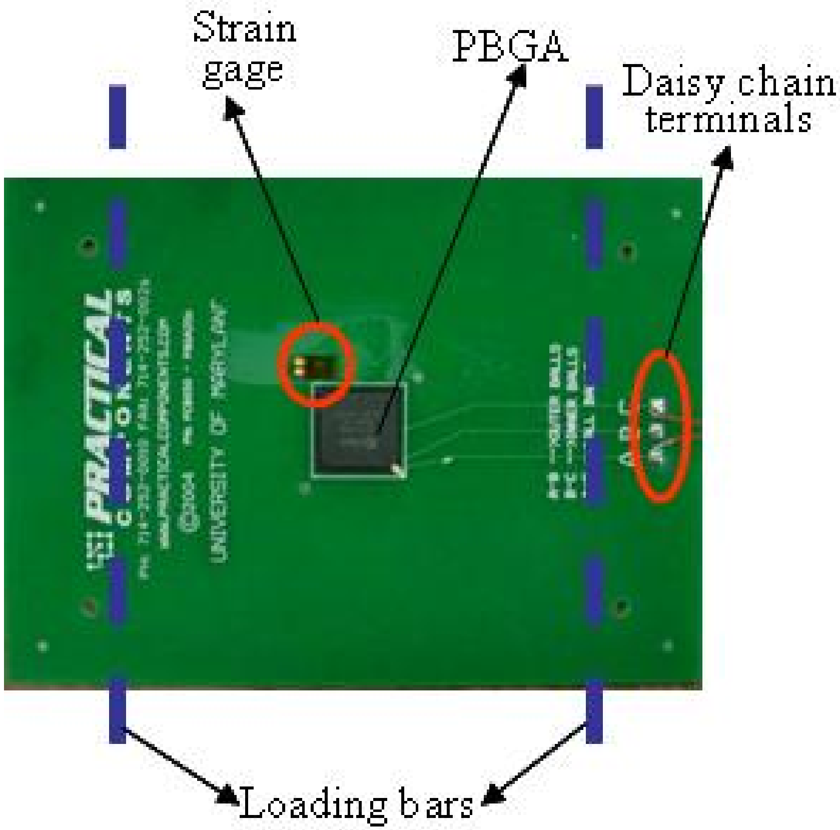
A and N components are position near the clamped edges

L and W components are closer to the centerline of the PWB

- Random vibration excitation at high ambient temperature appears to be more damaging than the low temperature experiment.
- The test result shown correspond to a SnPb assembly aged at 125ºC for 100 hours. Similar trends were observed for the for the Pb-free assemblies.

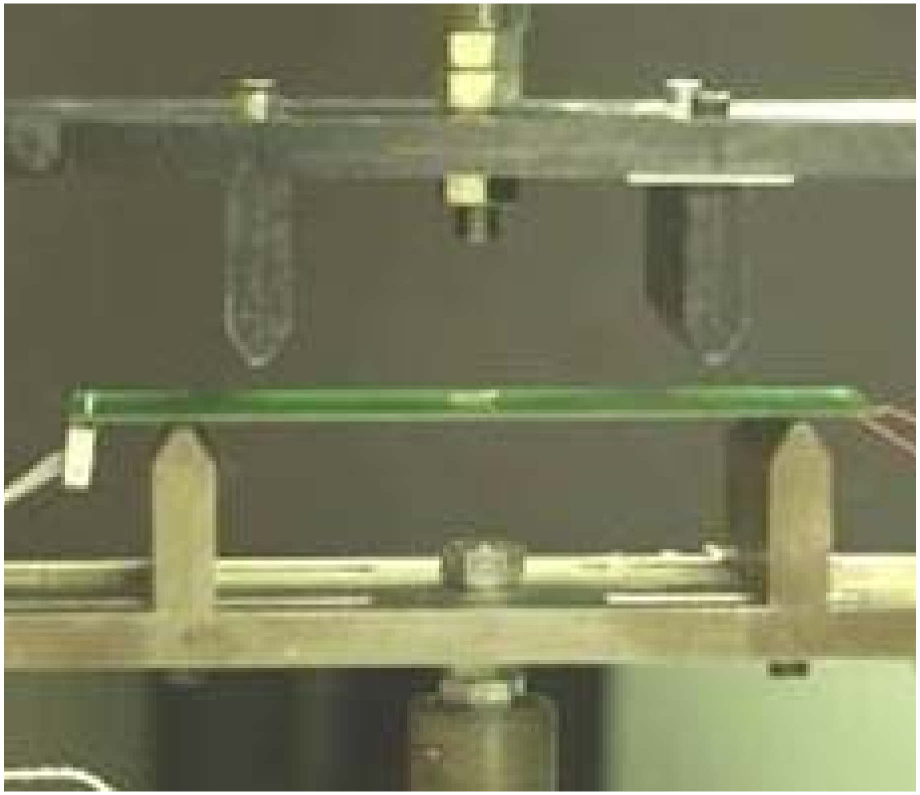
Test Setup: High Speed Flexure and Drop

Test Specimen



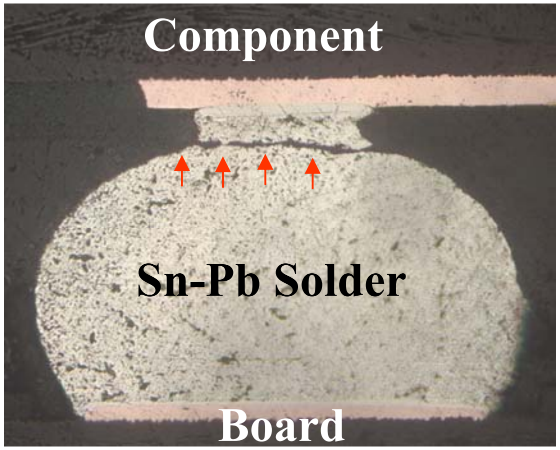
Instrumented PWA with BGA

4-Point Bend Fixture

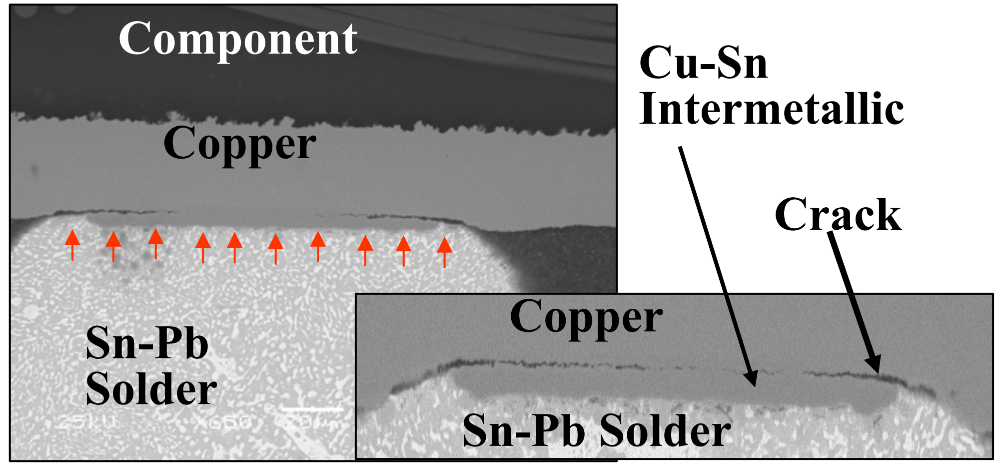


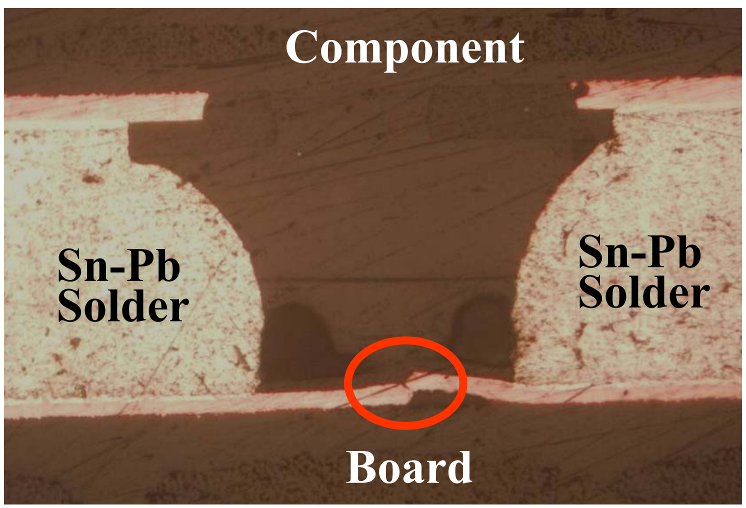
Failure Analysis: High Speed Flexure

Bulk solder failure

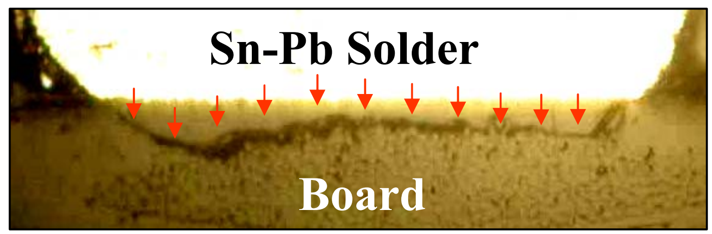


Intermetallic failure





Copper trace failure



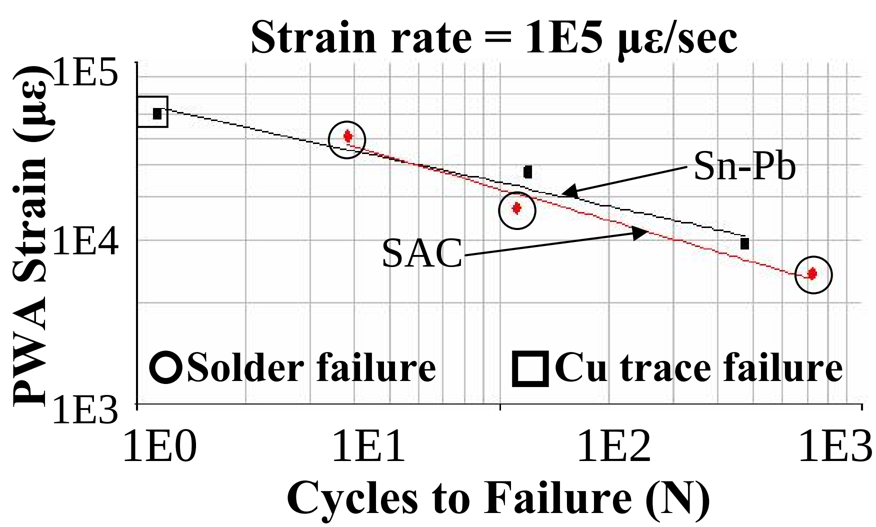
FR4 board failure

Failure site moves from bulk solder to intermetallic or copper trace as the PWA flexure rate increases.

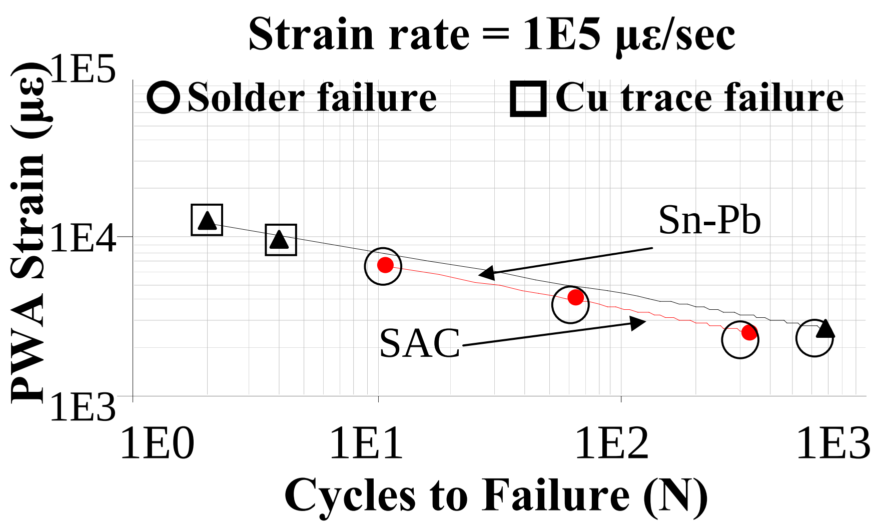
Dynamic Durability: Sn37Pb vs SAC305

- PBGA-256 interconnects (1 mm pitch balls on OSP pads)
- Dynamic 4-point bend test
- Effect of thermal aging (100 hrs at 125° C)

Un-aged

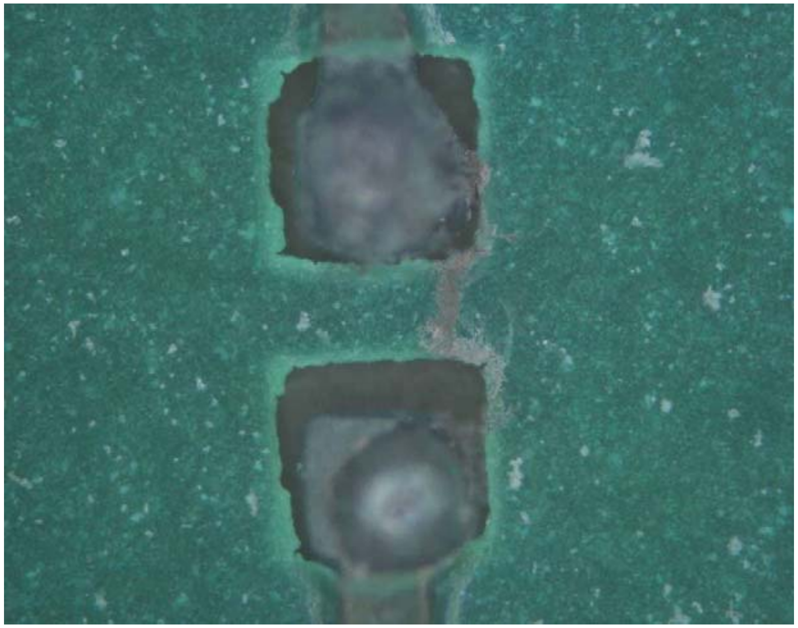


Aged

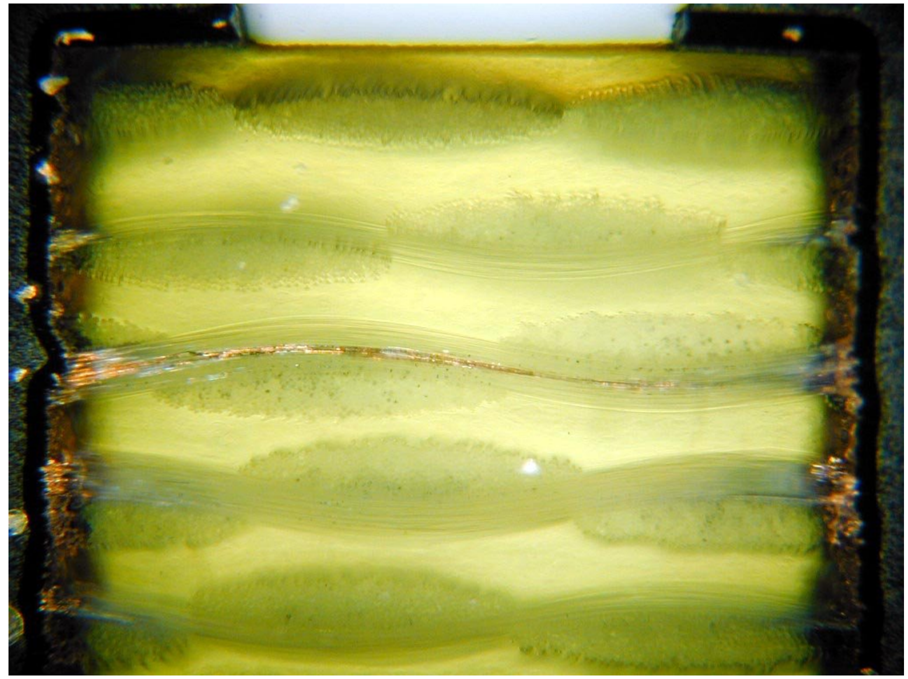


- SnPb outperforms SAC
- Failure modes include solder failure and Cu-trace failure
- Aging reduces drop durability

Electrochemical Migration



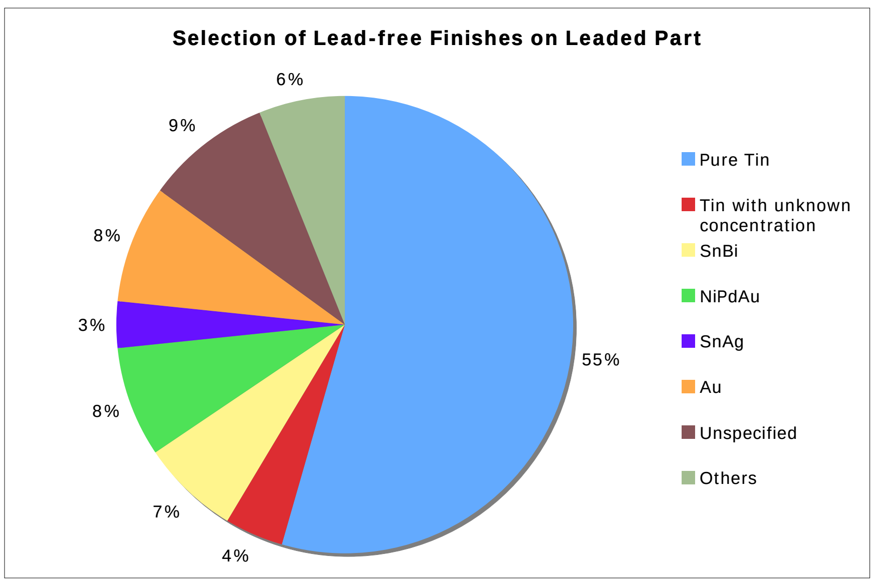
New fluxes, availability of silver, and higher reflow temperatures may increase surface resistance risk. Sn-3.5Ag Solder on Polyimide Substrate with Immersion Sn Plating

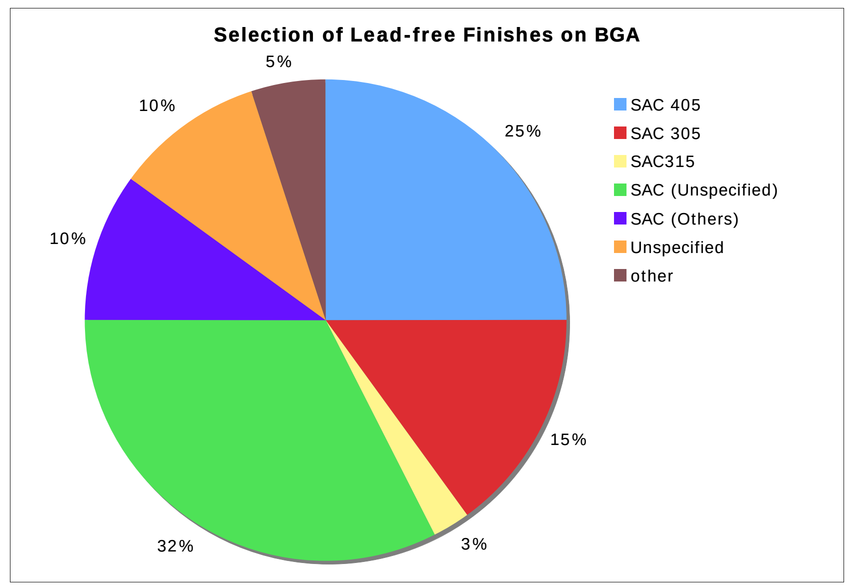


Conductive filament formation within the printed wiring board. Higher reflow temperature puts higher stress on printed wiring board and increases CFF risk.

Introduction of Lead-free Tin Finishes

Under pressure to comply with impending government regulations (EU RoHS (effective July 2006), China RoHS (effective March 2007), electronic part manufacturers converted to Pb-free finish that would be compatible with conventional Sn37Pb solder assembly process and the likely Pb-free solder assembly processes.





(Based on CALCE survey of 121 suppliers)

Pb-free Policies

- **Maintain conventional Pb-based products**
  - Examine costs and availability of parts and processes
  - May need to consider life time buys
  - Define policy for handling Pb-free parts (e.g. tin whiskers)
    - Mitigation strategies
    - Quality and reliability assurance strategies
  - Communicate plan to suppliers and customers
- **Convert to a Pb-free products**
  - Define a plan of action which considers
    - Current and future products
    - Availability of parts
  - Implement a part management and selection process for Pb-free
  - Define timeline for transition
  - Update quality and reliability assurance plans
  - Communicate plan to suppliers and customers
- **Combination of the two**

Issues with Using Pb-free Parts in a Pb-based Assembly

Backward incompatibility (component with lead-free termination soldered with tin-lead solder and a tin-lead temperature profile)

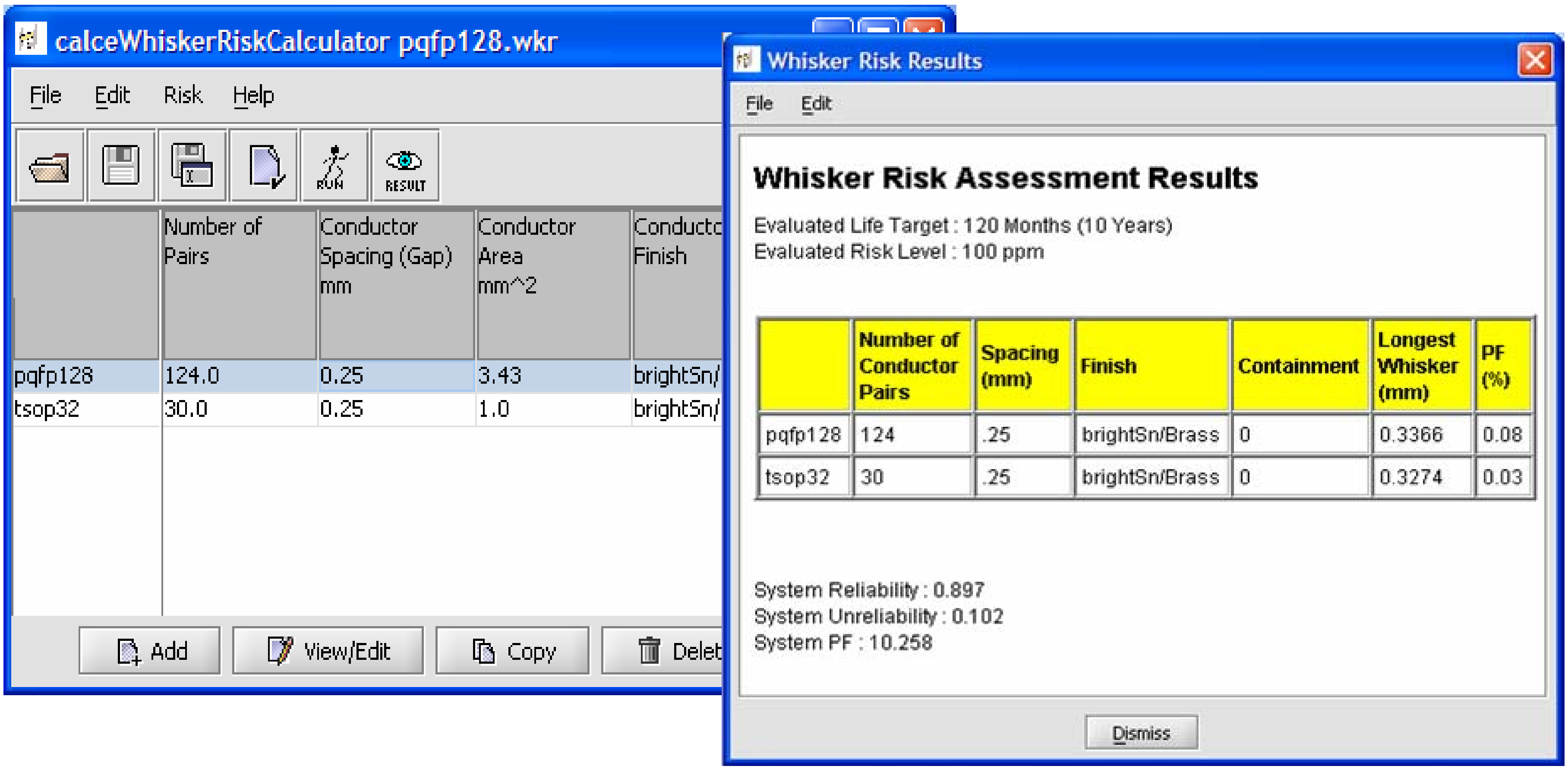
- Pb-free finished terminals containing high concentrations of Bismuth (Bi) >4% may produce poor joints. Current testing results indicate commercially available SnBi finish does not present a reliability issue. However, SnBi on Alloy 42 leadframes shows a marked reduced life as compared to pure tin when assembled with SnPb solder. Note, Alloy 42 lead frames have lower life than copper lead frames.
- Ball grid arrays (BGA) packages with Sn-Ag-Cu solder balls may not be compatible with tin-lead solder, as combination of these materials can result in "cold" joint formation during assembly. Higher reflow temperatures may be needed to avoid this issue but this give rise to other issues.
- Rework still under investigation
- Reballing still under investigation
- Tin Whiskers
  - Solder joint reliability of solder dipped parts under investigation

Issues with Converting to Pb-free

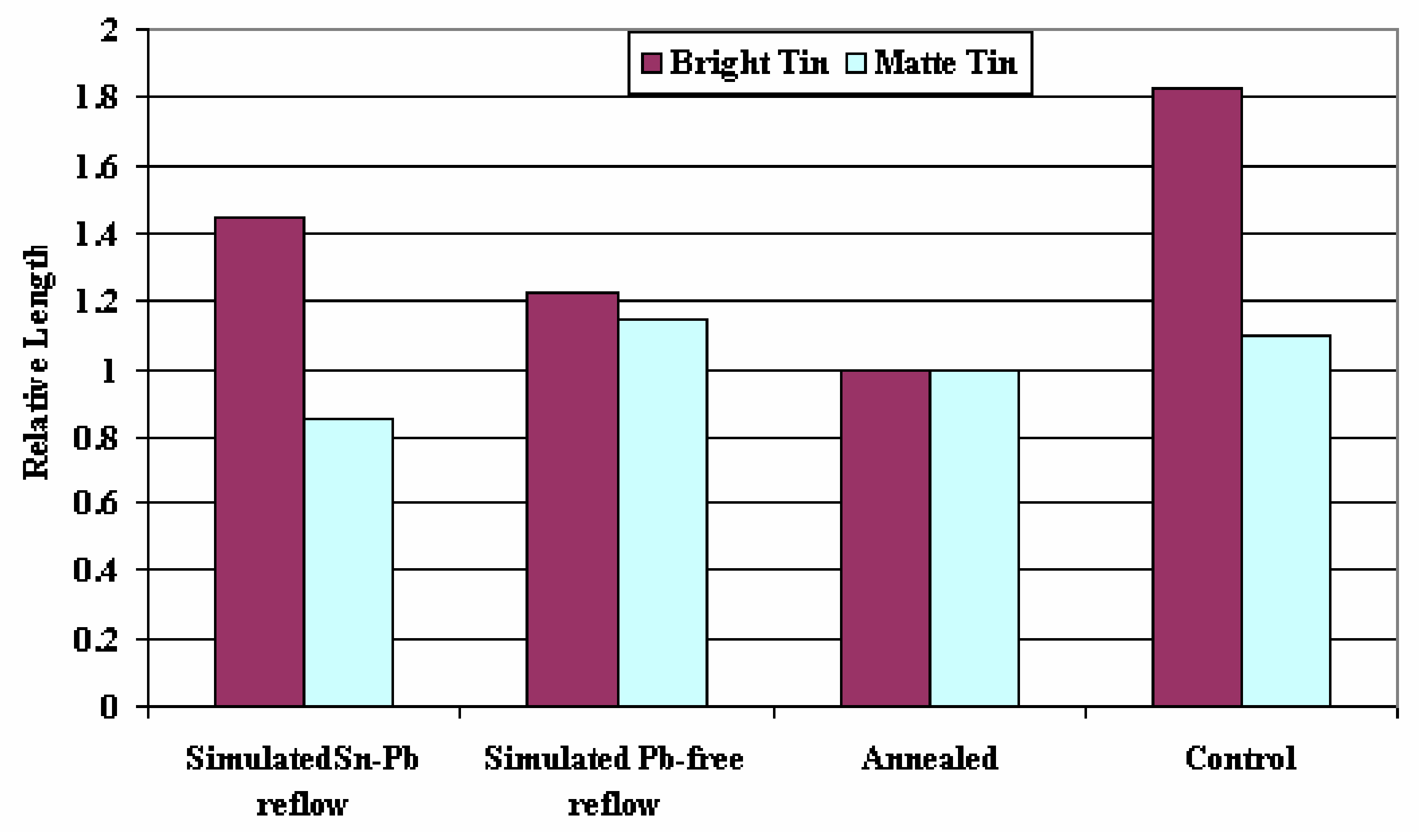
- **Forward incompatibility** (component with lead-based terminations soldered with lead-free solder and a lead-free temperature profile)
  - lead-based components may not be able to handle reflow temperatures.
  - lead forms a low temperature alloy in tin-silver-copper (SAC) solders at 179^{o}C and can result in interface separation.
- Tin Whiskers
- Lead-free solders (SAC305 and higher silver content SAC alloys) have lower vibration and mechanical shock durability. Industry is lowering silver content in SAC and adding additional elements. More study is needed.
- Acceleration factors and testing protocols still under investigation. However, temperature cycling reliability is expected to be better.
- Rework still under investigation

CALCE Tin Whisker Risk Assessment Software

A software package that calculates the probability of tin whisker failure for circuit card assemblies and products. Based on long-term test data.

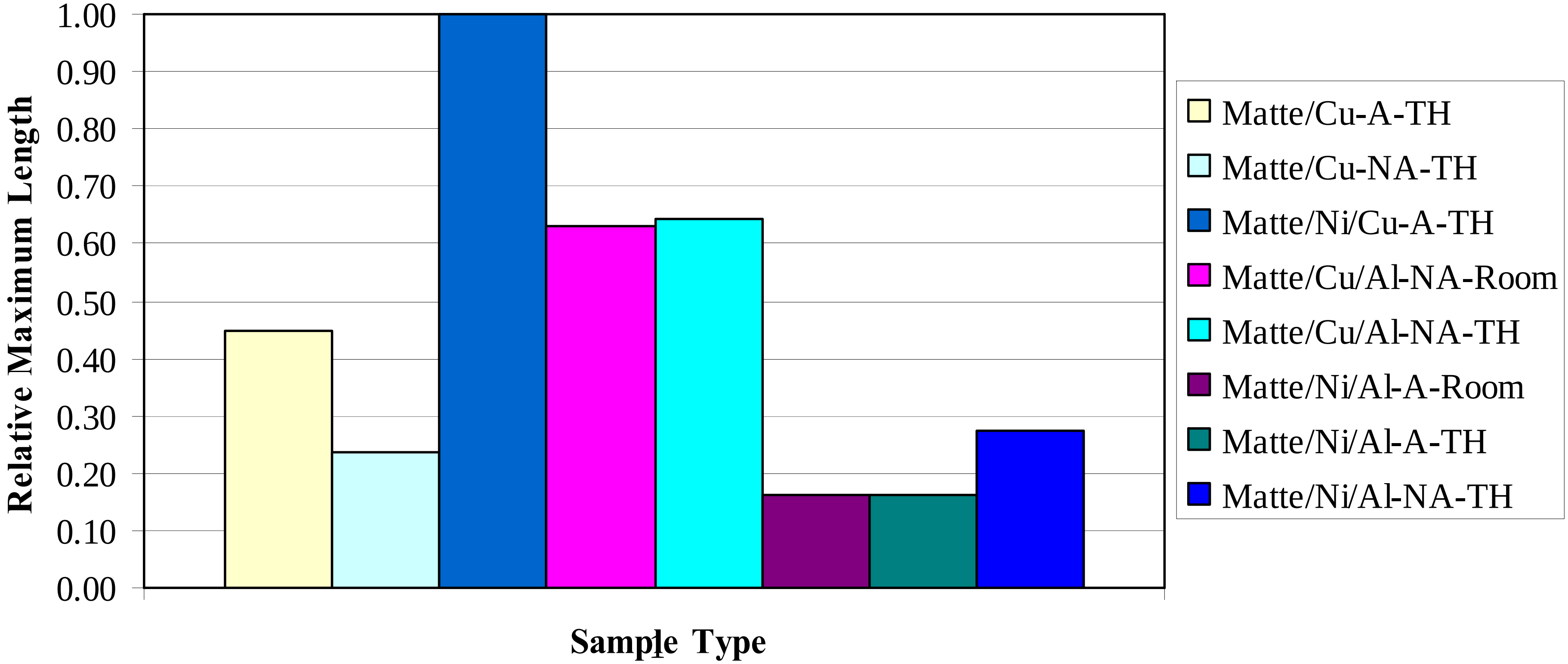


Effect of Reflow Temperatures on Whisker Formation



Conflicting results have been presented on the impact of exposure to solder reflow temperatures on whisker formation.

Relative Comparison of Longest Whisker



It is seen that annealing immediately after the plating has not contained tin whisker growth when the sample is subjected to temperature humidity (50°C/ 50%RH: 1.5 years) environmental exposure for 1.5 years.

Process and Durability Matrix

	Process Eutectic SnPb	Process Sn3-4Ag0.5-0.7Cu	Whisker Risk	Thermal Mechanical Solder Durability (SnPb Process)	Thermal Mechanical Solder Durability (SnAgCu Process)	Vibration/ Shock Solder Durability (SnPb Process)	Vibration/ Shock Solder Durability (SnAgCu Process)
Terminal/Substrate							
SnPb >3%	Low	Medium	Low	Low	Low-Medium	Low	Medium
Sn	Low	Low	High	Low	Low	Low	Medium
Sn Matte	Low	Low	Medium	Low	Low	Low	Medium
Sn Matte/ Ni Underlayer	Low	Low	Medium	Low	Low	Low	Medium
Sn Matte Annealed (150C 1 hr)	Low	Low	Medium	Low	Low	Low	Medium
SnBi <4% / Cu	Low	Low	Medium	Low	Low	Low	Medium
SnBi <4% / Alloy 42	Low	Low	Medium	Low-Medium	Low	Medium	Medium
SnBi >4%	Medium	Low	Medium	High	Low	High	Medium
SnCu	Low	Low	High	Low	Low	Low	Medium
SnAg	Low	Low	Medium	Low	Low	Low	Medium
SnPb > 3% Dipped	Low	Medium	Low	Low	Low-Medium	Low	Medium
SnAgCu Dipped	Low	Low	Low-Medium	Low	Low	Low	Medium
NiPdAu	Low	Low	NA	Low-Medium	Low-Medium	Low-Medium	Medium
NiPd	Low	Low	NA	Low-Medium	Low-Medium	Low-Medium	Medium
BGA							
SnPb	Low		NA	Low		Low	
Sn3-4Ag05-0.7Cu	Medium	Low	NA	Medium	Low	Medium	Medium

Summary

- Companies with products that are exempt or not in scope of the RoHS restrictions are being impacted by the global transition to Pb-free and RoHS compliant electronics.
- Under temperature cycling exposure, pure lead-free (SAC) solder will generally be as good or better than SnPb.
- Under vibration and shock loading, lead-free (SAC) solder is not expected to be as good as SnPb.
- Impact of aging on lead-free (SAC) assemblies is not completely understood.
- The ability to obtain lead-based parts is a challenge to manufacturers attempting to maintain lead-based assemblies.
  – Reprocessing is an option but needs further qualification.
  – Rework/repair also need further assessment.
- Tin whisker formation presents a real reliability risk.
- Industry is continuing to examine alternative lead-free solders.