JCAA/JG-PP Lead-Free Solder Testing for High-Reliability Applications

Results of Combined Environments Test

Jeff Bradford

Raytheon

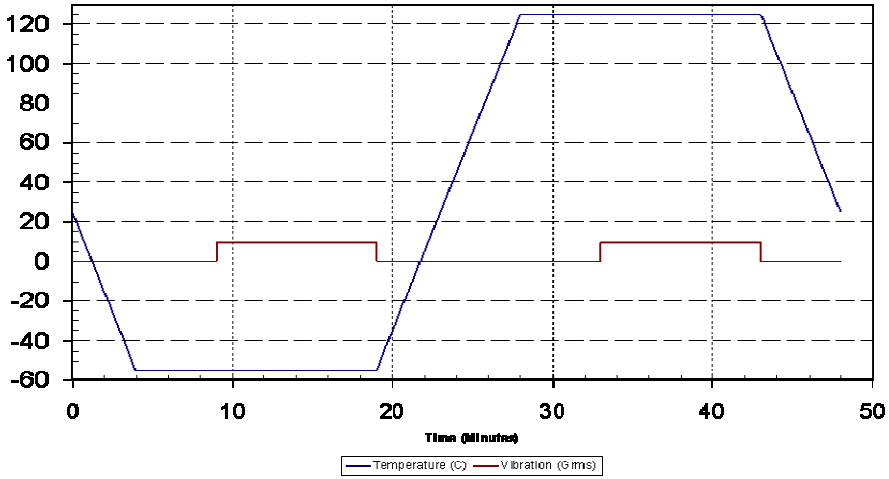
20 March 2006

Topics

- Combined Environments Test
- Test Results
  - Manufactured Test Vehicles
  - Hybrid Test Vehicles
  - Rework Test Vehicles
  - Effects of Lead Contamination
  - Statistical Analysis
  - SEM/EDS Analysis
- Summary

Combined Environments Test Parameters

- Thermal
  - -55 to 125 °C temperature cycle
  - 20 °C per minute ramp
  - 15 minute soak
- Vibration
  - Last 10 minutes of soak period
  - 10 Grms, initial
  - Increase 5 Grms after every 50 cycles
  - 55 Grms, maximum
- Test Vehicles
  - 15 Manufactured
  - 15 Rework
  - 15 Hybrid
- Monitored with Anatech Event Detectors



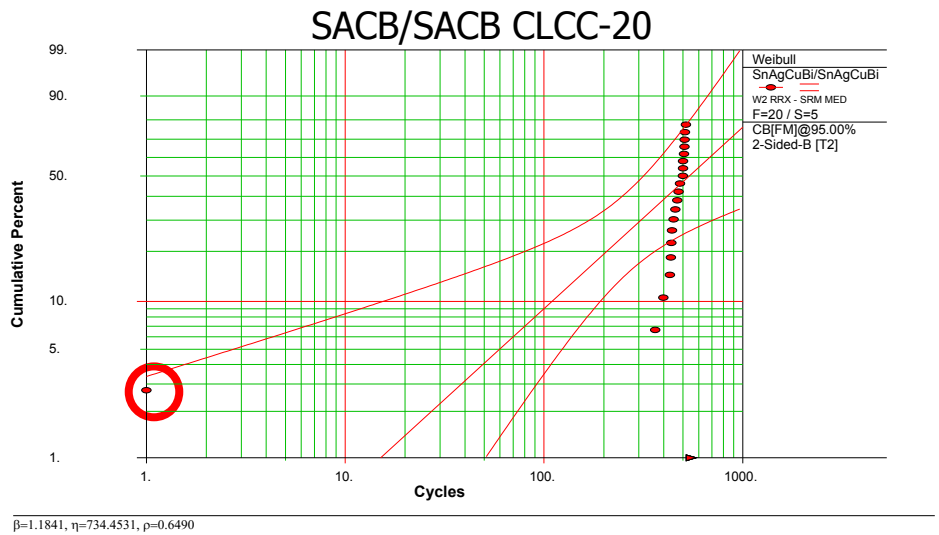
Manufactured Test Vehicle Results

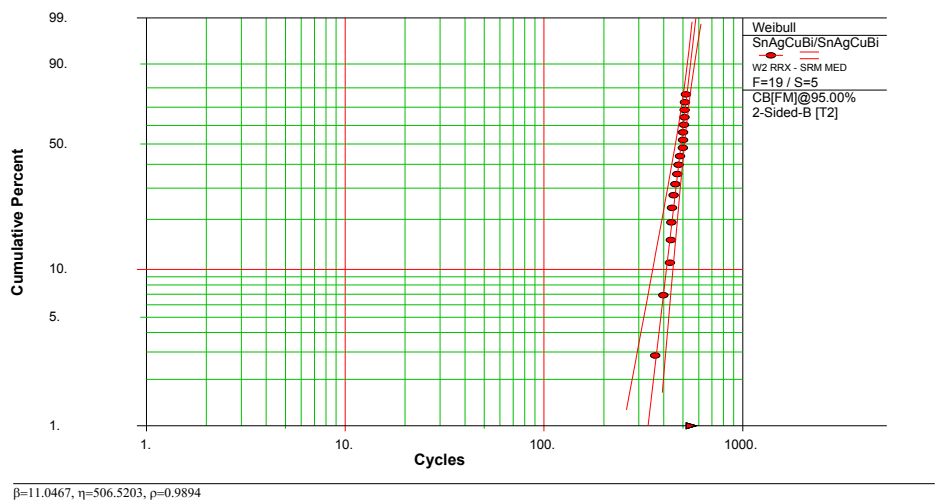
Manufactured Test Vehicle Results

Component & Finish	Solder Alloy					
	SAC Paste	SAC Wave	SACB Paste	SnCu Wave	SnPb Paste	SnPb Wave
BGA SnAgCu	100% (25 of 25)		80% (20 of 25)			
BGA SnPb	96% (23 of 24)		84% (21 of 25)		76% (38 of 50)	
CLCC SnAgCu	100% (25 of 25)					
CLCC SnAgCuBi			80% (20 of 25)			
CLCC SnPb	100% (25 of 25)		100% (25 of 25)		100% (50 of 50)	
PDIP AuPdNi		0% (0 of 23)		4% (1 of 25)		8% (2 of 25)
PDIP Sn		0% (0 of 25)		4% (1 of 25)		0% (0 of 25)
PLCC Sn	0% (0 of 25)		0% (0 of 25)		0% (0 of 25)	
TQFP-144 Sn	56% (14 of 25)		32% (8 of 25)		32% (8 of 25)	
TQFP-208 AuPdNi	8% (2 of 25)		16% (4 of 25)		32% (8 of 25)	
TSOP SnCu	100% (25 of 25)		36% (9 of 25)			
TSOP SnPb	100% (25 of 25)		100% (25 of 25)		76% (38 of 50)	
PTH		0% (0 of 5)		0% (0 of 5)		0% (0 of 5)
Grand Total	**73% (164 of 224)**	**0% (0 of 53)**	**59% (132 of 225)**	**4% (2 of 55)**	**63% (142 of 225)**	**4% (2 of 55)**

Early Life Failures

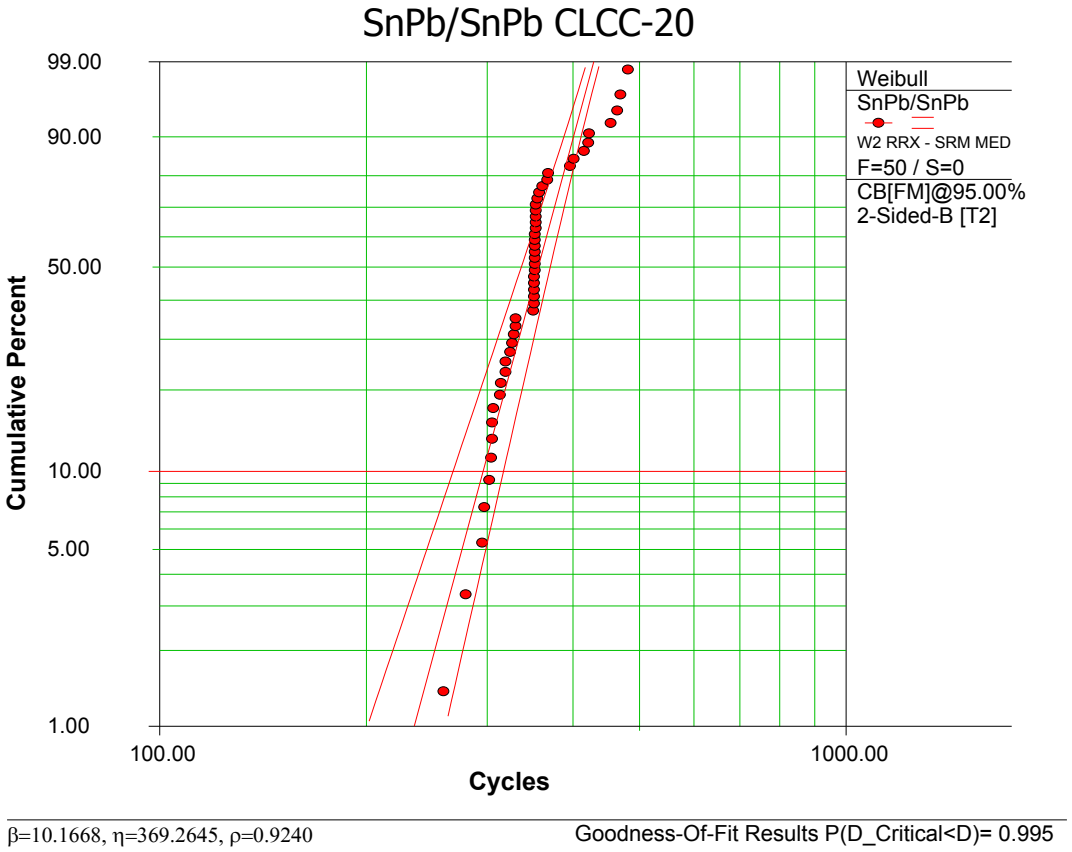
- Some components did not have electrical continuity before the test
  - Wire bonds missing
  - Data excluded
- Some solder joints failed in the first few cycles
  - May represent solder joints not properly formed
  - Data excluded
- Some examples are:
  - BGA-225 SAC/SACB
  - CLCC-20 SACB/SACB
  - TQFP-144 Sn/SACB
  - TQFP-208 AuPdNi/SnPb



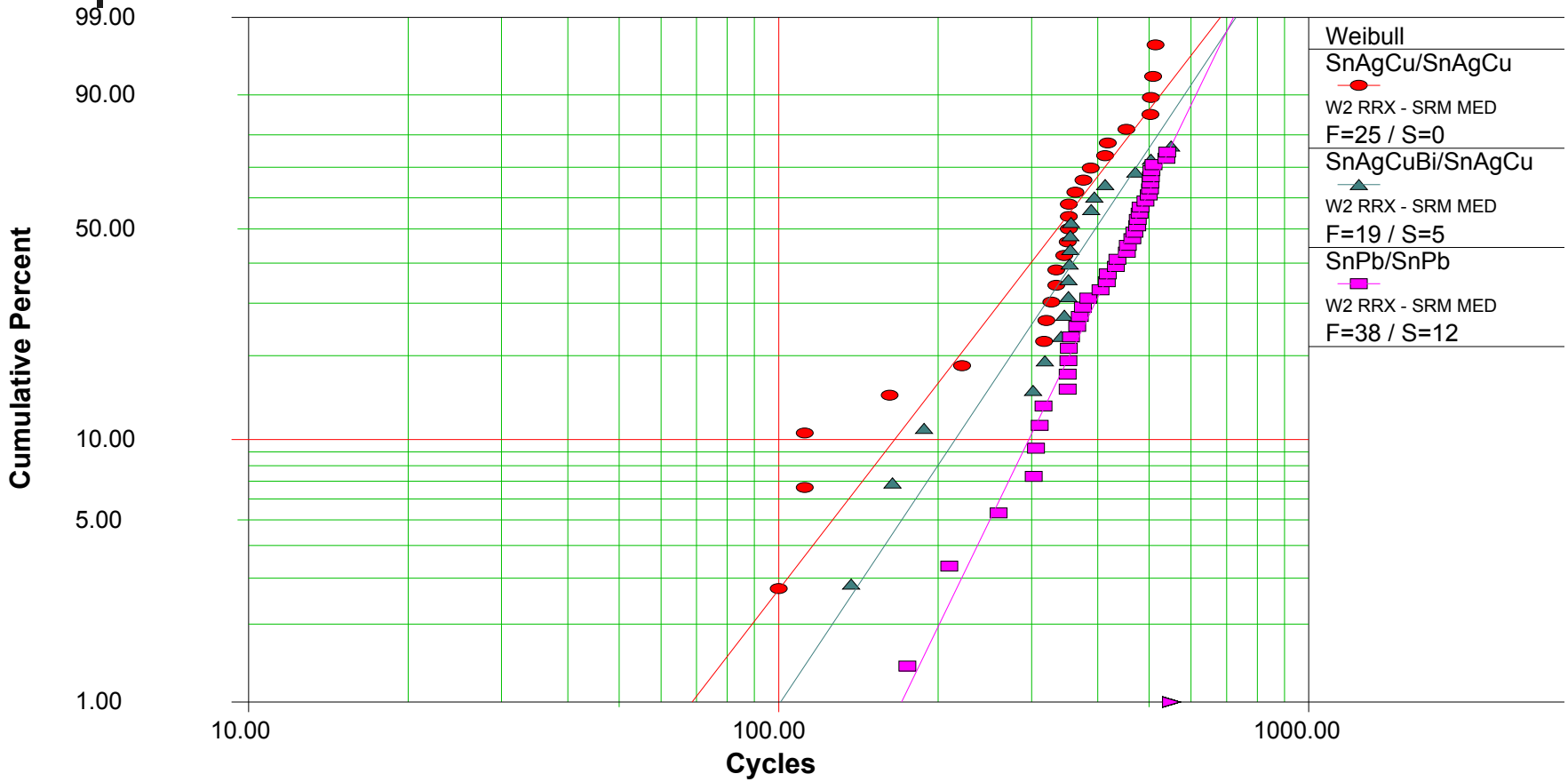


Multiple Failure Modes?

- Some of the failure data follow the Weibull distribution, some do not
- There may be more than one failure mechanism
  - Some curves show a knee or stairstep
  - Some stairstep coincide with increases in vibration levels, others do not
  - Indicates a new failure mechanism has been activated



BGA-225 Weibull Plot

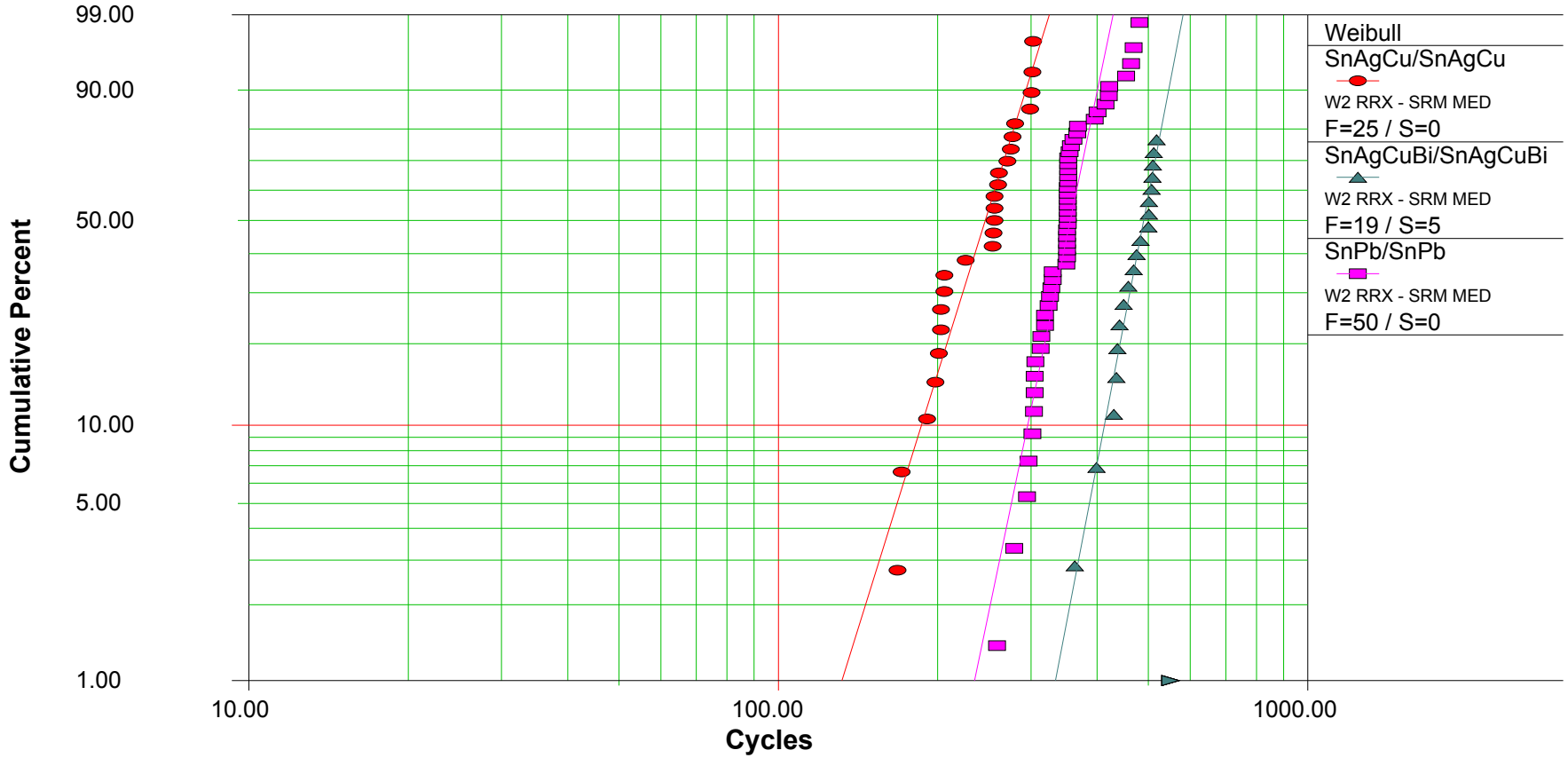


β1=2.6703, η1=384.6799, ρ=0.9414
β2=3.0979, η2=445.4471, ρ=0.9509
β3=4.2503, η3=503.7210, ρ=0.9916

Key: Solder Alloy/Component Finish

SnPb > SnAgCuBi > SnAgCu

CLCC-20 Weibull Plot

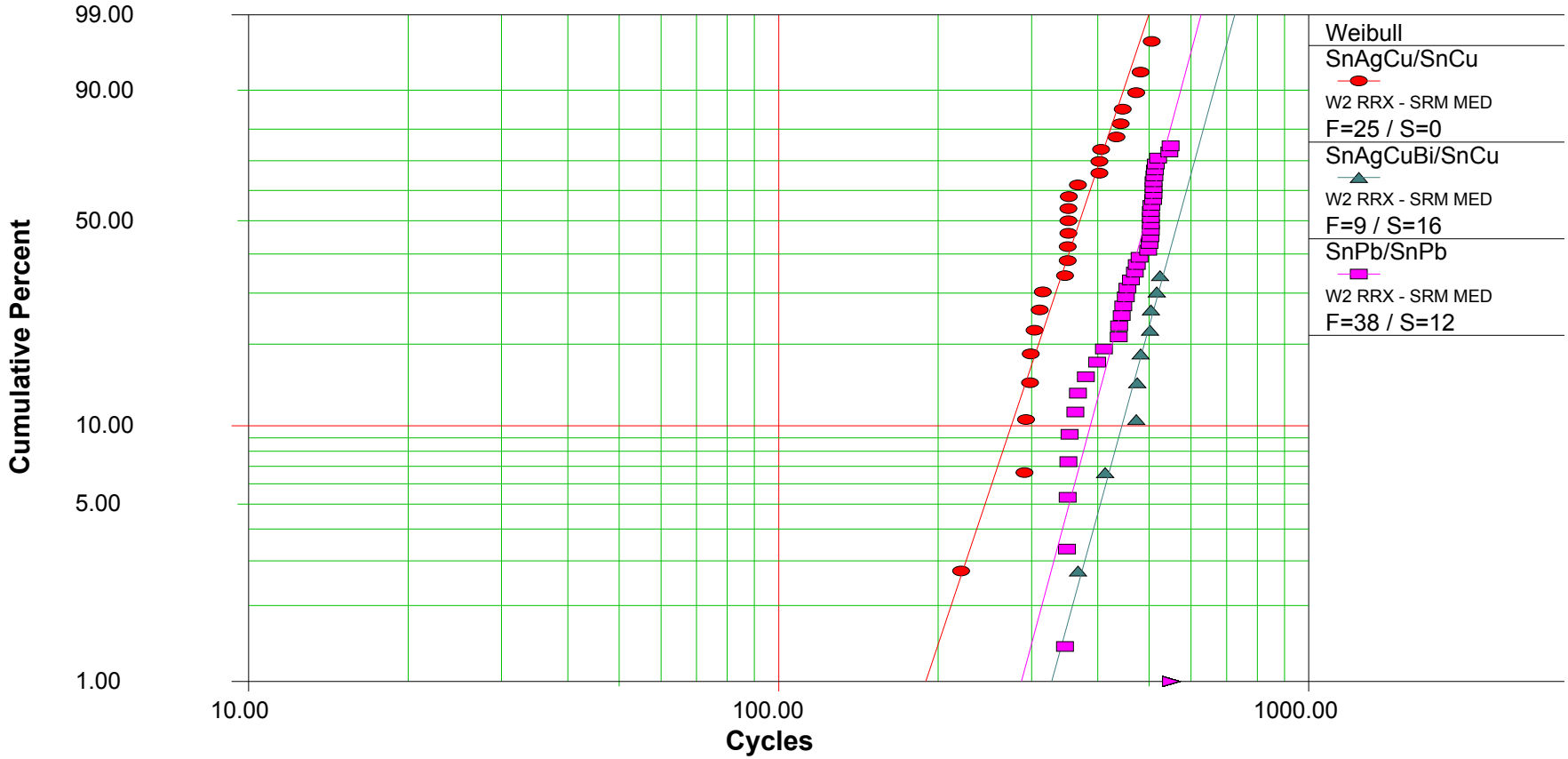


β1=6.7897, η1=259.6977, ρ=0.9683
β2=11.0467, η2=506.5203, ρ=0.9894
β3=10.1668, η3=369.2645, ρ=0.9240

Key: Solder Alloy/Component Finish

SnAgCuBi > SnPb > SnAgCu

TSOP-50 Weibull Plot



β1=6.3243, η1=392.3031, ρ=0.9677
β2=7.7014, η2=595.4180, ρ=0.9796
β3=7.8473, η3=516.0737, ρ=0.9539

Key: Solder Alloy/Component Finish

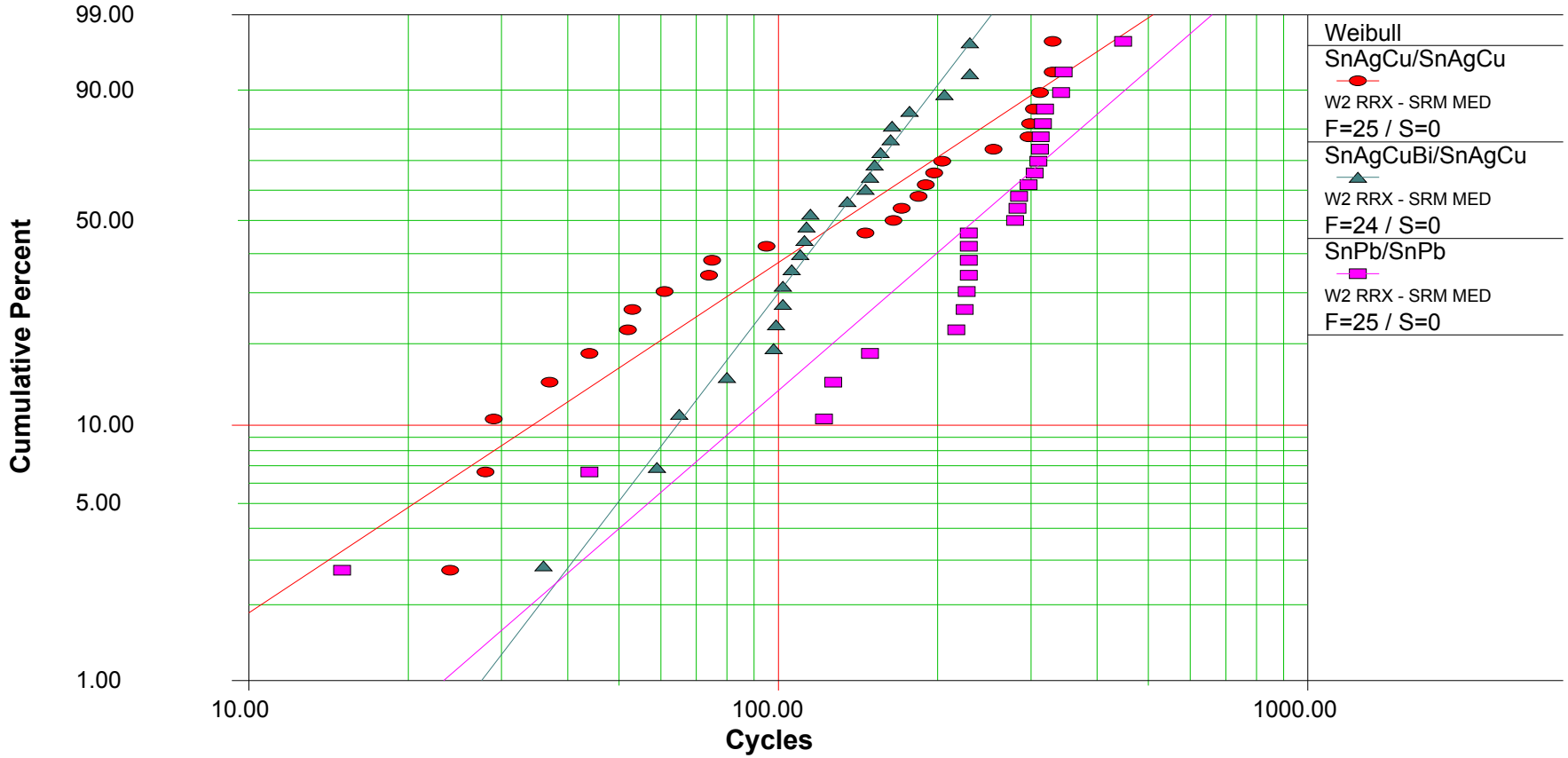
SnAgCuBi > SnPb > SnAgCu

Hybrid Test Vehicle Results

Hybrid Test Vehicle Results

Component & Finish	Solder Alloy		
	SnAgCu Paste	**SnAgCuBi Paste**	**SnPb Paste**
CSP SnAgCu	100% (25 of 25)	100% (25 of 25)	
CSP SnPb			100% (25 of 25)
Hybrid SnAgCu	80% (12 of 15)		
Hybrid SnAgCuBi		53% (8 of 15)	
Hybrid SnPb			100% (15 of 15)
Grand Total	**92% (37 of 40)**	**82% (33 of 40)**	**100% (40 of 40)**

CSP-100 Weibull Plot

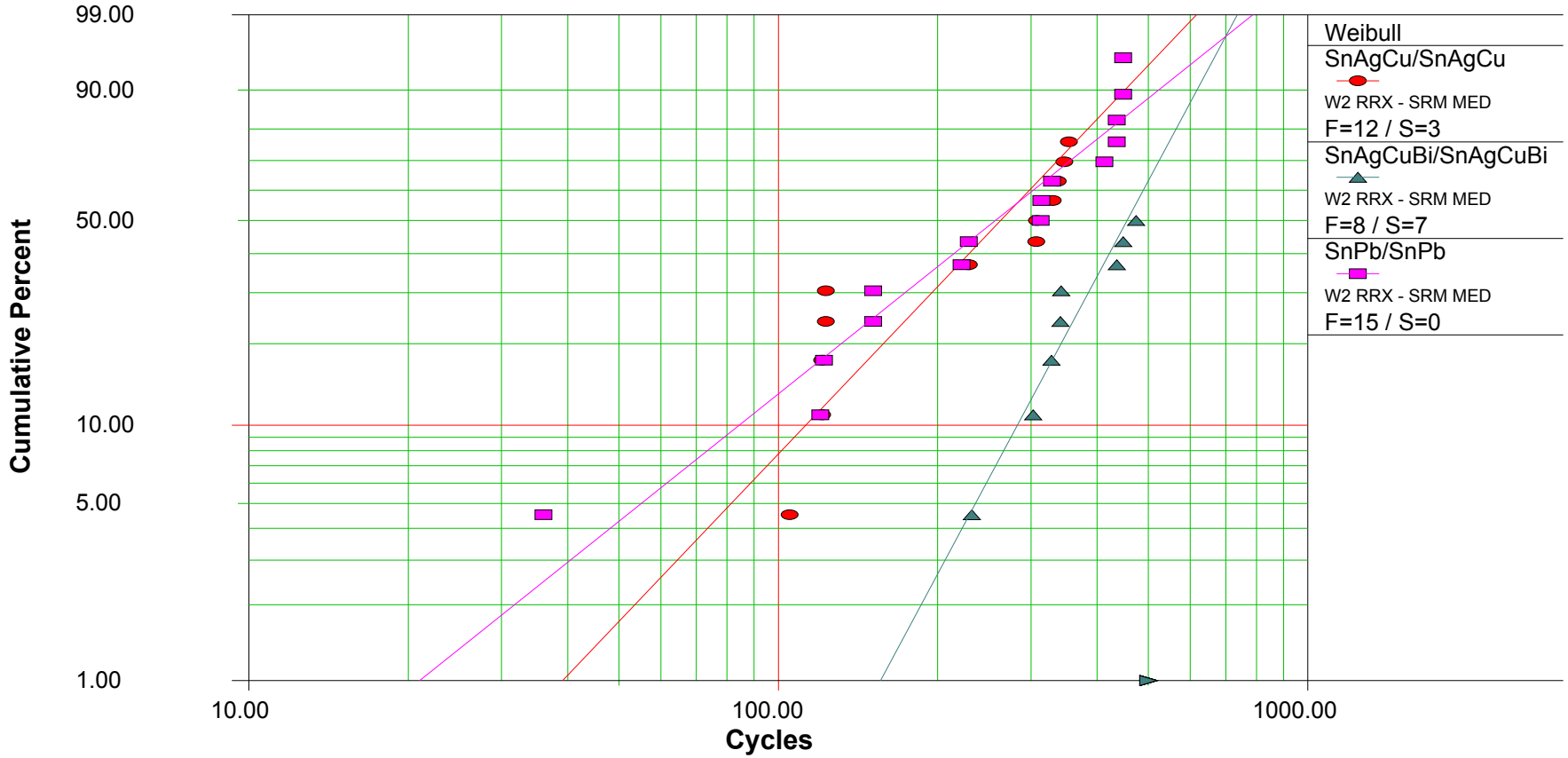


$\beta 1=1.3996$, $\eta 1=171.4153$, $\rho=0.9644$
$\beta 2=2.7619$, $\eta 2=145.4682$, $\rho=0.9872$
$\beta 3=1.8331$, $\eta 3=287.0076$, $\rho=0.8991$

Key: Solder Alloy/Component Finish

SnPb > SnAgCu > SnAgCuBi

Hybrid-30 Weibull Plot



β1=2.2221, η1=310.1839, ρ=0.8944
β2=3.9490, η2=500.3230, ρ=0.9661
β3=1.6906, η3=319.4206, ρ=0.9665

Key: Solder Alloy/Component Finish

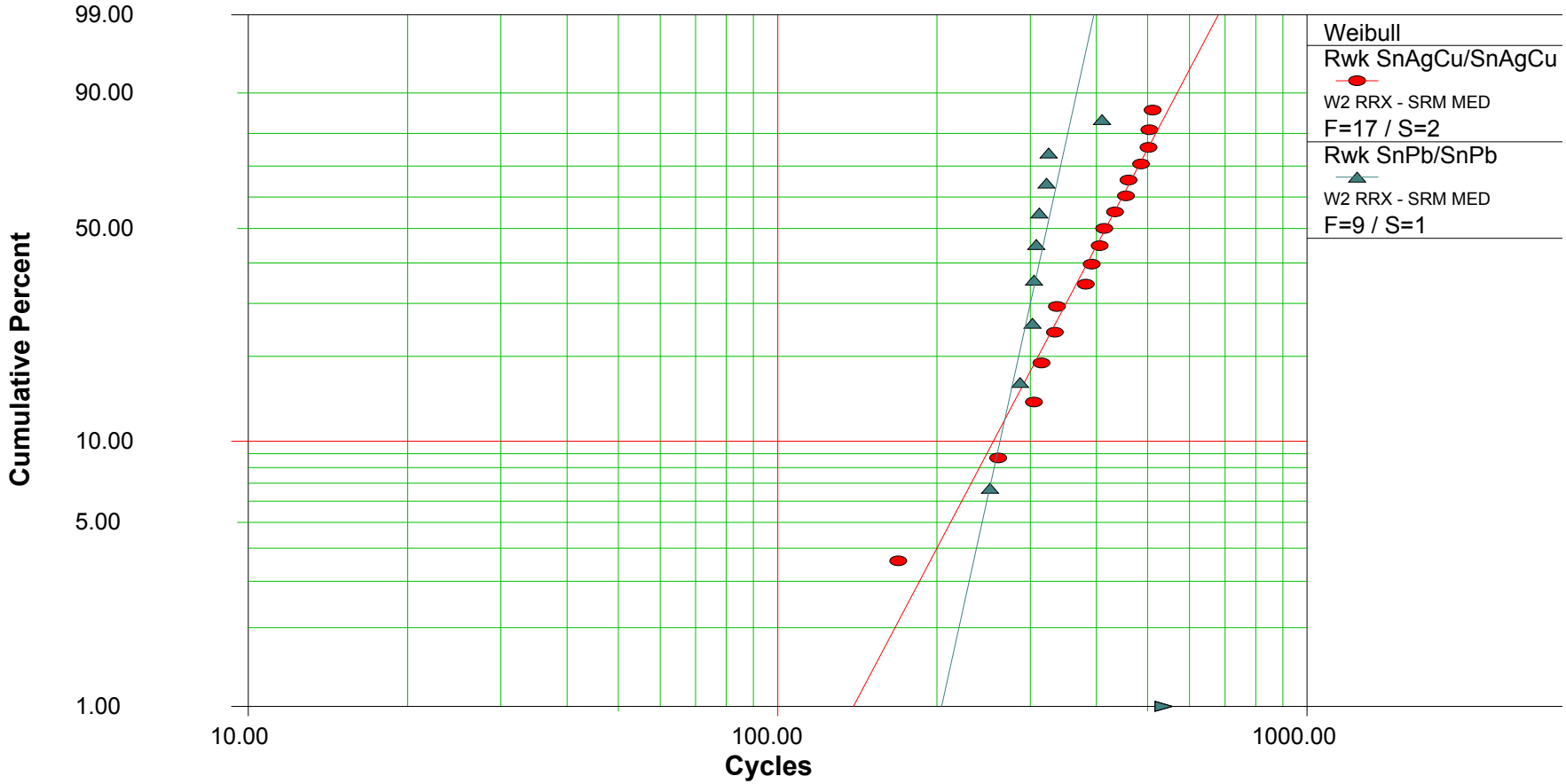
SnAgCuBi > SnPb > SnAgCu

Rework Test Vehicle Results

Rework Test Vehicle Results

Component & Finish	No Rework	SAC Rework	SACB Rework	SnCu Rework	SnPb Rework
BGA SnAgCu	100% (80 of 80)	90% (18 of 20)			
BGA SnPb	98% (39 of 40)				90% (9 of 10)
CLCC SnAgCu	100% (50 of 50)				
CLCC SnAgCuBi	100% (50 of 50)				
CLCC SnPb	100% (50 of 50)				
PDIP AuPdNi	0% (0 of 43)	70% (7 of 10)		22% (2 of 9)	11% (1 of 9)
PDIP Sn	0% (0 of 75)				
PLCC Sn	7% (5 of 74)				
TQFP-144 Sn	61% (46 of 75)				
TQFP-208 AuPdNi	56% (25 of 45)	80% (8 of 10)	100% (10 of 10)		90% (9 of 10)
TSOP SnCu	100% (80 of 80)	100% (10 of 10)	100% (10 of 10)		
TSOP SnPb	98% (39 of 40)				100% (10 of 10)
PTH	0% (0 of 15)				
Grand Total	**65% (464 of 715)**	**86% (43 of 50)**	**100% (20 of 20)**	**22% (2 of 9)**	**74% (29 of 39)**

Reworked BGA-225 Weibull Plot

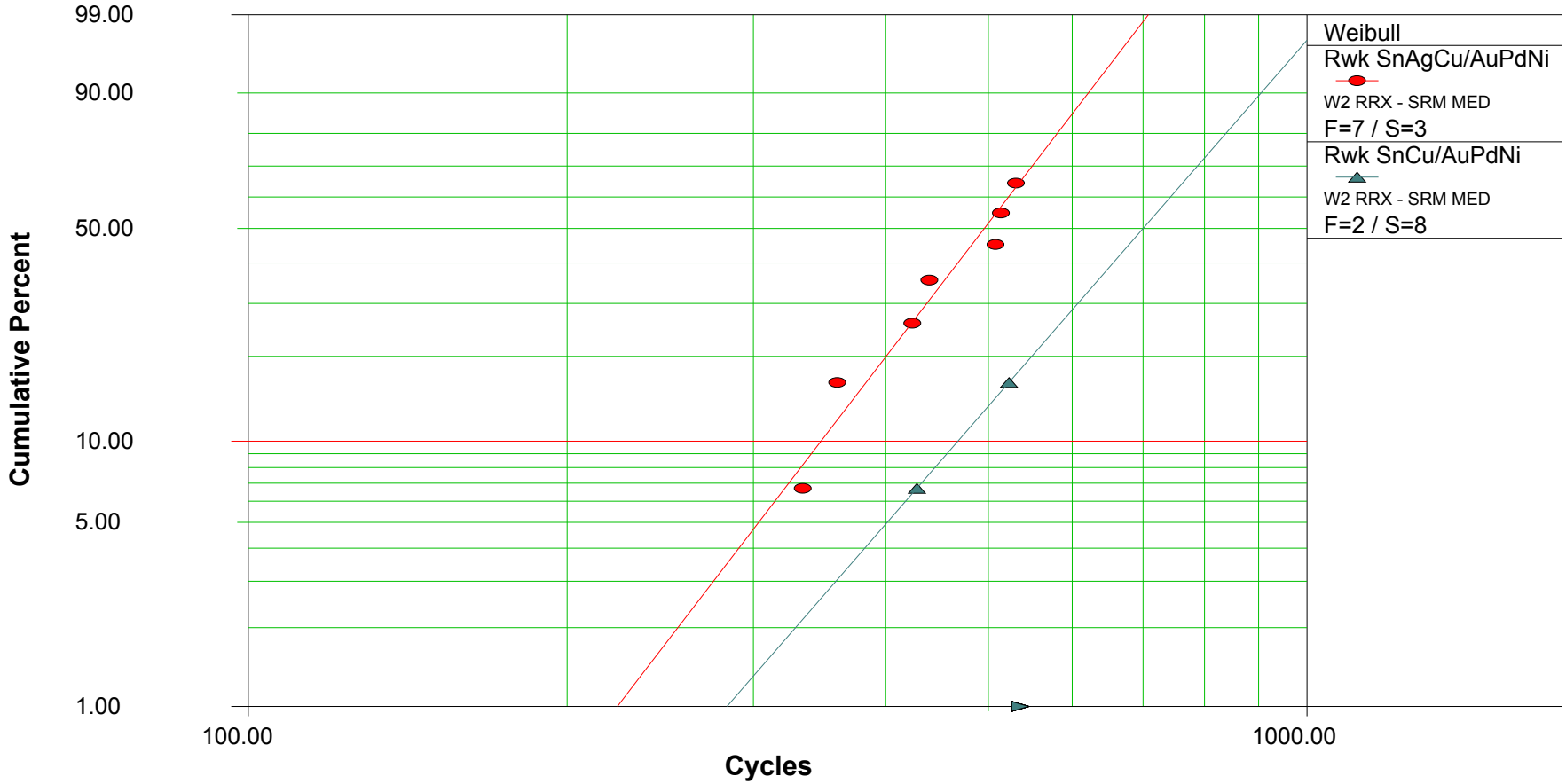


β1=3.8600, η1=458.0270, ρ=0.9842
β2=9.2479, η2=335.6582, ρ=0.8799

Key: Solder Alloy/Component Finish

SnAgCu/SnAgCu > SnPb/SnPb

Reworked PDIP-20 Weibull Plot

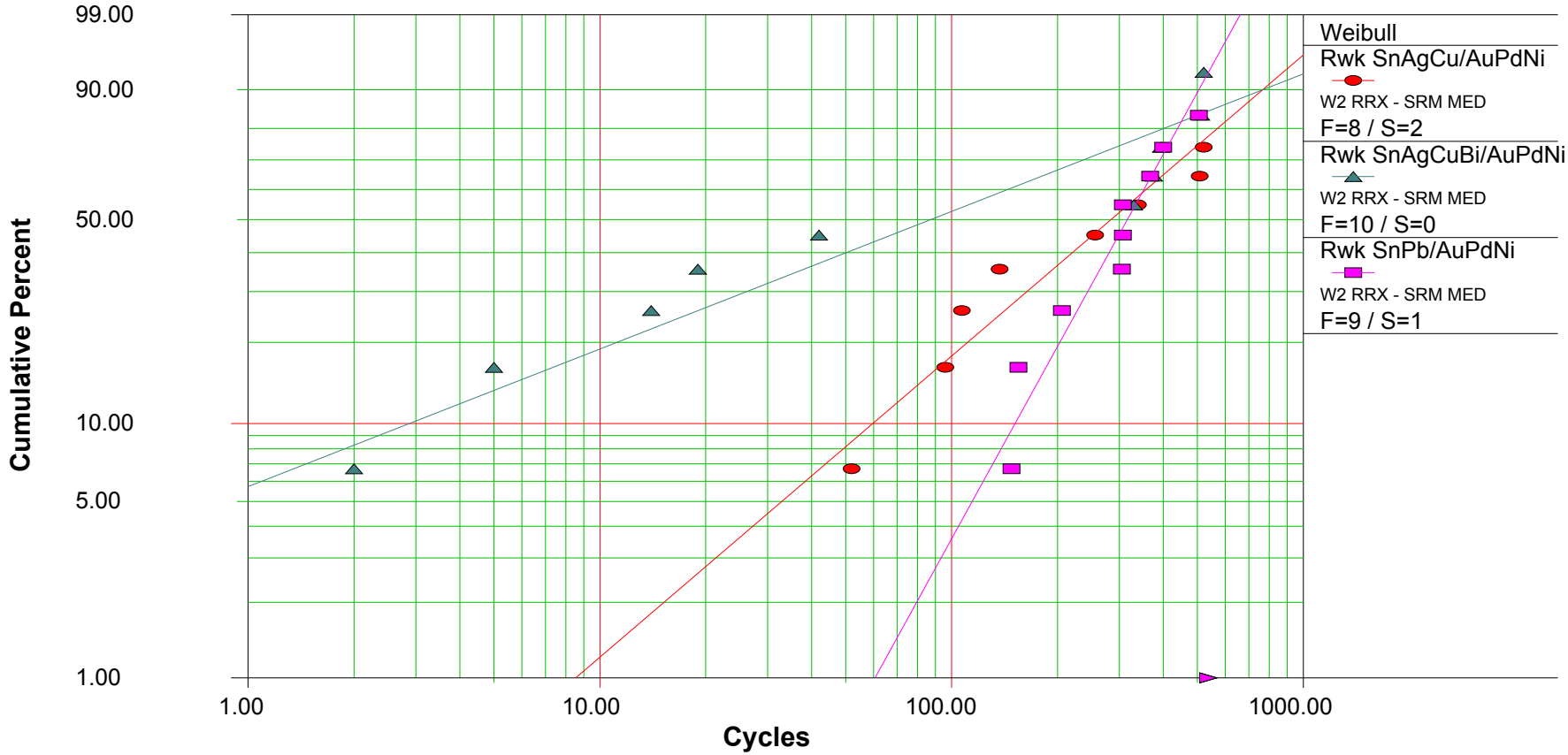


$\beta 1=5.3033$, $\eta 1=531.2548$, $\rho=0.9761$
$\beta 2=4.6782$, $\eta 2=757.2297$, $\rho=1.0000$

Key: Solder Alloy/Component Finish

SnCu > SnAgCu (SnPb only 1 failed)

Reworked TQFP-208 Weibull Plot

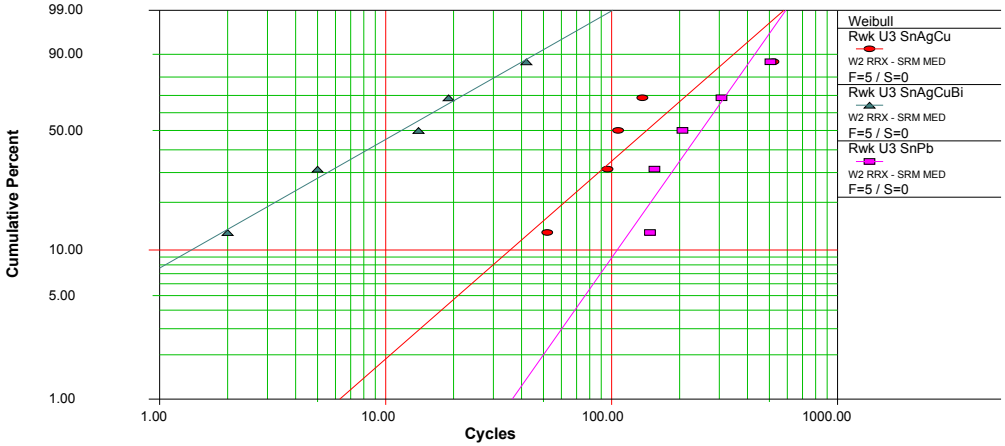


$\beta 1=1.2083$, $\eta 1=384.7764$, $\rho=0.9678$
$\beta 2=0.5521$, $\eta 2=169.2877$, $\rho=0.9573$
$\beta 3=2.5636$, $\eta 3=364.8808$, $\rho=0.9645$

Key: Solder Alloy/Component Finish

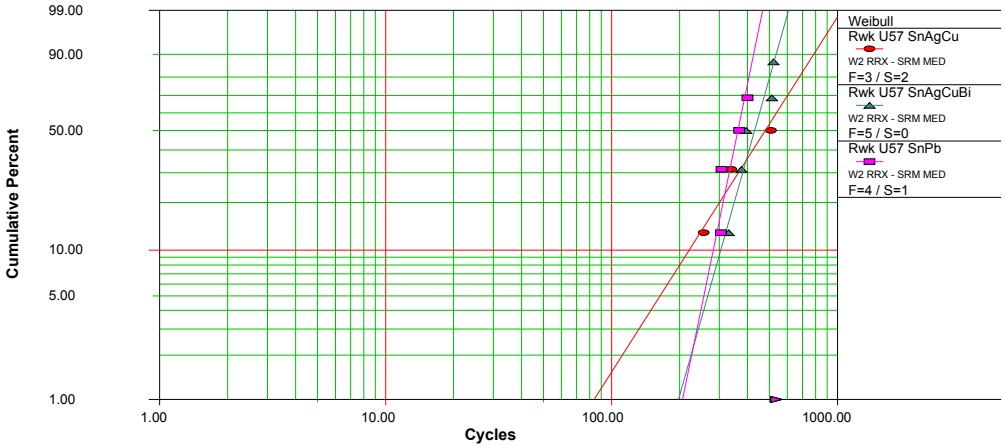
SnAgCu > SnPb > SnAgCuBi

Reworked TQFP-208 by Location



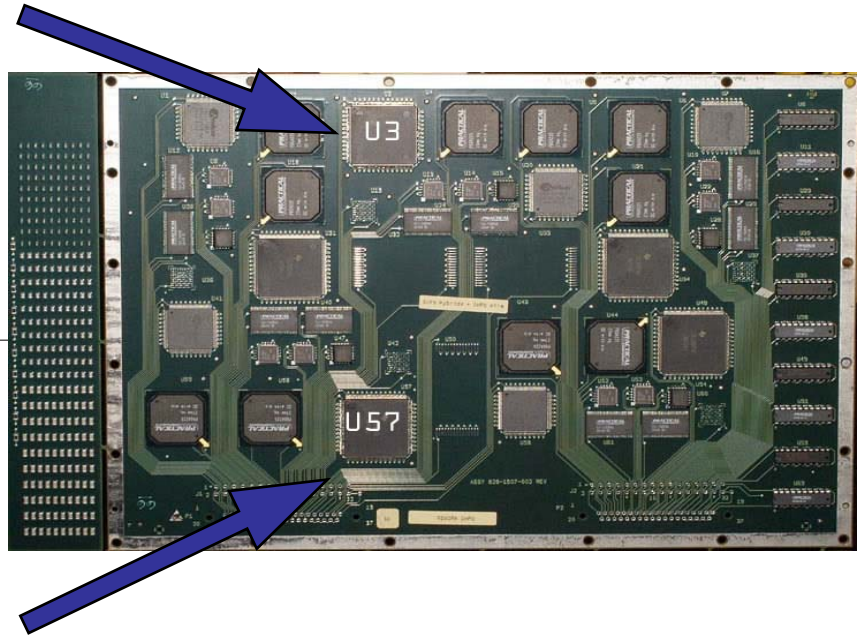
β1=1.3532, η1=187.8921, ρ=0.9019
β2=0.8797, η2=17.8709, ρ=0.9935
β3=2.1972, η3=295.1767, ρ=0.9183

Key: Component Location Solder Alloy

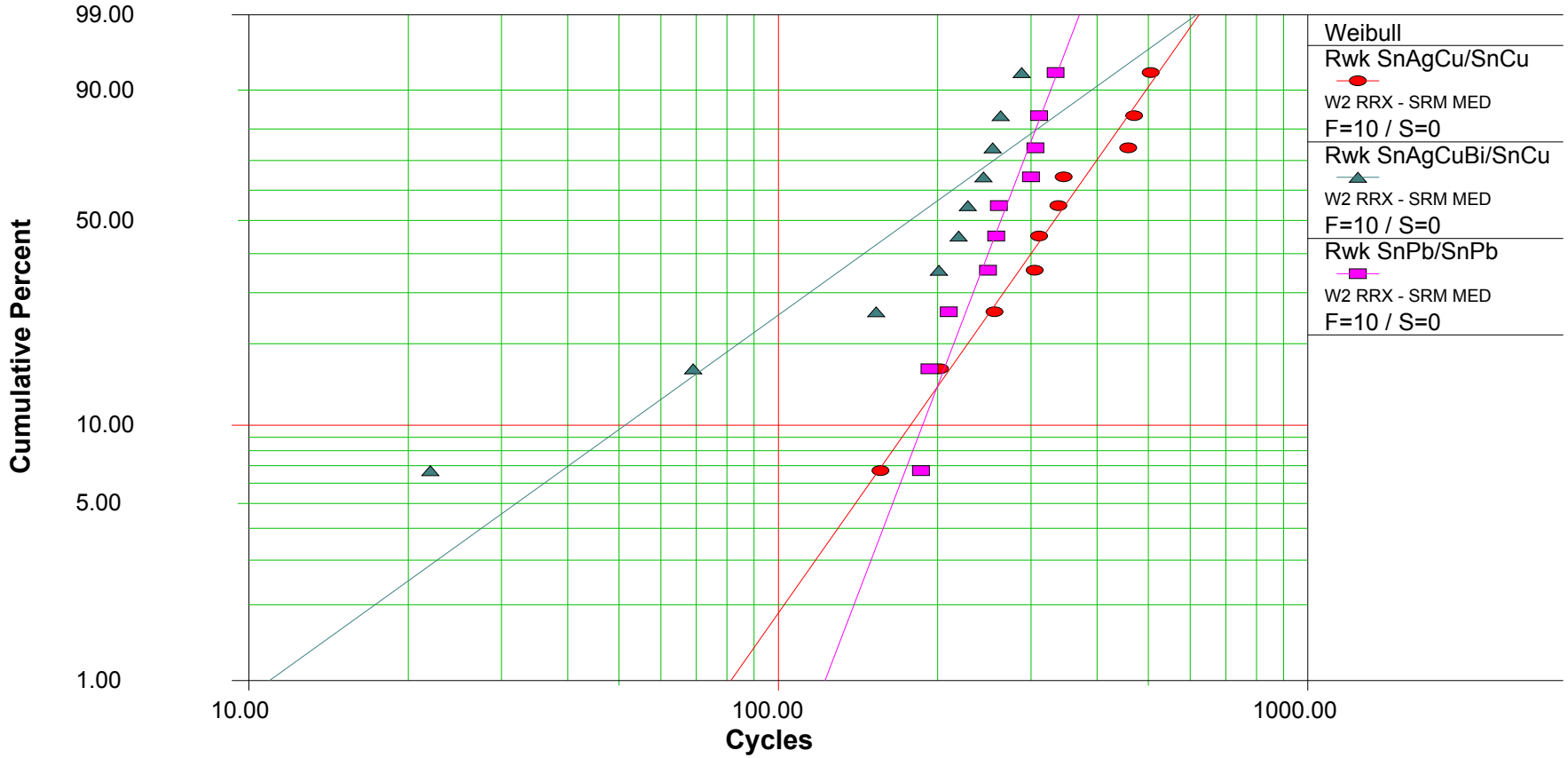


β1=2.4297, η1=557.0024, ρ=0.9707
β2=5.4649, η2=459.3063, ρ=0.9502
β3=7.5131, η3=380.5161, ρ=0.9032

Key: Component Location Solder Alloy



Reworked TSOP-50 Weibull Plot



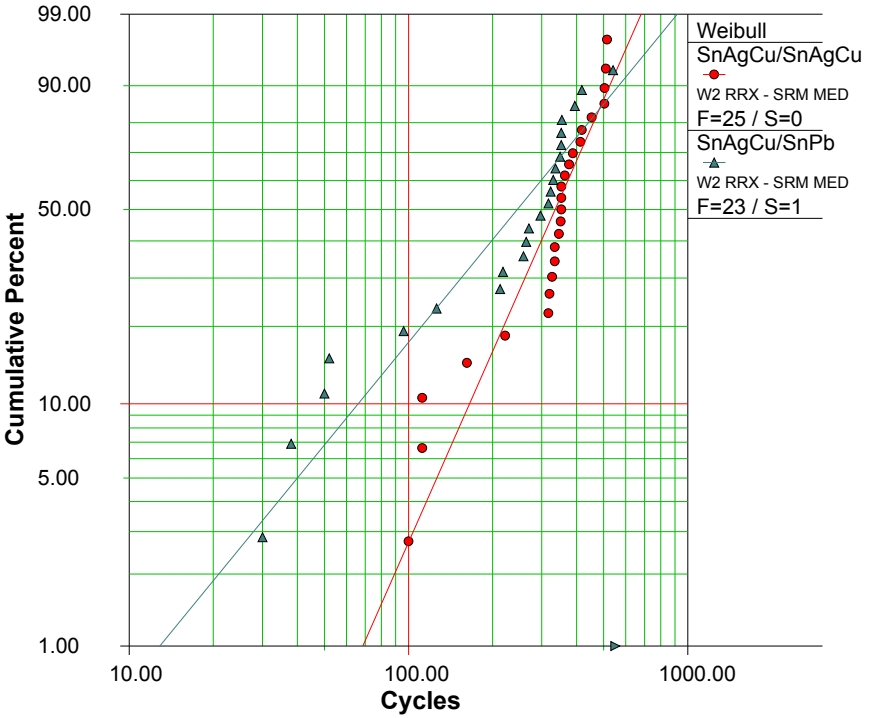
$\beta 1=3.0087$, $\eta 1=375.3635$, $\rho=0.9889$
$\beta 2=1.5197$, $\eta 2=225.7774$, $\rho=0.9086$
$\beta 3=5.5370$, $\eta 3=281.3299$, $\rho=0.9731$

Key: Solder Alloy/Component Finish

SnAgCu > SnPb > SnAgCuBi

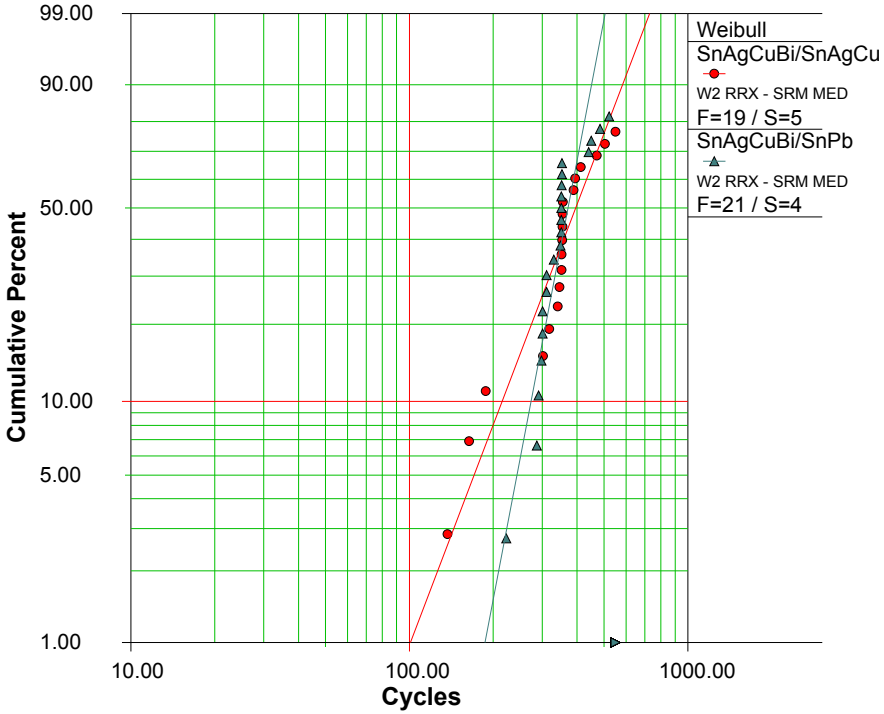
Effects of Lead Contamination

Effects of Lead Contamination on BGA-225



β1=2.6703, η1=384.6799, ρ=0.9414
β2=1.4361, η2=316.8921, ρ=0.9532

Key: Solder Alloy/Component Finish



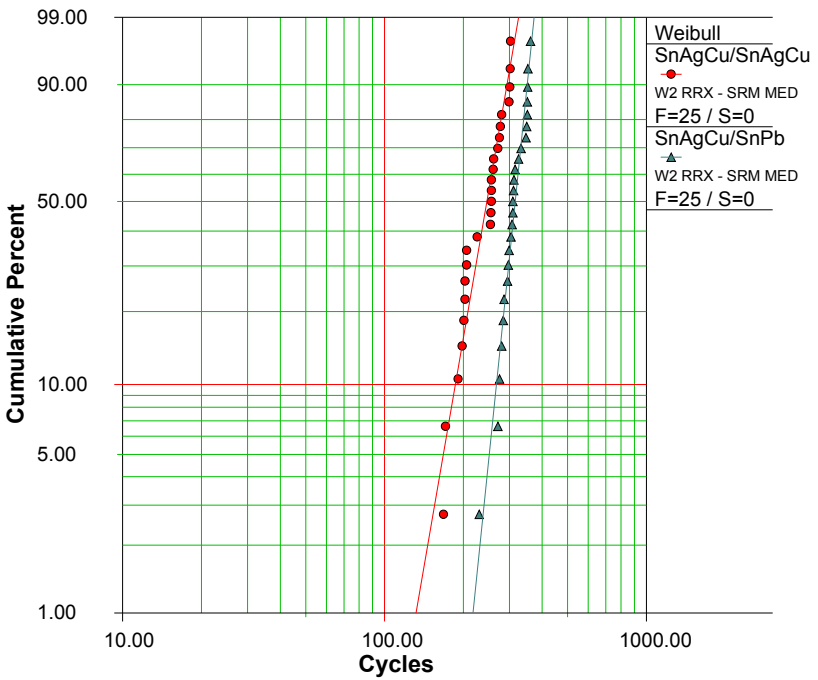
β1=3.0979, η1=445.4471, ρ=0.9509
β2=6.1699, η2=393.9114, ρ=0.8995

Key: Solder Alloy/Component Finish

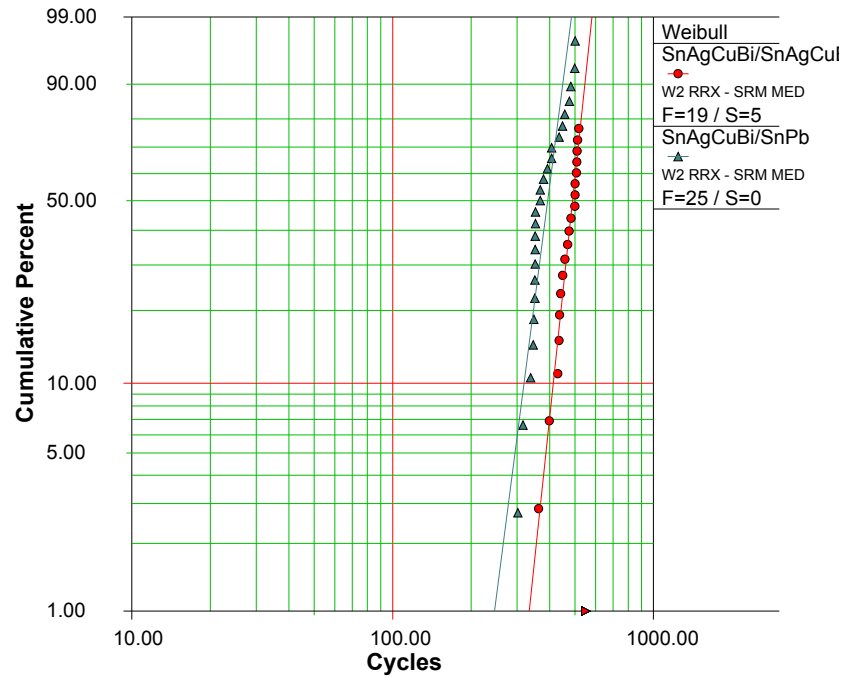
SnAgCu/SnAgCu > SnAgCu/SnPb

SnAgCuBi/SnAgCu > SnAgCuBi/SnPb

Effects of Lead Contamination on CLCC-20



β1=6.7897, η1=259.6977, ρ=0.9683
β2=11.3967, η2=325.9074, ρ=0.9786 Key: Solder Alloy/Component Finish

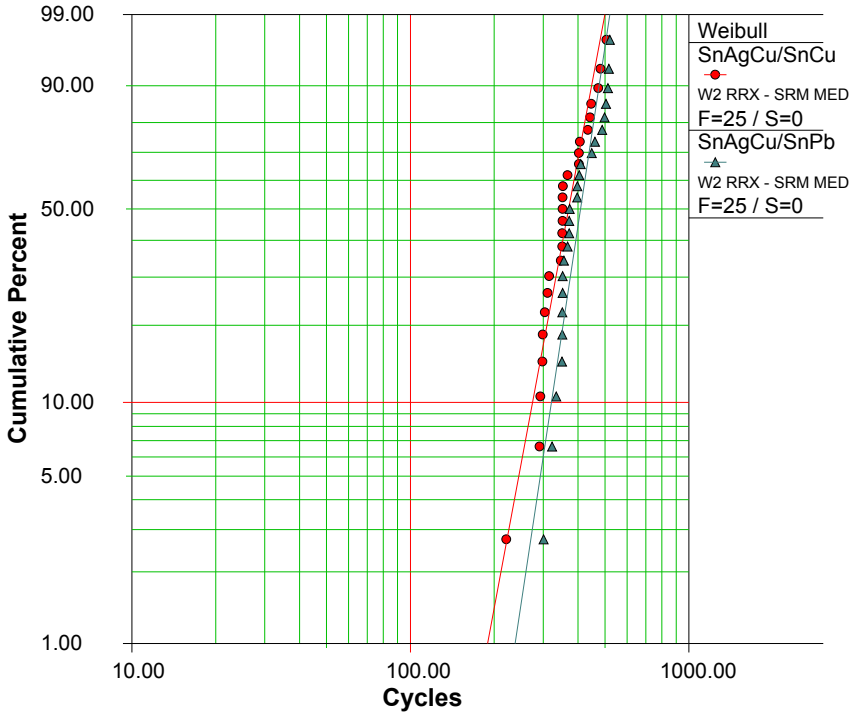


β1=11.0467, η1=506.5203, ρ=0.9894
β2=9.0111, η2=409.6173, ρ=0.9121 Key: Solder Alloy/Component Finish

SnAgCu/SnPb > SnAgCu/SnAgCu

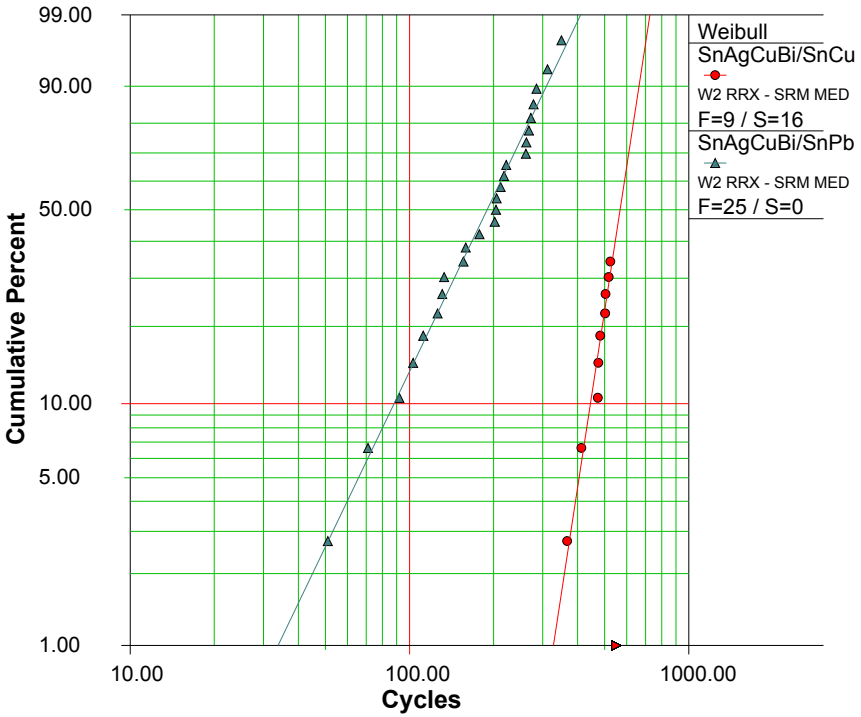
SnAgCuBi/SnAgCuBi > SnAgCuBi/SnPb

Effects of Lead Contamination on TSOP-50



β1=6.3243, η1=392.3031, ρ=0.9677
β2=7.8237, η2=428.1143, ρ=0.9251

Key: Solder Alloy/Component Finish



β1=7.7014, η1=595.4180, ρ=0.9796
β2=2.4560, η2=220.3415, ρ=0.9947

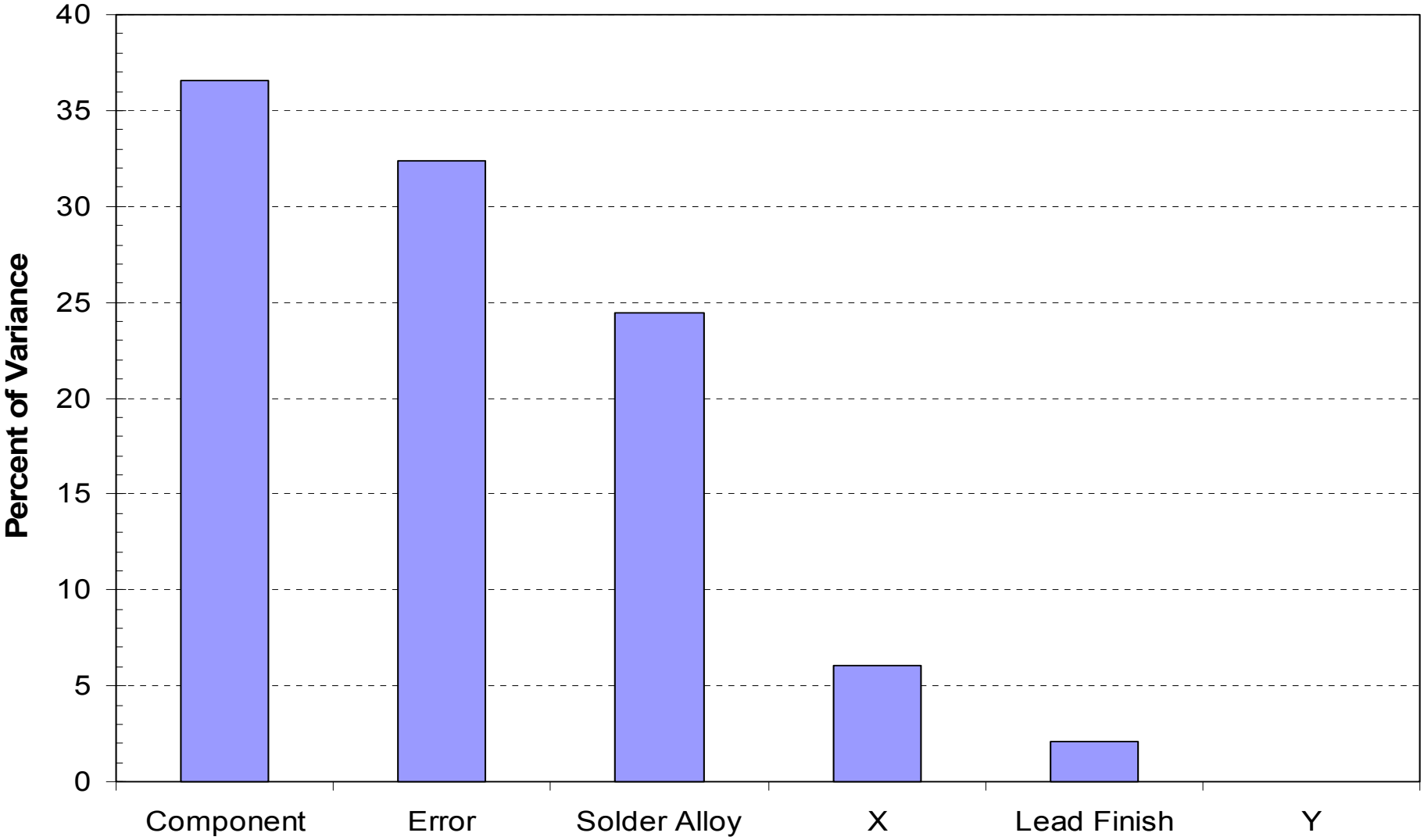
Key: Solder Alloy/Component Finish

SnAgCu/SnPb > SnAgCu/SnCu

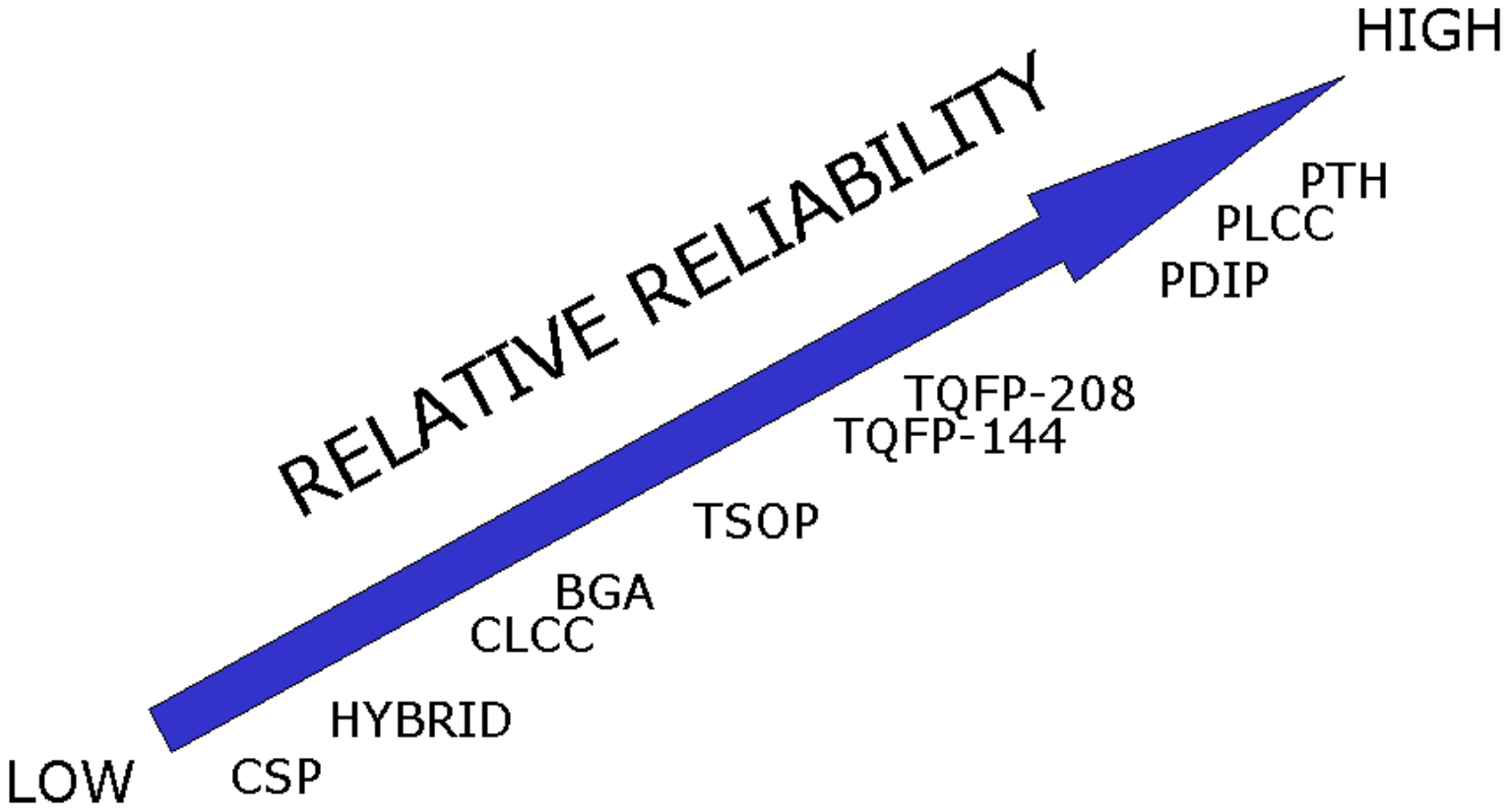
SnAgCuBi/SnCu > SnAgCuBi/SnPb

Statistical Analysis

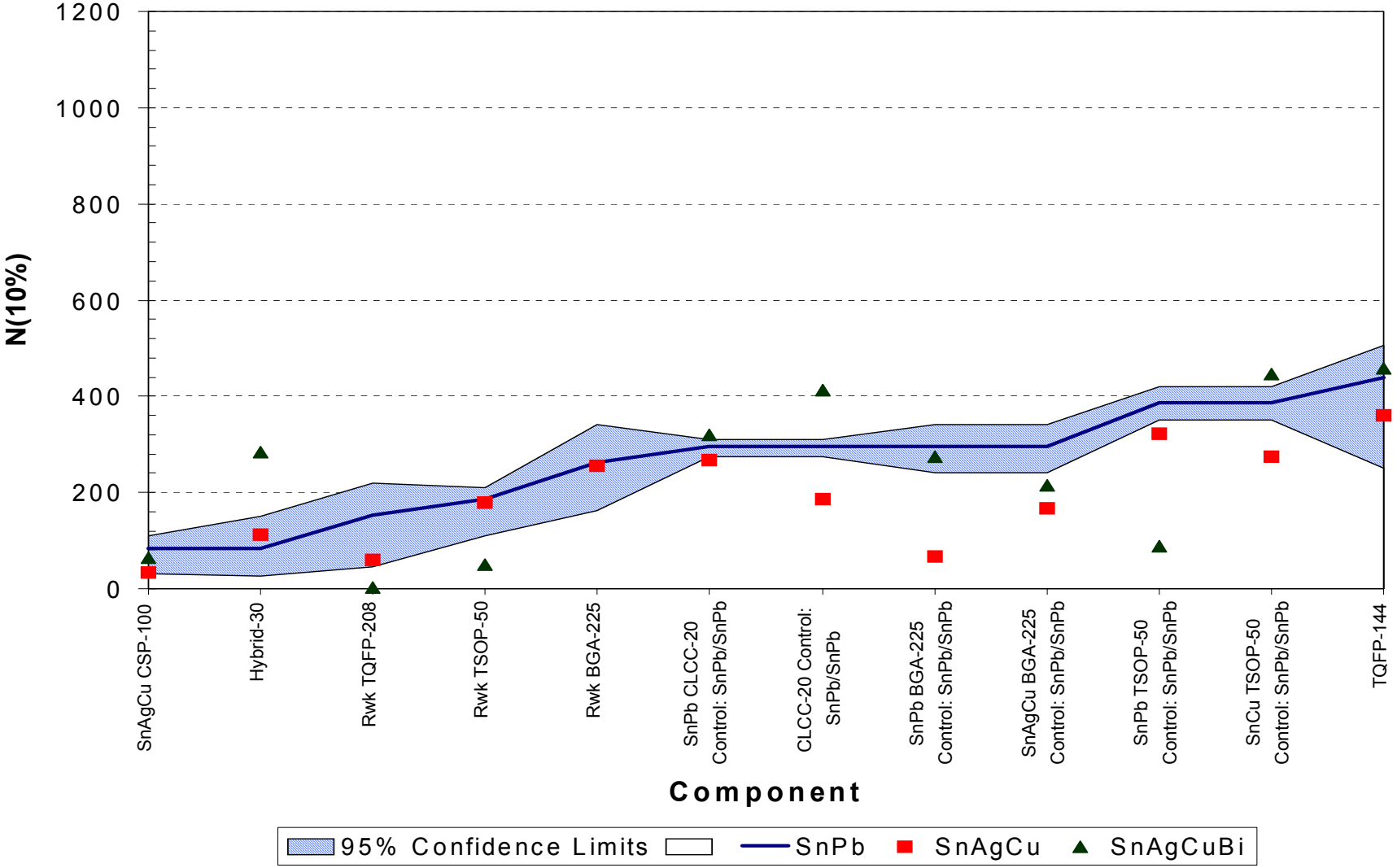
Variance Component Analysis



Component Type



Summary of Lead-Free Solder Performance by Component Type



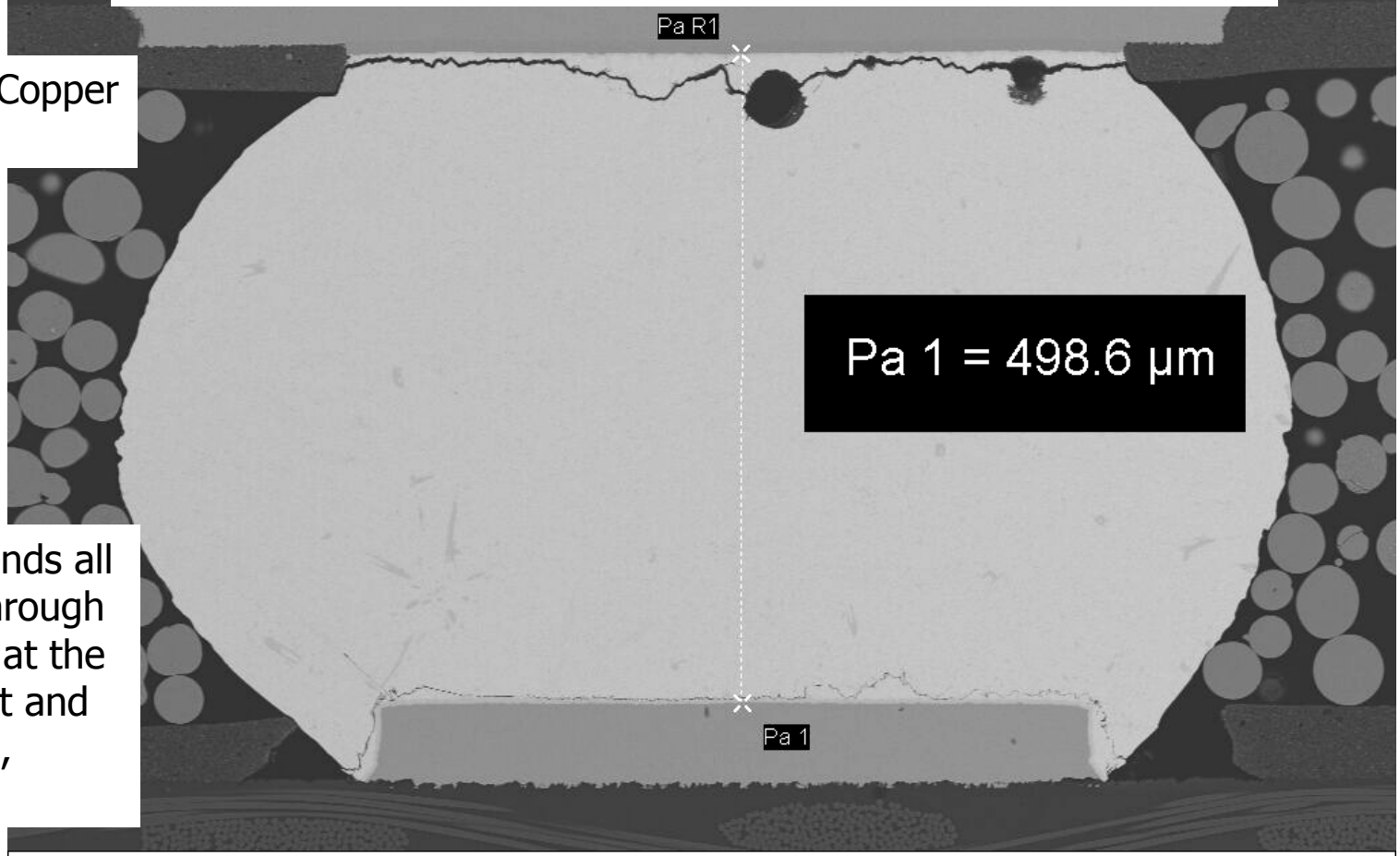
SEM/EDS Analysis

SnAgCuBi/SnAgCu BGA-225 SEM/EDS Analysis Results

Tin-Silver-Copper-Bismuth Solder Joints of BGA-225 Components

Tin-Silver-Copper Finish

Crack extends all the way through the solder at the component and board side, 1X failure



Mag = 107 X WD = 12 mm
Vacuum Mode = High Vacuum
Chamber = 1.25e-003 Pa
Raytheon Failure Analysis Lab
McKinney, Texas

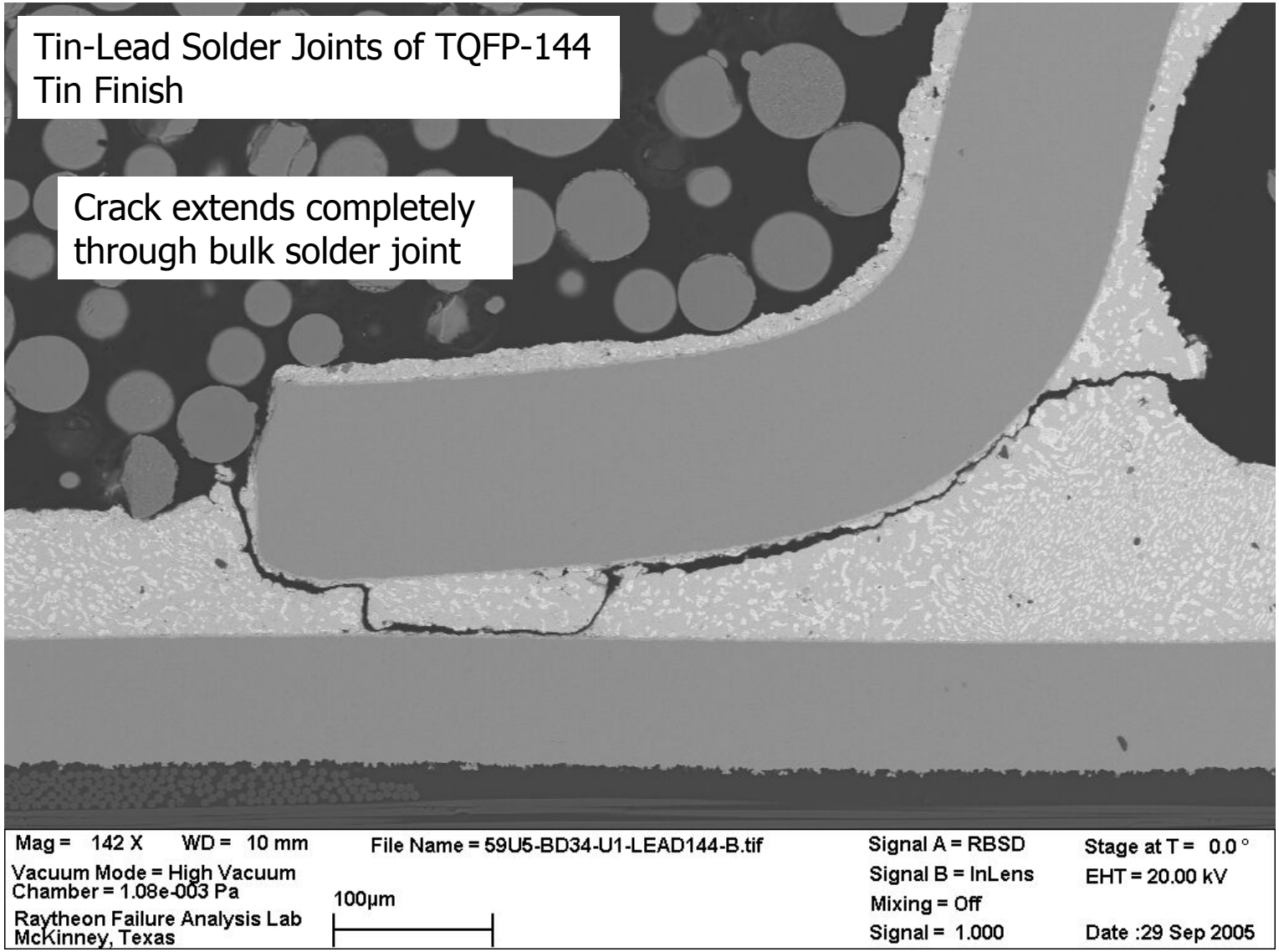
File Name = 59U7-BD142-U55-LEAD15A-A.tif

100µm

Signal A = RBSD
Signal B = InLens
Mixing = Off
Signal = 1.000

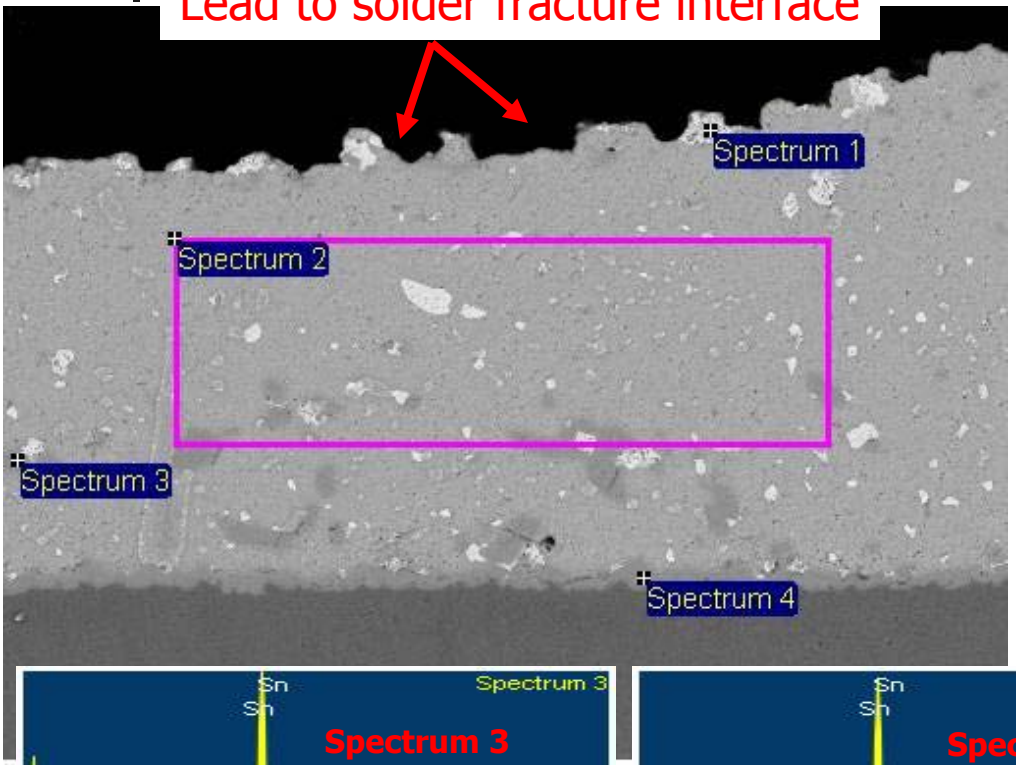
Stage at T = 0.0 °
EHT = 20.00 kV
Date :16 Nov 2005

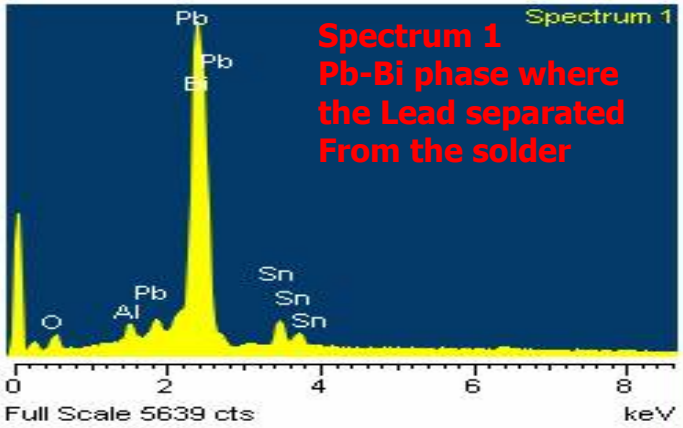
SnPb/Sn TQFP-144 SEM/EDS Analysis Results



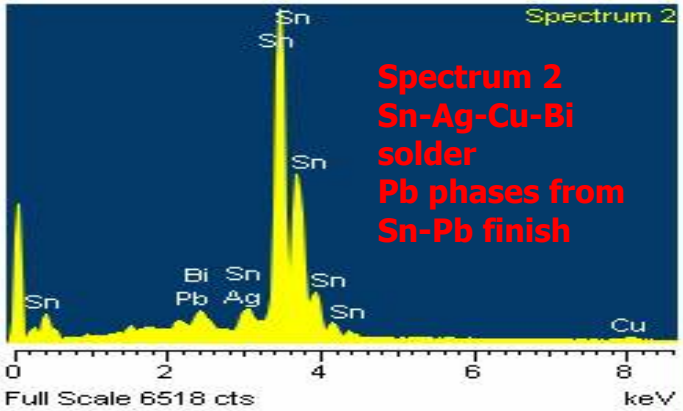
SnAgCuBi/SnPb TSOP-50 SEM/EDS Analysis Results

Lead to solder fracture interface

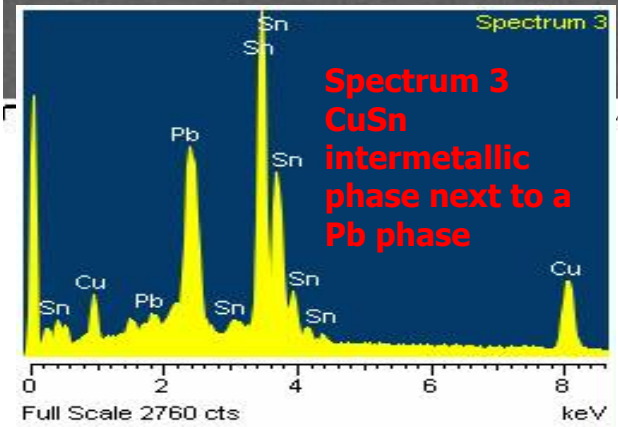




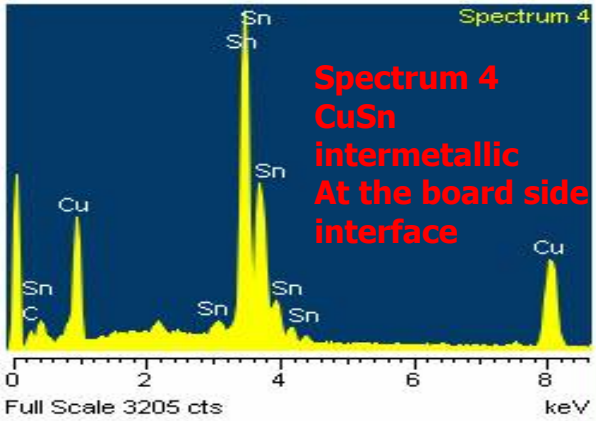
Spectrum 1
Pb-Bi phase where the Lead separated From the solder



Spectrum 2
Sn-Ag-Cu-Bi solder
Pb phases from Sn-Pb finish



Spectrum 3
CuSn intermetallic phase next to a Pb phase



Spectrum 4
CuSn intermetallic At the board side interface

Solder Alloy Performance

Solder Performance				
Component	**Solder/Finish**	**1st Failure**	**N10**	**N63**
BGA-225	SnPb/SnPb	175	297	504
	SAC/SAC	100	166	317
	SACB/SAC	1 (137)	215	394
	SAC/SnPb	30	66	385
	SACB/SnPb	223	274	445
CLCC-20	SnPb/SnPb	259	296	369
	SAC/SAC	168	186	260
	SACB/SACB	1 (363)	413	507
	SAC/SnPb	230	268	326
	SACB/SnPb	302	319	410
TQFP-144	SnPb/Sn	327	438	667
	SAC/Sn	308	360	566
	SACB/Sn	29 (353)	459	653
TSOP-50	SnPb/SnPb	347	387	516
	SAC/SnCu	221	275	392
	SACB/SnCu	367	445	595
	SAC/SnPb	301	321	428
	SACB/SnPb	51	88	220
CSP-100	SnPb/SnPb	15	84	287
	SAC/SAC	24	34	171
	SACB/SAC	2 (36)	64	145
Hybrid-30	SnPb/SnPb	36	84	319
	SAC/SAC	105	113	310
	SACB/SACB	232	283	500
Rwk BGA-225	NA/SnPb	252	263	336
	NA/SAC	169	256	458
Rwk TQFP-208	SnPb/AuPdNi	148	152	365
	SAC/AuPdNi	52	60	385
	SACB/AuPdNi	2	3	169
Rwk TSOP-50	SnPb/SnPb	186	187	281
	SAC/SnCu	156	178	375
	SACB/SnCu	22	51	226

Summary of Relative Solder Alloy Performance

Relative Solder Performance				
Component	**Solder/Finish**	**1st Failure**	**N10**	**N63**
BGA-225	SnPb/SnPb	0	0	0
	SAC/SAC	--	--	--
	SACB/SAC	--	--	--
	SAC/SnPb	--	--	--
	SACB/SnPb	++	-	-
CLCC-20	SnPb/SnPb	0	0	0
	SAC/SAC	--	--	--
	SACB/SACB	++	++	++
	SAC/SnPb	-	-	-
	SACB/SnPb	+	+	+
TQFP-144	SnPb/Sn	0	0	0
	SAC/Sn	-	-	-
	SACB/Sn	+	0	0
TSOP-50	SnPb/SnPb	0	0	0
	SAC/SnCu	--	--	--
	SACB/SnCu	+	+	+
	SAC/SnPb	-	-	-
	SACB/SnPb	--	--	--
CSP-100	SnPb/SnPb	0	0	0
	SAC/SAC	++	--	--
	SACB/SAC	++	--	--
Hybrid-30	SnPb/SnPb	0	0	0
	SAC/SAC	++	++	0
	SACB/SACB	++	++	++
Rwk BGA-225	NA/SnPb	0	0	0
	NA/SAC	--	0	++
Rwk TQFP-208	SnPb/AuPdNi	0	0	0
	SAC/AuPdNi	--	--	+
	SACB/AuPdNi	--	--	--
Rwk TSOP-50	SnPb/SnPb	0	0	0
	SAC/SnCu	-	0	++
	SACB/SnCu	--	--	-

Summary from Combined Environments Test

- Component type had greatest effect on solder joint reliability
  - PDIP and PLCC more reliable than other SMT parts

Summary from Combined Environments Test

- Solder alloy had a major effect on solder joint reliability
  - In some cases, tin-silver-copper-bismuth samples more reliable than tin-lead controls
    - Exceptions: Components with SnPb present or SnAgCu finishes
  - In general, tin-silver-copper samples less reliable than tin-lead controls

Summary from Combined Environments Test

- Impact of lead contamination on lead-free solder reliability mixed
  - Impact on tin-silver-copper varied
    - Sometimes improved & sometimes degraded performance
  - Degradation in tin-silver-copper-bismuth performance appears to be inversely proportional to amount of lead contamination

CET Samples Meeting the JTP Acceptance Criteria

Test Vehicle	Solder Alloy	Component Finish	Component Type
“Manufactured”	SnAgCuBi	SnAgCuBi	CLCC-20
“Manufactured”	SnAgCuBi	SnPb	CLCC-20
“Manufactured”	SnAgCuBi	Sn	TQFP-144
“Manufactured”	SnAgCuBi	SnCu	TSOP-50
“Rework”	N/A	SnAgCu	BGA-225
“Hybrid”	SnAgCuBi	SnAgCuBi	Hybrid-30
“Hybrid”	SnAgCu	SnAgCu	Hybrid-30