NASA DoD -55°C to +125°C Thermal Cycle Test Results

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{A NASA-DoD Lead-Free Electronics Project Consortium Testing Effort}

ABSTRACT
The implementation of lead-free soldering processes and materials in the commercial electronics sector has been completed due to the European Union Waste Electrical and Electronic Equipment (WEEE) and Reduction of Hazardous Waste (RoHS) Directives. These environmental legislative directives were targeted at industrial and commercial electronic products but had an unintended impact on aerospace/defense products due to global supply chain transition actions. A group of industry, academia, and government agencies initiated a lead-free solder alloy reliability investigation, building on an previous successfully completed activity, to characterize and understand various aspects of lead-free solder joint integrity under -55°C to +125°C thermal cycle conditions. The goal of the testing was to generate reliability data for test vehicles that were representative of IPC Class III High Performance Electronic products.

Key words: lead-free, reliability, thermal cycle testing, aerospace

BACKGROUND
The NASA-DoD Lead-Free Electronics Project is a continuation of the Joint Council on Aging Aircraft/Joint Group on Pollution Prevention (JCAA/JGPP) Lead-Free Solder Project [1]. This project included an investigation of a series of lead-free solder alloys using the requirements of the aerospace and military community, with a focus on the rework of SnPb and lead-free solder alloys and the mixing SnPb and lead-free solder alloys (i.e. mixed metallurgy solder joints) on a printed wiring assembly.

The JCAA/JGPP investigation selected the following solder alloys for testing:

- **Sn3.9Ag0.6Cu** (SAC) for reflow and wave soldering
- **Sn3.4Ag1.0Cu3.3Bi** (SACB) for reflow soldering
- **Sn0.7Cu0.05Ni** (SNIC) for wave soldering
- **Sn37Pb** (SnPb) for reflow and wave soldering

The NASA DoD Lead-free investigation selected these solder alloys for testing:

- **Sn3.0Ag0.5Cu** for reflow and manual soldering (SAC305: Tin (Sn); Silver (Ag); Copper (Cu))
- **Sn0.7Cu0.05Ni** for reflow, wave, and manual soldering (SNIC:Tin (Sn); Copper (Cu); Nickel (Ni); Germanium (Ge)
- **Sn37Pb** (SnPb) for reflow, wave, and manual soldering

The NASA DoD Lead-free investigation revised the solder alloys selected for this round of testing due to the pervasive industry use of SAC305 alloy and the emerging interest of the electronics industry in Tin/Copper–modified solder alloy compositions such as the SNIC (SN100C) alloy. The Sn37Pb solder alloy was again included for a baseline comparison.

The majority of NASA DoD test tasks were identical to those completed for JCAA/JGPP LFS Project. However, several additional investigation variables were included to address questions identified from the initial investigation results:

1. Determine the reliability of reworked solder joints in high-reliability military and aerospace electronics assemblies including mixed metallurgy situations.
2. Assess the process parameters for reworking high-reliability lead-free military and aerospace electronics assemblies.
3. Assess the reliability of chip scale packages (CSPs) and quad flat pack no-lead package (QFNs)
4. Characterize the solder joint reliability of the test vehicles under Drop Shock test conditions

OBJECTIVE
The objective of the study was to compare the solder joint integrity of selected lead-free solder alloys to Sn63/Pb37 solder alloy for a -55°C to +125°C temperature range in accordance with the IPC-9701 specification under various as-manufactured and reworked conditions.

PROCEDURES
Test vehicle
Figure 1 illustrates the test vehicle used in thermal cycle testing; it was 14.5 inches wide by 9 inches high by 0.090 inches thick and contained 6 layers of 0.5 ounce copper. The test vehicle was designed to meet IPC-6012, Class 3, Type 3 requirements. The laminate was FR4 per IPC-4101/26 with a minimum Tg of 170ºC and an immersion silver surface finish. A small subset of test vehicles was also procured with an electroless nickel / immersion gold (ENIG) surface finish. This laminate is the same material used in the JCAA/JGPP test vehicle thus enabling “apples-to-apples” data comparisons. In total, 193 test vehicles were produced

using the same printed wiring board fabricator who manufactured the JCAA/JGPP test vehicle.

Figure 1 Test Vehicle Design

All test vehicles were categorized as “Manufactured” or “Reworked”. “Manufactured” test vehicles represent printed wiring assemblies newly manufactured for use in new product. “Rework” test vehicles represent printed wiring assemblies manufactured and reworked prior to being tested. Mixed metallurgy situations were created allowing for the following test scenarios:

1. Forward Compatibility: a SnPb component is attached to a printed wiring assembly using lead-free solder with a lead-free profile.
2. Backward compatibility: a lead-free is component attached to a printed wiring assembly using SnPb solder with a SnPb solder profile.

In addition to the NASA-DoD Lead-Free Electronics Project test vehicles, the Naval Surface Warfare Center Crane Division (a NASA-DoD Consortium member), added 30 test vehicles to the NASA-DoD project in support of their Naval Supply Command (NAVSUP) sponsored “Logistics Impact of Lead-Free Circuits/Components” project. The primary purpose of the 30 test vehicle add-on was to perform multiple pass SnPb rework, once or twice, or randomly selected lead-free DIP, TQFP-144, TSOP-50, LCC and QFN components from SAC305 and SN100C soldered assemblies. Five of these test assemblies were included in the -55°C to +125°C thermal cycle testing to allow for data comparison purposes.

Test Components

A variety of component types and component finishes were included on the test vehicle. The test vehicle design incorporates components that are representative of the parts used in military/aerospace systems and is designed to reveal relative differences in solder alloy performance. The ceramic leadless chip carrier (CLCC) and thin small outline package (TSOP) component types were selected due to industry acknowledged solder joint integrity issues in Class III High Performance electronic products. The dual in-line package (DIP) components were selected to represent plated thru hole technology. The thin quad flat packages (TQFPs), ball grid arrays (BGAs), chip scale packages (CSPs) and quad flat pack no leads (QFNs) were selected to represent surface mount technology. Table 1 lists the various component types, their associated surface finishes and procurement component number. All components were “dummy” devices with pins internally daisy-chained and contained simulated die. All the components were procured from two sources – Practical Components and Texas Instruments.

Component Type	Component Finish	Part Number
CLCC-20	SAC305	20LCC-1.27mm-8.9mm-DC
	SnPb	
QFN-20	Sn	A-MLF20-.5mm-.65mm-DC
	SnPb	
QFP-144	Sn	A-TQFP144-20mm-.5mm-2.0-DC
	SnPb	
	NiPdAu	
	SAC305	
PBGA-225	SnPb	PBGA225-1.5mm-27mm-DC
	SAC405	
PDIP-20	Sn	A-PDIP20T-7.6mm-DC
	NiPdAu	
	SnPb	
CSP-100	SnPb	A-CABGA100-.8mm-1.0mm-DC
	SAC105	
	SN100C	
TSOP-50	Sn	A-TII-TSOP50-10.16x20.95mm-.8mm-DC
	SnBi	
	SnPb	

Table 1 Component types and finishes

Destructive Physical Analysis (DPA) was performed on samples from each of the component types used on the test vehicles. This was done to ensure that the components used in testing met the consortia required standards and to provide component specific dimensions/properties for use by the modeling community.

Test Vehicle Assembly

The test vehicles were assembled at the BAE Systems Irving, Texas facility. A detailed description of the specific tin/lead and lead-free soldering processes was detailed in the NASA-DoD Lead-Free Electronics Project Plan [2]. Table 2 lists the various categories of test vehicles that were assembled for the consortia testing plan.

Test Vehicle Type	Reflow Solder	Wave Solder	Number of Boards
Lead-Free Rework All Test Vehicles	SAC305	SN100C	33
SnPb Rework* All Test Vehicles	SnPb*	SnPb*	40
SnPb Manufactured Test Vehicles Thermal Cycle and Combined Environments Tests	SnPb	SnPb	17
SnPb Manufactured Test Vehicles Vibration, Mechanical Shock and Drop Tests	SnPb	SnPb	17
Lead-Free Manufactured Test Vehicles Thermal Cycle and Combined Environments Tests	SAC305	SN100C	20
Lead-Free Manufactured Test Vehicles Vibration, Mechanical Shock and Drop Tests	SAC305	SN100C	43
Lead-Free Manufactured Test Vehicles Thermal Cycle and Combined Environments Tests	SN100C	SN100C	11
Lead-Free Manufactured Test Vehicles Vibration, Mechanical Shock and Drop Tests	SN100C	SN100C	6
Lead-Free Manufactured Test Vehicles Crane Rework Effort	SN100C	SN100C	6

Table 2 Test Vehicle Assembly Details

* Table note: lead-Free profiles were used for reflow and wave soldering due to component finish configuration

All of the test vehicles were X-rayed and visually inspected in accordance with the IPC-JSTD-001 specifications for solder joint quality.

Test Vehicle Rework

One of the primary investigation variables was the rework of specific component types. Multiple facilities performed the rework activities – BAE Systems in Irving, Texas, Lockheed Martin in Ocala, Florida, and Rockwell Collins in Cedar Rapids, Iowa – in accordance with a very detailed, regimented consortia defined protocol. The rework protocol was based on IPC rework/repair specifications with some tailoring due to the consortia test vehicle component locations. Components reworked were grouped by rework solder alloy / material (i.e. SnPb, Flux only, SAC305 and SN100C). The location performing the rework chose what order to rework the solder alloy / material groups, but was required to use the detailed procedure for specific component locations within the solder alloy / material group. When reworking a component, the component was removed and replaced before moving to the next component. All details regarding the rework procedure, including temperature profiles, are contained in the NASA-DoD Lead-Free Electronics Project Plan [2].

TESTING PARAMETERS AND METHODOLOGY

THERMAL CYCLE PARAMETERS AND METHODOLOGY

The temperature cycle range used in the investigation was -55ºC to +125ºC with a 30 minute dwell at the high temperature extreme and a 10 minute dwell at the low temperature extreme. A maximum temperature ramp of 10°C/minute was used in the testing. The continuity of the components was continuously monitored throughout thermal cycle testing by an event detector in accordance with the IPC-9701 specification, with each component treated as a single resistance channel. An 'event' was recorded if the resistance of a channel exceeded 300 Ω for more than 0.2 μsec. A failure was defined when a component either:

- Recorded an event for 15 consecutive cycles,
- Had five consecutive detection events within 10% of current life of test, or
- Became electrically open.

Once a solder joint was designated a failure, the event detection system software excluded it from the remainder of the test. Detailed temperature profiling was conducted prior to the beginning of the thermal cycle conditioning to ensure that each test vehicle was subjected to uniform, consistent exposure to the test chamber temperatures. In the Rockwell Collins consortia thermal cycle testing effort, a total of 15 Manufactured, 15 Reworked and 5 Crane test vehicles were placed in the chamber (the total component population of 2,240). Figure 2 illustrates the thermal cycle temperature profile for the -55ºC to +125ºC testing and the resulting measured test vehicle temperatures. Figure 3 illustrates the test vehicles positioned in the -55ºC to +125ºC test chamber.

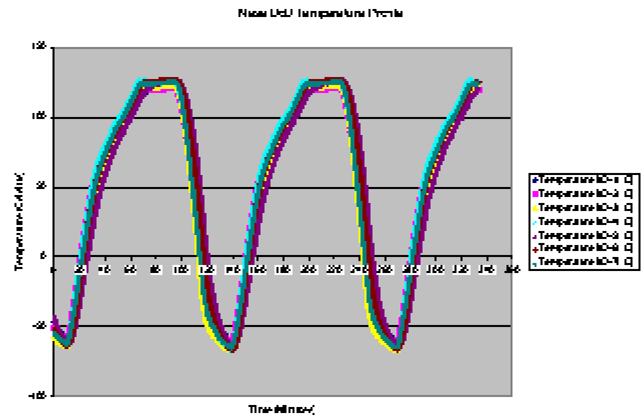

Figure 2 Thermal cycle profile for the -55ºC to +125ºC conditioning

Figure 3 Test Vehicles in the Thermal Cycle Chamber

TEST RESULTS

The -55ºC to +125ºC thermal cycle testing was not completed by the manuscript deadline and therefore no physical failure analysis activities for the test vehicles was available for publication. However, nearly all of the components had reached an N63 statistical value (i.e. most of the population had reached at lest 63% failure rate) thus allowing for a preliminary graphical analysis of the compiled failure data. The Manufactured test vehicle failure rates are shown in Table 3 and Reworked test vehicle failure rates are shown in Table 4.

Component Type	Total Failures	Population	Percent Failed
CLCC-20	232	311	74.6%
QFN-20	70	134	52.2%
QFP-144	228	309	73.8%
PBGA-225	156	279	56.0%
PDIP-20	160	220	72.7%
CSP-100	175	281	62.3%
TSOP-50	178	249	71.5%

Table 3 Manufactured Test Vehicle Component Population Failure Rates after 3600 Thermal Cycles

Component Type	Total Failures	Population	Percent Failed
PBGA-225	27	66	40.9%
PDIP-20	41	60	68.3%
CSP-100	31	67	46.3%
TSOP-50	62	99	62.6%

Table 4 Reworked Test Vehicle Component Population Failure Rates after 3600 Thermal Cycles

A preliminary statistical analysis for each component type was completed with the following sections summarizing the results for each specific component style

Ceramic Leadless Chip Carriers (CLCC-20) Results

The CLCC-20 components had accumulated 74.6% population failure after the completion of 3600 thermal cycles. The CLCC-20 components were included on the test vehicles because of their poor reliability track record on electronic assemblies used in harsh environments. Industry data [3] has demonstrated that the CLCC component style undergoes solder joint integrity degradation under IPC Class 3 use environments due to coefficient of thermal expansion (CTE) mismatch with the printed wiring assembly. CLCC-20 components had six different combinations (SAC/SAC, SAC/SnPb, SnPb/SAC, SnPb/SnPb, SNIC/SAC, SNIC/SnPb) tested and the results showed statistically significant differences in thermal cycle reliability. The completely lead-free combinations (SAC/SAC and SNIC/SAC) were out performed by solder/finish combinations that contained SnPb. The Weibull plot in Figure 4 summarizes the CLCC-20 thermal cycle test results.

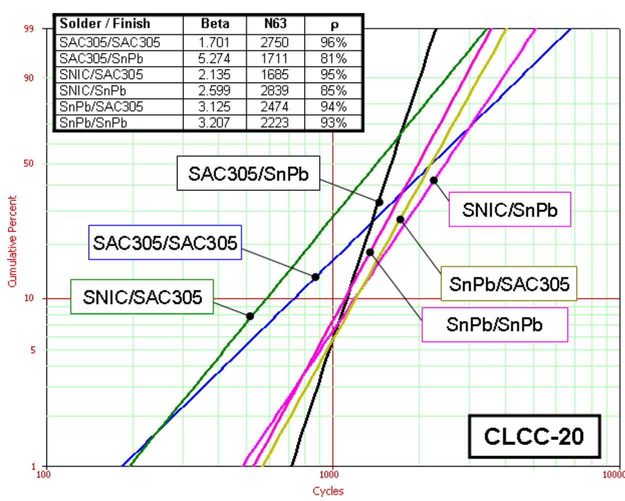

Figure 4 CLCC-20 Weibull Plot

Quad Flatpack No-Lead (QFN-20) Results

The QFN-20 components had accumulated 52.2% population failure after the completion of 3600 thermal cycles and were the most robust component type in the investigation. QFN-20 components had three different combinations (SAC/Sn, SNIC/Sn, SnPb/Sn) tested and the results showed statistically significant differences in thermal cycle reliability. The SnPb/Sn combination has the best thermal cycle performance. The Weibull plot in Figure 5 summarizes the QFN-20 thermal cycle test results.

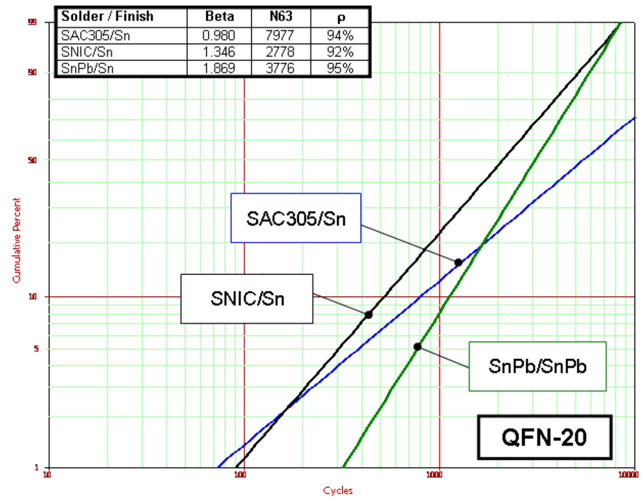

Figure 5 QFN-20 Weibull Plot

Quad Flatpack Package (QFP-144) Results

The TQFP-144 components had accumulated 73.4% population failure after the completion of 3600 thermal cycles. TQFP-144 components had eight different combinations (SAC/Sn, SAC/SnPb, SAC/SAC, SnPb/NiPdAu, SnPb/SnPb, SnPb/Sn, SNIC/Sn, SNIC/SnPb) tested for thermal cycle reliability. The SnPb/SnPb Dip combination had the best thermal cycle performance with all other combinations having similar performances. The Weibull plot in Figure 6 summarizes the TQFP-144 thermal cycle test results.

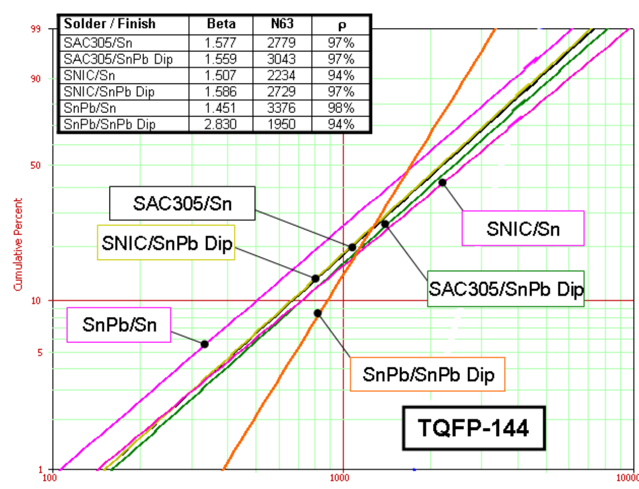

Figure 6 TQFP-144 Weibull Plot

Ball Grid Array (PBGA-225) Results

The PBGA-225 components had accumulated 56% population failure after the completion of 3600 thermal cycles. PBGA-225 components had six different combinations (SAC/SAC, SAC/SnPb, SNIC/SAC, SNIC/SnPb, SnPb/SAC, SnPb/SnPb) tested and the results showed statistically significant differences in thermal cycle reliability. The SnPb/SAC405 and the SAC305/SnPb had the best performance compared to the other combinations as shown in Figure 7. As shown in Figure 8, BGA components that were reworked, i.e. “1 RWK” exhibited similar reliability to their counterparts on the Reworked test vehicles that were not reworked.

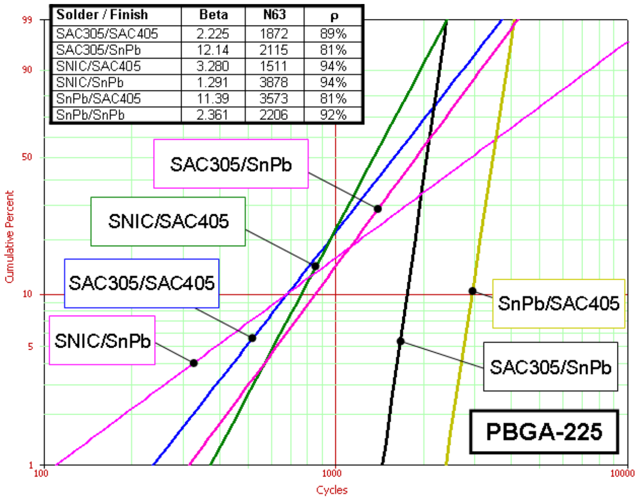

Figure 7 PBGA-225 Weibull Plot

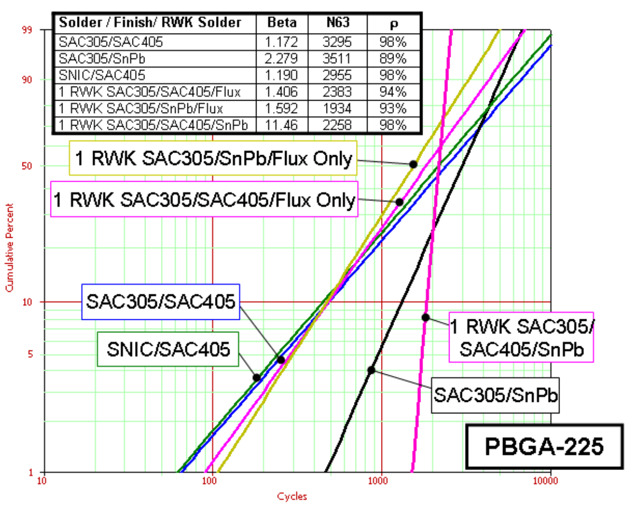

Figure 8 Reworked PBGA-225 Weibull Plot

Chip Scale Package (CSP-100) Results

The CSP-100 components had accumulated 62.3% population failure after the completion of 3600 thermal cycles. CSP-100 components had seven different combinations (SAC/SAC105, SAC/SnPb, SNIC/SAC105, SNIC/SNIC, SNIC/SnPb, SnPb/SAC105, SnPb/SnPb) tested and the results showed statistically significant differences in thermal cycle reliability as shown in Figure 9. The SnPb/SAC105 had the best performance and the SNIC/SAC105 had the poorest performance of the combinations tested. The reworked CSP-100 components (Figure 10) generally showed higher reliability than the manufactured components not reworked on the same test vehicle.

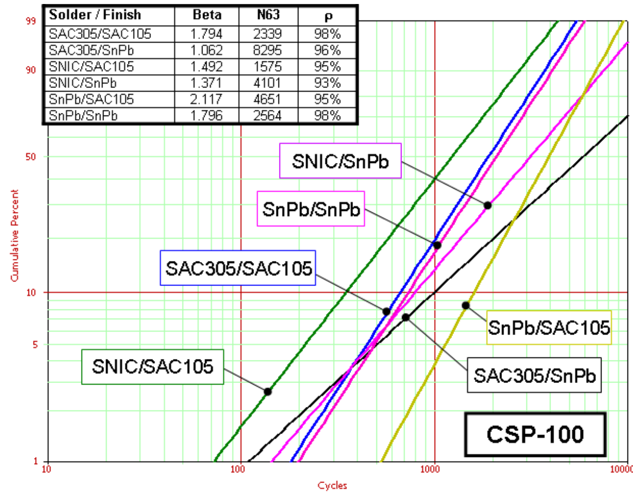

Figure 9 CSP-100 Weibull Plot

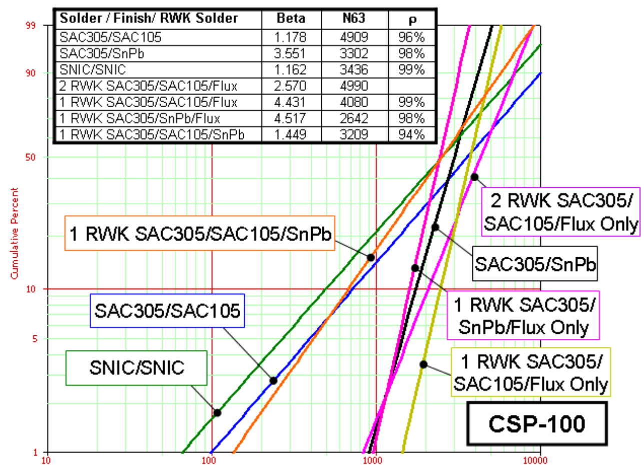

Figure 10 Reworked CSP-100 Weibull Plot

Thin Small Outline Package (TSOP-50) Results

The TSOP-50 components had accumulated 71.5% population failure after the completion of 3600 thermal cycles. TSOP-50 components had nine different combinations (SAC/SnPb, SAC/SnBi, SAC/Sn, SNIC/SnPb, SNIC/SnBi, SNIC/Sn, SnPb/SnBi, SnPb/Sn, SnPb/SnPb) tested. The lead (Pb) containing combinations slightly out preformed the lead-free combinations tested. The rework TSOP-50 components exhibited significantly different trends compared to those on the manufactured test vehicle. These results require further statistical review before drawing any conclusions. The Weibull plots in Figure 11 and Figure 12 summarize the TSOP-50 thermal cycle test results. Table 5 lists the Weibull characteristics for the TSOP-50 combinations.

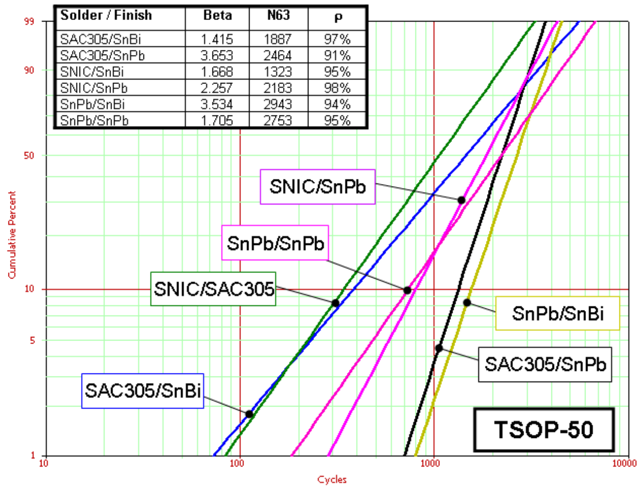

Figure 11 TSOP-50 Weibull Plot

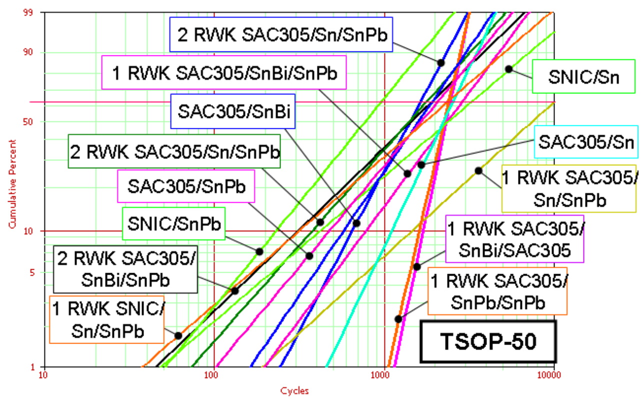

Figure 12 Reworked TSOP-50 Weibull Plot

Solder / Finish/ RWK Solder	Beta	N63	ρ
2 RWK SAC305/Sn/SnPb	2.407	1659	94%
2 RWK SAC305/SnBi/SnPb	1.225	1946	97%
2 RWK SAC305/Sn/SnPb	1.436	1806	92%
1 RWK SAC305/SnBi/SAC305	6.029	2470	86%
1 RWK SAC305/Sn/SnPb	1.157	10220	97%
1 RWK SAC305/SnBi/SnPb	1.706	2917	93%
1 RWK SAC305/SnPb/SnPb	5.567	2413	96%
1 RWK SNIC/Sn/SnPb	1.086	3345	97%
SAC305/Sn	2.670	2570	85%
SAC305/SnBi	1.856	1937	95%
SAC305/SnPb	1.520	2095	90%
SNIC/Sn	1.1065	2415	90%
SNIC/SnBi	1.562	976	96%

Table 5 TSOP-50 Weibull Statistics Table for Figure 12

Dual In-Line Package (PDIP-20) Results

The PDIP-20 components had accumulated 72.7% population failure after the completion of 3600 thermal cycles. The solder joint failure behavior of the PDIP-20 components was a surprise to the consortia team as the PDIP-20 failure rate documented in the JCAA/JGPP investigation results was only 8% after 4743 total thermal cycles. PDIP-20 components had four different combinations (SNIC/Sn, SNIC/NiPdAu, SnPb/NiPdAu, SnPb/Sn) tested and the results showed statistically significant differences in thermal cycle reliability. The SnPb/Sn combination registered the best performance. The reworked PDIP-20 component thermal cycle performance was not statistically different than a non-reworked PDIP-20 component. Additional resources will be focused on determining the exact root cause of the unexpected PDIP-20 failure rates. The Weibull plots in Figure 13 and Figure 14 summarize the PDIP-20 thermal cycle test results.

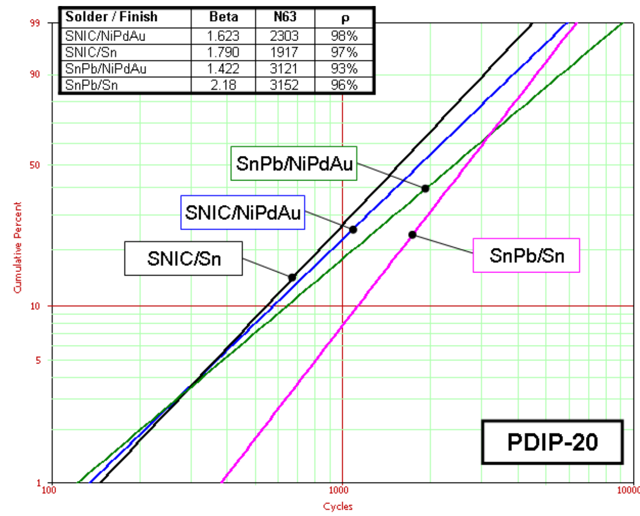

Figure 13 PDIP-20 Weibull Plot

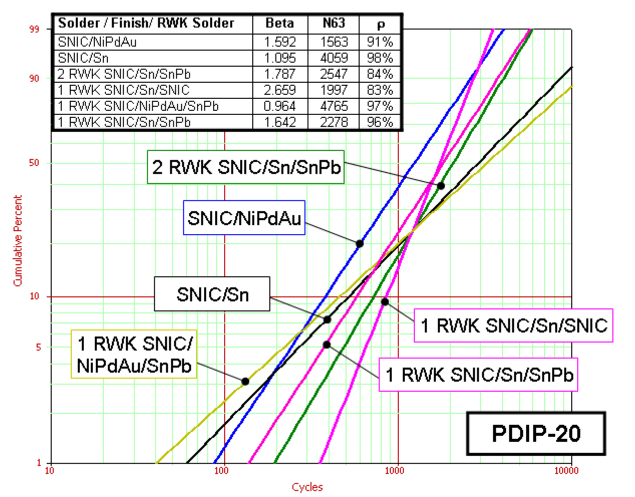

Figure 14 Reworked PDIP-20 Weibull Plot

DISCUSSION

Due to the large number of multiple combinations of solder paste alloys and component surface finishes, significant statistical analysis with comparison to physical failure analysis efforts will be required to fully understand the results once thermal cycle testing is completed. In general, the preliminary results show that the SnPb solder alloy out performed the two lead-free solder alloys. Test result outliers will be investigated to determine if they have a root cause due to non thermal cycle conditioning factors such as a component, test vehicle fabrication or manufacturing process defect. Statistical analysis of the reviewed test results will be conducted a second time in order to present a more concise picture of the solder joint root cause failure and revision of the Weibull characteristics listed in Table 6.

FUTURE WORK

Future work on the -55ºC to +125ºC thermal cycle testing efforts will be heavily focused on the physical failure analysis of the test vehicles and will include:

- Completion of thermal cycling of test vehicles
- Assessment for tin pest phenomenon
- Assessment for tin whisker phenomenon
- Assessment for pad cratering phenomenon
- Assessment for printed wiring board fabrication defects and anomalies
- Assessment for BGA/CSP process void and shrinkage void phenomenon
- Assessment PDIP-20 for copper dissolution degradation
- Metallographic cross-sectional analysis of solder joint failures
- Scanning Electron Microscopy (SEM) analysis including solder joint microstructure phase identification and elemental mapping
- Analysis of mixed metallurgy impact on solder joint integrity
- Verification of statistical analysis calculations

Once completed, the future work results will be published at an industry forum.

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Component Type	Solder	Finish	Rework Alloy	# Reworks	Board	Beta	N63	Component Type	Solder	Finish	Rework Alloy	# Reworks	Board	Beta	N63
CLCC-20	SAC305	SAC305	n/a	n/a	MAN	1.701	2750	TSOP-50	SAC305	SnBi	n/a	n/a	MAN	1.42	1887
CLCC-20	SAC305	SnPb	n/a	n/a	MAN	5.274	1711	TSOP-50	SAC305	SnPb	n/a	n/a	MAN	3.65	2464
CLCC-20	SNIC	SAC305	n/a	n/a	MAN	2.135	1685	TSOP-50	SNIC	SnBi	n/a	n/a	MAN	1.67	1323
CLCC-20	SNIC	SnPb	n/a	n/a	MAN	2.599	2839	TSOP-50	SNIC	SnPb	n/a	n/a	MAN	2.26	2183
CLCC-20	SnPb	SAC305	n/a	n/a	MAN	3.125	2474	TSOP-50	SnPb	SnBi	n/a	n/a	MAN	3.53	2943
CLCC-20	SnPb	SnPb	n/a	n/a	MAN	3.207	2223	TSOP-50	SnPb	SnPb	n/a	n/a	MAN	1.71	2753
QFN-20	SAC305	Sn	n/a	n/a	MAN	0.98	7977	TSOP-50	SAC305	Sn	SnPb	2	RWK	2.41	1659
QFN-20	SNIC	Sn	n/a	n/a	MAN	1.346	2778	TSOP-50	SAC305	SnBi	SnPb	2	RWK	1.23	1946
QFN-20	SnPb	Sn	n/a	n/a	MAN	1.869	3776	TSOP-50	SAC305	Sn	SnPb	2	RWK	1.44	1806
TQFP-144	SAC305	Sn	n/a	n/a	MAN	1.577	2779	TSOP-50	SAC305	SnBi	SAC305	1	RWK	6.03	2470
TQFP-144	SAC305	SnPb Dip	n/a	n/a	MAN	1.559	3043	TSOP-50	SAC305	Sn	SnPb	1	RWK	1.16	10220
TQFP-144	SNIC	Sn	n/a	n/a	MAN	1.507	2234	TSOP-50	SAC305	SnBi	SnPb	1	RWK	1.71	2917
TQFP-144	SNIC	SnPb Dip	n/a	n/a	MAN	1.586	2729	TSOP-50	SAC305	SnPb	SnPb	1	RWK	5.57	2413
TQFP-144	SnPb	Sn	n/a	n/a	MAN	1.451	3376	TSOP-50	SNIC	Sn	SnPb	1	RWK	1.09	3345
TQFP-144	SnPb	SnPb Dip	n/a	n/a	MAN	2.83	1950	TSOP-50	SAC305	Sn	n/a	n/a	RWK	2.67	2570
PBGA-225	SAC305	SAC405	n/a	n/a	MAN	2.225	1872	TSOP-50	SAC305	SnBi	n/a	n/a	RWK	1.86	1937
PBGA-225	SAC305	SnPb	n/a	n/a	MAN	12.14	2115	TSOP-50	SAC305	SnPb	n/a	n/a	RWK	1.52	2095
PBGA-225	SNIC	SAC405	n/a	n/a	MAN	3.28	1511	TSOP-50	SNIC	Sn	n/a	n/a	RWK	1.11	2415
PBGA-225	SNIC	SnPb	n/a	n/a	MAN	1.291	3878	TSOP-50	SNIC	SnBi	n/a	n/a	RWK	1.56	976
PBGA-225	SnPb	SAC405	n/a	n/a	MAN	11.39	3573	PDIP-20	SNIC	NiPdAu	n/a	n/a	MAN	1.62	2303
PBGA-225	SnPb	SnPb	n/a	n/a	MAN	2.361	2206	PDIP-20	SNIC	Sn	n/a	n/a	MAN	1.79	1917
PBGA-225	SAC305	SAC405	n/a	n/a	RWK	1.172	3295	PDIP-20	SnPb	NiPdAu	n/a	n/a	MAN	1.42	3121
PBGA-225	SAC305	SnPb	n/a	n/a	RWK	2.279	3511	PDIP-20	SnPb	Sn	n/a	n/a	MAN	2.18	3152
PBGA-225	SNIC	SAC405	n/a	n/a	RWK	1.19	2955	PDIP-20	SNIC	NiPdAu	n/a	n/a	RWK	1.59	1563
PBGA-225	SAC305	SAC405	Flux Only	1	RWK	1.406	2383	PDIP-20	SNIC	Sn	n/a	n/a	RWK	1.1	4059
PBGA-225	SAC305	SnPb	Flux Only	1	RWK	1.592	1934	PDIP-20	SNIC	Sn	SnPb	2	RWK	1.79	2547
PBGA-225	SAC305	SAC405	SnPb	1	RWK	11.46	2258	PDIP-20	SNIC	Sn	SNIC	1	RWK	2.66	1997
CSP-100	SAC305	SAC105	n/a	n/a	MAN	1.794	2339	PDIP-20	SNIC	NiPdAu	SnPb	1	RWK	0.96	4765
CSP-100	SAC305	SnPb	n/a	n/a	MAN	1.062	8295	PDIP-20	SNIC	Sn	SnPb	1	RWK	1.64	2278
CSP-100	SNIC	SAC105	n/a	n/a	MAN	1.492	1575								
CSP-100	SNIC	SnPb	n/a	n/a	MAN	1.371	4101								
CSP-100	SnPb	SAC105	n/a	n/a	MAN	2.117	4651								
CSP-100	SnPb	SnPb	n/a	n/a	MAN	1.796	2564								
CSP-100	SAC305	SAC105	n/a	n/a	RWK	1.178	4909								
CSP-100	SAC305	SnPb	n/a	n/a	RWK	3.551	3302								
CSP-100	SNIC	SNIC	n/a	n/a	RWK	1.162	3436								
CSP-100	SAC305	SAC105	Flux Only	2	RWK	2.57	4990								
CSP-100	SAC305	SAC105	Flux Only	1	RWK	4.431	4080								
CSP-100	SAC305	SnPb	Flux Only	1	RWK	4.517	2642								
CSP-100	SAC305	SAC105	SnPb	1	RWK	1.449	3209								

Table 6 Thermal Cycle Weibull Characteristics Summary