NASA-DoD Lead-Free Electronics Project: -20 to +80°C Thermal Cycle Test

Tom Woodrow, Ph.D.
Boeing Research & Technology

SMTAI 2011
Fort Worth, TX
October 16 - 20, 2011

BOEING is a trademark of Boeing Management Company.
Copyright © 2009 Boeing. All rights reserved.

NASA-DoD Lead-Free Electronics Project

- **Objective:** Formed to determine reliability of lead-free solders for military/aerospace. Effects of rework and solder mixing are being examined. Builds on the earlier JCAA/JG-PP Lead-Free Solder Project.

- **Testing**
  - Vibration (up to 28 Grms)
  - Mechanical Shock
  - Thermal Cycle (-55 to +125°C)
  - **Thermal Cycle (-20 to +80°C)**
  - Combined Vibration/Thermal Cycle
  - Copper Dissolution
  - IST Testing

- **Website**
  http://www.acqp2.nasa.gov/NASA_DODLeadFreeElectronics_Proj2.html

Thermal Cycle Testing

- **Solders tested:**
  - Sn3.0Ag0.5Cu (reflow) (SAC305)
  - Sn0.7Cu0.05%Ni (reflow, wave) (SN100C)
  - Sn4.0Ag0.5Cu (BGA balls)(SAC405)
  - Sn1.0Ag0.5Cu (CSP balls)(SAC105)
  - Sn37Pb as a control

- **Board finishes:** Immersion silver, ENIG
- **Board:** 6 layers,0.090 in.,FR4 (Tg of 170°C)

Thermal Cycle Testing

- **Components**
  - BGA-225
  - CSP-100
  - CLCC-20
  - QFN-20
  - PDIP-20
  - TQFP-144
  - Alloy 42 TSOP-50

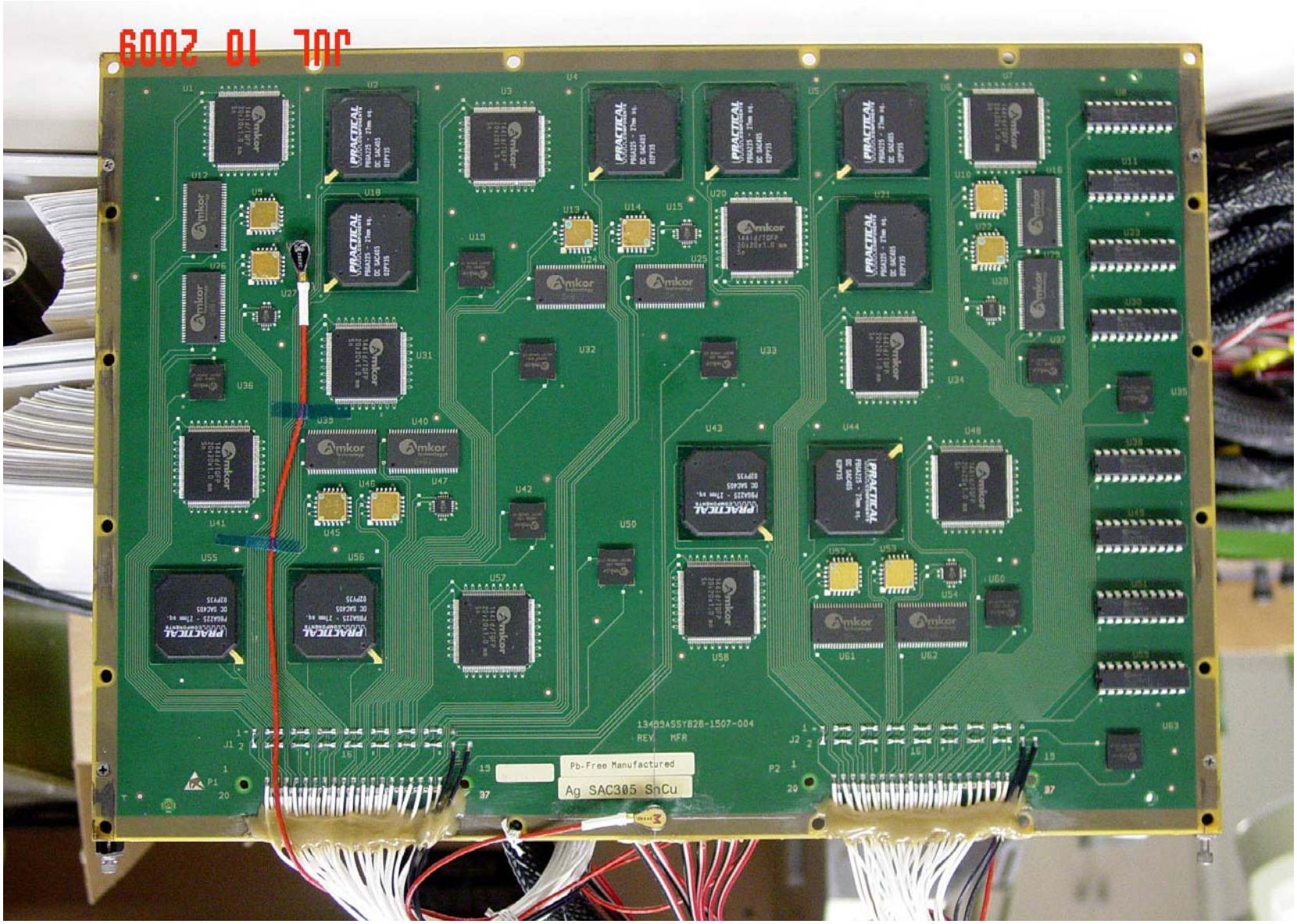
- Two types of test vehicles

  - **"Manufactured"** – 5 SnPb; 6 lead-free (SAC305 paste); 5 lead-free (SN100C paste)

  - **"Rework"** – 6 SnPb; 5 lead-free (SAC305 paste). Reworked six BGA's; six CSP's; two PDIP's; and four TSOP's on each. Also mixed SnPb/lead-free.

  - One test vehicle had an ENIG finish (SnPb "Rework").

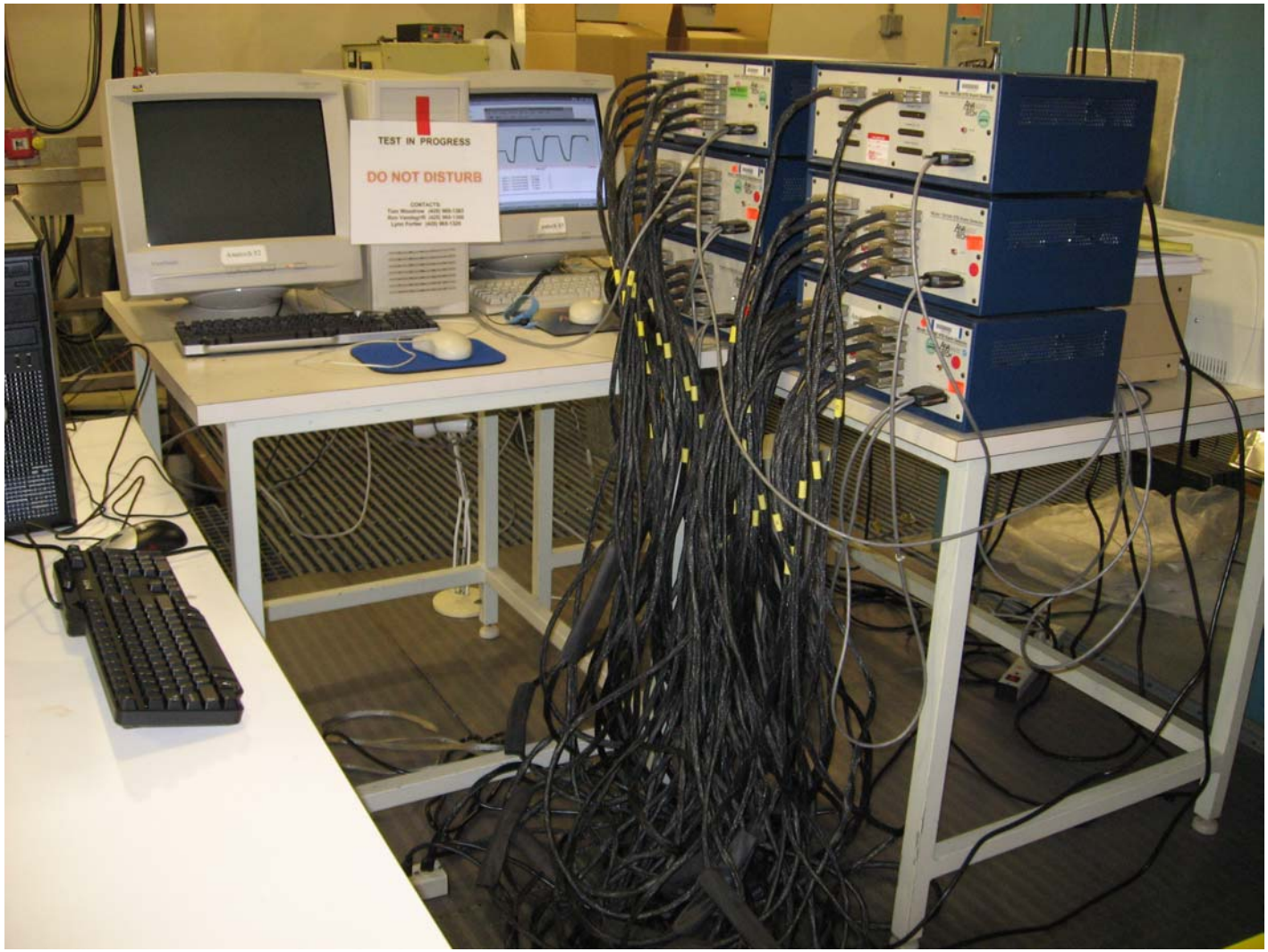
NASA-DoD Test Vehicle



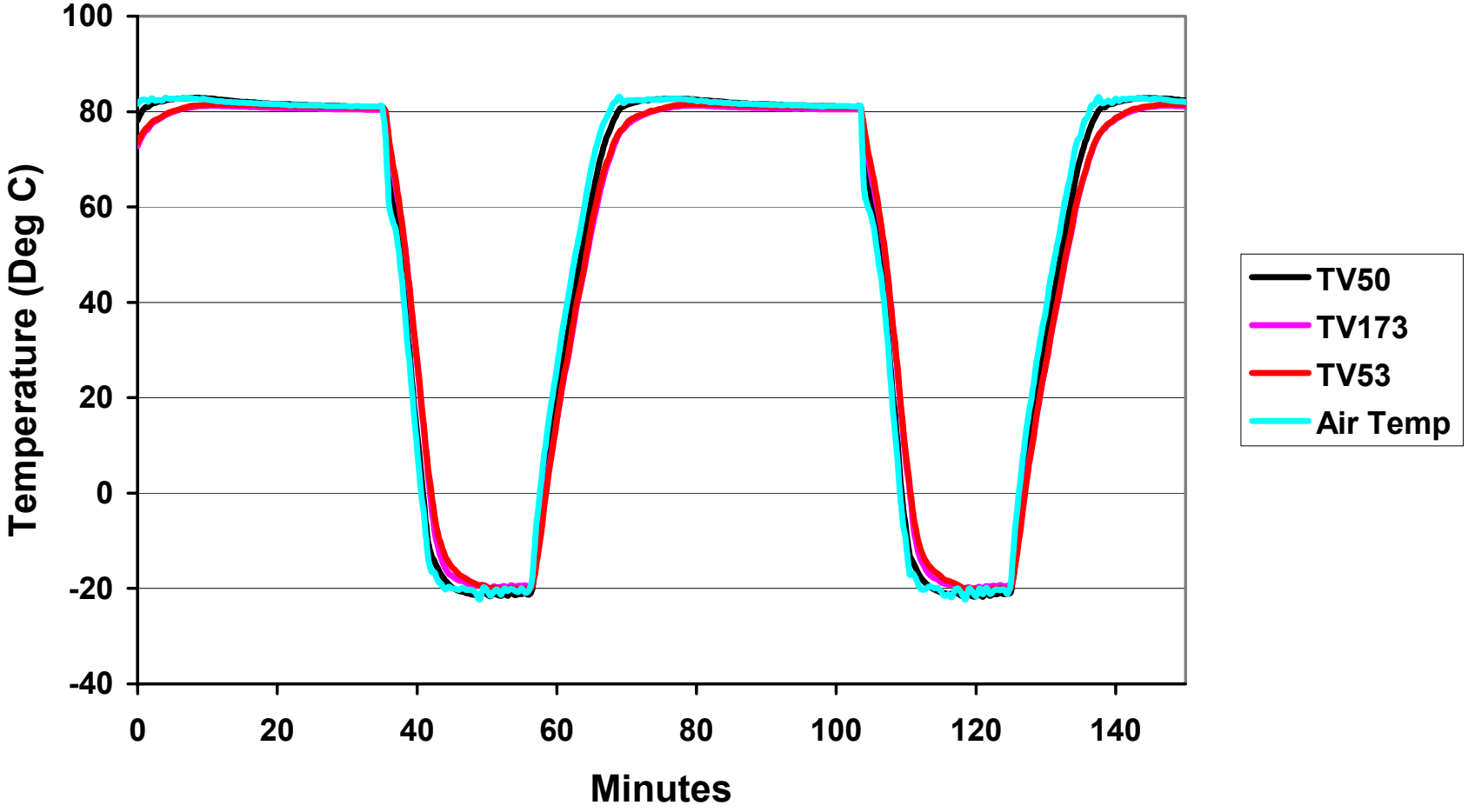
Thermal Cycle Chamber

Test Vehicles in Thermal Cycle Chamber

Event Detectors and Data Collection System



Thermal Cycle (-20°C to +80°C)



Reflow Profile for SnPb Solder Paste
(Source: BAE Systems)

SuperM.O.L.E.(r) Gold SPC V5.22 - Lead Free.mpc
File Tag:SM_SORMBED_000139 Date: 12/02/07

M.O.L.E.(r) STATUS
Max Internal T: 27C
Battery: 4.246
Points: 424

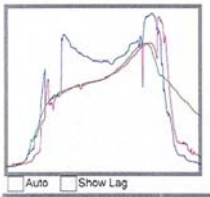
Active: X234XX
Interval: 00:00:01.0

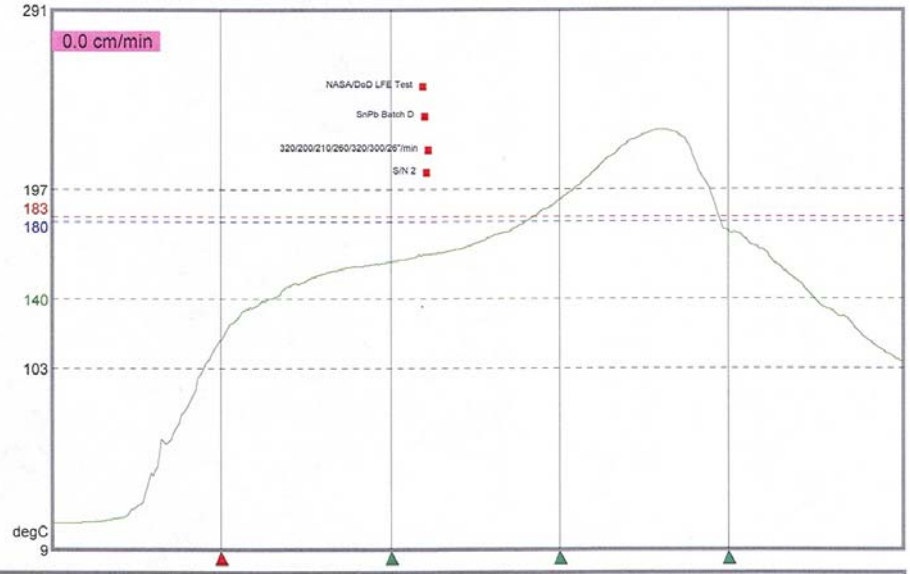
Date: 12/02/07
Time: 09:25:47 V08.58

Tool status box

NASA/DoD Lead Free

26"/min
826-00004-205





	Value	C1 = 00:01:24 r	C2 = 00:02:48 r	C3 = 00:04:12 r	C4 = 00:05:36 r	Units
▫	open					
▫	bad t/c					
▪	below U50 CSP center edge	119	159	192	174	degC
▫	trailing end U4/U55					
▫	open					
▫	open					

	T Above Ref	Low = 140	Med = 180	Hi = 183	Cure Factor	Units
▫	open					
▫	bad t/c					
▪	below U50 CSP center edge	00:04:32	00:01:37	00:01:32	0%	Time
▫	trailing end U4/U55					
▫	open					
▫	open					

	Statistics	Minimum	Minimum X	Maximum	Maximum X	Average	Std Deviation	Units
▫	open							
▫	bad t/c							
▪	below U50 CSP center edge	23	00:00:00 r	228	00:05:00 r	143.9	56.1	degC
▫	trailing end U4/U55							
▫	open							
▫	open							

Reflow Profile for SAC305 Solder Paste
(Source: BAE Systems)

SuperM.O.L.E.(r) Gold SPC V5.22 - No-lead NASA.mpc
File Tag:SM_COCHRAJ_000221 Date: 07/27/08

M.O.L.E.(r) STATUS
Max Internal T: 28C
Battery: 4.599
Points: 433

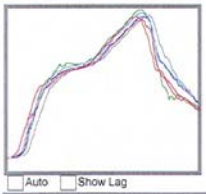
Active: 123456
Interval: 00:00:01.0

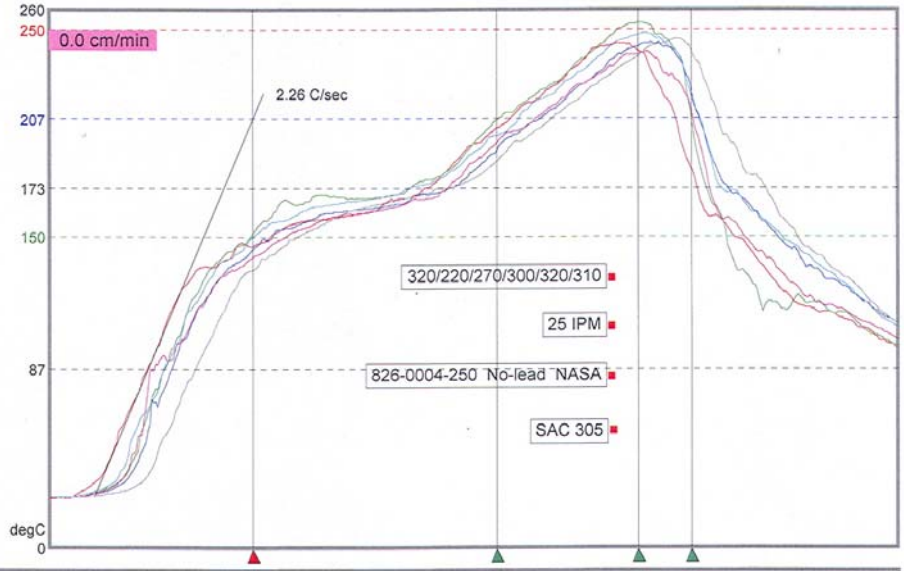
Date: 02/12/80
Time: 23:39:33 V08.58

Tool status box

NASA no-lead

320/220/270/300/320/310
SAC 305 826-0004-205





Auto Show Lag

Value	C1 = 00:01:43 r	C2 = 00:03:48 r	C3 = 00:05:00 r	C4 = 00:05:27 r	Units
South of U37 CSP	146	203	239	182	degC
North of U32 hybrid	144	193	242	218	degC
North of U42 CSP	151	207	253	204	degC
North of U4	140	196	238	209	degC
South of U58	149	199	248	216	degC
North of U36 CSP	134	187	237	238	degC

T Above Ref	Low = 150	Med = 207	Hi = 250	Cure Factor	Units
South of U37 CSP	00:03:57	00:01:24	00:00:00	0%	Time
North of U32 hybrid	00:04:17	00:01:21	00:00:00	0%	Time
North of U42 CSP	00:04:02	00:01:38	00:00:19	0%	Time
North of U4	00:03:54	00:01:21	00:00:00	0%	Time
South of U58	00:04:29	00:01:33	00:00:00	0%	Time
North of U36 CSP	00:04:15	00:01:25	00:00:00	0%	Time

Statistics	Minimum	Minimum X	Maximum	Maximum X	Average	Std Deviation	Units
South of U37 CSP	24	00:00:00 r	243	00:04:48 r	151.6	56.7	degC
North of U32 hybrid	24	00:00:00 r	244	00:05:06 r	151.9	59.8	degC
North of U42 CSP	24	00:00:06 r	253	00:04:59 r	152.7	63.2	degC
North of U4	24	00:00:00 r	239	00:05:04 r	148.5	58.2	degC
South of U58	24	00:00:00 r	248	00:05:02 r	156.3	60.1	degC
North of U36 CSP	24	00:00:04 r	246	00:05:18 r	150.6	63.5	degC

Chemical Analysis of Solder Joints Contaminated with Pb (by ICP Spectroscopy)

Component	Ref. Des.	Test Vehicle ID	Reworked?	Component Finish	Board Finish	Solder	%Ag	%Cu	%Pb	%Sn	%Bi	%Au
BGA-225	U04	149	No	SAC405	Ag	Sn37Pb	3.46	0.94	3.77	91.71	0.00	0.13
BGA-225	U04	193	No	Sn37Pb	Ag	SAC305	0.31	0.26	33.91	65.44	0.00	0.08
BGA-225	U43	193	Yes	SAC405	Residual SAC	Sn37Pb	3.13	3.18**	5.52	88.07	0.00	0.10
CLCC-20	U09	149	No	SAC305	Ag	Sn37Pb	1.35	0.49	24.68	73.48	0.00	0.00
CLCC-20	U09	193	No	Sn37Pb	Ag	SAC305	1.92	0.39	16.46	81.19	0.04	0.00
CSP-100*	U33	149	Yes	SAC105	Residual Sn37Pb	Sn37Pb	0.90	0.73	1.81	96.23	0.00	0.33
CSP-100*	U33	193	Yes	SAC105	Residual SAC	Sn37Pb	0.83	0.63	4.43	93.82	0.00	0.29
QFN-20	U15	193	No	SnPb	Ag	SAC305	3.39	0.85	0.93	94.83	0.00	0.00
TSOP-50	U16	149	No	SnBi	Ag	Sn37Pb	0.44	2.68**	35.73	61.06	0.09	0.00
TSOP-50	U16	193	No	SnPb	Ag	SAC305	3.53	6.10**	1.51	88.86	0.00	0.00

*PWB Cu pads had to be cut from the CSP balls. This operation also removed that end of each ball.

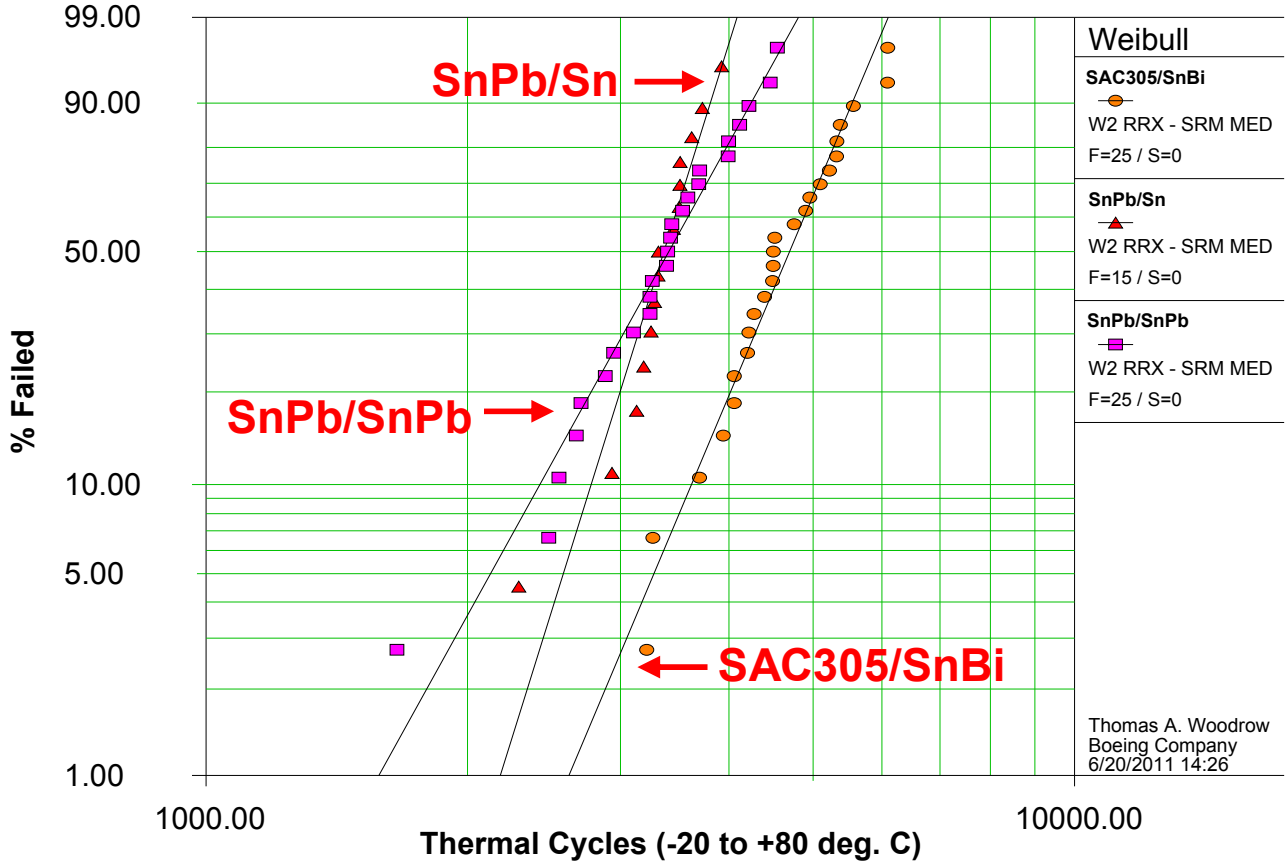
** Copper may have been removed from the PWB pads when the solder joints were cut from the test vehicle.

	% of Components Failed During Thermal Cycle Testing (at 11,676 Cycles)	
	"Manufactured" Test Vehicles	
	SnPb Paste	SAC305 Paste
Component		
BGA-225		
Unmixed Technology	100	0
Mixed Technology	52	100
CLCC-20		
Unmixed Technology	84	96
Mixed Technology	96	92
CSP-100		
Unmixed Technology	100	0
Mixed Technology	0	68
QFN-20	0	4
TQFP-144	90	34
TSOP-50	100	100

Observations at 11,676 Cycles

- Pure Pb-free solder joints are outperforming pure SnPb solder joints
  - ✓ This is in line with previous studies that used less aggressive thermal cycles (JG-PP; iNEMI; HDPUG)
- Reworked pure SnPb solder joints are outperforming unreworked SnPb solder joints (for TSOP's, BGA's, and CSP's)
  - ✓ Reason not clear at this time
  - ✓ In contrast, reworked Pb-free joints are less reliable than unreworked Pb-free joints (TSOP data only)

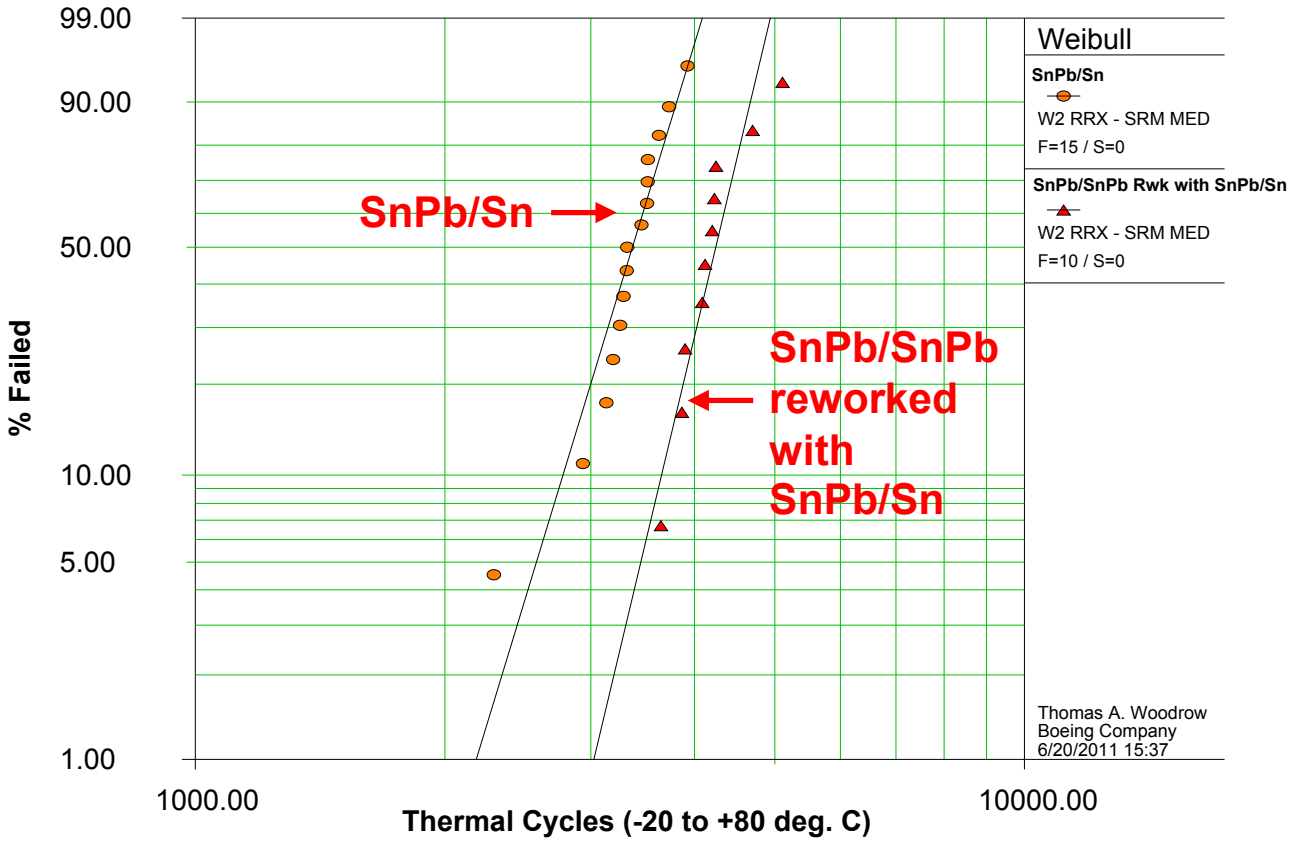
TSOP-50 Data



$\beta 1=7.2378$, $\eta 1=4942.8859$, $\rho=0.9835$
$\beta 2=9.7584$, $\eta 2=3497.0642$, $\rho=0.9473$
$\beta 3=5.5063$, $\eta 3=3645.8470$, $\rho=0.9828$

Key: Solder Alloy/Component Finish

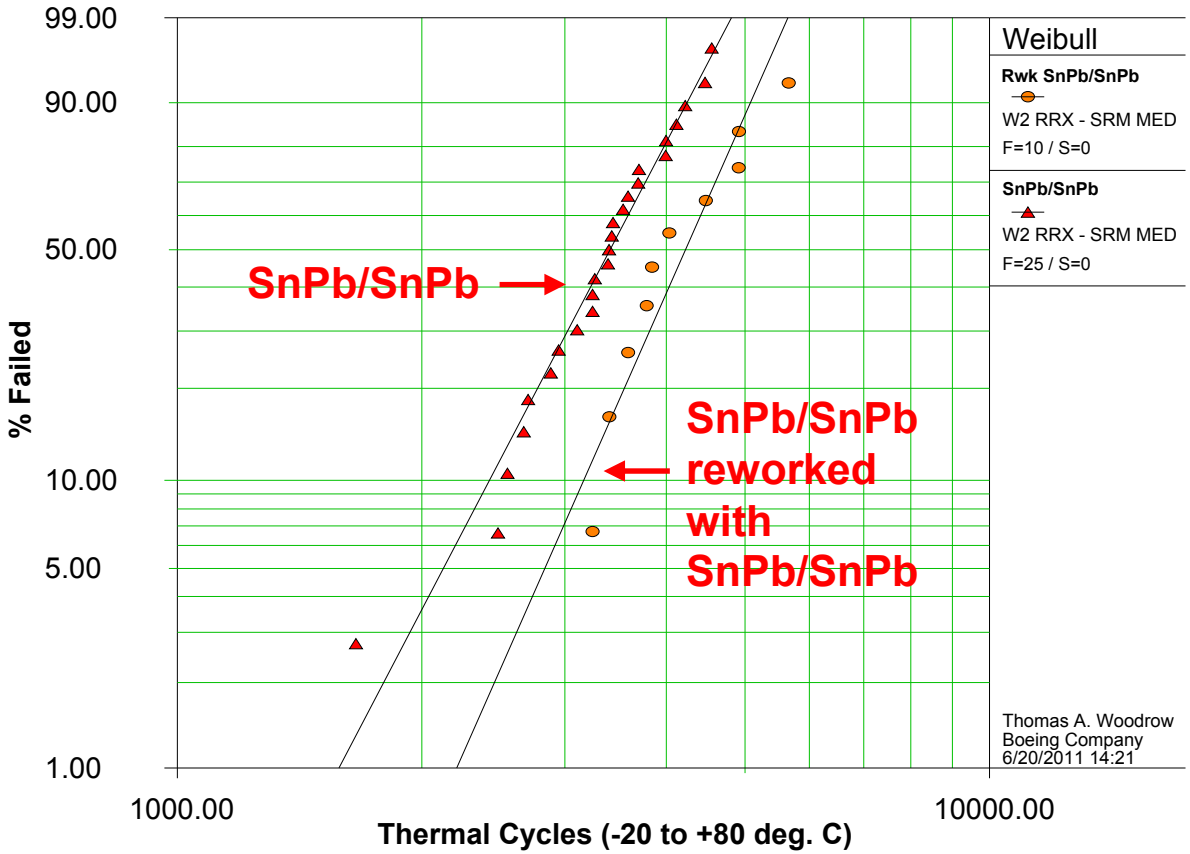
Reworked SnPb TSOP-50 Data



$\beta 1=9.7584$, $\eta 1=3497.0642$, $\rho=0.9473$
$\beta 2=12.4950$, $\eta 2=4370.7731$, $\rho=0.9207$

Key: Solder Alloy/Component Finish

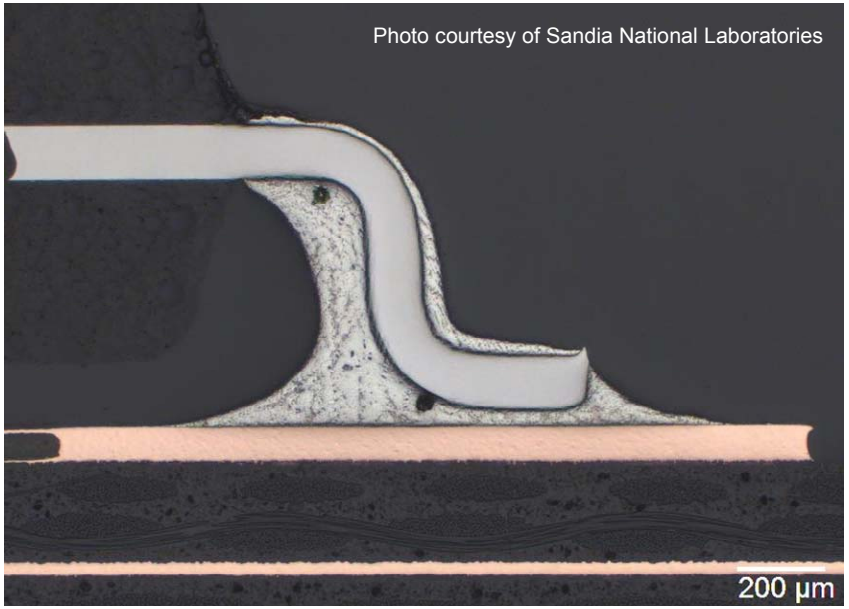
Reworked SnPb TSOP-50 Data



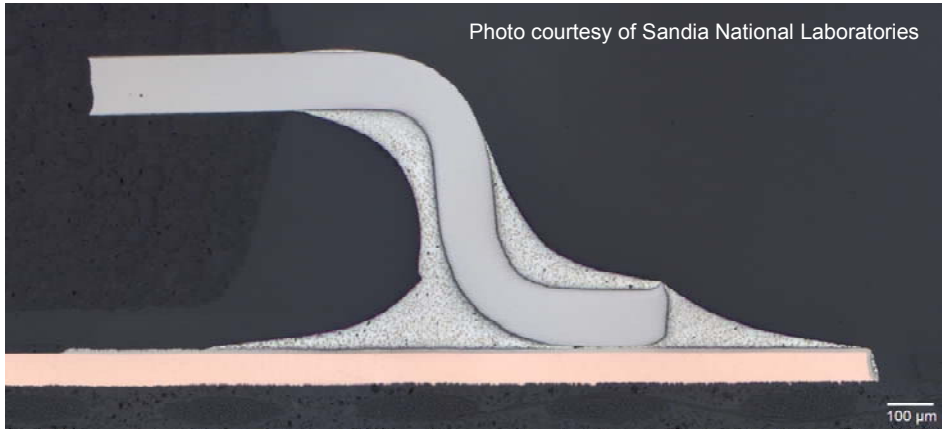
$\beta 1=6.5246$, $\eta 1=4467.9686$, $\rho=0.9478$
$\beta 2=5.5063$, $\eta 2=3645.8470$, $\rho=0.9828$

Key: Solder Alloy/Component Finish

Comparison of As-Assembled and Reworked TSOP Solder Joints

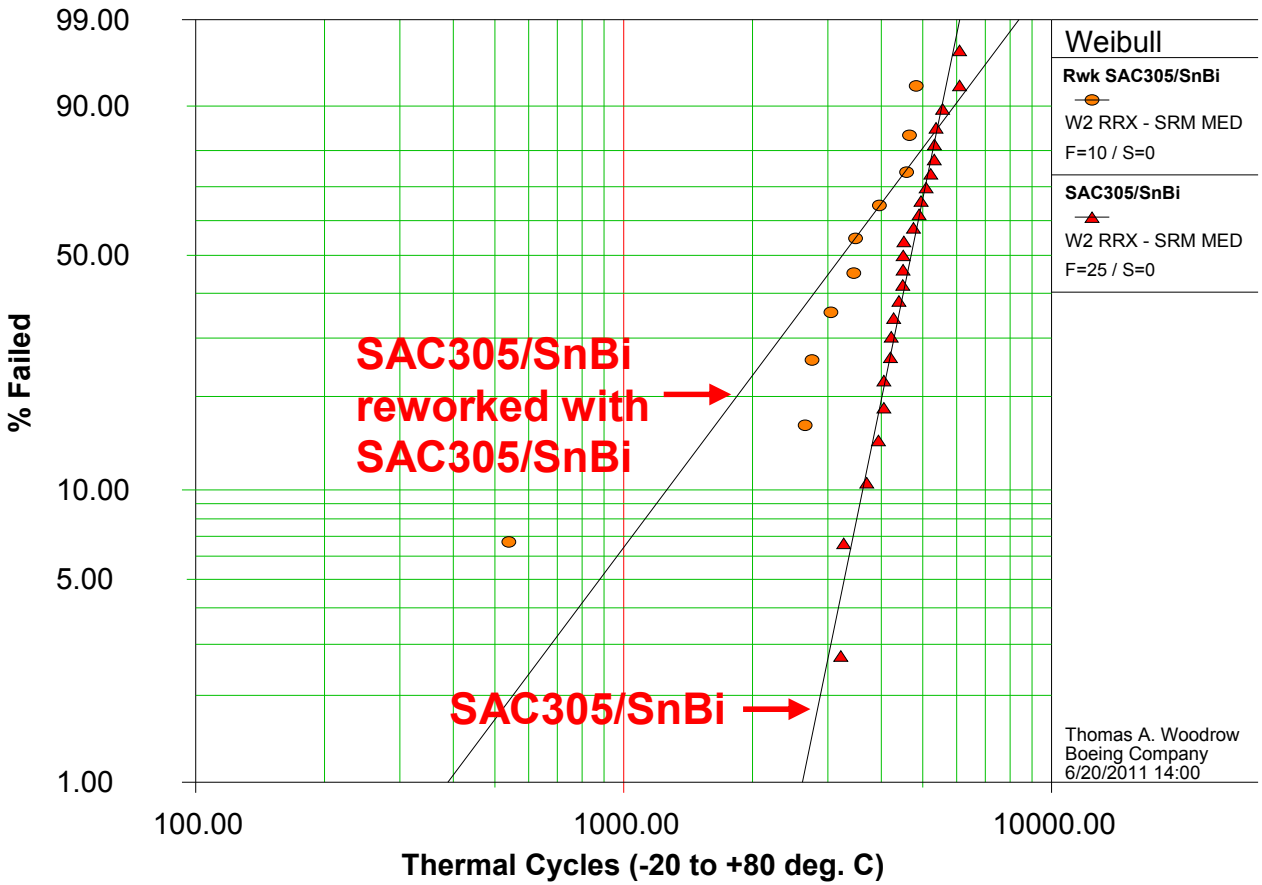


SnBi TSOP-50 Assembled with SnPb Solder (Pre-Test Microsection)



SnPb/SnPb TSOP-50 Reworked with SnPb/SnPb (Pre-Test Microsection)

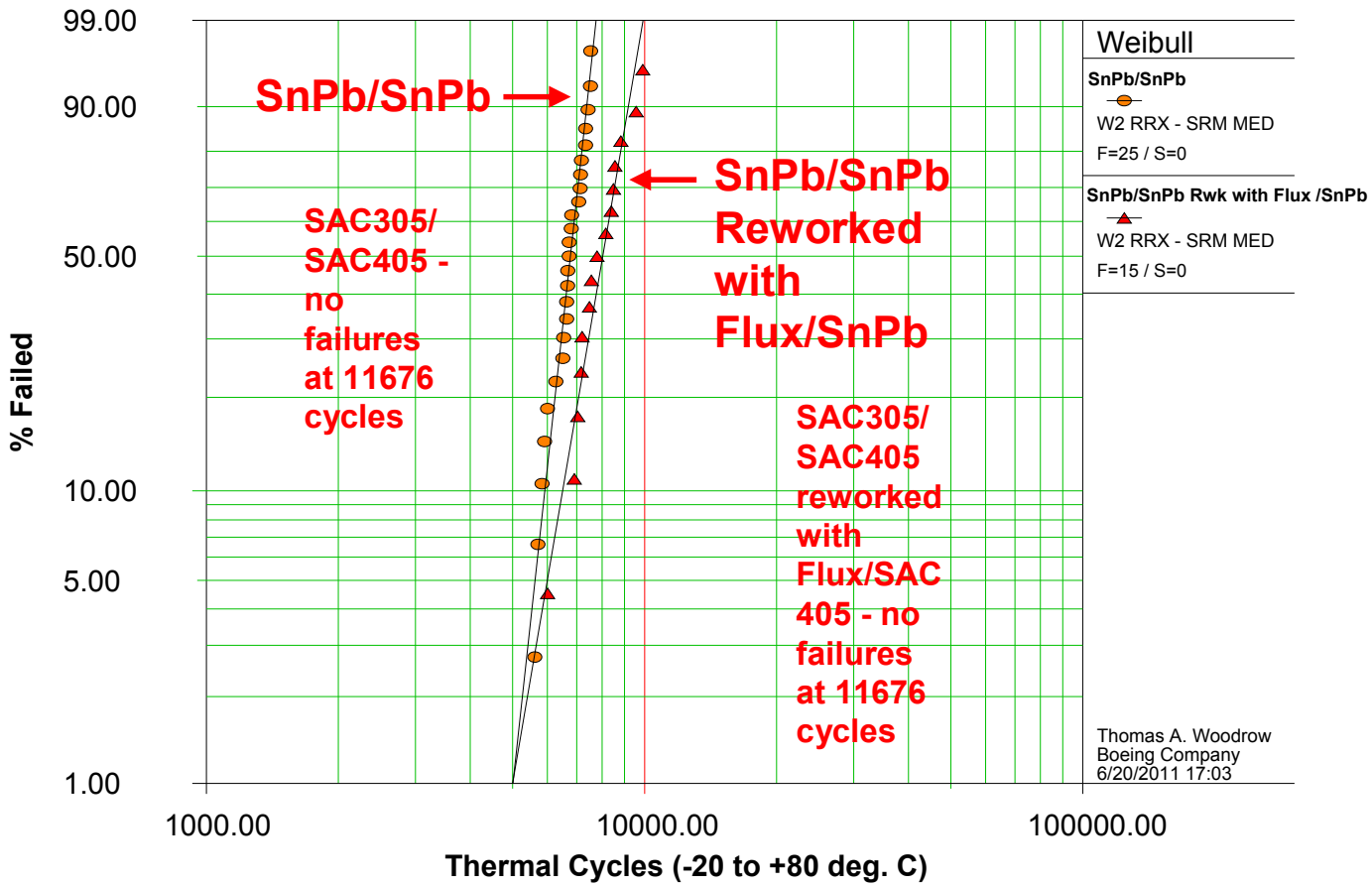
Reworked Pb-Free TSOP-50 Data



$\beta 1=1.9936$, $\eta 1=3901.5564$, $\rho=0.8766$
$\beta 2=7.2378$, $\eta 2=4942.8859$, $\rho=0.9835$

Key: Solder Alloy/Component Finish

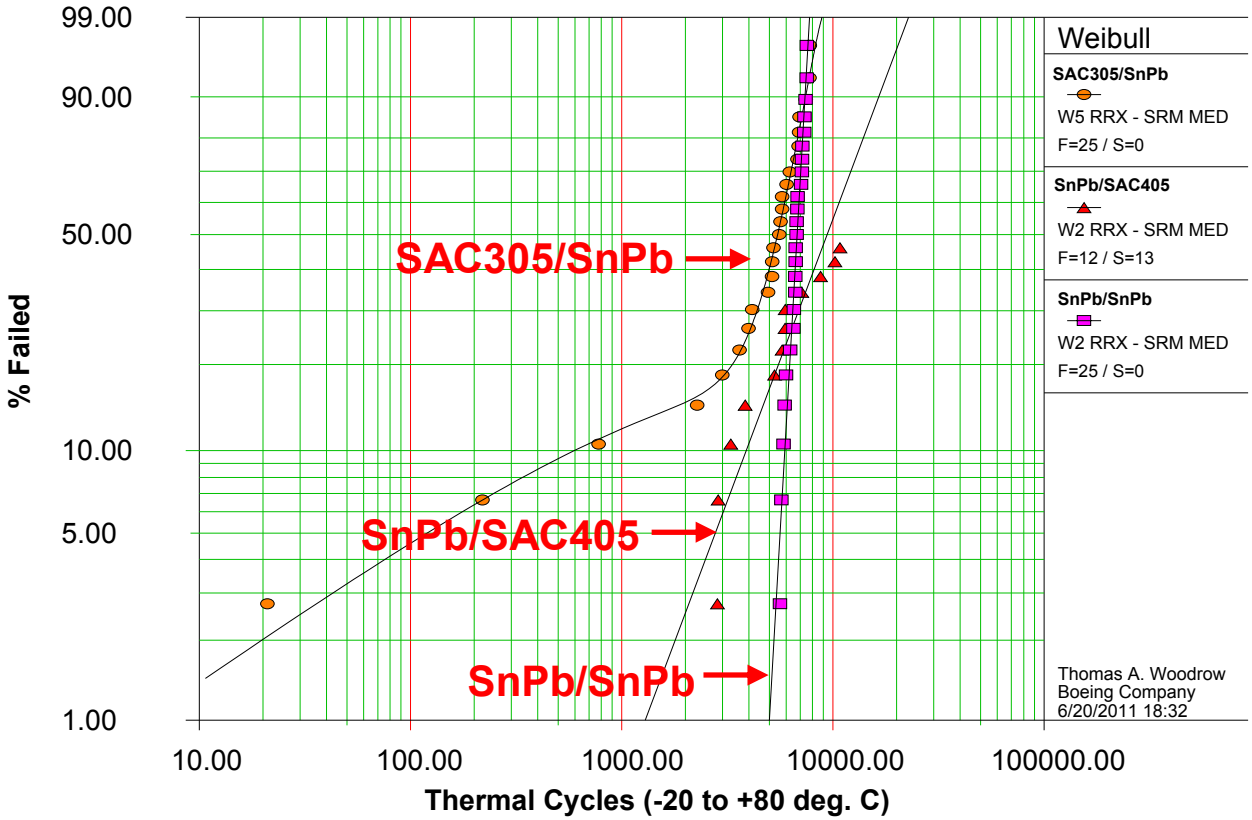
BGA-225 Data



$\beta 1=14.0212$, $\eta 1=6953.2528$, $\rho=0.9814$
$\beta 2=8.9342$, $\eta 2=8359.9217$, $\rho=0.9763$

Key: Solder Alloy/Component Finish

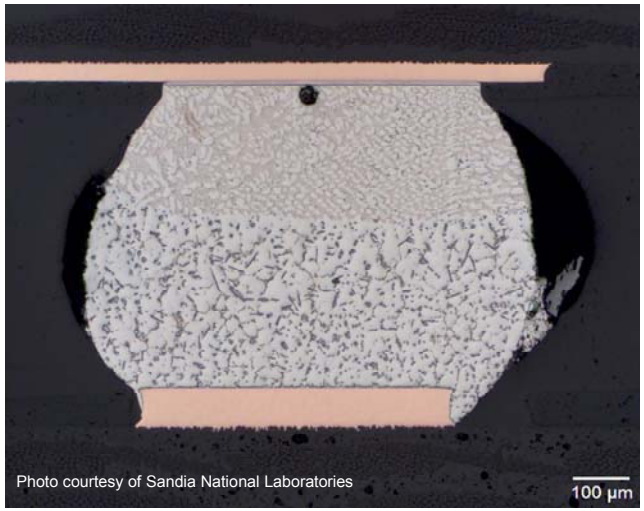
BGA-225 Data (Mixed Solders)



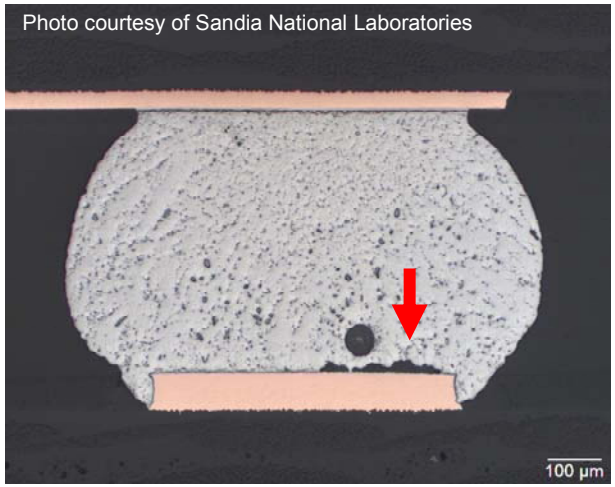
β1[1]=0.5644, η1[1]=901.2608, P1[1]=0.1826 ; β1[2]=4.7275, η1[2]=6302.7439, P1[2]=0.8174
β2=2.1325, η2=1.1174E+4, ρ=0.9349
β3=14.0212, η3=6953.2528, ρ=0.9814

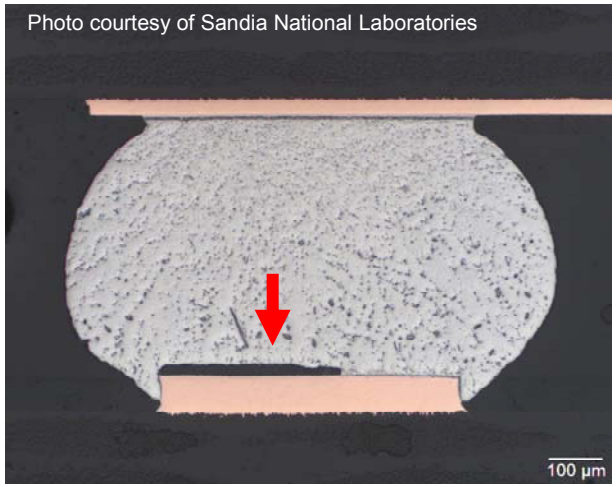
Key: Solder Alloy/Component Finish

BGA-225 Microsections (Mixed Solders)



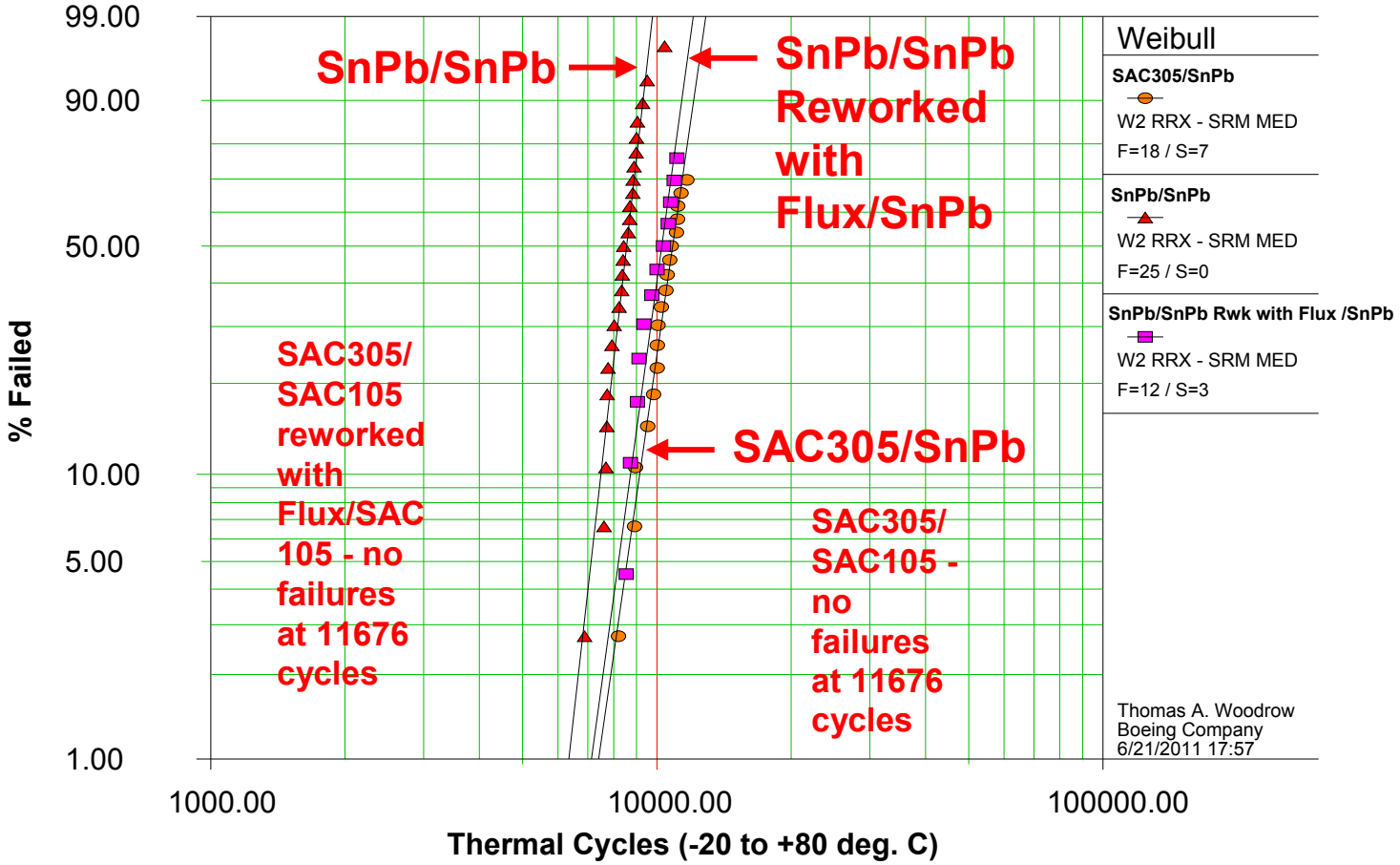
SAC405 Balls Assembled with SnPb Paste (SnPb Reflow Profile; Pre-Test Microsection)





SnPb Balls Assembled with SAC305 Paste (Pb-free Reflow Profile; Pre-Test Microsection)

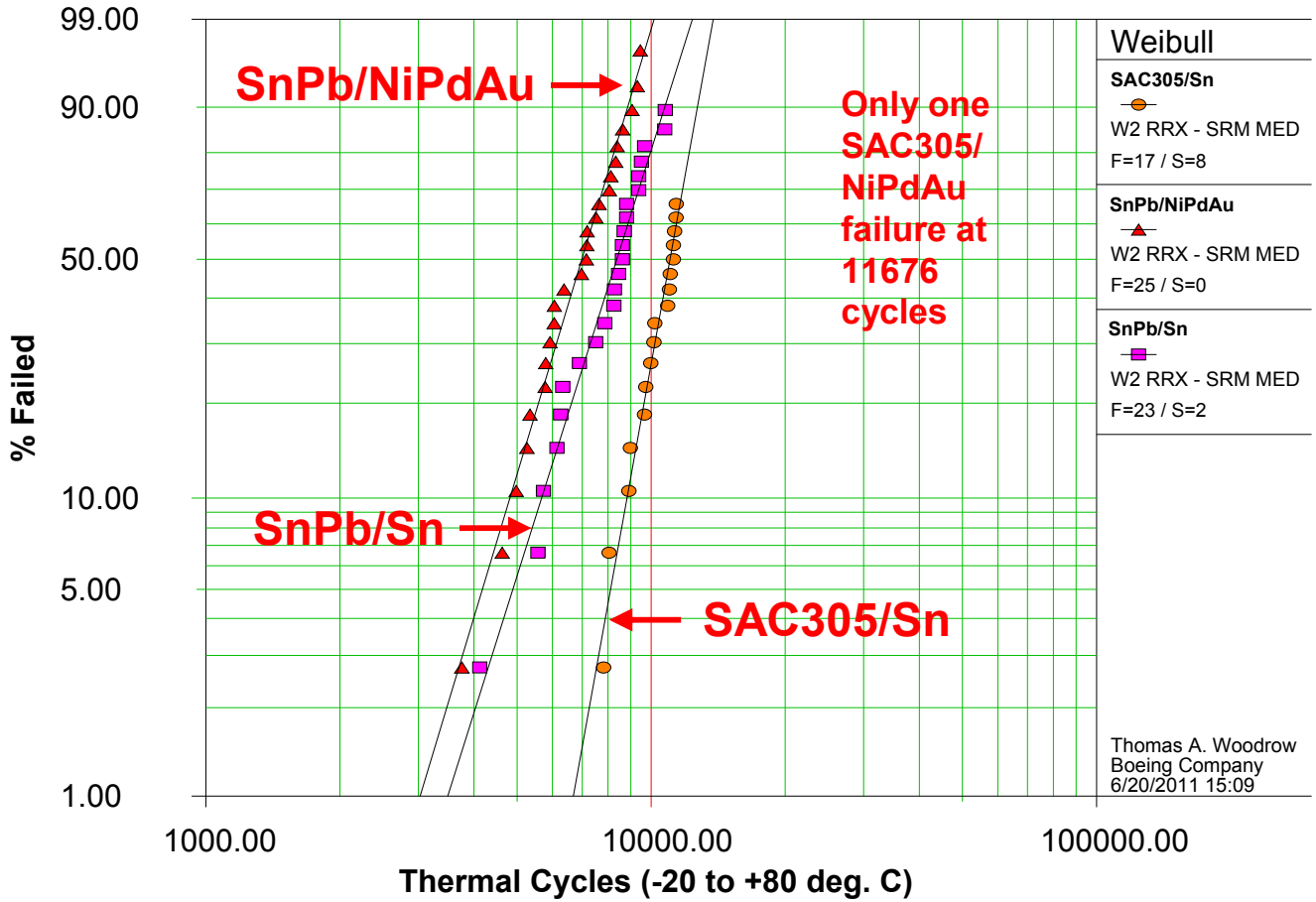
CSP-100 Data



$\beta 1=11.0651$, $\eta 1=1.1218E+4$, $\rho=0.9911$
$\beta 2=14.2044$, $\eta 2=8779.4419$, $\rho=0.9670$
$\beta 3=11.6464$, $\eta 3=1.0585E+4$, $\rho=0.9612$

Key: Solder Alloy/Component Finish

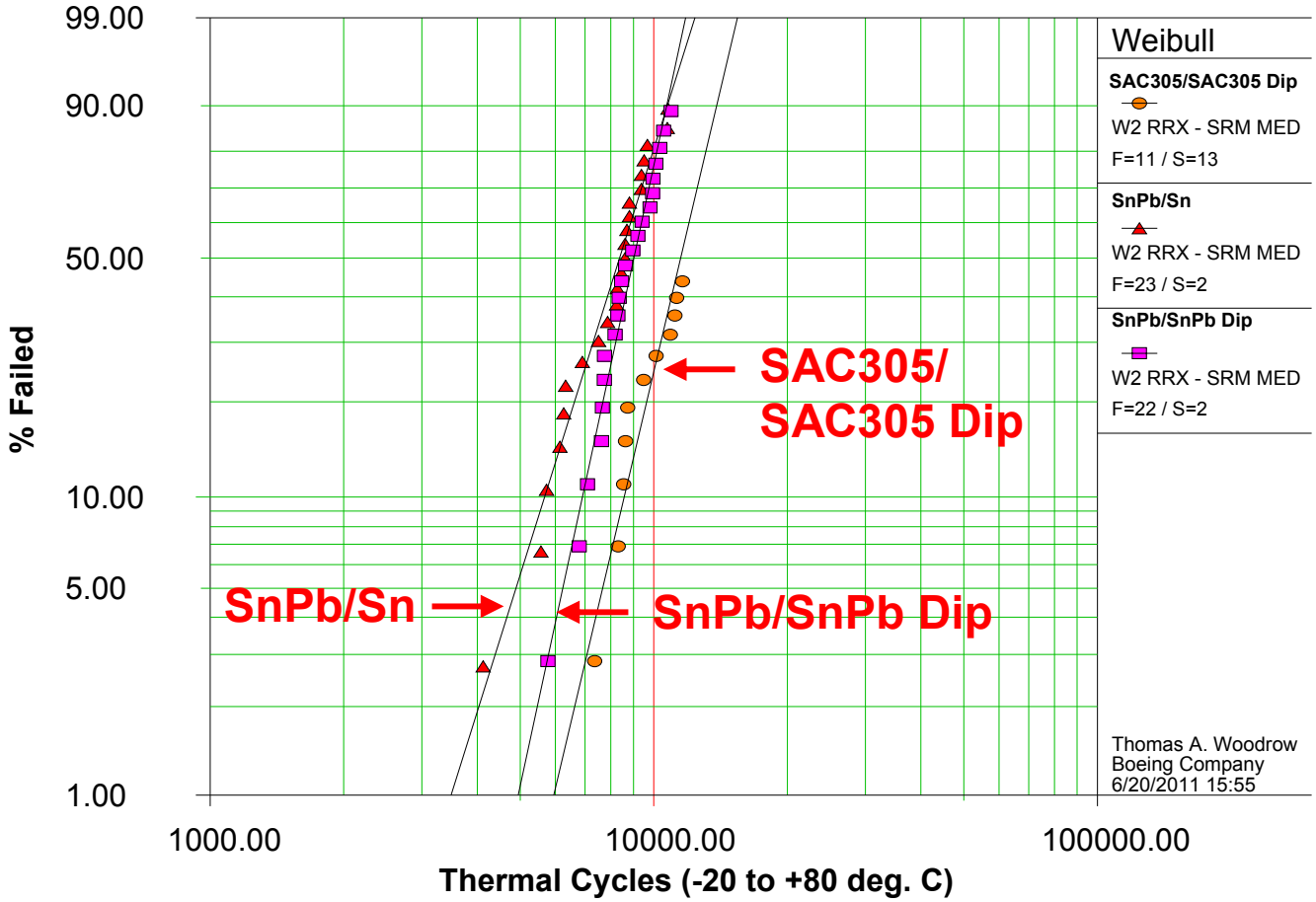
TQFP-144 Data



$\beta 1=8.4634$, $\eta 1=1.1514E+4$, $\rho=0.9846$
$\beta 2=5.0626$, $\eta 2=7511.8983$, $\rho=0.9927$
$\beta 3=4.8409$, $\eta 3=9032.9926$, $\rho=0.9877$

Key: Solder Alloy/Component Finish

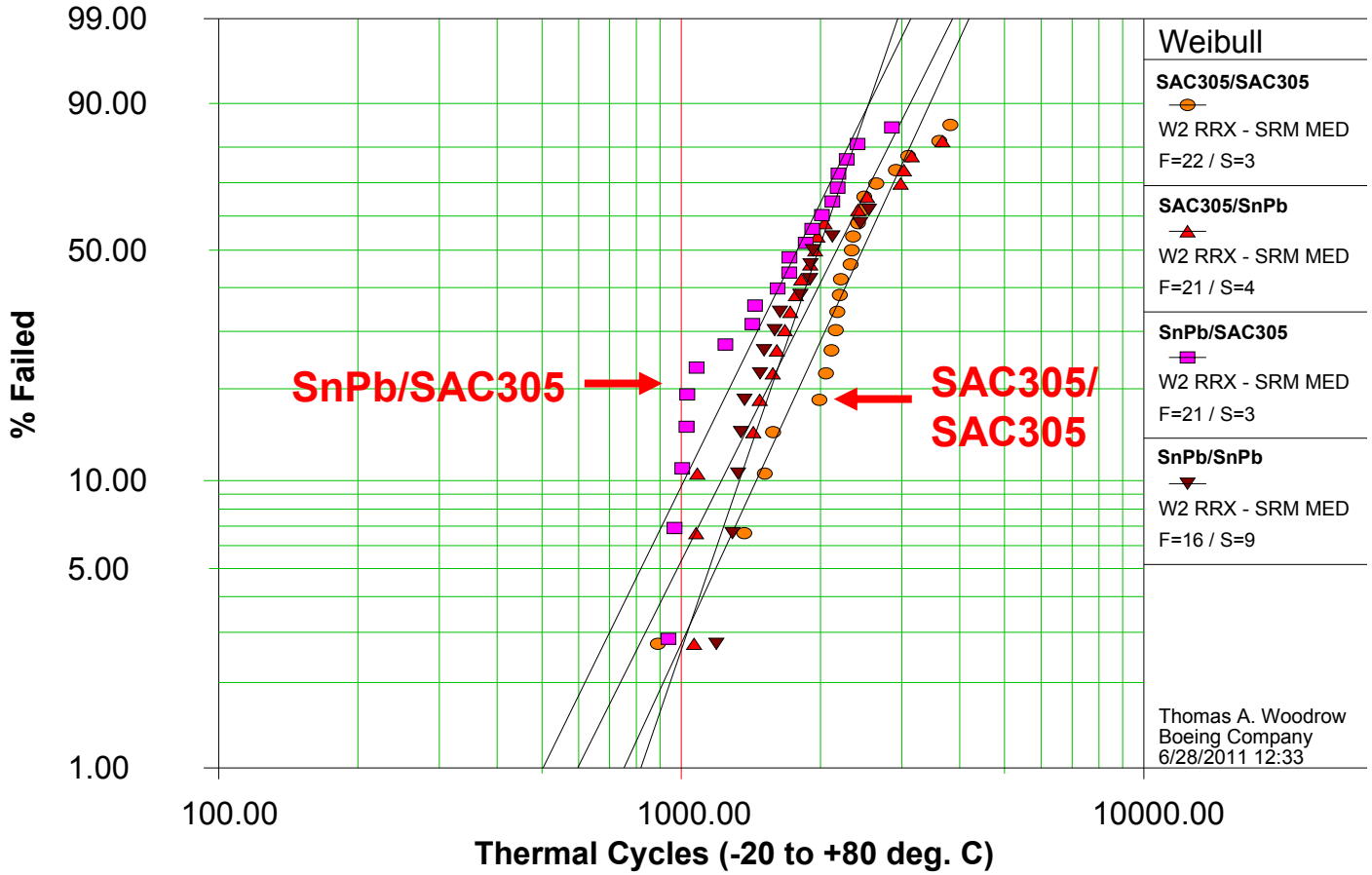
TQFP-144 Data (Dipped Leads)



$\beta 1=6.4225$, $\eta 1=1.2176E+4$, $\rho=0.9479$
$\beta 2=4.8409$, $\eta 2=9032.9926$, $\rho=0.9877$
$\beta 3=7.0514$, $\eta 3=9503.6298$, $\rho=0.9887$

Key: Solder Alloy/Component Finish

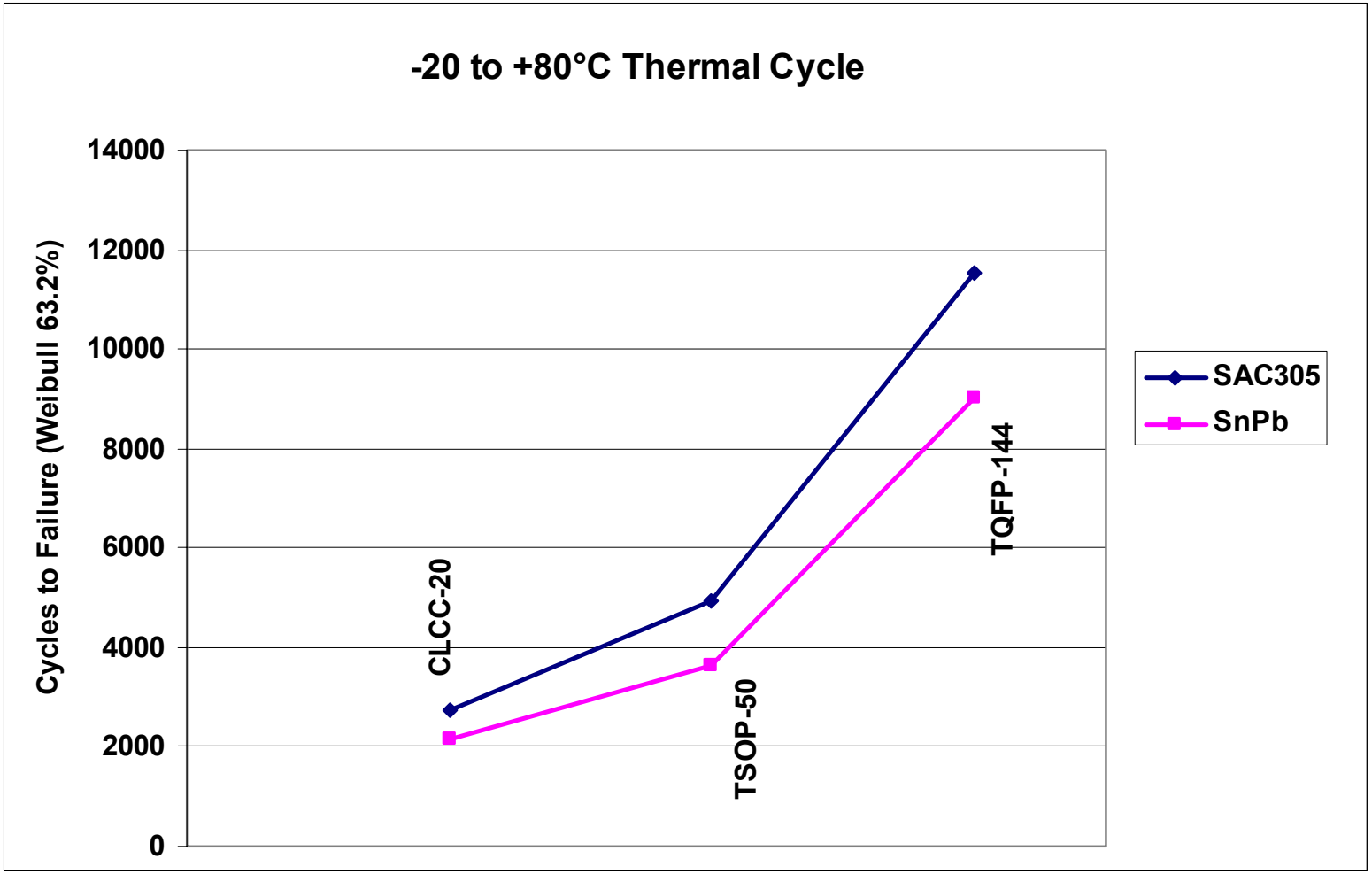
CLCC-20 Data



$\beta 1=3.5658$, $\eta 1=2732.5943$, $\rho=0.9664$
$\beta 2=3.2819$, $\eta 2=2426.2009$, $\rho=0.9360$
$\beta 3=3.3468$, $\eta 3=1988.0529$, $\rho=0.9434$
$\beta 4=4.7909$, $\eta 4=2137.7196$, $\rho=0.9052$

Key: Solder Alloy/Component Finish

Reliability Comparison of Eutectic SnPb and SAC305 Solder Joints on Various Components



Summary

- The results of this study to date suggest that for all component types, SAC305 is more reliable than eutectic SnPb solder with respect to mild thermal cycling.
- Rework increased SnPb solder joint performance and decreased lead-free solder joint performance.
- Mixing solders on BGA's gave poor performance.

Acknowledgements

- Thanks to Paul Vianco of Sandia National Laboratories for permission to use his microsections of pre-test NASA/DoD components.

Questions?