JCAA/JGPP Lead-Free Solder Testing for High Performance Applications

Thermal Cycle Testing: -55°C to +125°C

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Rockwell Collins

Outline:

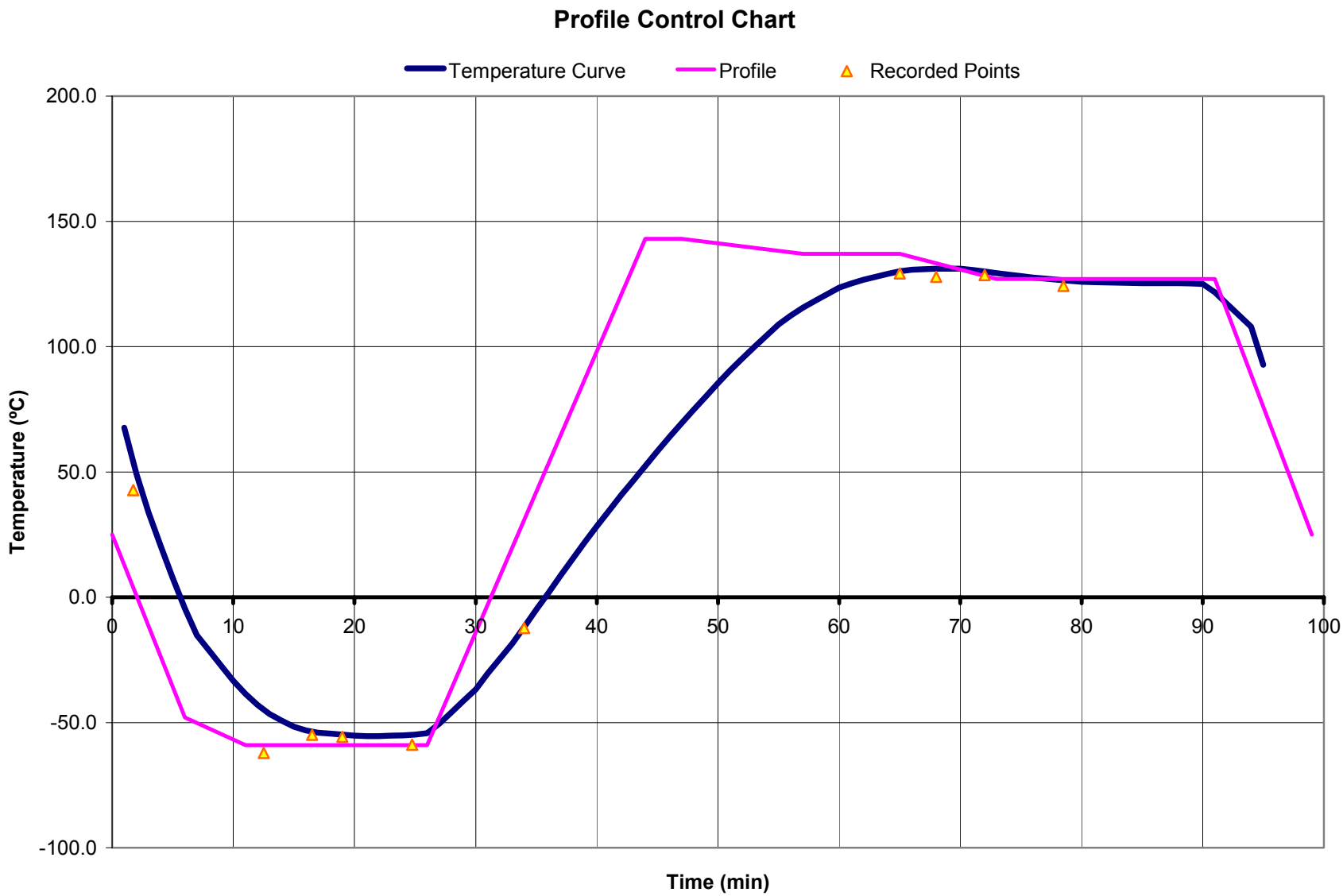
- Background, TV, Components, Assembly (Lety's PPT!)
- Thermal Cycle Protocol
- Statistical Results
- Physical Failure Analysis Results
- Conclusions

Thermal Cycle Testing Methodology:

- In accordance with IPC-9701
- Temperature Extremes: -55°C and +125°C
- Temperature Ramp: 5°C-10°C per minute maximum
- Temperature Dwells: 10 minutes @ -55°C

  30 minutes @ +125°C
- Continuous Monitoring with Event Detector:
  - An Event = channel resistance exceeded 300 Ω for longer than 0.2 μsec within a 30-second period

- A failure was defined when a component either:
  1. 15 consecutive maximum resistance events,
  2. 5 consecutive detection events within 10% of current life, or
  3. Became electrically open


Profile Control Chart
Temperature Curve
Profile
Recorded Points
200.0
150.0
100.0
50.0
0.0
-50.0
-100.0
Temperature (ºC)
0
10
20
30
40
50
60
70
80
90
100
Time (min)

Thermal Cycle Results:

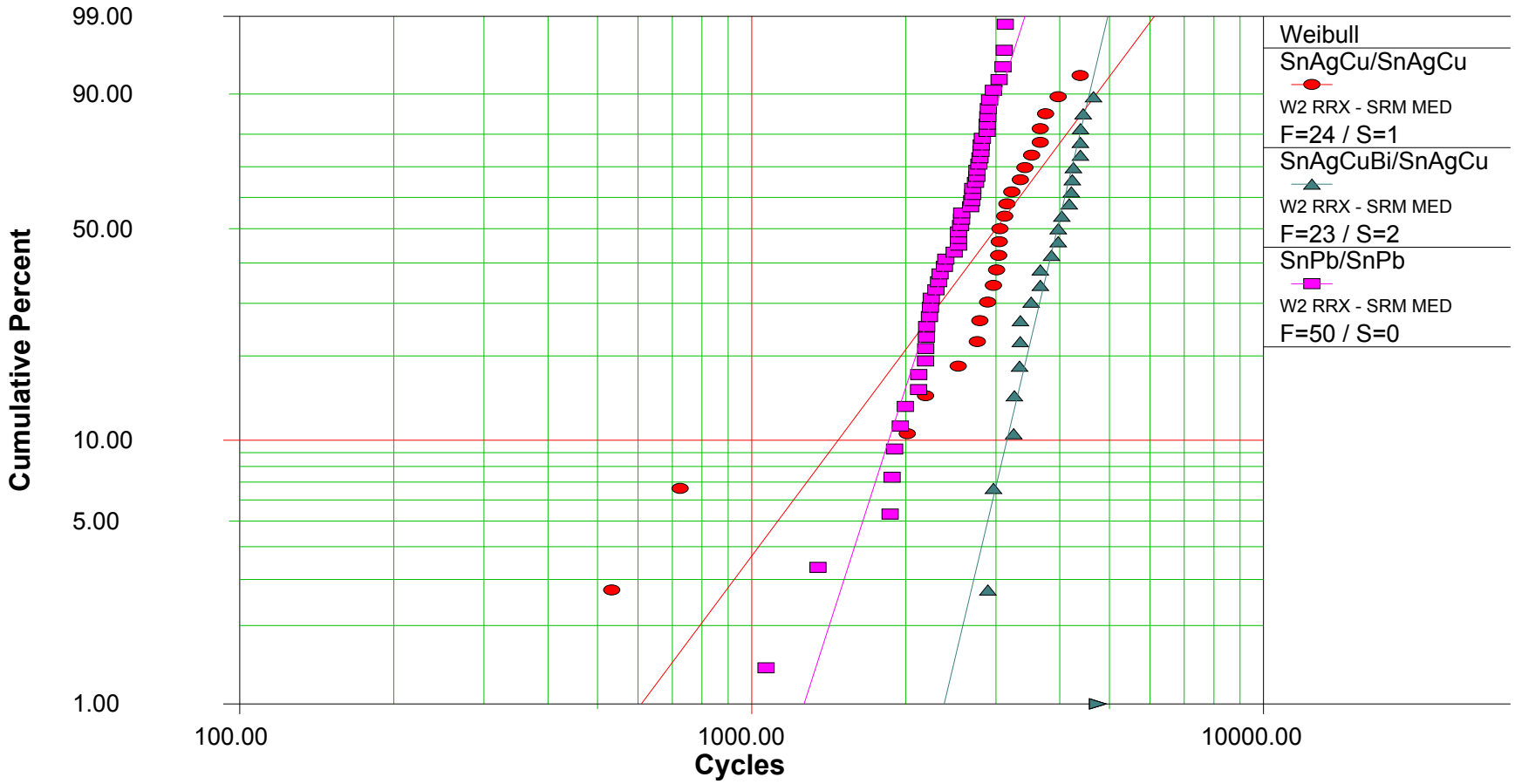
- **4743 Total Thermal Cycles Completed**
  - **12 months of Testing !!!**

Component Type	Total Failures	Total Population	Percent Failured
BGA 225	257	300	85.7
CLCC 20	300	300	100
PDIP 20	24	300	8
PLCC 20	8	150	5.3
TQFP 144	136	150	90.7
TQFP 208	110	150	73.3
TSOP 50	296	300	98.7

Thermal Cycle Results:

Thermal Cycle Results:

BGA-225 test results - Manufactured test vehicles (170ºC Tg)

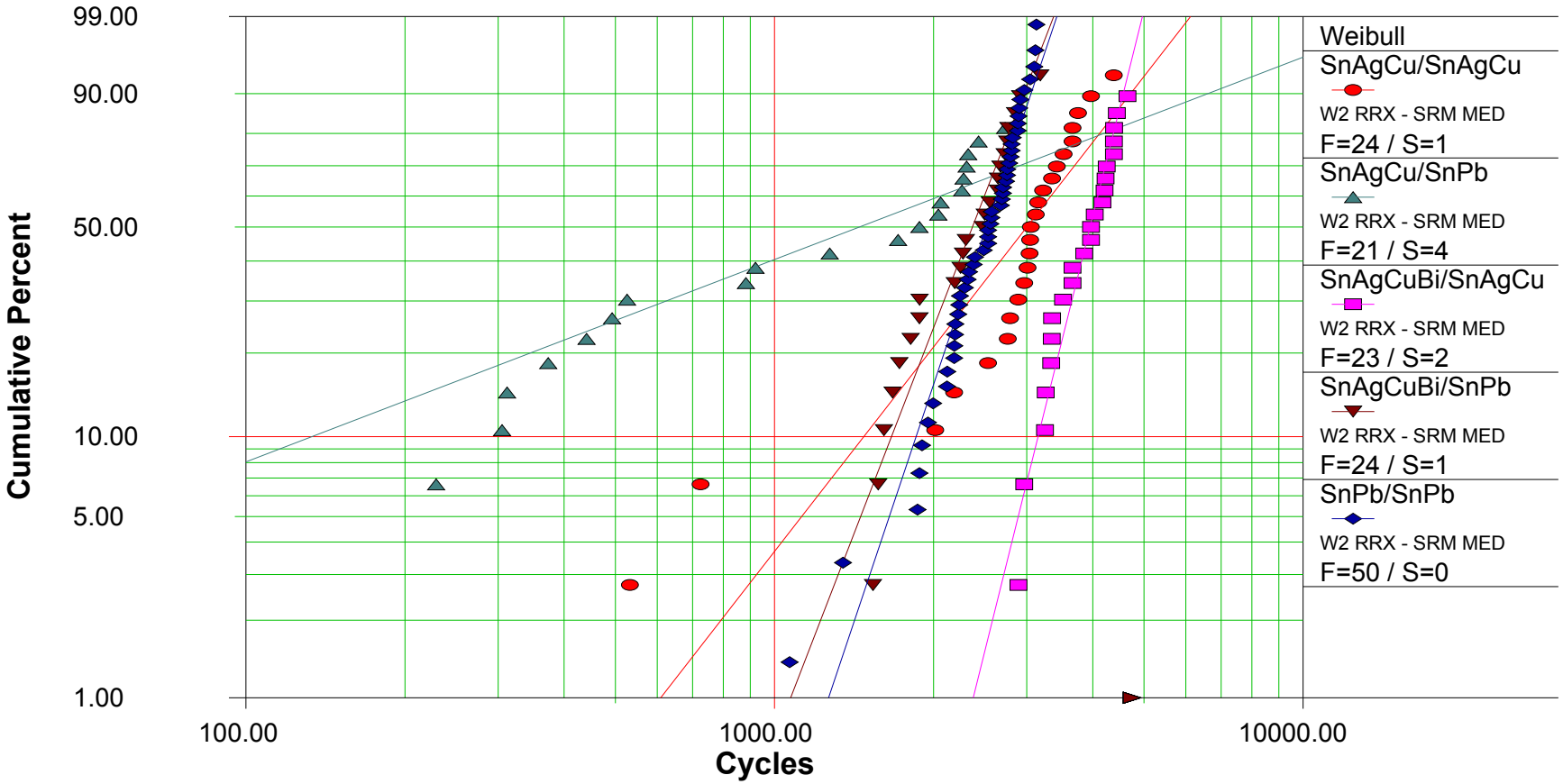


β1=2.6542, η1=3447.0666, ρ=0.8874
β2=8.3199, η2=4134.2424, ρ=0.9764
β3=6.1624, η3=2670.6991, ρ=0.9710

Key: Solder Alloy/Component Finish

Thermal Cycle Results:

BGA-225 test results - Manufactured test vehicles (170ºC Tg)

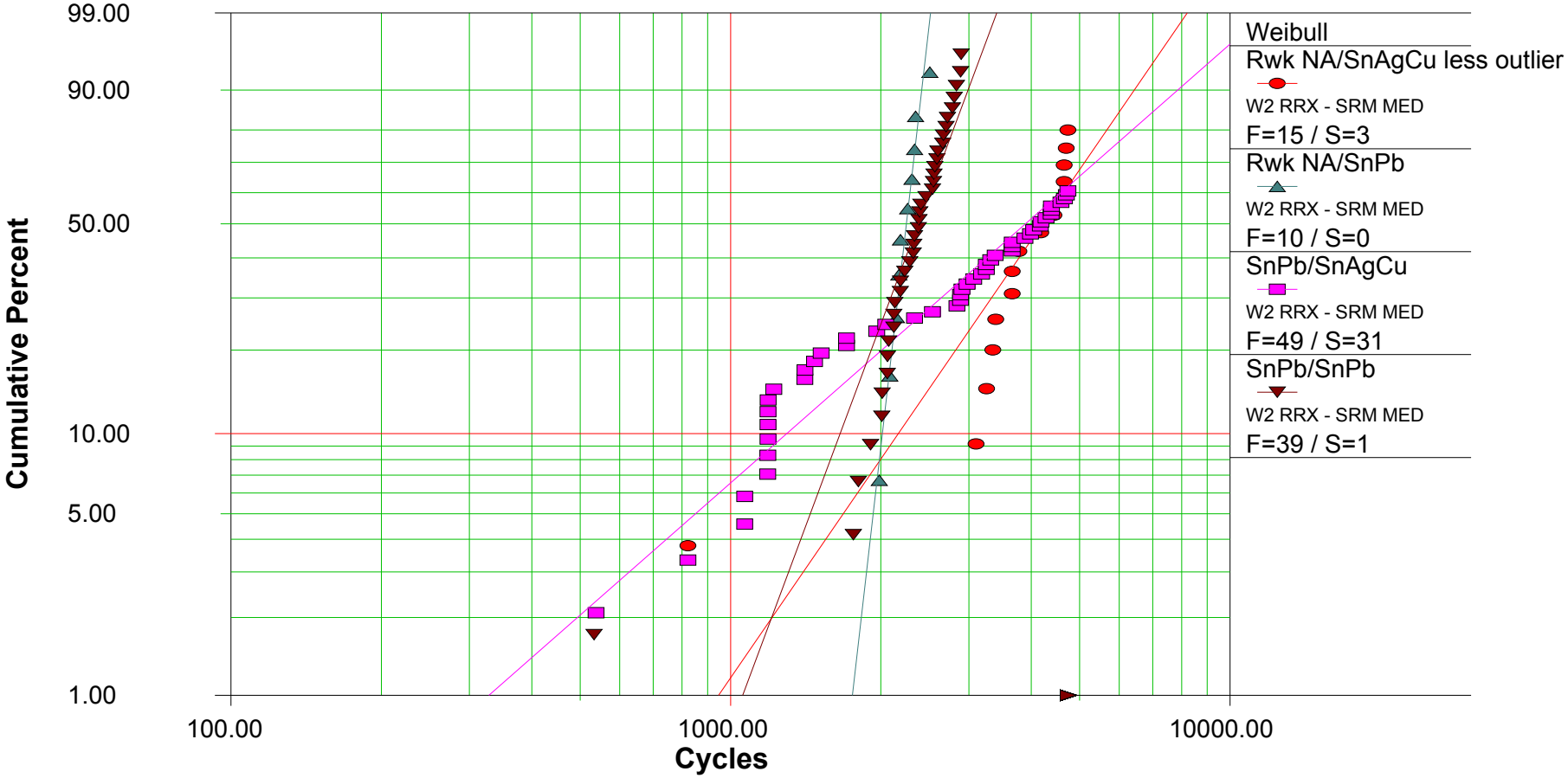


β1=2.6542, η1=3447.0666, ρ=0.8874
β2=0.7906, η2=2301.0183, ρ=0.9262
β3=8.3199, η3=4134.2424, ρ=0.9764
β4=5.3473, η4=2536.9533, ρ=0.9649
β5=6.1624, η5=2670.6991, ρ=0.9710

Key: Solder Alloy/Component Finish

Thermal Cycle Results:

BGA-225 test results - Manufactured test vehicles (140ºC Tg)

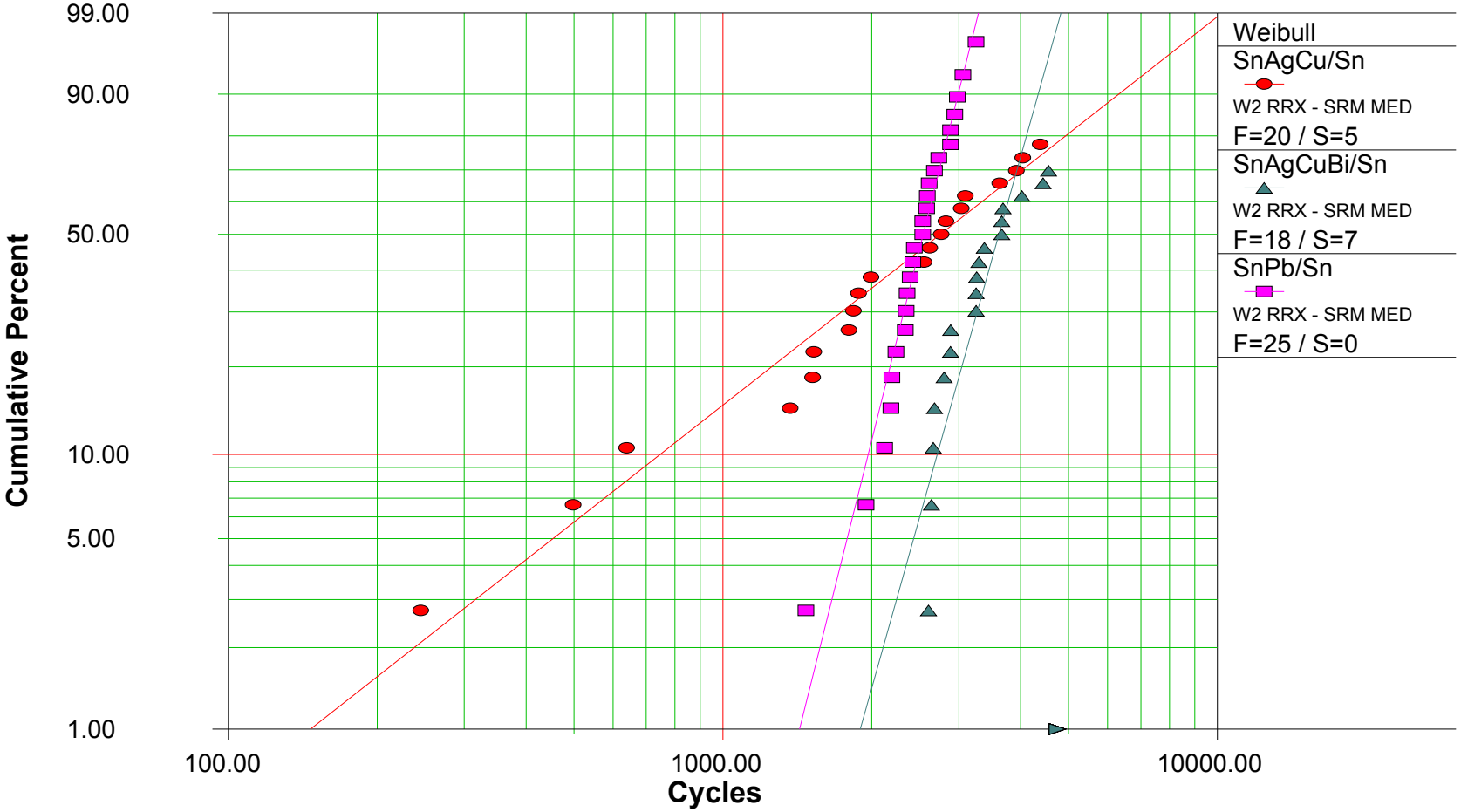


$\beta 1=2.8360$, $\eta 1=4793.8892$, $\rho=0.8559$
$\beta 2=17.0339$, $\eta 2=2299.0505$, $\rho=0.9799$
$\beta 3=1.7117$, $\eta 3=4827.3427$, $\rho=0.9768$
$\beta 4=5.2327$, $\eta 4=2548.4173$, $\rho=0.8368$

Key: Solder Alloy/Component Finish

Thermal Cycle Results:

TQFP-144 test results:Manufactured test vehicles (170ºC Tg)

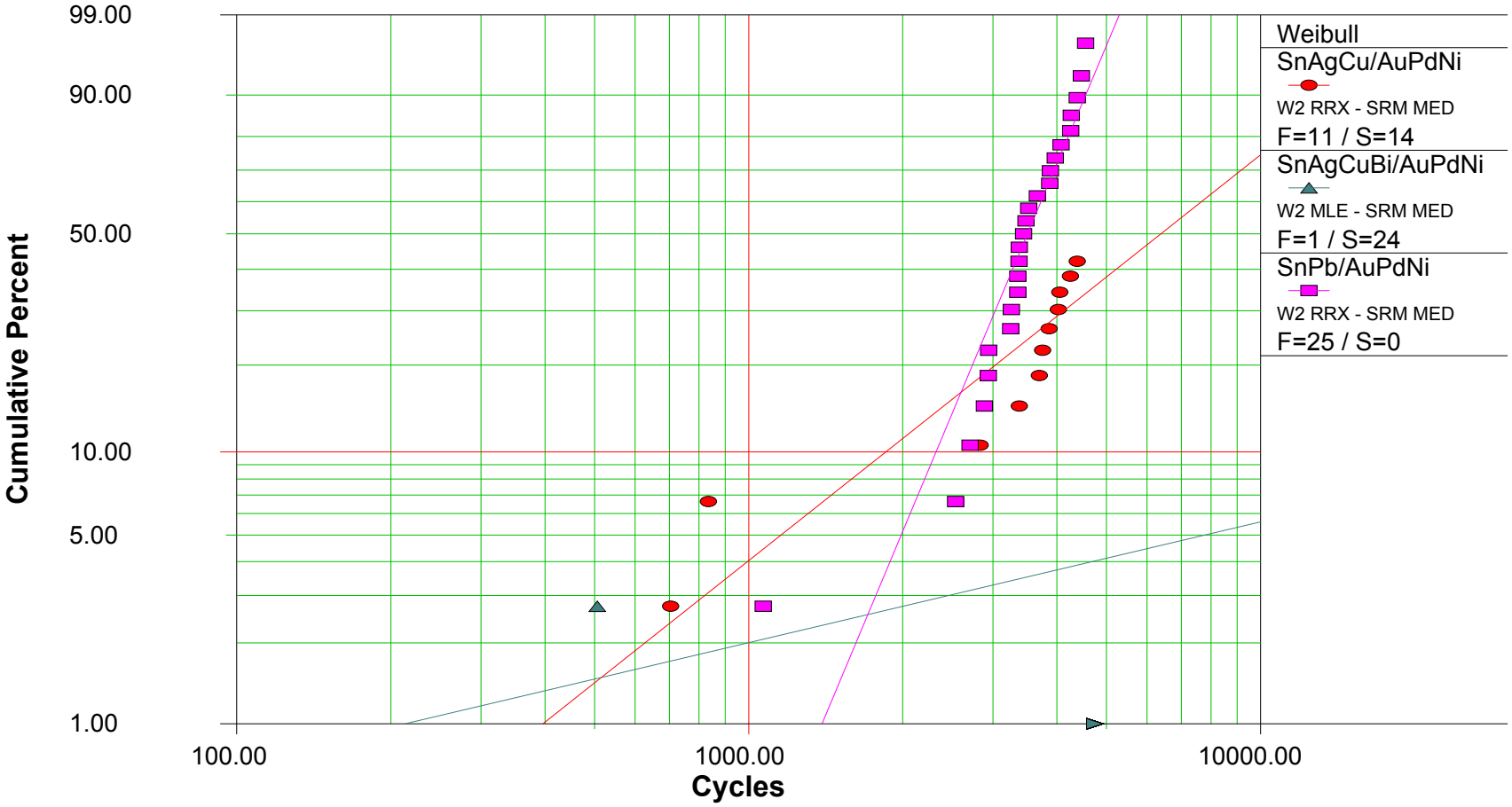


β1=1.4438, η1=3549.7161, ρ=0.9839
β2=6.5549, η2=3826.0852, ρ=0.8910
β3=7.3598, η3=2672.0067, ρ=0.9785

Key: Solder Alloy/Component Finish

Thermal Cycle Results:

TQFP-208 test results:Manufactured test vehicles (170ºC Tg)

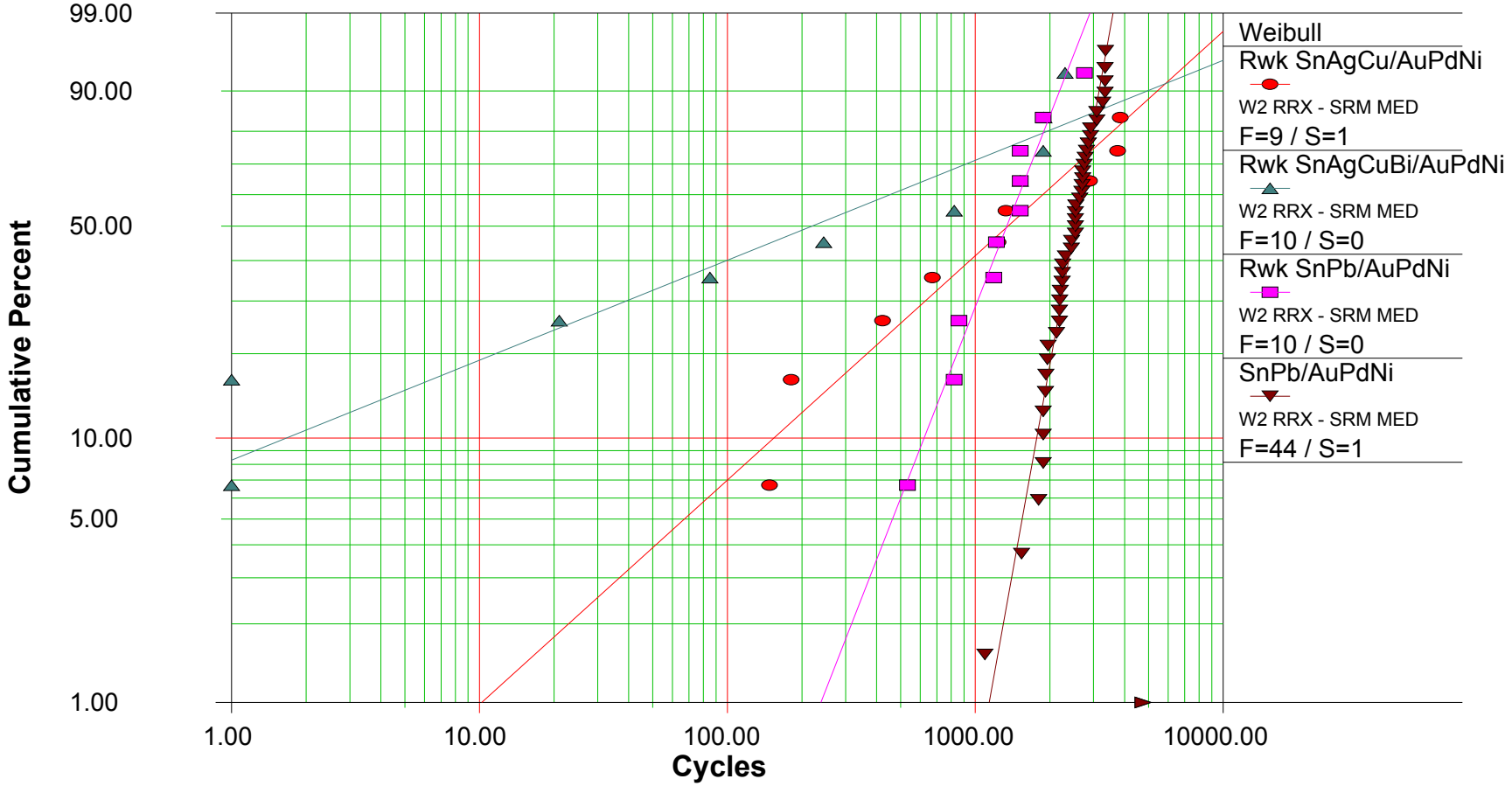


β1=1.5234, η1=8121.4258, ρ=0.9133
β2=0.4536, η2=5.4118E+6
β3=4.5821, η3=3797.8345, ρ=0.9051

Key: Solder Alloy/Component Finish

Thermal Cycle Results:

TQFP-208 test results:Manufactured test vehicles (140ºC Tg)

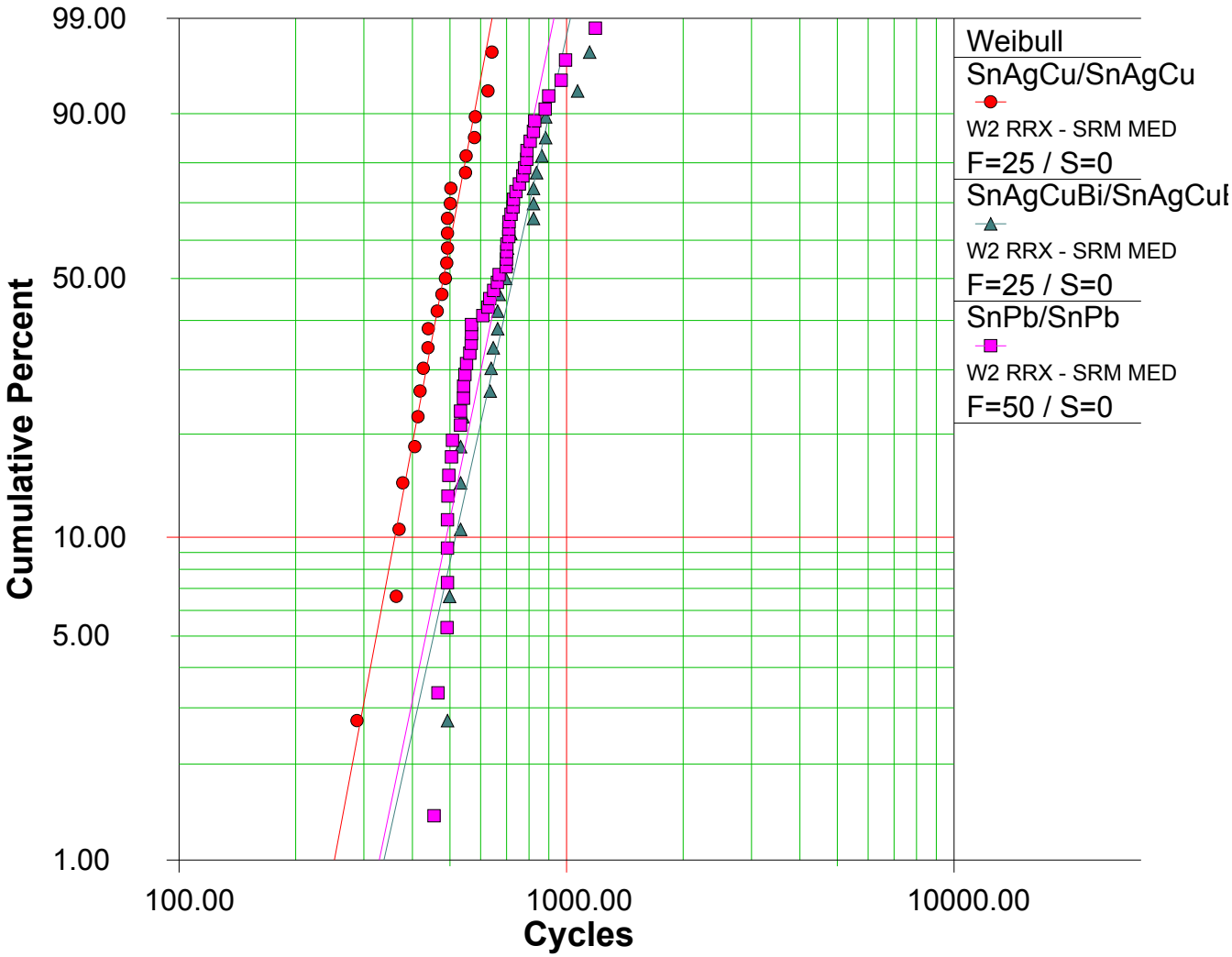


β1=0.8662, η1=2070.1009, ρ=0.9733
β2=0.3858, η2=568.8850, ρ=0.9539
β3=2.4522, η3=1557.5409, ρ=0.9795
β4=5.3252, η4=2702.1488, ρ=0.9845

Key: Solder Alloy/Component Finish

Thermal Cycle Results:

CLCC-20 test results - Manufactured test vehicles (170ºC Tg)

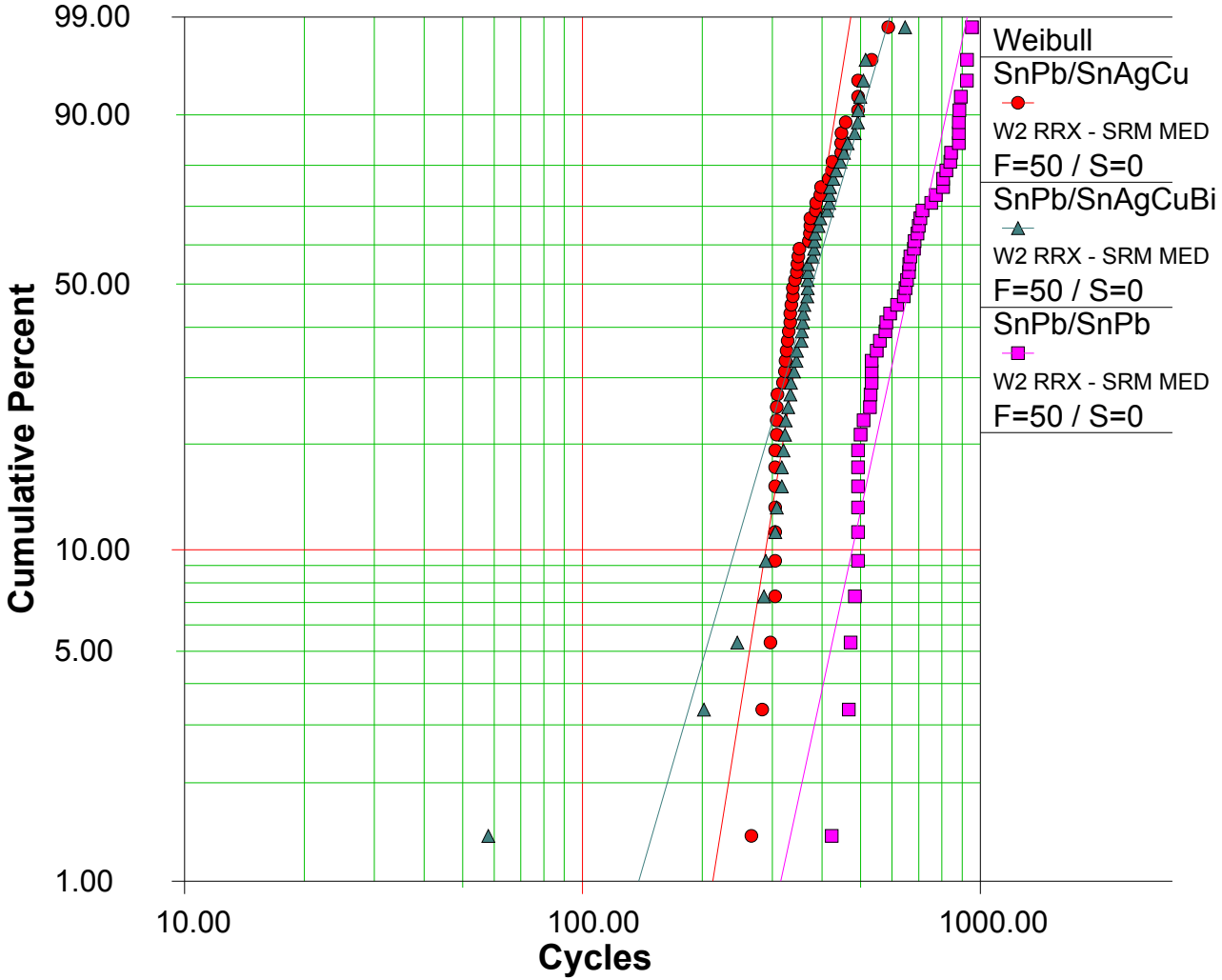


$\beta 1=6.5409$, $\eta 1=508.6653$, $\rho=0.9864$
$\beta 2=5.5317$, $\eta 2=776.3182$, $\rho=0.9453$
$\beta 3=5.9047$, $\eta 3=716.4935$, $\rho=0.9326$

Key: Solder Alloy/Component Finish

Thermal Cycle Results:

CLCC-20 test results: Legacy test vehicles (140ºC Tg)

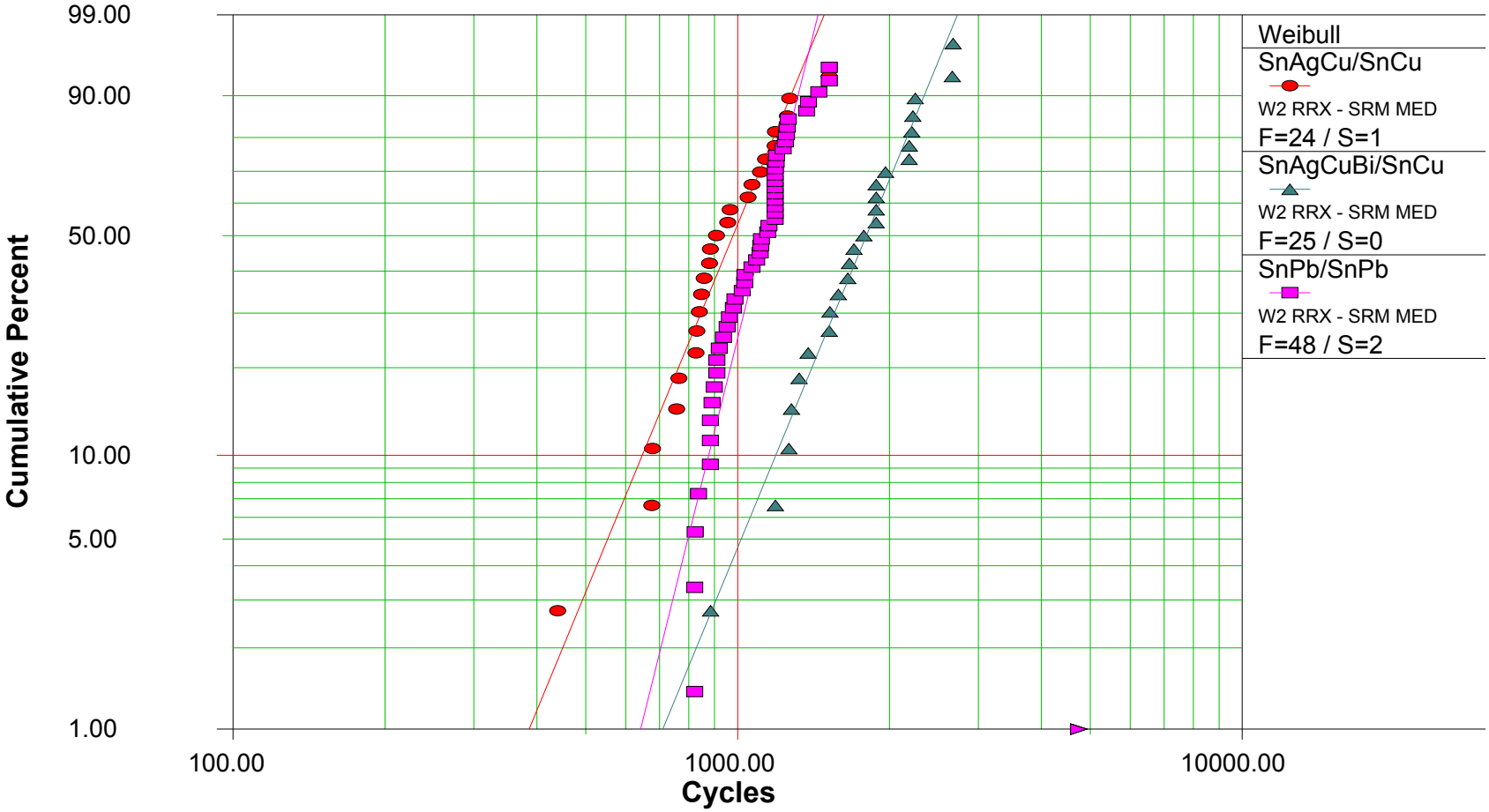


$\beta 1=7.6691$, $\eta 1=387.3908$, $\rho=0.8914$
$\beta 2=4.2149$, $\eta 2=412.5278$, $\rho=0.8758$
$\beta 3=5.6773$, $\eta 3=708.6388$, $\rho=0.9368$

Key: Solder Alloy/Component Finish

Thermal Cycle Results:

TSOP-50 test results: Manufactured test vehicles (170ºC Tg)

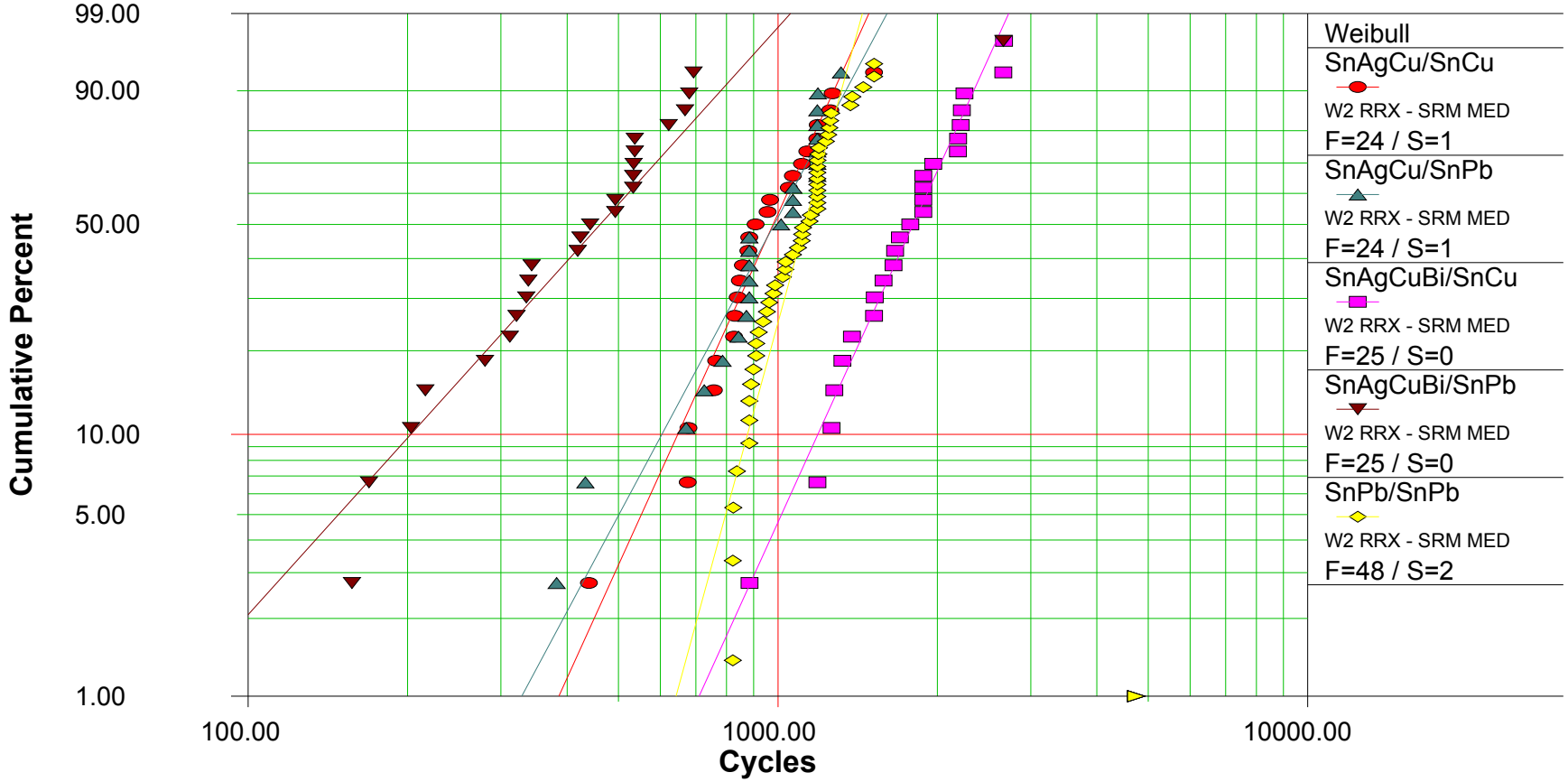


β1=4.5501, η1=1061.7576, ρ=0.9732
β2=4.5553, η2=1950.6106, ρ=0.9890
β3=7.5694, η3=1179.9001, ρ=0.9443

Key: Solder Alloy/Component Finish

Thermal Cycle Results:

TSOP-50 test results: Manufactured test vehicles (170ºC Tg)



β1=4.5501, η1=1061.7576, ρ=0.9732
β2=3.8599, η2=1082.2162, ρ=0.9642
β3=4.5553, η3=1950.6106, ρ=0.9890
β4=2.2892, η4=542.1344, ρ=0.9096
β5=7.5694, η5=1179.9001, ρ=0.9443

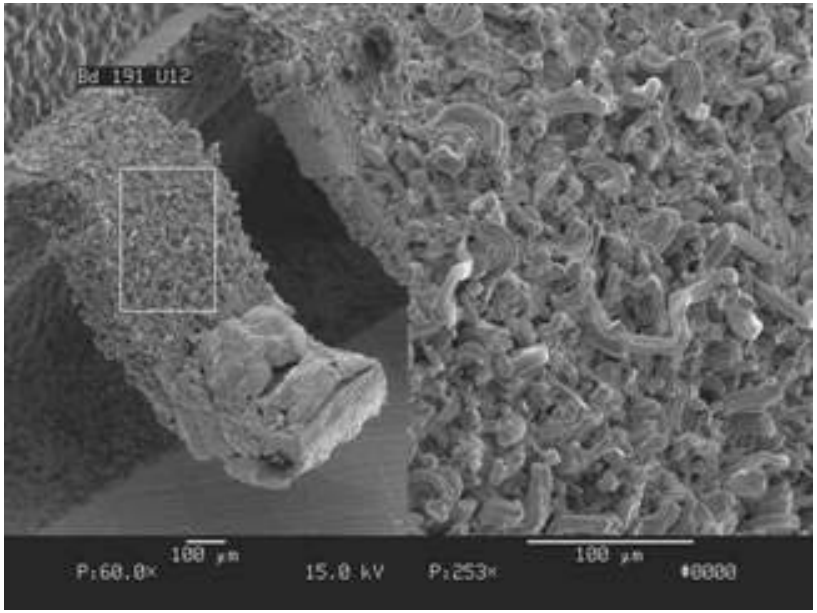
Key: Solder Alloy/Component Finish

Failure Analysis Results: Tin Pest Observations

Allotropic tin transformation: Graphic from K. Sweatman, "Suppression of Tin Pest in Pbfree Solders", IPC/JEDEC 8th International Conference on Lead Free Electronic Components and Assemblies Proceedings, April 2005.

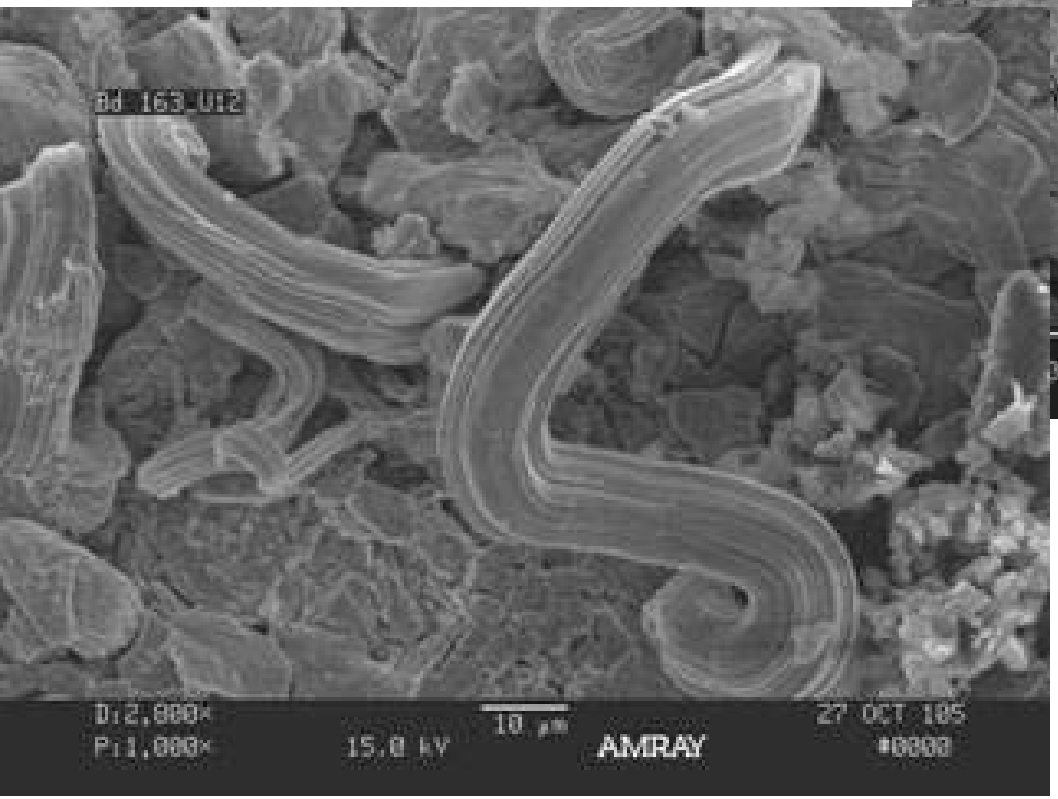
Failure Analysis Results: Components/Finishes:

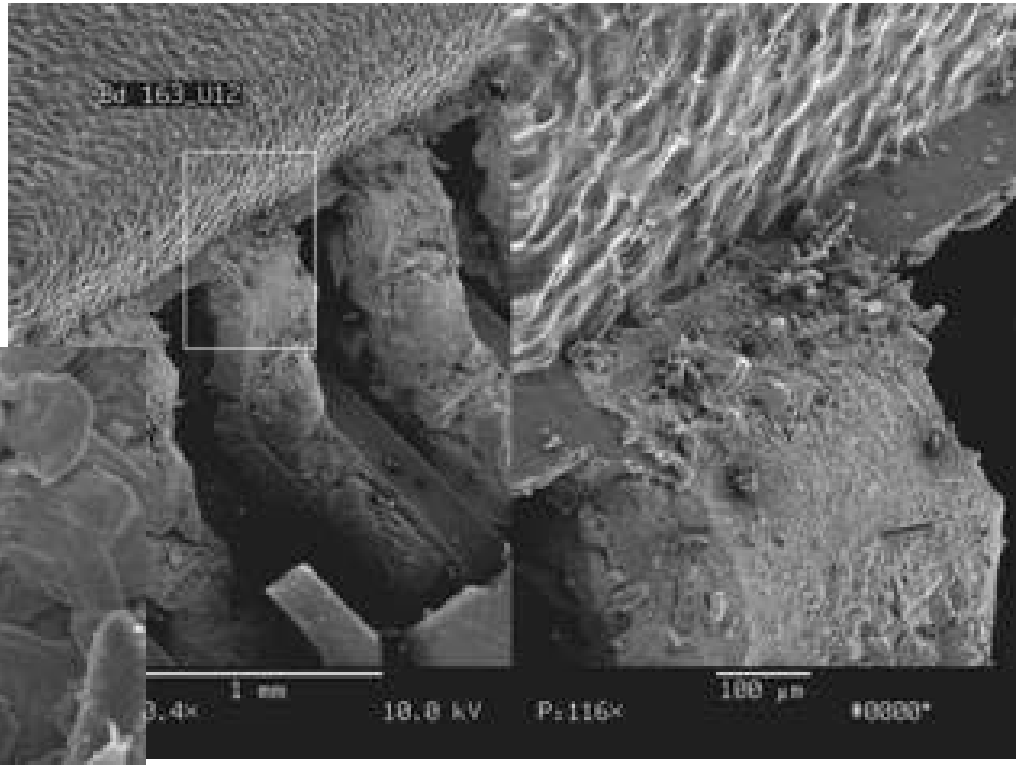
Component Type	Component Finish
CLCC -20	SnPb
	SnAgCu
	SnAgCuBi
PLCC-20	Sn
TSOP-50	SnPb
	SnCu
TQFP-144	Sn
TQFP-208	NiPdAu
BGA-225	SnPb
	SnAgCu
DIP-20	Sn
	NiPdAu
0402 Capacitor	Sn
0805 Capacitor	Sn
1206 Capacitor	Sn
1206 Resistor	Sn



Failure Analysis Results:

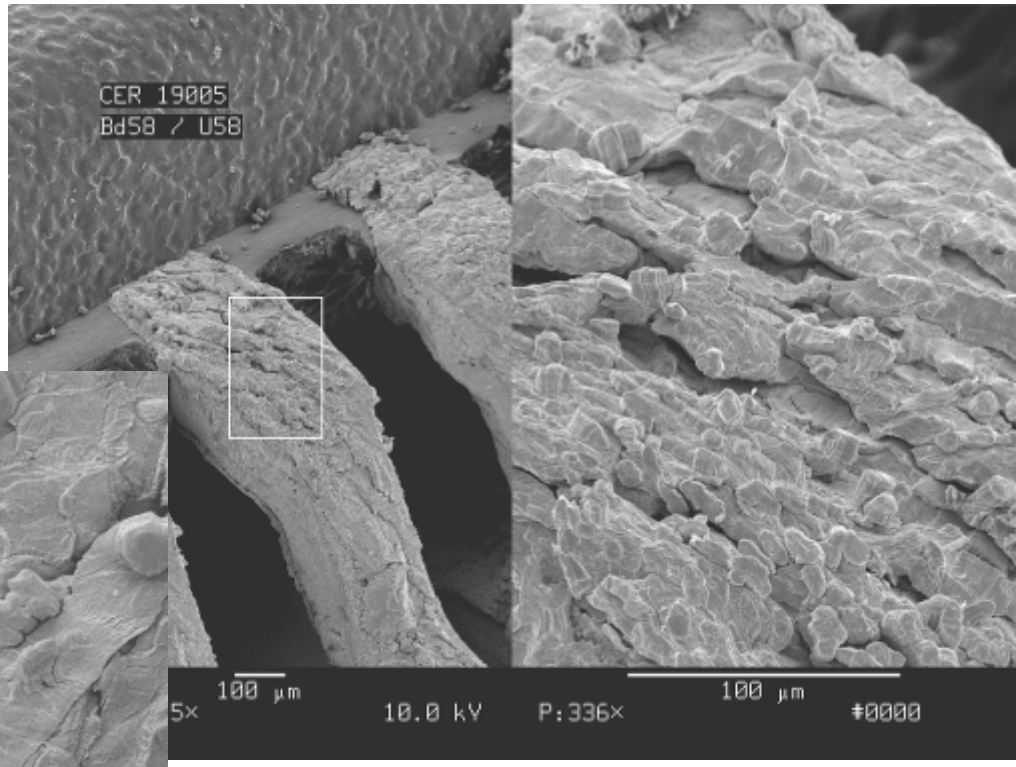
SEM image of TSOP component with SnCu surface finish – Originally soldered with SnPb (140ºC Tg PWB) then manually reworked with SAC

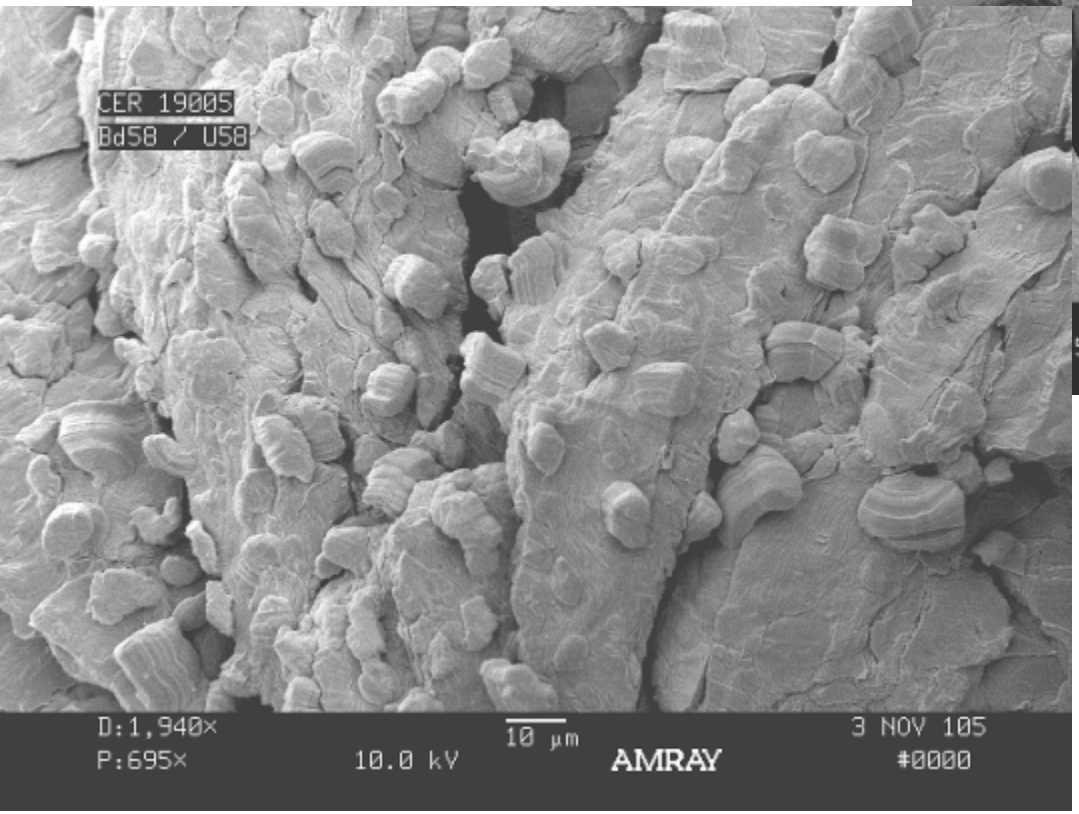




Failure Analysis Results:

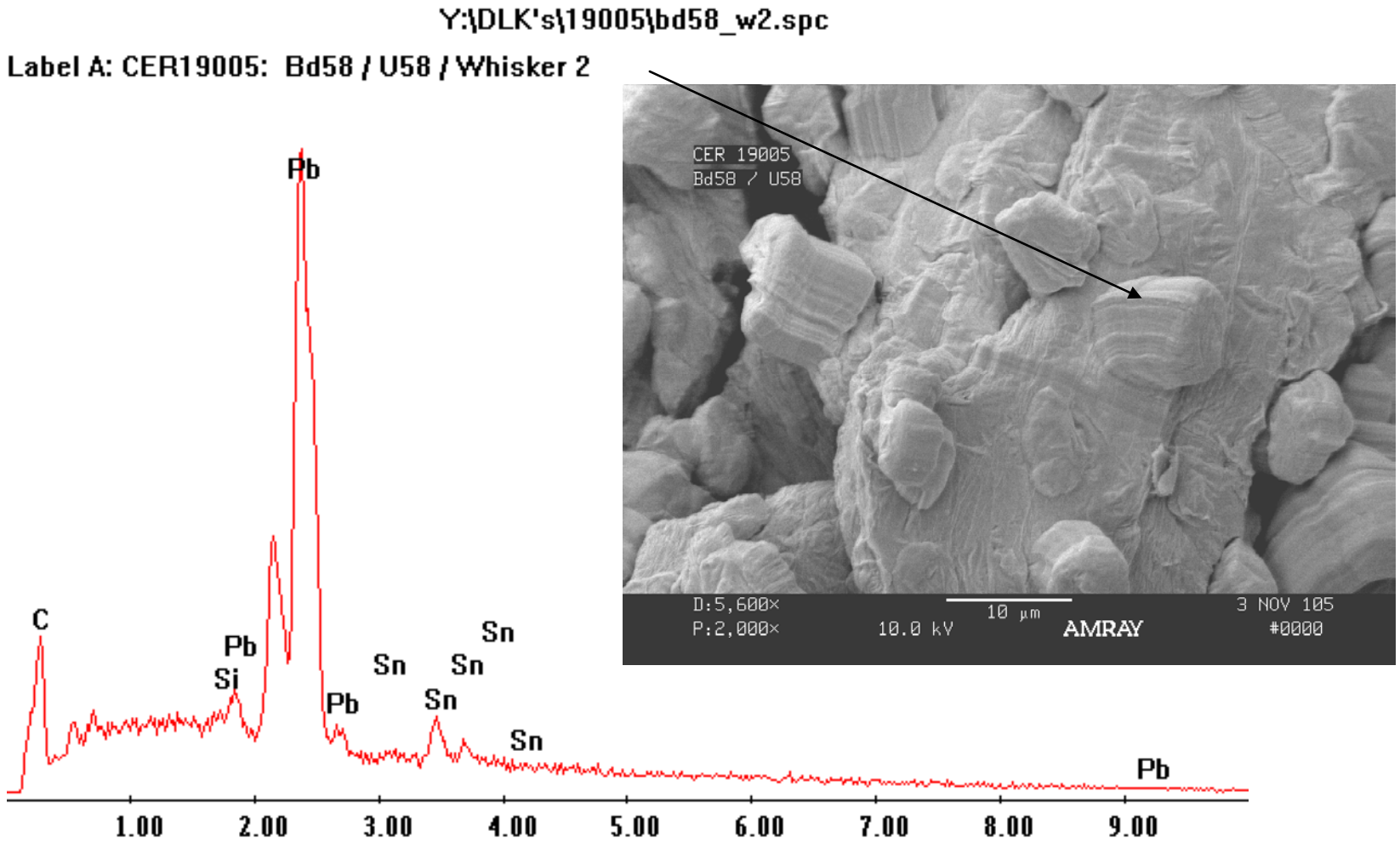
SEM image of TQFP component with Sn surface finish – Originally soldered with SnPb (140ºC Tg PWB)





Failure Analysis Results:

SEM image of TQFP component with Sn surface finish – Originally soldered with SnPb (140ºC Tg PWB)



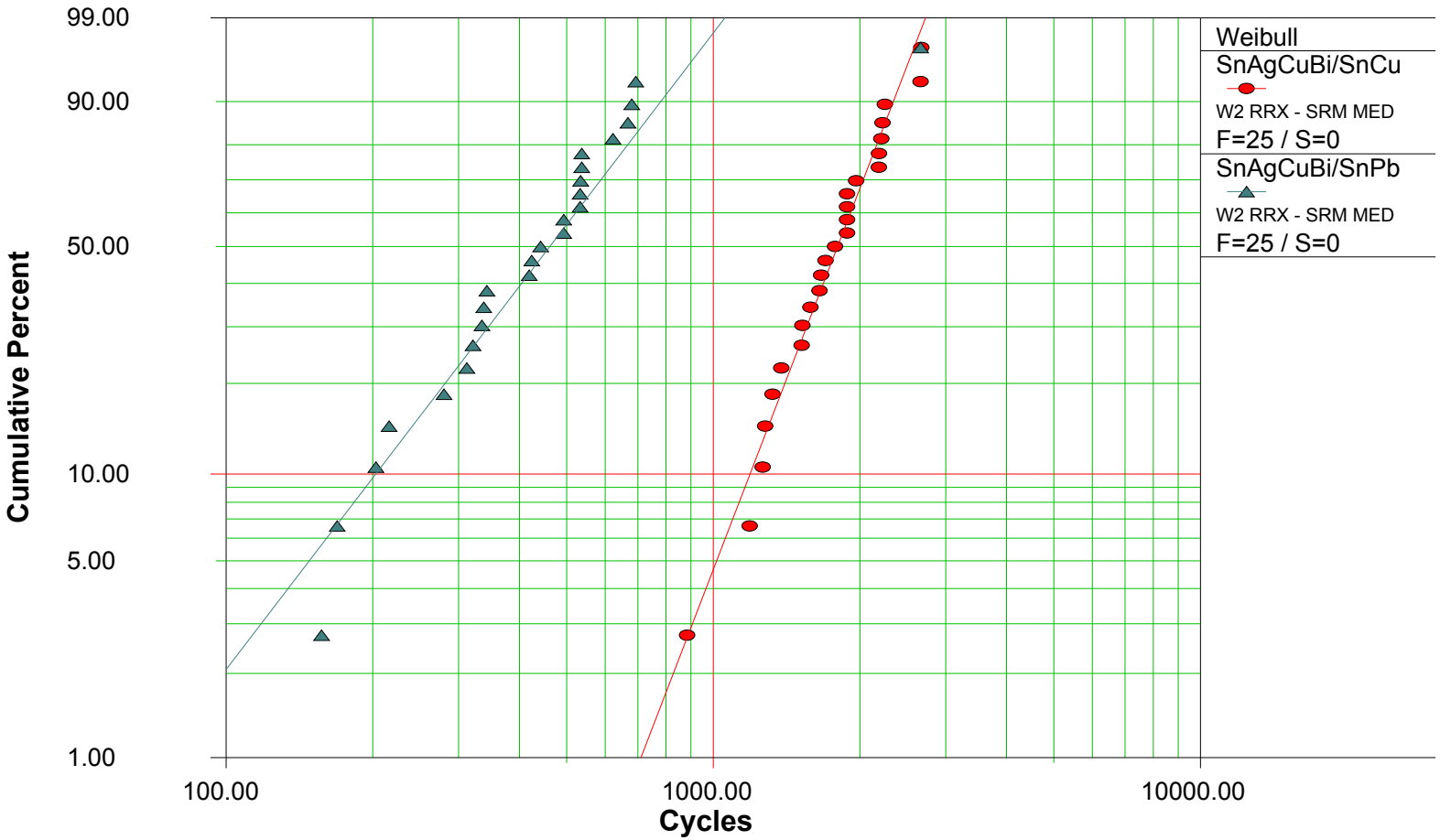
Failure Analysis Results: Tin Whisker Summary

Component Type	Component Finish	Whisker Observations	Typical Whisker Diameter	Typical Whisker Length	Maximum Length Observed
TSOP	SnPb	Significant Whiskering Observed	8 µm	5 - 20 µm	50 µm
	SnCu	Significant Whiskering Observed	8 µm	10 - 30 µm	120 µm
DIP	Sn	No Whiskers Observed	NA	NA	NA
PLCC	Sn	No Whiskers Observed	NA	NA	NA
TQFP	Sn	Sporatic Whiskering Observed	8 µm	8 - 12 µm	12 µm
Note: Whiskers observed with severely twisted/contorted shapes or with stubby shapes					

Note: No Tin Whiskers were observed on any of the other component/surface finish combinations

Failure Analysis Results: Lead (Pb) and Bismuth Interaction

TSOP-50 SACB test results for the "Manufactured" test vehicles (170°C Tg)

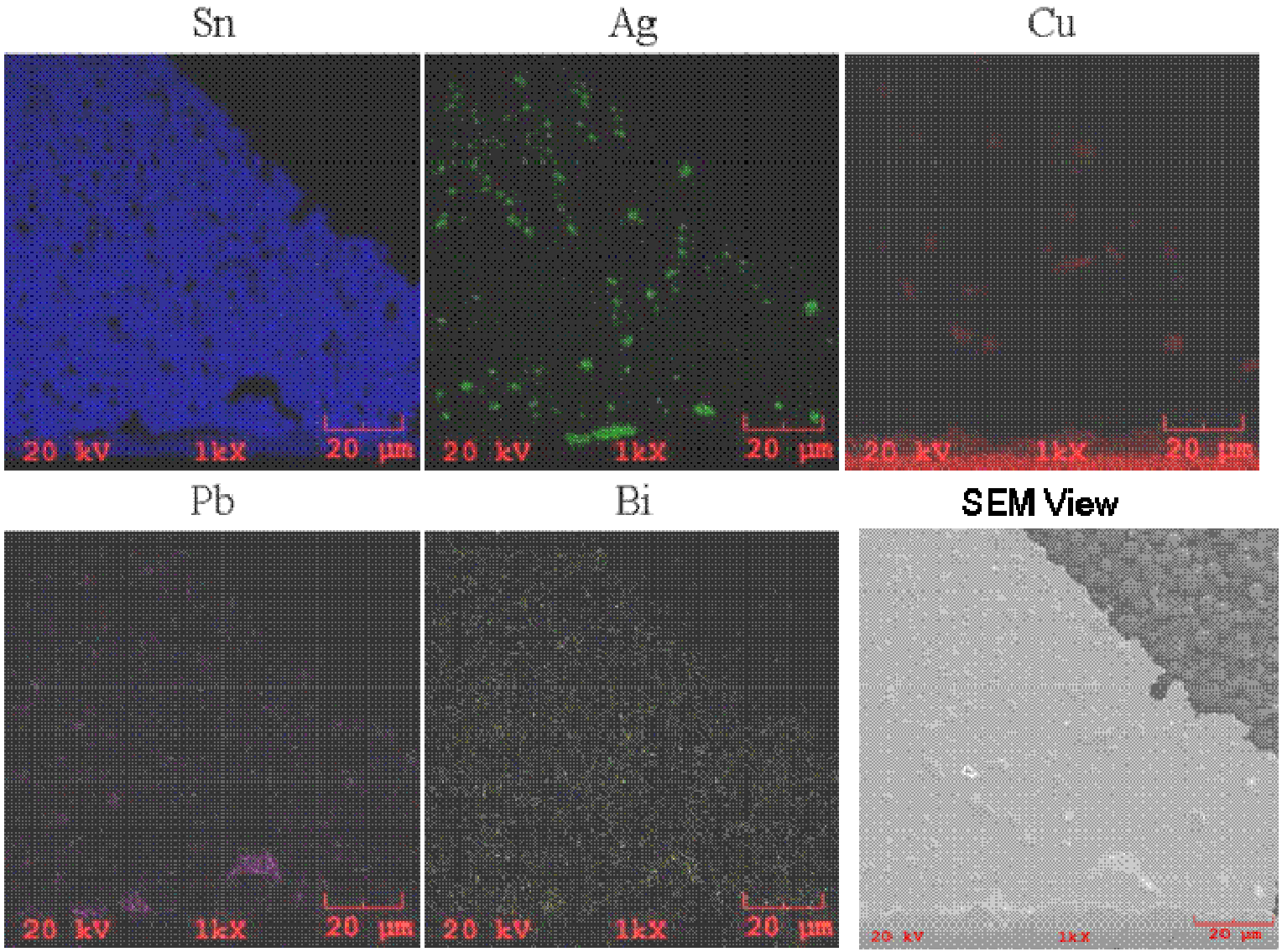


$\beta 1=4.5553$, $\eta 1=1950.6106$, $\rho=0.9890$
$\beta 2=2.2892$, $\eta 2=542.1344$, $\rho=0.9096$

Key: Solder Alloy/Component Finish

Failure Analysis Results: Lead (Pb) and Bismuth Interaction

SEM elemental mapping results for SACB-SnPb solder joint after 4743 cycles



Failure Analysis Results: Lead (Pb) and Bismuth Interaction
TSOP-50 SACB/Component Finish DSC Data

Solder Alloy/Component Finish	DSC Data
SACB/SnPb	196.9°C
SACB/SnCu	210.0°C
SACB Melting Range	205°C-214°C
DSC settings: 10°C/min ramps, 25°C to 300°C range	

Failure Analysis Results: Lead (Pb) and Bismuth Interaction Two Possible Explanations:

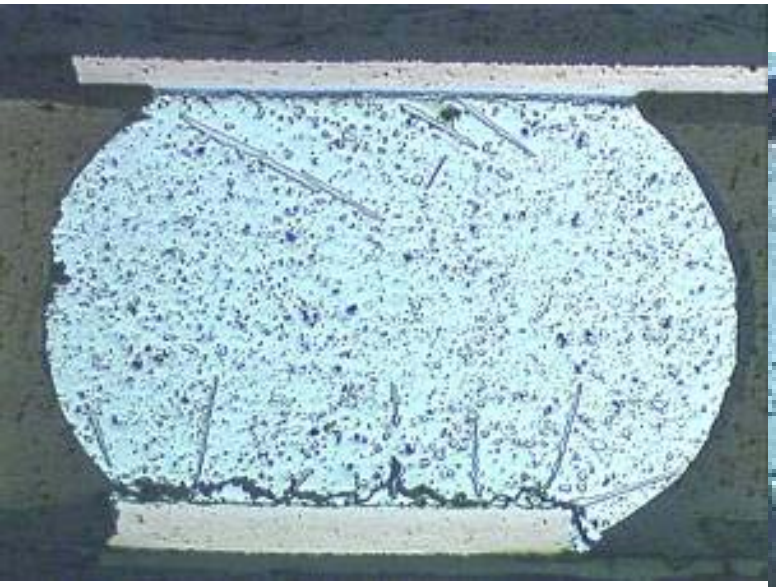
- **The Pb contamination is impacting the SACB solder joint integrity by the formation of non-equilibrium SnPbBi microstructure phases. The Pb contamination is not great enough to form the microstructure phases associated with the 58Bi42Sn solder alloy (138C), the 16Sn32Pb52Bi ternary eutectic phase (96C) or the 62.5Sn/36.1Pb/1.4Ag ternary eutectic alloy (177ºC) [15]. The formation of non-equilibrium ternary phases can cause broad melting effects on the melting behavior on solder alloy solidification. The DSC data of this investigation shows a nondescript impact rather than a specific ternary reaction in a similar manner.**

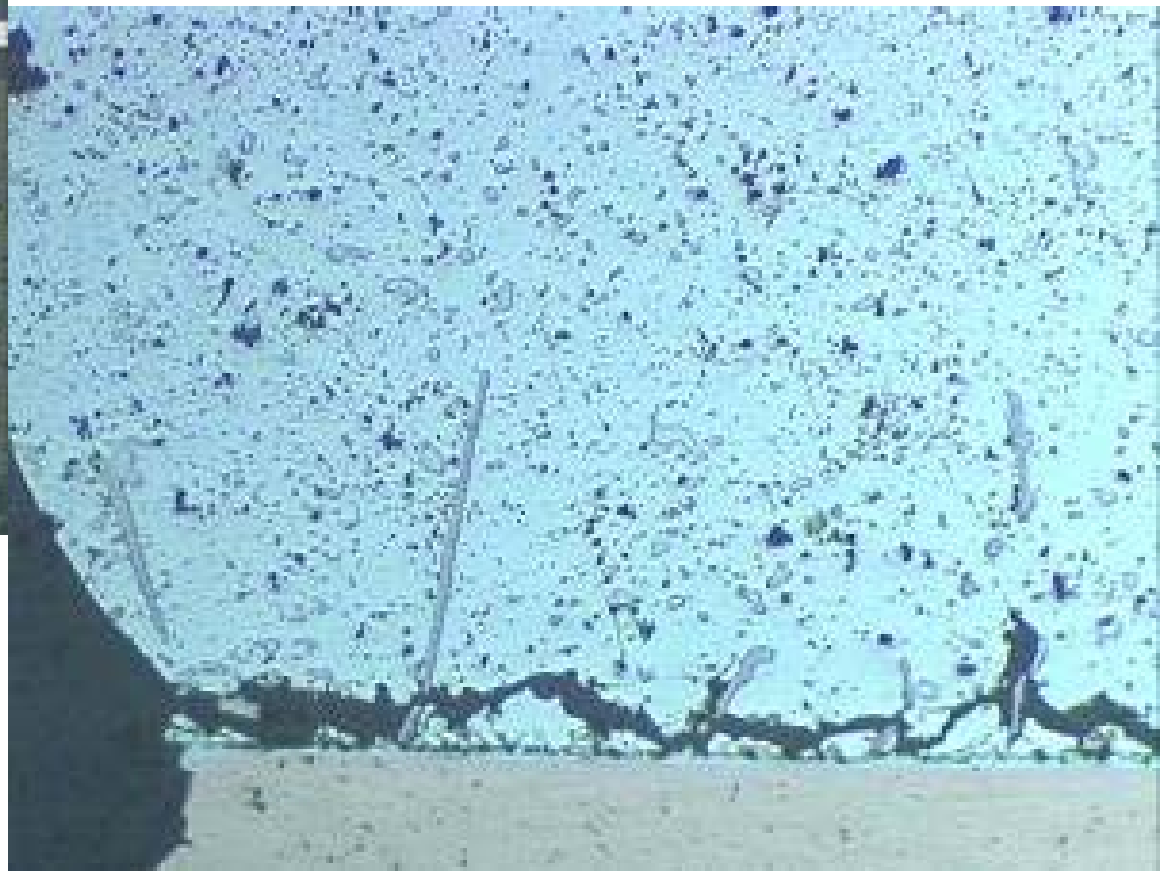
- **The DSC test results may be an indication of the Sn63Pb37 eutectic alloy development at the solder joint grain boundaries. The development of the Sn63Pb37 alloy at the grain boundaries would impact the thermal cycle solder joint integrity. The SEM elemental mapping did show some evidence of segregated Pb regions in the SACB solder joint thus the existence of the eutectic alloy at the grain boundaries would be possible.**

Sandia/ATT Data, Table 6 in final report

Thermal Cycles	SnAgBi	
	SnPb/OSP	Sn/OSP
0	2.75 +/- 0.61	5.31 +/- 0.67
10,106	3.13 +/- 1.24	5.34 +/- 0.74

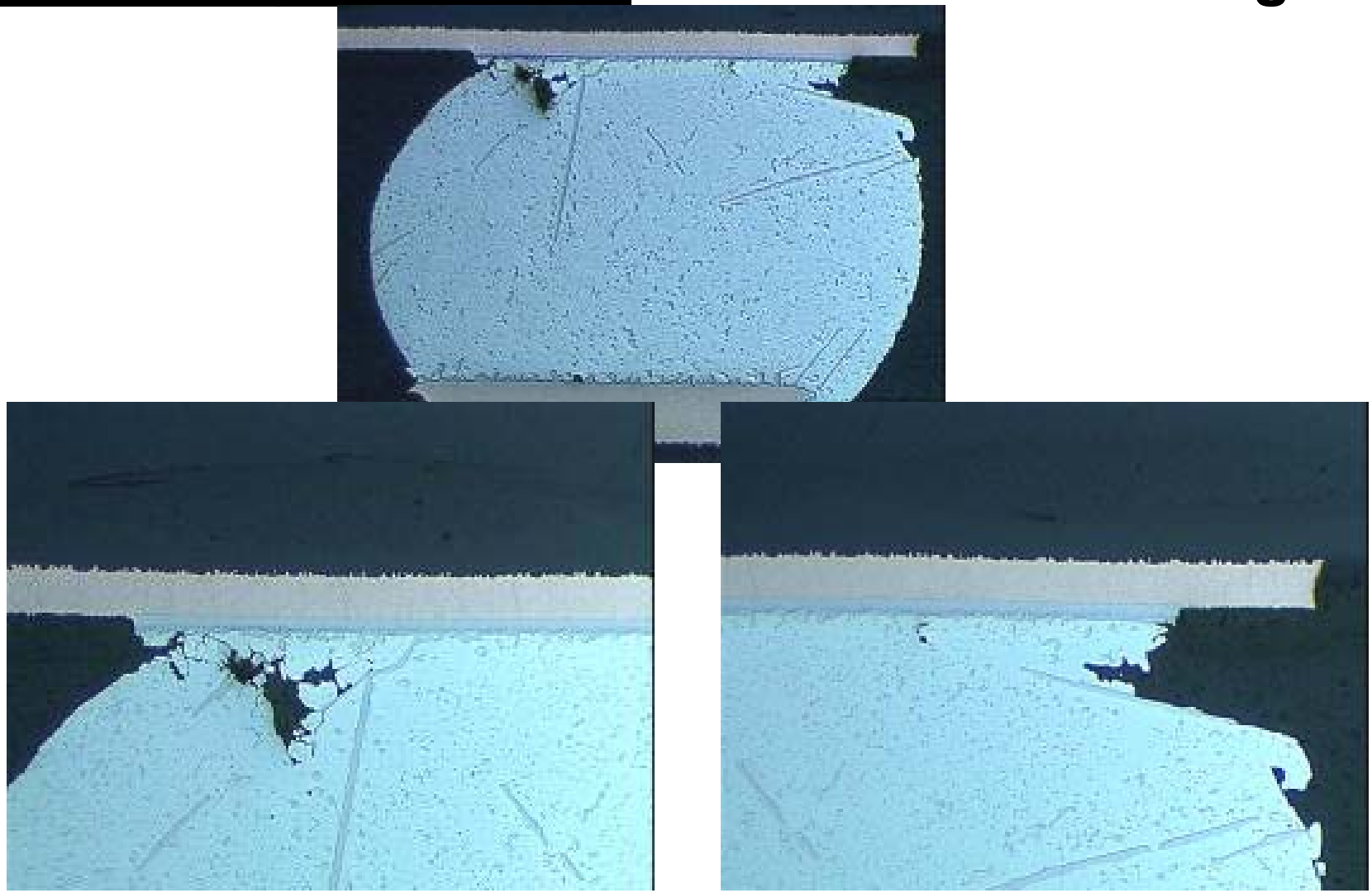
Failure Analysis Results: Mixed BGA Metallurgies





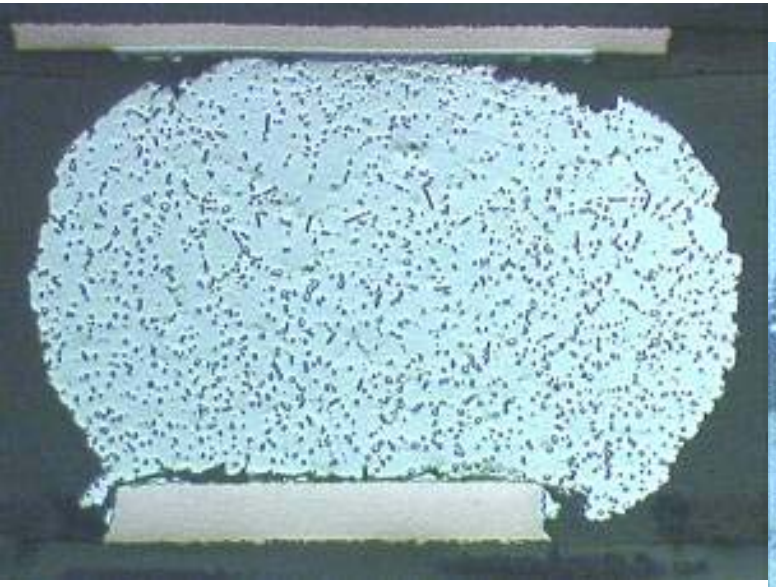
BGA-225 SAC-SAC solder joint magnified view of solder joint crack path - Failed after 3011 thermal cycles (Original pwb finish was Immersion Silver)

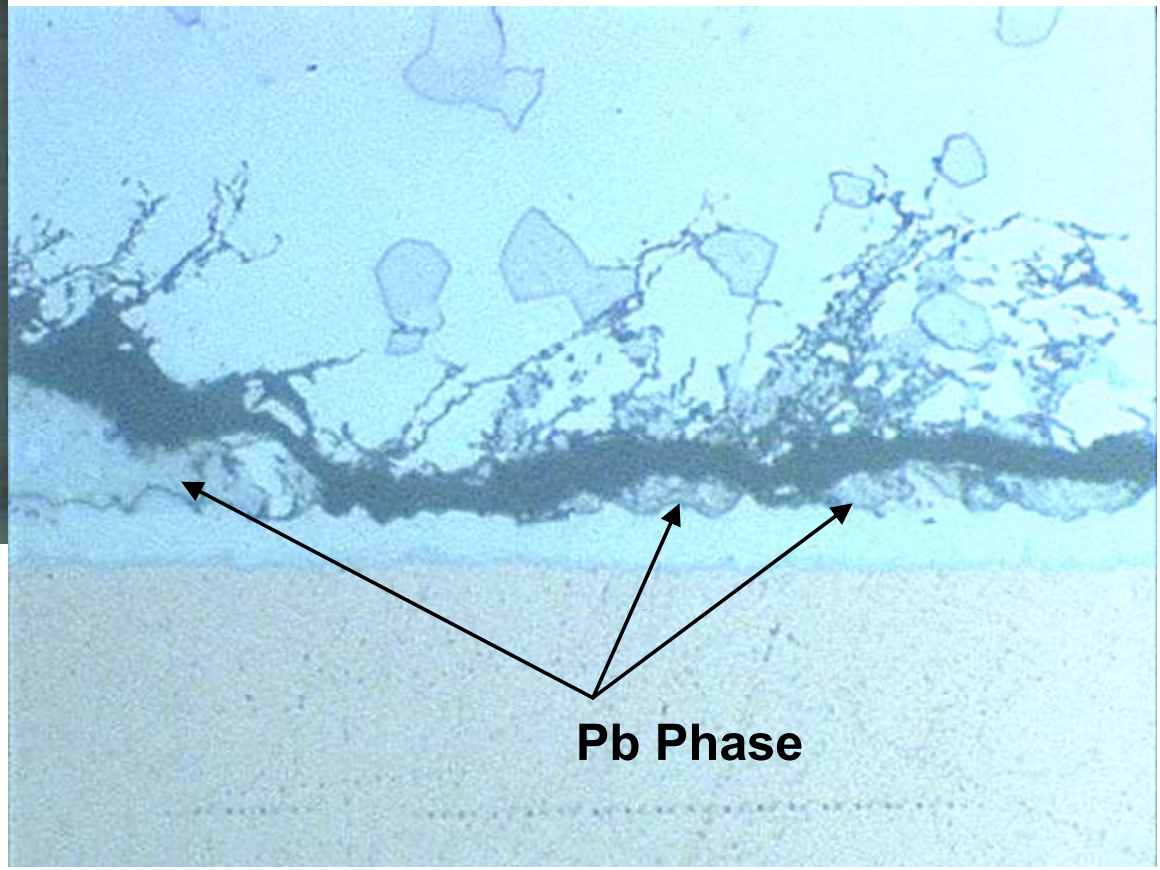
Failure Analysis Results: Mixed BGA Metallurgies



BGA-225 SAC-SAC solder joint magnified view of solder joint crack path – No Failure after 4743 thermal cycles

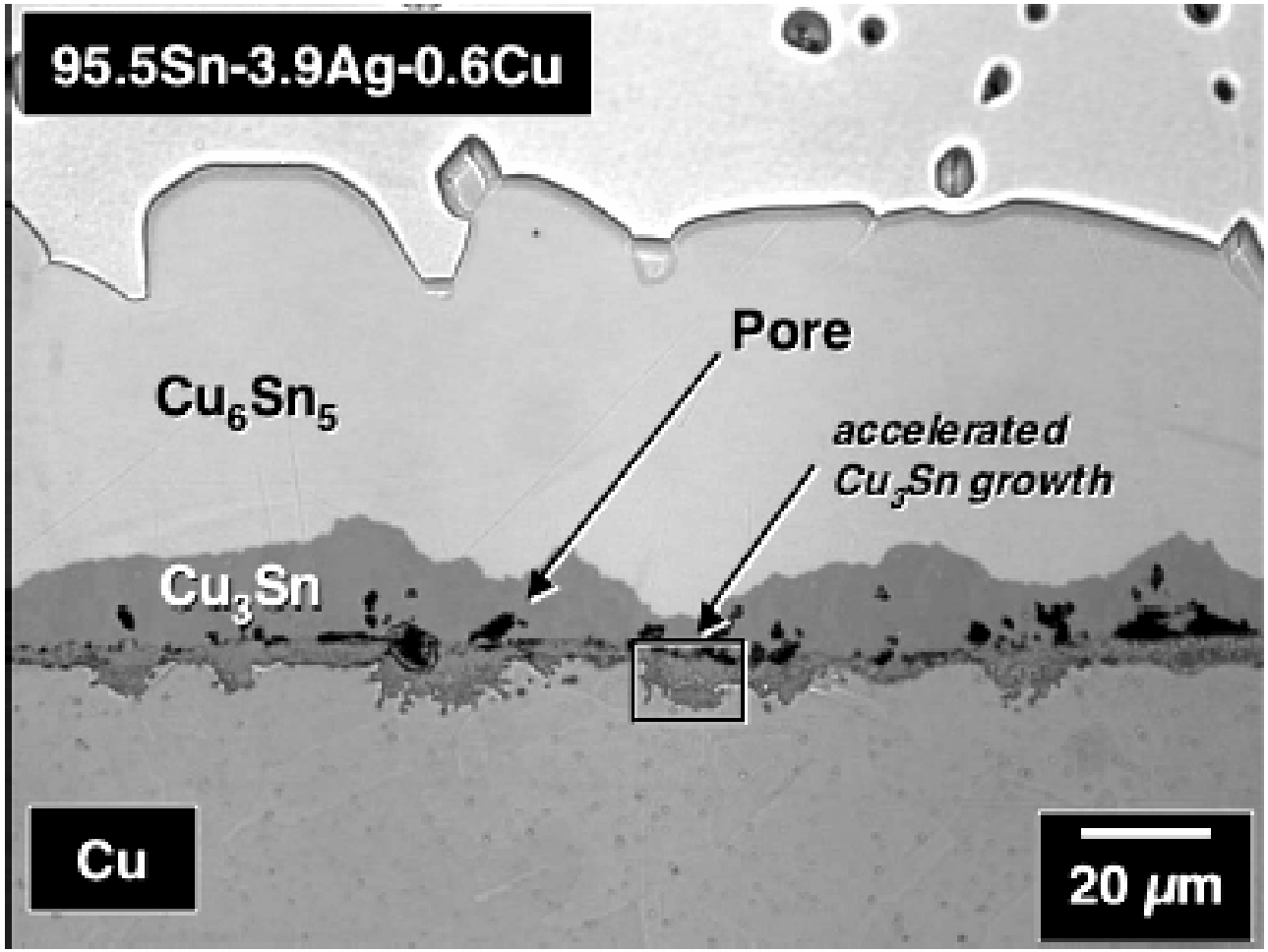
Failure Analysis Results: Mixed BGA Metallurgies





BGA-225 SAC-SAC solder joint; magnified view of crack with Pb phase present- Failed after 822 thermal cycles (Original pwb finish was SnPb HASL!)

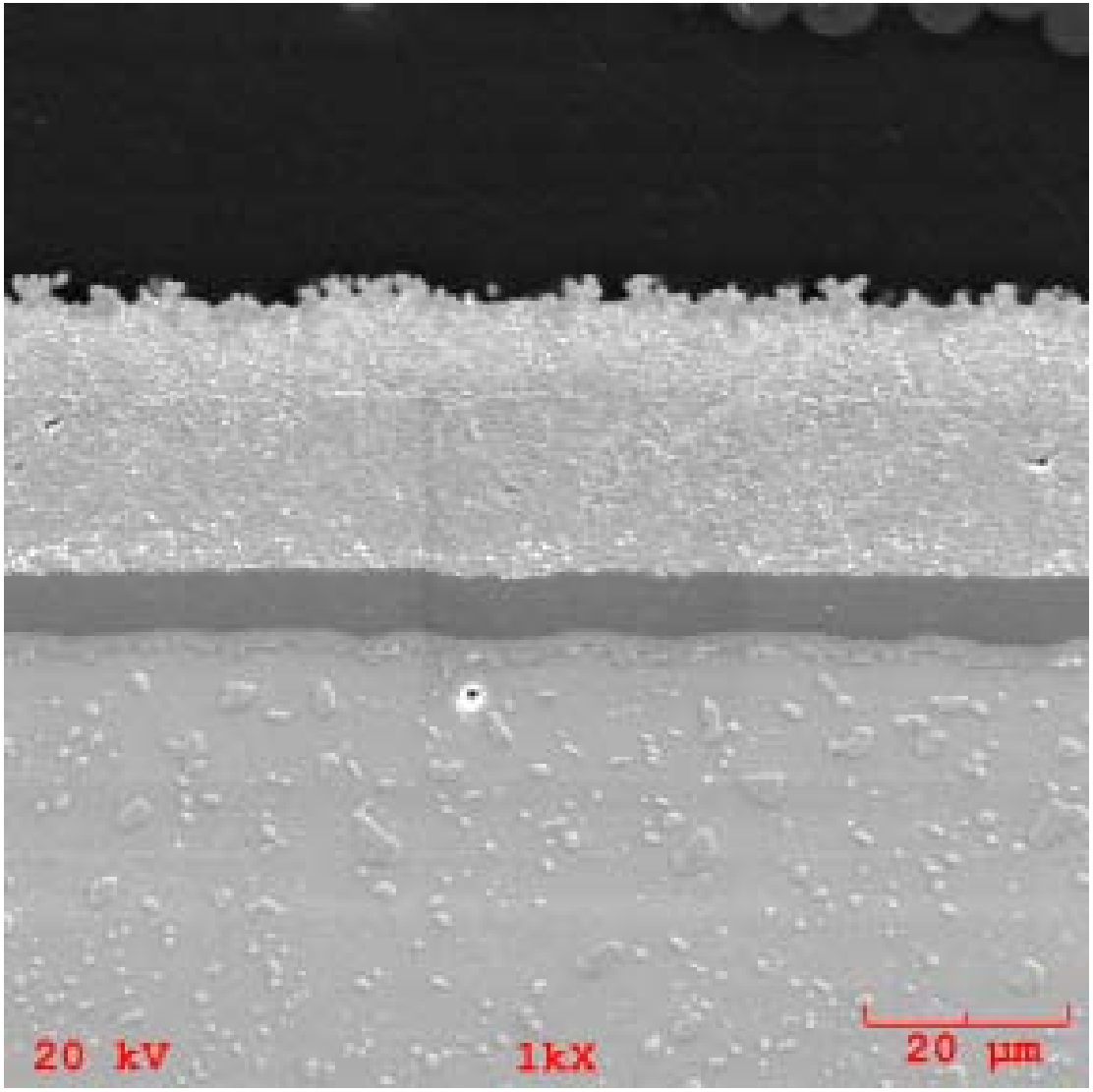
Failure Analysis Results:
Solder Joint/Intermetallic Interface Voiding



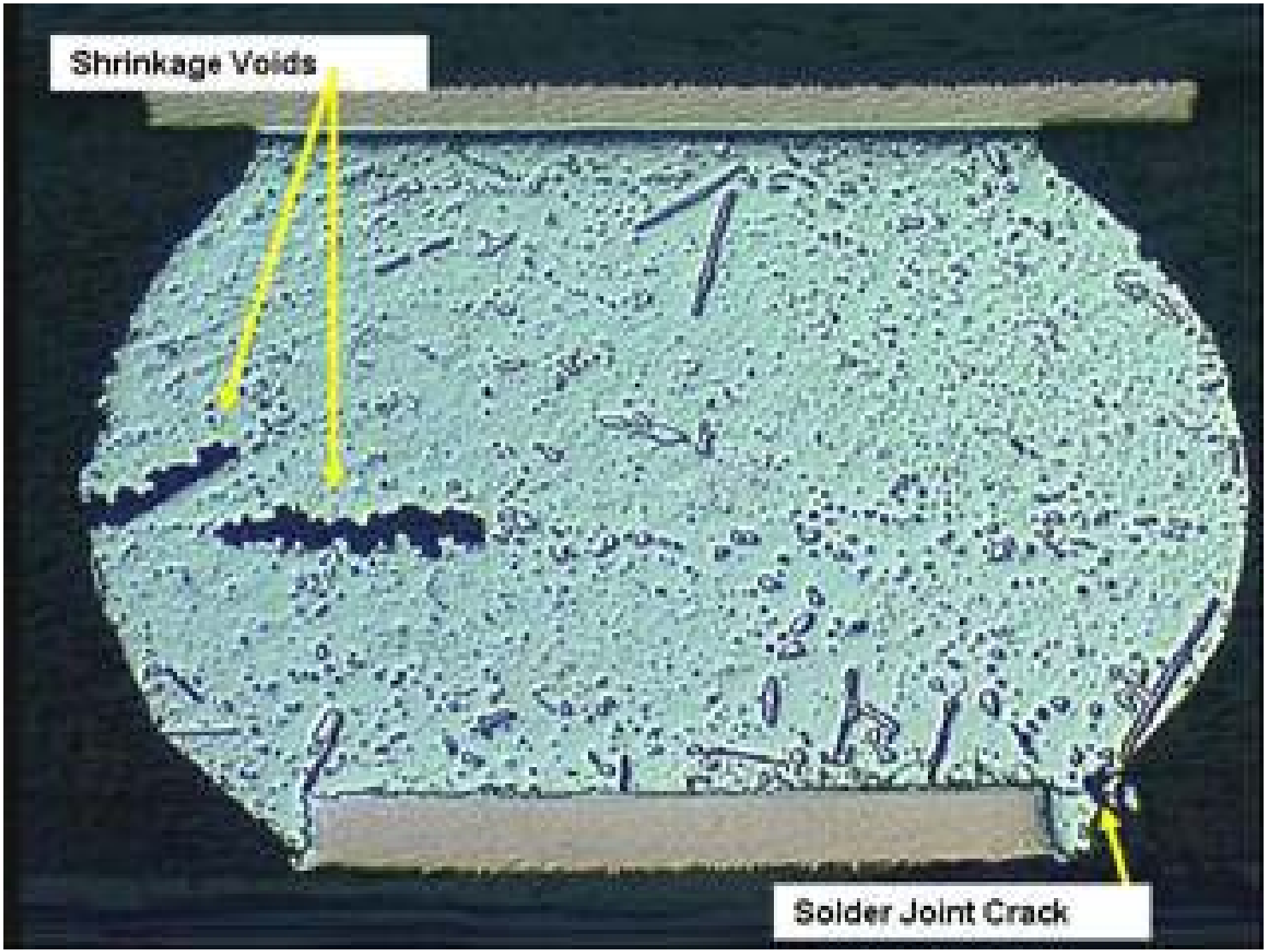
Graphic from Vianco reference: P. Vianco etal, "Solid State Intermetallic Compound Layer Growth Between Copper and 95.5Sn-3.9Ag-0.6Cu Solder", Journal of Electronic Materials, Vol. 33, No. 9, 2004.

Failure Analysis Results:
Solder Joint/Intermetallic Interface Voiding

BGA-225 SAC-SnPb combination SEM view of solder joint/intermetallic interface – 2372 accumulated hours @ 125°C



Failure Analysis Results:
Solder Joint Shrinkage Voids



Failure Analysis Results: Solder Joint Fillet Lifting

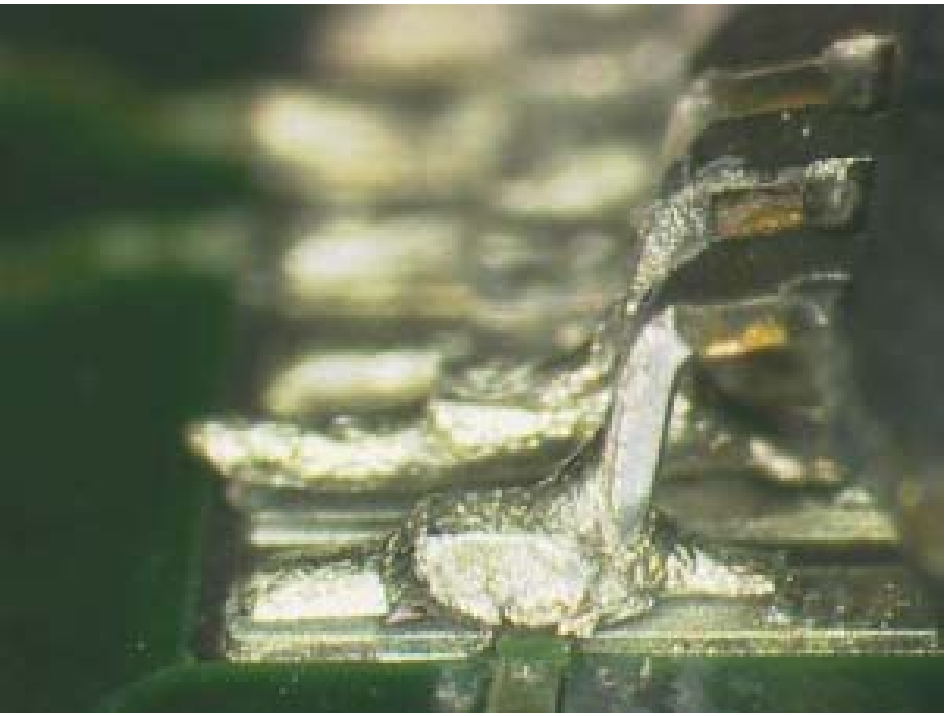
DIP-20 SAC-NiPdAu combination illustrating a fillet lift
No solder joint failure after 4743 thermal cycles)

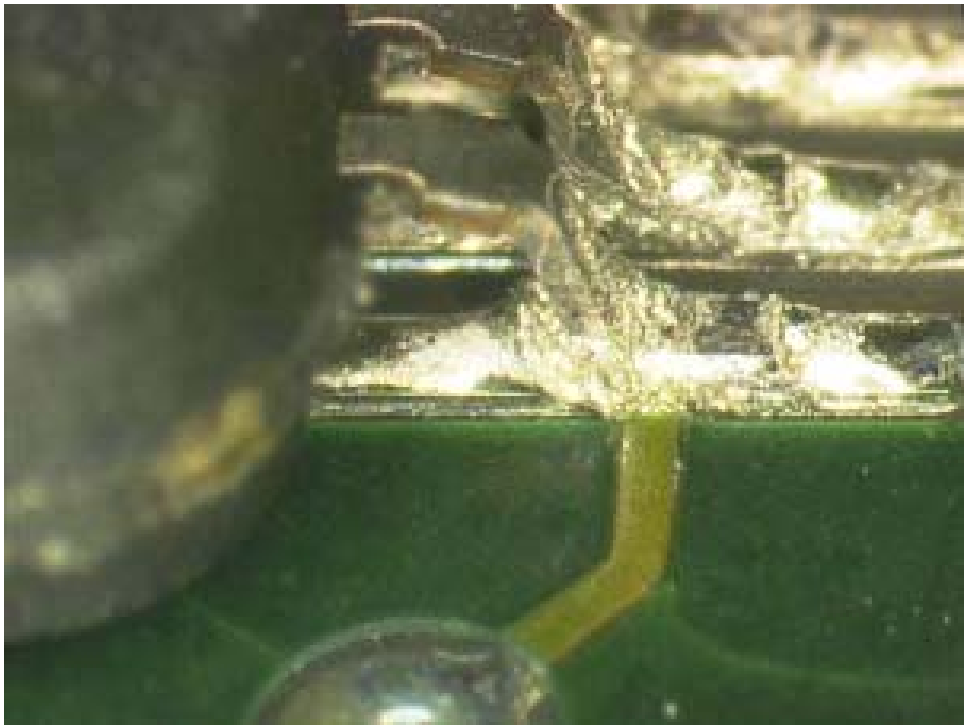
Failure Analysis Results: Copper Pad Dissolution

DIP-20 copper pads; (left) SAC alloy; (center) SNIC alloy; (right) SnPb alloy

Solder Alloy	Pre Wave Pad Thickness	Post Wave Pad Thickness	Pre/Post Pad Thickness Delta
SnPb	0.00217 inches	0.00178 inches	loss of 0.0004 inches
SAC	0.00226 inches	0.00226 inches	0.0000 inches
SNIC	0.00208 inches	0.00222 inches	gain of 0.0001 inches

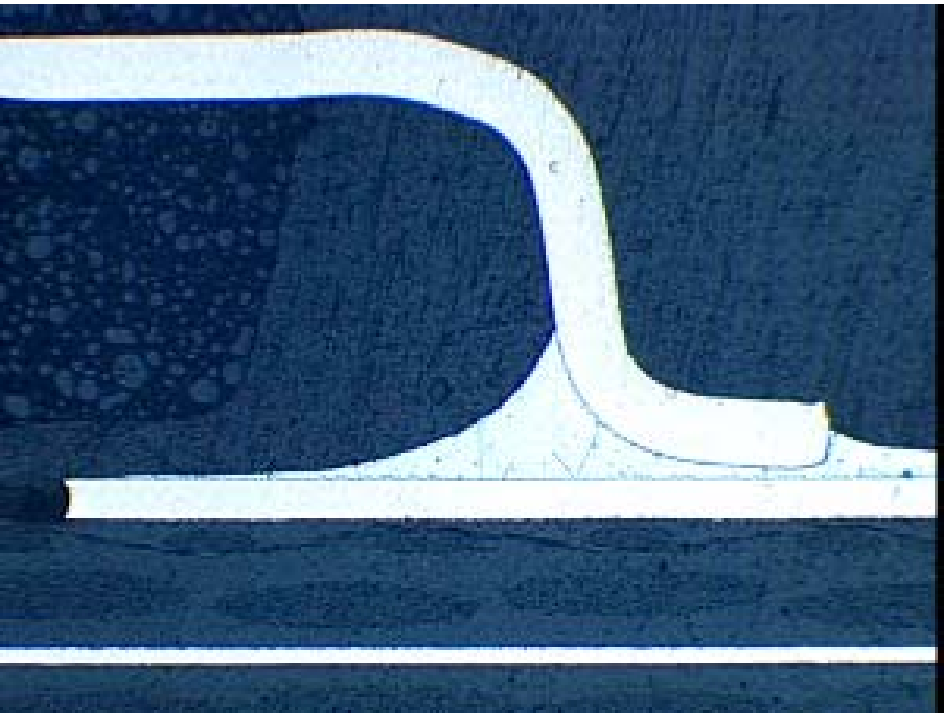
Failure Analysis Results: U3 Versus U57 A-Ha!

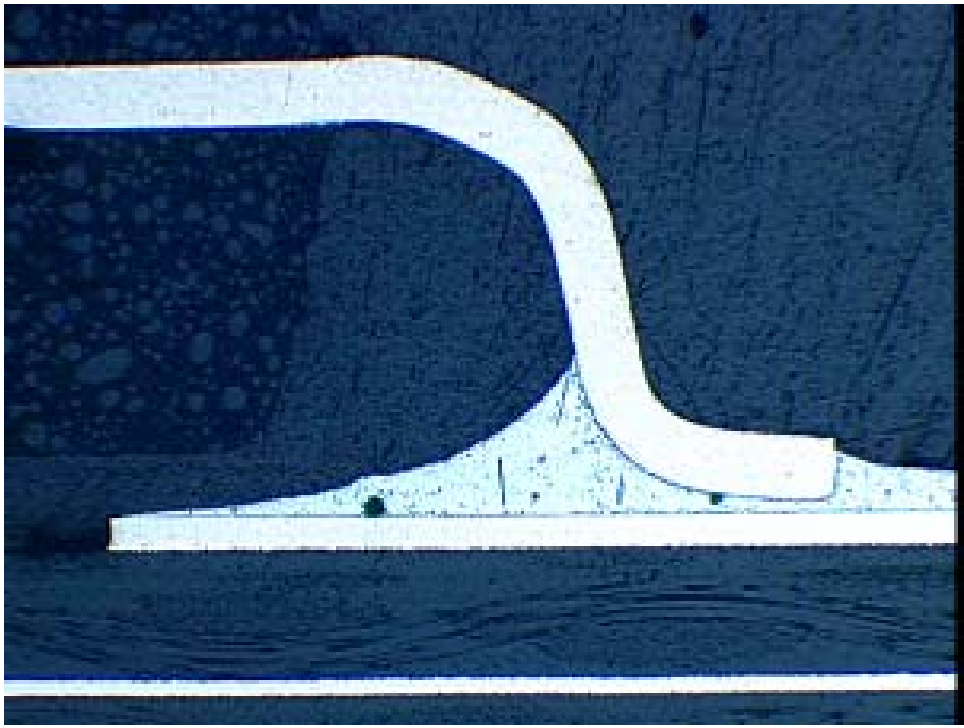




TQFP-208 SACB U3 (left) versus U57 (right) optical wettability comparison

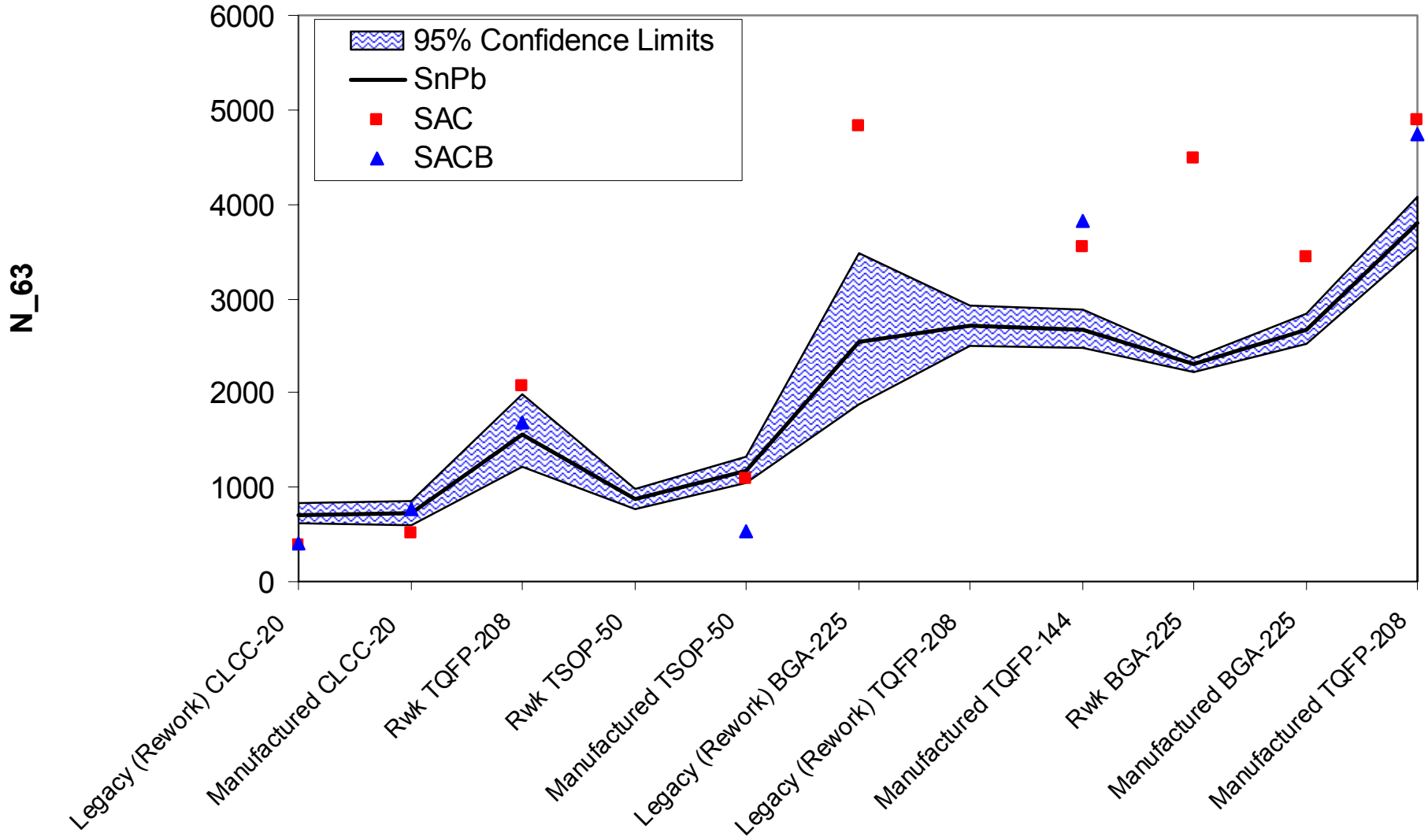
Failure Analysis Results: U3 Versus U57 A-Ha!





TQFP-208 SAC U3 (left) versus U57 (right) cross-sectional wettability comparison

Conclusions:



Pbfree Compared to Tin-Lead Controls: 63% Failure Level in Thermal Cycling

Questions ???