A Method to Evaluate PCBA Suppliers' Pb Free vs. Leaded Processes for Telecom Applications

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Abstract
The purpose of this program was to evaluate the solder joint reliability, using the IPC-9701 standard as a guideline, of PCBAs that were assembled with conventional leaded and ROHS compliant lead free processes and to evaluate the capabilities of multiple PCBA assembly houses. 6 sample groups of 26 samples each from 3 different suppliers were subjected to a full qualification plan, SEM, cross-sectional imaging and EDX analysis. The groups consisted of lead free (SAC) test coupons and standard leaded (SnPb) test coupons. The test coupons were populated with surface mount daisy chained dummy components. The component finishes were SnCu and the board finishes were immersion Ag. The coupons were subjected to mechanical strength (lead pull testing, vibration and impact tests), long term reliability (damp heat, temperature cycling and whisker growth tests) and solder joint quality (cross-sectioning, SEM imaging and EDX of components). The test results were analyzed to compare the capabilities of the 3 PCBA assembly houses and to evaluate the relative differences between the conventional leaded and ROHS compliant lead free processes.

Introduction
This program was used to assess and quantify 3 PCBA suppliers (labeled as A, B and C in this paper) to assemble leaded and lead free PCBAs. Data already exists for the long-term SnPb PCBA reliability of the three suppliers being evaluated in this program through the field data of all the products shipped. However the long-term reliability of lead free PCBAs is an unknown. In addition to comparing suppliers directly on SnPb or SAC processes, this program also assesses the long-term reliability of the lead free SAC PCBAs by comparing them to the leaded assembly.

Test Coupon Description
Six sample groups were used in this qualification program. A seventh group was added for supplier A since some deficiencies were found with the first group received. 6 of the 7 sample groups used in this qualification were PC008 test coupons from Practical components as pictured in figures 1 and 2. Suppliers A and B were evaluated using the PC008 test coupon for both the SnPb and SAC solders. Due to availability, supplier C was evaluated using PC008 test coupons for the SAC solder and a product PCBA was used for the SnPb process. In addition, supplier A SnPb process was qualified using two groups. The first PC008 group had deficiencies which were corrected and re-qualified using the second PC008 group. All the boards were populated and processed through the respective suppliers standard manufacturing lines. All of the board finishes were immersion silver on copper, and the lead finish was the default lead-free finishes provided in the kits for the PC008 test coupons (i.e., either 100% Sn or Sn/Cu alloy for leaded devices and 95.5Sn/4.0Ag/0.5Cu on lead free devices). Suppliers A and B use water soluble flux and supplier C used no-clean flux in their manufacturing processes. The paste used was the lead-free (SAC variant) used by the CM assembling the samples.

Test Description
Table 1 describes the tests that were performed on all the PCBA boards in order to qualify the various suppliers and verify the quality of the various boards. Table 1 lists the 6 (3 sets with SnPb and 3 with SAC solder) sets of 26 samples each into its various sub-groups for testing. Because the PCBAs from potential suppliers are used in telecom finished goods, some of the test conditions such as the damp heat, impact, vibration and temperature cycling test were chosen in order to represent the tests telecom finished goods are subjected to in their qualification program.

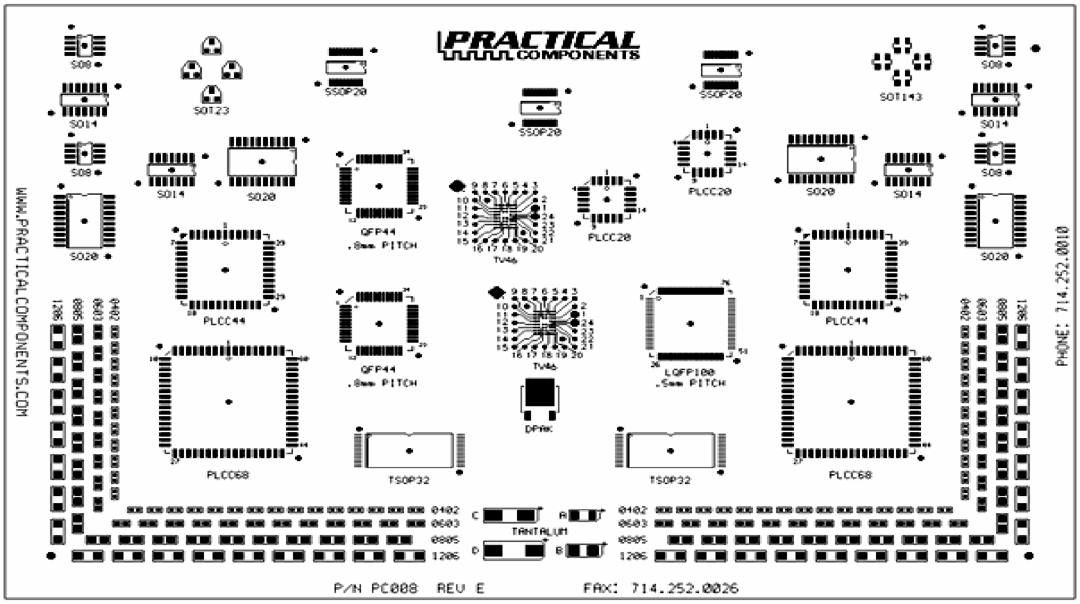


Figure 1 - Front Side of PC008 Test Coupon

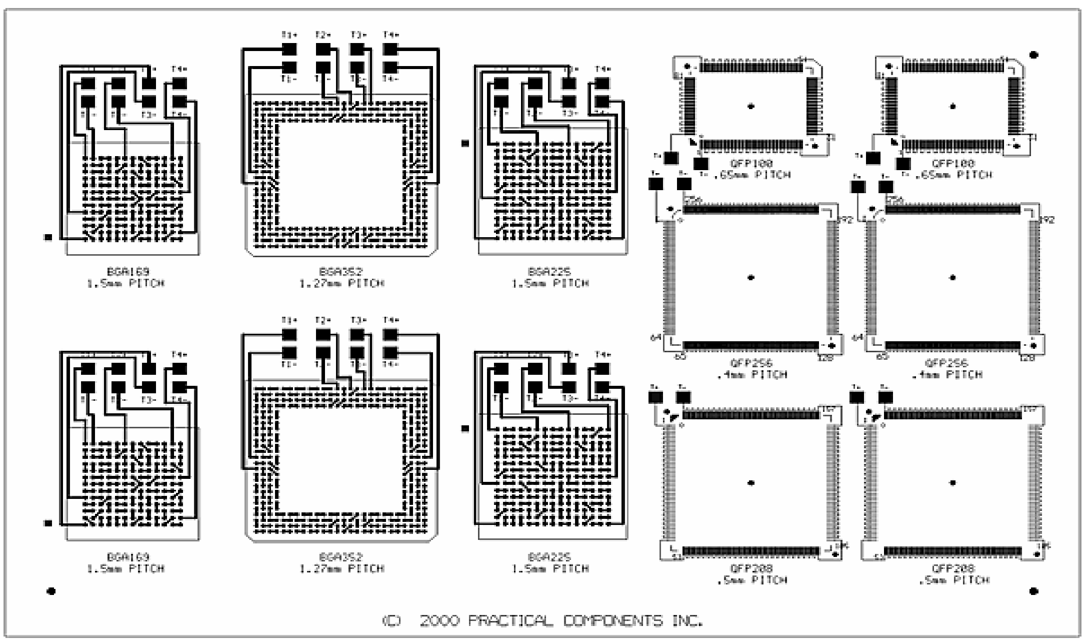


Figure 2 - Back Side of PC008 Test Coupon

Table 1 - Summary of test matrix for PCBA qualification

Test	Conditions	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
First Article Review	IPC-610, class 2	SS=3	SS=3	SS=11	SS=3	SS=3	SS=3
Inspection of Solder Joints	IPC-610, class 2	SS=3	SS=3	SS=11	SS=3	SS=3	SS=3
SEM 1000x + SEM dot maps of cross-section material boundaries	IPC-TM-650	SS=3					
Cross-section analysis of solder joints		SS=3					
Mechanical Strength of solder joints: lead pull strength	• IPC-TM-650 • Statistical analysis of data.		SS=3	SS=3, Post TC			
Electrical measurement	Functional Testing or ICT			SS=11	SS=3	SS=3	SS=3
Mechanical Impact	200g, 1.33ms, 5 pulses, 6 directions				SS=3		
Vibration - Sinusoidal	5-50Hz, 0.1oct/min, 0.5g and 50-500 Hz, 0.25oct/min, 3g				SS=3		
Vibration - Random	Mil-810-e Random, 10-40Hz @0.015 (g^2/Hz), 40-500Hz from 0.015 to 0.00015 linear (g^2/Hz), Duration = 1hr per axis, total = 3hrs				SS=3		
Temperature Cycle	• Soak= -40°C/125°C • Dwell time 15min • Rate change <10°C /min. Measurements at100, 500 & 1000 cycles.			SS=11			
Damp Heat	85ºC /85% RH, 1000 hours. Measurements at 168, 500 &1000 hrs.					SS=3	
Whisker Growth	60ºC /93%RH, 4000 hours. Measurements at 168, 500 & 1, 2, 3, 4000 hrs.						SS=3
Electrical Measurement	Functional Testing or ICT			SS=11	SS=3	SS=3	SS=3
Cross-section of solder joints and SEM Imaging	IPC-TM-650			SS=3			

Inspection of Solder Joints (All groups)

All PCBAs and all the populated components were inspected using standard, IPC-A-610, Acceptability of Electronic Assemblies, Revision D, (IPC, January 2000) to class 2 conditions. For clarity and ease of comparison, only the results for the QFP256 component will be presented in this paper. In addition, because the lead size and pitch is one of the smallest on the PC008 test coupon, the QFP256 is the worse case component and so was extensively analyzed for inter-metallics and lead-pull strength.

In addition to inspection, all suppliers were asked for a qualification report detailing there process and optimization methods. Suppliers B and C provided a report, while supplier A did not perform such qualification work.

Upon initial inspection, it was found that test coupons from supplier A for both the SnPb (group 1) and SAC test coupons demonstrated a significant amount of leads with blotchy and unsmooth solder reflow at the toe. Incidentally, IPC-610-D Class 2 considers these solder joints a pass because the solder height is at least 50% of the lead height at the heel, in cross-section the heel fillets looked good. However, it was found, (refer to lead pull data) that if the solder at the toe was blotchy or was not a smooth ski slope type fillet, the lead resulted in inferior lead-pull data both at pre and post stress levels, that is pre and post temperature cycling. Supplier A was retested using a new set of SnPb PC008 boards (group 2) and the lead-pull data between the first and second groups is presented in figure 3 and table 2.

Cross-section Analysis of Solder Joints (Groups 1 and 3)

Cross sections were performed on 3 boards as received and on 3 boards after the temperature cycling. All of the following components were cross-sectioned on each board.

- 1 high-pitch PQFP, QFP256 (only these results will be presented in this paper).
- 1 BGA with the highest joint count, BGA225.
- 1 micro-BGA or one with the finest pitch, BGA352.
- 1 passive 0402 component.
- 1 SOIC package, SO14.
- 1 PLCC, leadless chip carrier, PLCC68.
- 1 TSOP32 component.

The cross-sections were used to assess the quantity and coverage of solder at the solder joints.

Optical, SEM 1000x and EDX Dot Map imaging of Material Boundaries (Groups 1 and 3)

The solder joint cross-sections were imaged optically and by SEM with attached EDX. The optical images included 50x, 100x, 200x and 500x images of the solder under the heel, lead and toe of the component lead. SEM and EDX DOT MAP imaging was also done on the PLCC68 component. SEM imaging of at least 1000x magnification was performed to image the various material (e.g.: SAC, Immersion Ag and copper) boundaries. SEM dot maps were also generated to determine the thicknesses of the inter-metallic layers.

No deficiencies were found within these images. The images demonstrated good inter-metallic formations.

Lead-Pull Test (Group 2 and 3)

An Instron load machine was used to perform this part of the testing. Six samples from each group were tested. Three samples were tested after temperature cycling. Only the finest pitch PQFP was tested, QFP256. All data was examined statistically. 40 lead pulls were done per QFP256 component. 10 lead pulls per edge of the QFP256 component. A total of 120 lead pulls (40 per PCBA) were done per PCBA type. The lead was pulled along an imaginary perpendicular line half way between the lead toe and knee. All joints with cohesive failure of the solder were considered a failure and joints with adhesive failure of the solder, joints that came apart at the PCBA pad were considered passes. All data was examined statistically and the distributions were plotted in figures 3, 4 and 5.

Figure 3 and table 2 show SnPb lead-pull data and compare supplier A, groups 1 and 2. Group 1, are the initial PCBAs received from supplier A. They demonstrated a reflow deficiency, mainly a blotchy, non-smooth ski slope type fillet. The supplier corrected their process and supplied a second group. The data clearly shows the difference in performance of the two boards. Group 1 demonstrated a wider distribution of lead pull force, beta of 3.95 and an eta of 14.47 with 23 lead-pull failures. Post temperature cycling, the distribution was similar with a beta of 3.64 but had 98 lead pull failures and an eta dropping by half to 7.32. Group 2, with the excellent reflow, demonstrated a tighter distribution of lead pull force with a beta of ~11 and an eta of 7.74 with 0 lead-pull failures. Post temperature cycling, demonstrated a tighter distribution of lead pull force with a beta of 12.98 and an eta of 6.68 with 12 lead-pull failures. The tighter distribution of the initial and post temperature cycling tests suggests that reflow of the PCBAs was more uniform and consistent and all joints aged similarly. Consistency across all leads (demonstrated by a tighter distribution and a lower eta) is preferred over a wider distribution with a higher eta, which seems to suggest there are a lot of good leads with high lead pull forces, but there are equal amounts of substandard leads with extremely low lead-pull forces. In terms of long-term reliability, i.e.: post stress data, the tighter distribution is best.

Figure 4 and table 3 show SnPb lead-pull data and compares suppliers A group 2, B and C. Supplier A data, as above seems to suggest uniform solder joint strength with a similar beta pre and post temperature cycling and a slight uniform aging of the joints with a drop in eta from 7.74 to 6.68. Supplier B demonstrated similar beta and eta numbers as supplier A, but post temperature cycling beta was half of initial value. This suggests that the joints were not completely uniform and some joints aged more than others. Supplier C, was the opposite of supplier B. It had a low initial beta, and so low initial uniformity of the solder joints, but a very high beta after temperature cycling, suggesting the joints all aged in a similar way.

Figure 5 and table 4 show SAC lead-pull data and compares suppliers A, B and C. Supplier A was the worse performing. A lower initial beta and higher eta and a large drop in post temperature cycling eta suggest a large variation in solder joint quality. This is not surprising as initial inspection of these boards showed many leads with blotchy and unsmooth reflow. Suppliers B and C demonstrated very similar lead-pull data. The betas and eta of both suppliers are similar for both pre and post stress suggesting uniform aging across leads and so uniform reflow.

Looking at supplier B data and comparing the SnPb and SAC lead-pull results, we see that the post temperature cycling data for the SnPb and SAC are very similar. This suggests that when boards are assembled with good solder joints, the aging of the joints will be similar.

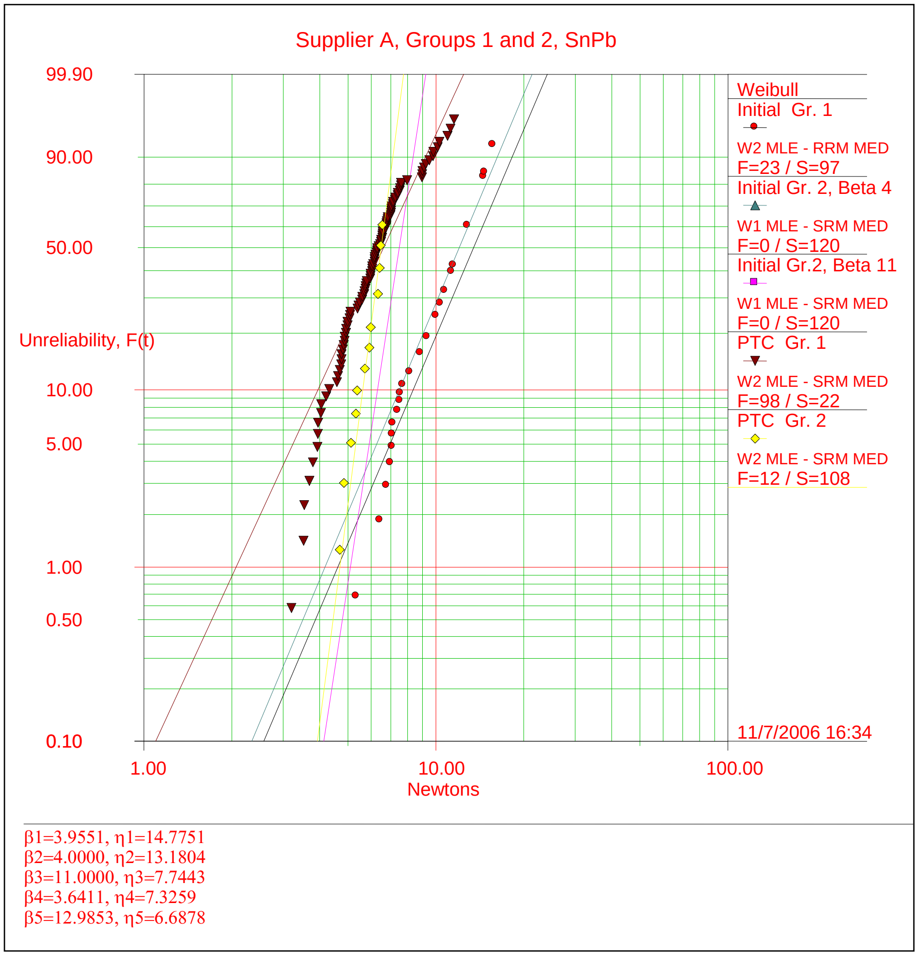


Figure 3 - Lead pull data of QFP256, SnPb, supplier A, test group 1 and 2.

Table 2 - Summary of data from SnPb lead-pull test, supplier A, group 1 and 2.

Supplier A	Groups	Slope (β)	Eta (η)
Initial	1	3.95	14.77
	2	4*	13.18
	2	11*	7.74
Post Temp Cycling	1	3.64	7.32
	2	12.98	6.68

*Since no failures (solder joint breaks) occurred the slope was set at 4 and 11 for comparison. There was no significant change in eta when the slope was varied from 9 and above. This suggests that eta for this set of data is around 7.7N. We can see from the PTC results that this INITIAL data slope is closer to 12 than 4.

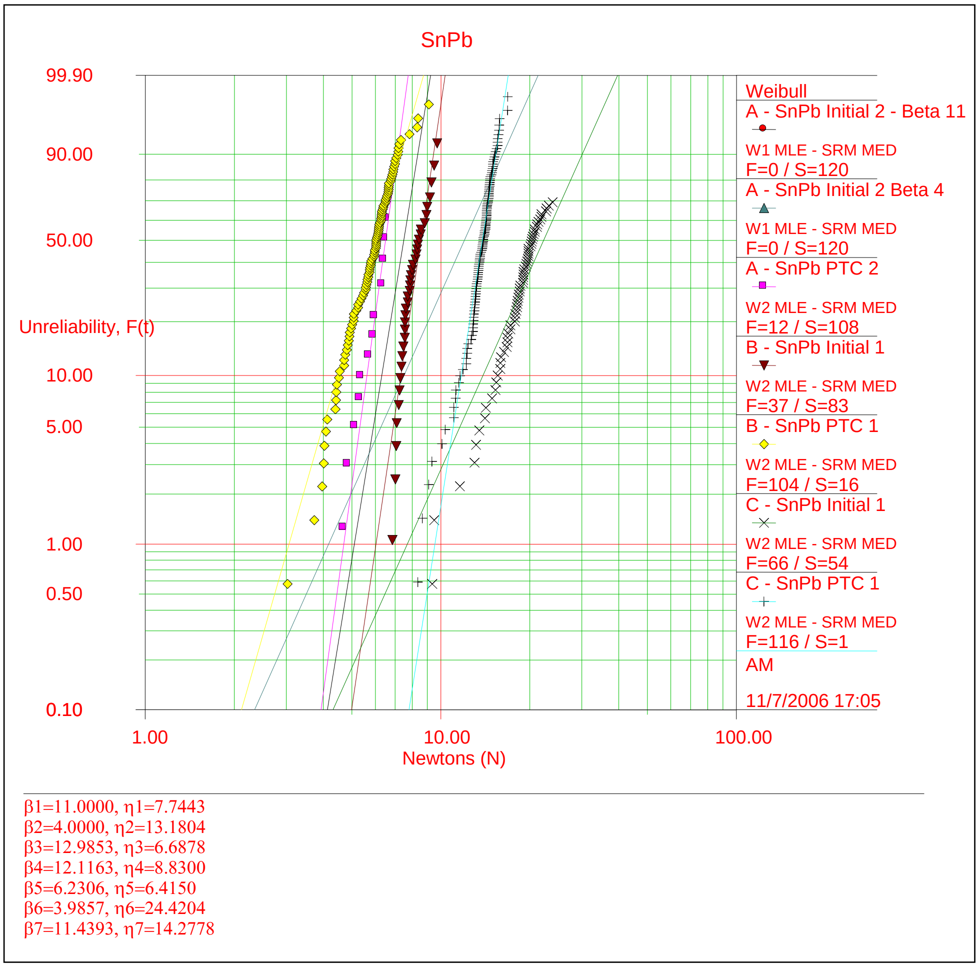


Figure 4 - Lead pull data of QFP 256, SnPb, all suppliers.**

Table 3 - Summary of data from SnPb lead-pull test, all suppliers.

Supplier	Supplier	Slope (β)	Eta Force (η)
Initial	A	4*	13.18
	A	11*	7.74
	B	12.11	8.83
	C**	3.98	24.42
Post Temp Cycling	A	12.98	6.68
	B	6.23	6.41
	C**	11.43	14.27

* Since no failures (solder joint breaks) occurred the slope was set at 4 and 11 for comparison. There was no significant change in eta when the slope was varied from 9 and above. This suggests that eta for this set of data is around 7.7N. We can see from the PTC results that this INITIAL data slope is closer to 12 than 4.
** Data for supplier C was collected on a QFP160 component with a lead thickness that was twice the QFP256 lead thickness of the PC008 test coupons.

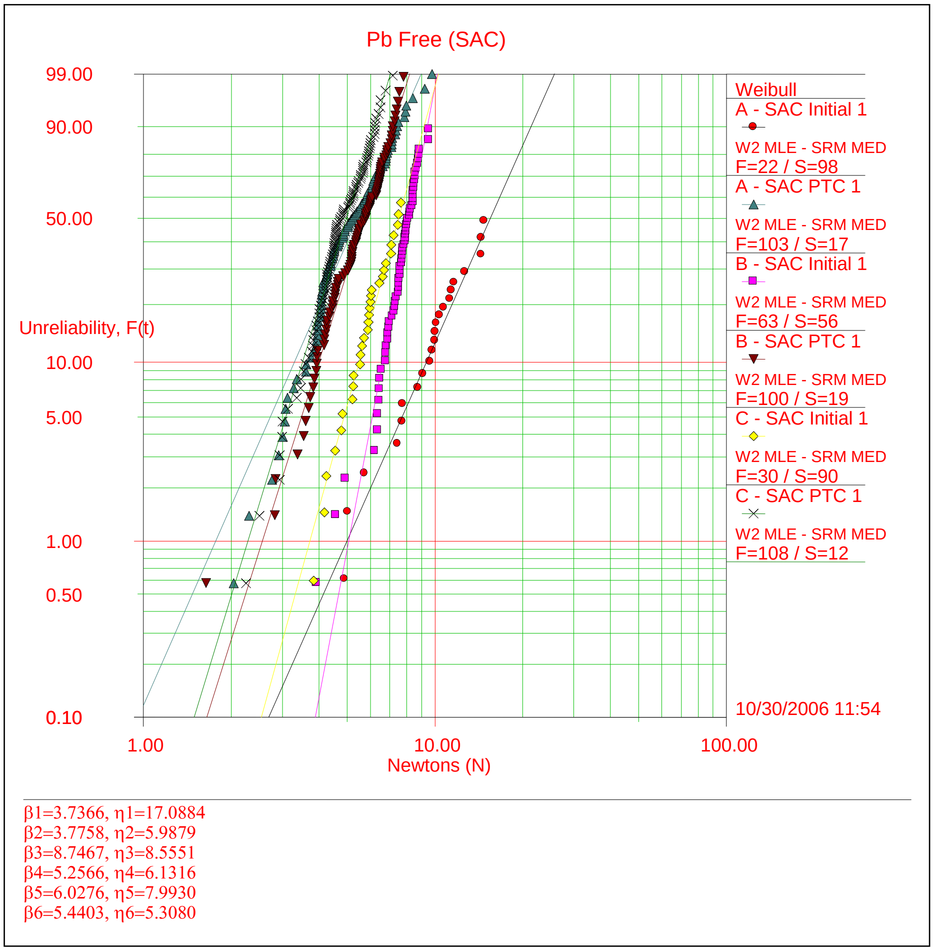


Figure 5 - Lead pull data of QFP256, SAC, all suppliers.

Table 4 - Summary of data from SAC lead-pull test, all suppliers.

Supplier	Supplier	Slope (β)	Eta (η)
Initial	A	3.73	17.08
	B	8.74	8.55
	C	6.02	7.99
Post Temp Cycling	A	3.77	5.98
	B	5.25	6.13
	C	5.44	5.30

Temperature Cycling (Group 3)

Since temperature cycling is the best stressor to accelerate solder creep and fatigue, 11 samples of each underwent this test. Using the before stress and after TC lead-pull data, we were able to evaluate the relative (between suppliers) long-term reliability of the PCBAs.

The pictures in figure 6 show two QFP256 SnPb solder joints. The one on the left shows a joint that had bad initial reflow. This type of reflow leads to inferior post temperature cycling performance, more cracks in the lead solder and some components on these boards actually came off the board after the temperature cycling test. Although only the SnPb case (supplier A, group 1) is pictured, this was also found to be true for the SAC soldered PCBAs. The picture on the right shows a QFP256 solder joint after temperature cycling from supplier A (group 2), but this time with the reflow process improved. Since SAC solder is much more difficult to reflow and has a greater chance to not reflow into a nice ski slope type toe fillet like a SnPb solder joint, incoming inspections for SAC based PCBAs will require a ski slope toe fillet to at least 50% lead height.

Figure 7 are representative cross-sections of a SnPb QFP256 solder joint post temperature cycling test. The images show excellent wetting and inter-metallic formations and no voiding. On the other hand for SAC joints as pictured in figure 8, the additional voiding expected from SAC based solder acted as nucleation sites for crack formation and propagation.

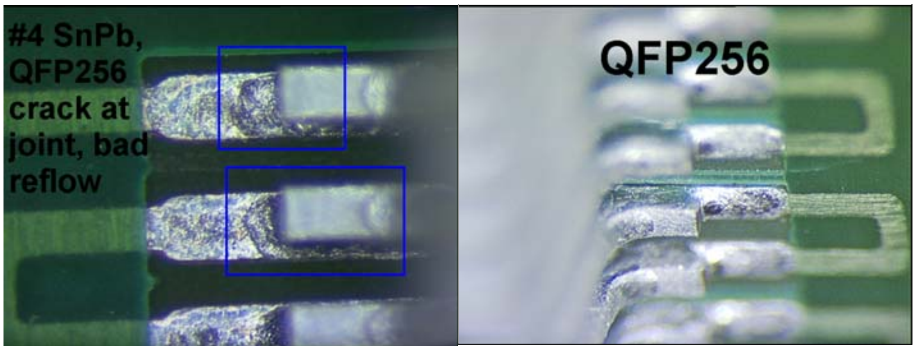


Figure 6 - Post 1000 cycles temperature cycling optical pictures of SnPb QFP256. Although the SnPb solder case is pictured, it was found that the same applies to SAC solder.

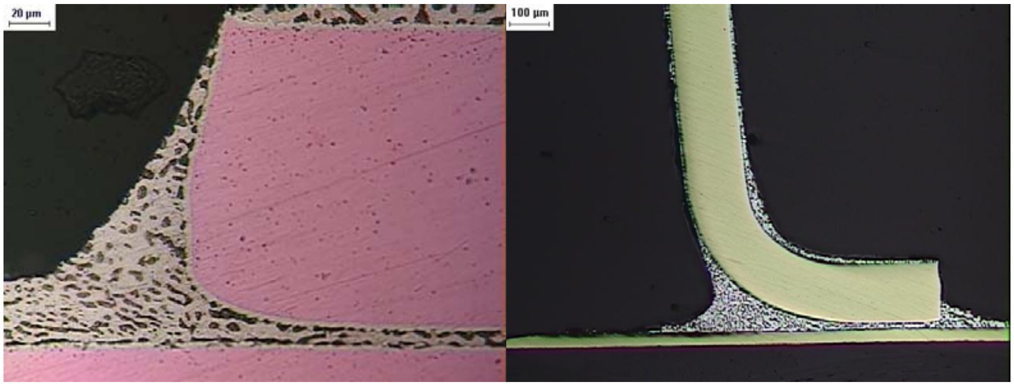


Figure 7 - Post temperature cycling cross-sections of SnPb QFP256.

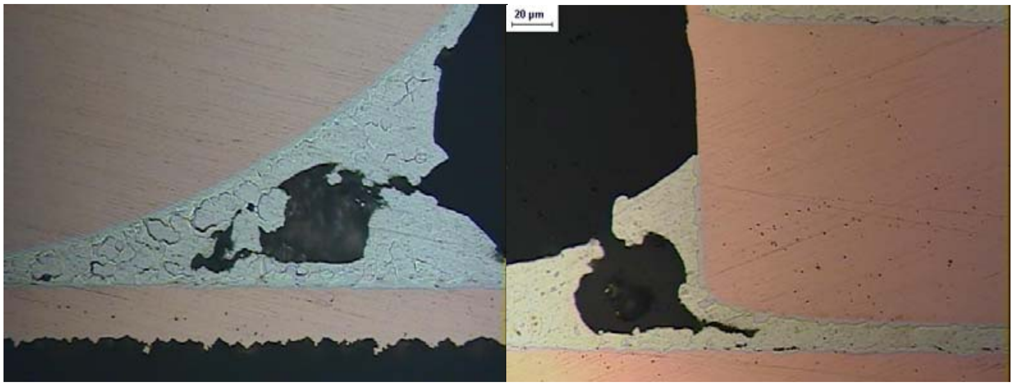


Figure 8 - Post temperature cycling cross-sections of SAC QFP256.

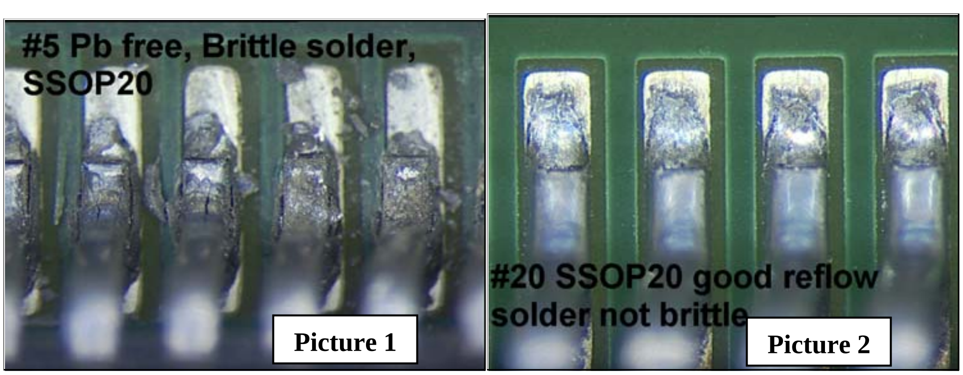
Mechanical Test (Group 4)
Three samples from each group underwent vibration and impact testing in order to evaluate the strength of the solder joint. This test was a de-risking test due to the telecom requirements.

No deficiencies were found within these samples. All boards (SnPb and SAC) were inspected after each test and no defective solder joints were observed. The resistance of all the daisy chained components was also measured and no defects were found. No differences were found between SnPb and SAC test coupons.

Damp Heat (Group 5)
Three samples from each group underwent 1000hrs of damp heat (85°C / 85% RH) testing in order to evaluate the cleanliness of the soldering process. Damp heat testing was used to evaluate if the various fluxes used in the various supplier processes were active after the heat from soldering was removed. The humidity from the damp heat test will activate any left over active flux and start causing corrosion on the lead and board surface. This test is also a telecom requirement.

No deficiencies were found within these samples. All boards (SnPb and SAC) were inspected after each test and no defective solder joints or corrosion was observed. In addition, samplings of BGAs were pulled off the boards so an inspection of the cleanliness underneath the BGAs could be conducted. No corrosion was observed for either SnPb or SAC solders. The resistance of all the daisy chained components was also measured and no defects were found. No difference found between SnPb and SAC test coupons.

Whisker Growth (Group 6)
The solder used in the soldering process of half the test coupons was a SAC (Tin, Silver, Copper alloy) lead free solder. 3 samples from each supplier underwent 4000hrs of whisker growth (60°C / 93% RH) testing in order to evaluate the propensity of whiskers to grow out of the component lead. The SnPb boards were also added to this group as control units. This test verified whether the solder reflow in the process was good. Good solder reflow produces no or very little whiskers and even if whiskers are produced, the length is so small that it does not short a neighbouring pin. Bad reflow produces very long whiskers which short to the neighbouring lead and also renders the joint brittle. This test also demonstrated how consistent and uniform the reflow was across the board. Pictures 3 and 4 in figure 9 show a joint from the same component from the same PCBA and the joints aged very differently. Refer to figure 9. All board components were examined at 50X magnification for Sn whiskers.



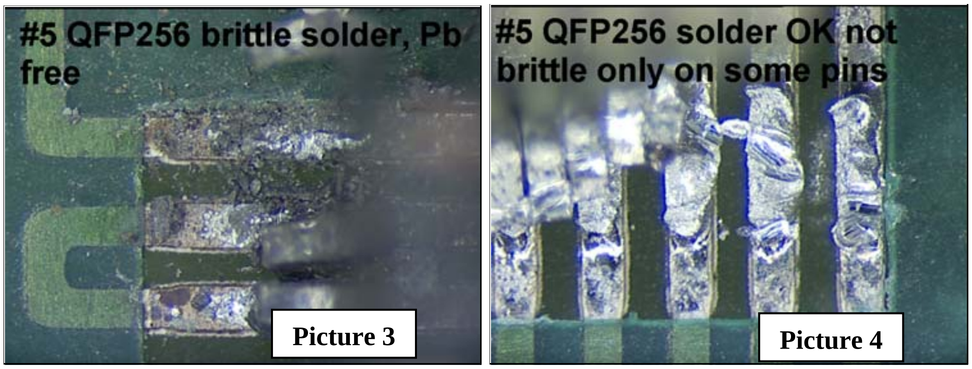


Figure 9 - Post 4000hrs whisker growth. The four pictures show the difference between a good and badly reflowed joint. Pictured is supplier A, group 1. Pictures 1 and 2 show a SSOP20 joint from 2 different boards that underwent whisker growth testing. In picture 1 the toe fillet is not very smooth but in picture 2 we see a smooth ski slope type toe fillet. The joint in picture 1 is brittle and in picture 2 is very strong. Both pictures 3 and 4 are of the same component QFP256 from the same PCBA. After 4000hrs of whisker growth testing a tweezers was used to push on the solder joint. In picture 3 the solder joint was very brittle and shattered due to bad solder reflow, ie: blotchy and non-smooth toe ski-slope fillet. In picture 4 the solder joint remained soft and malleable.

Interval Measurements (All groups)

All PCBAs were inspected using standard IPC-A-610, Acceptability of Electronic Assemblies, Revision D, (IPC, January 2000). All boards were inspected to IPC-A-610D, class 2. All PCBAs were appropriately tested electrically (resistivity test) to ensure proper continuity of all daisy chained components.

Conclusion

Some general conclusions can be drawn from the data collected:

- PCBAs with good ski-slope type toe fillets are a good indicator as to whether a supplier performed a good reflow on a particular PCBA. Whisker growth and lead-pull data validates the need for a good ski-slope solder joint, particularly for lead free solders. We found this connection to be so strong, that we will make it a requirement for our suppliers for all SAC solder based PCBAs even though IPC-610 does not have this as a requirement.
- Whisker growth data also suggests that in order to minimize whiskers and joint brittleness, a good ski-slope type toe fillet is needed for SAC based joints. It was found that leads with excellent reflow did not become brittle and did not grow any large (as seen under 50X magnification) whiskers. The whisker growth test was also a good indicator of reflow uniformity across a PCBA.
- From the temperature cycling test the added voiding sites seen in SAC solders act like nucleation sites for crack propagation. Although the cross-sectional images show this, when a good reflow was present, (looking at supplier B lead-pull data) this did not seem to be an issue for solder joint strength.
- From the lead pull data, when PCBAs are assembled with good solder joints, the initial distribution of lead-strengths is tighter for SnPb than for SAC but the eta is similar. Post aging or temperature cycling, both SnPb and SAC joints seem to age the same and the lead-pull strength distributions, beta, and eta become similar.
- No differences were found between SnPb and SAC solder joints after impact and vibration testing.
- No differences were found between SnPb and SAC solder joints after damp heat testing.

In light of these results, it would be prudent to implement an on-going reliability test program when SAC PCBAs become a requirement. A test matrix based on a subset of tests performed in this program implemented on a random sampling of SAC based PCBAs from the supplier should go through at least whisker growth, temperature cycling and lead-pull testing. When suppliers can demonstrate a consistent performance on all three tests, the on-going reliability program requirements can be reduced. For whisker growth, no brittle joints are to be present after 4000hrs. For temperature cycling no cracking of solder joints is to be present and for the lead-pull data initial and post stress betas and etas are to be similar.

References

- **IPC-A-610**, Acceptability of Electronic Assemblies, Revision D, (IPC, January 2000).
- **IPC-9701**, Performance Test Methods and Qualification Requirements for Surface Mount Solder Attachments, (IPC, January 2000).
- Tin Whisker Acceptance Test Requirements, NEMI Tin Whisker Users Group, July 28, 2004.
- **JEDEC Standard JESD201**, Environmental Acceptance Requirements for Tin Whisker Susceptibility of Tin and Tin Alloy Surface Finishes, March 2006.

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Angelo Miele & Bill Birkas

Content:

- Summary
- Strategy
- Test Vehicle
- Qualification Test Plan
- Results
- Conclusion

A Method to Evaluate PCBA Suppliers' Pb Free and Leaded Processes for Telecom Applications

- A test coupon that had electrical packaging technologies on it representative of all JDSU PCBAs was tested and qualified. JDSU PCBA product assemblies are considered qualified by similarity to the test coupons.

- IPC-9701, Performance Test Methods and Qualification Requirements for Surface Mount Solder Attachments, and JEDEC standard JESD201, Environmental Acceptance Requirements for Tin Whisker Susceptibility of Tin and Tin Alloy Surface Finishes, were used as the guidelines to test and qualify the test coupons.

Materials Used in PCBA Assembly

The test coupon selected is a double sided board with fine pitch PQFPs and BGAs on one side and course pitch surface mount and passive components on the other side.

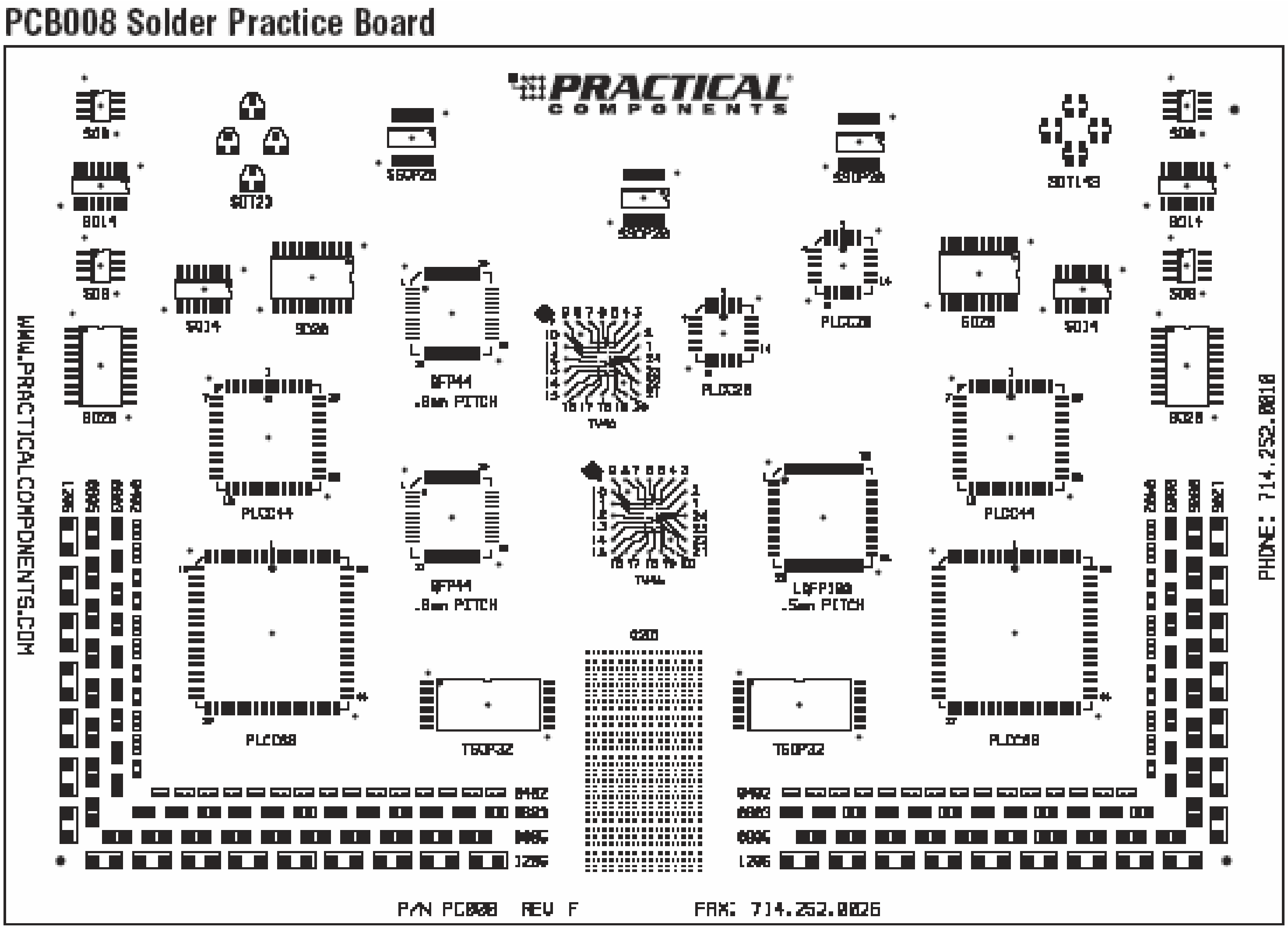
Components were either Sn, of CuSn plated, and the board finish was immersion silver. Both clean, and no-clean flux SAC 305 solder paste was used.

The following table is a summary of the board used.

Board manufacturer	Practical Components
Board material	Isola 410
Board finish	Immersion silver
Solder paste	Alphametals WST-619
Solder flux	Alphametals Lonco 3355-11 Water Soluble Flux
Solder wire	Alphametals Pure Core Wire SAC 305
Stencil (top)	Stainless steel - laser cut (5 mil)
Stencil (bottom)	Stainless steel - laser cut (6 mil)

JDSU Test Coupon (Top Side)

The following schematic shows the package types mounted on the top side of the PCB.



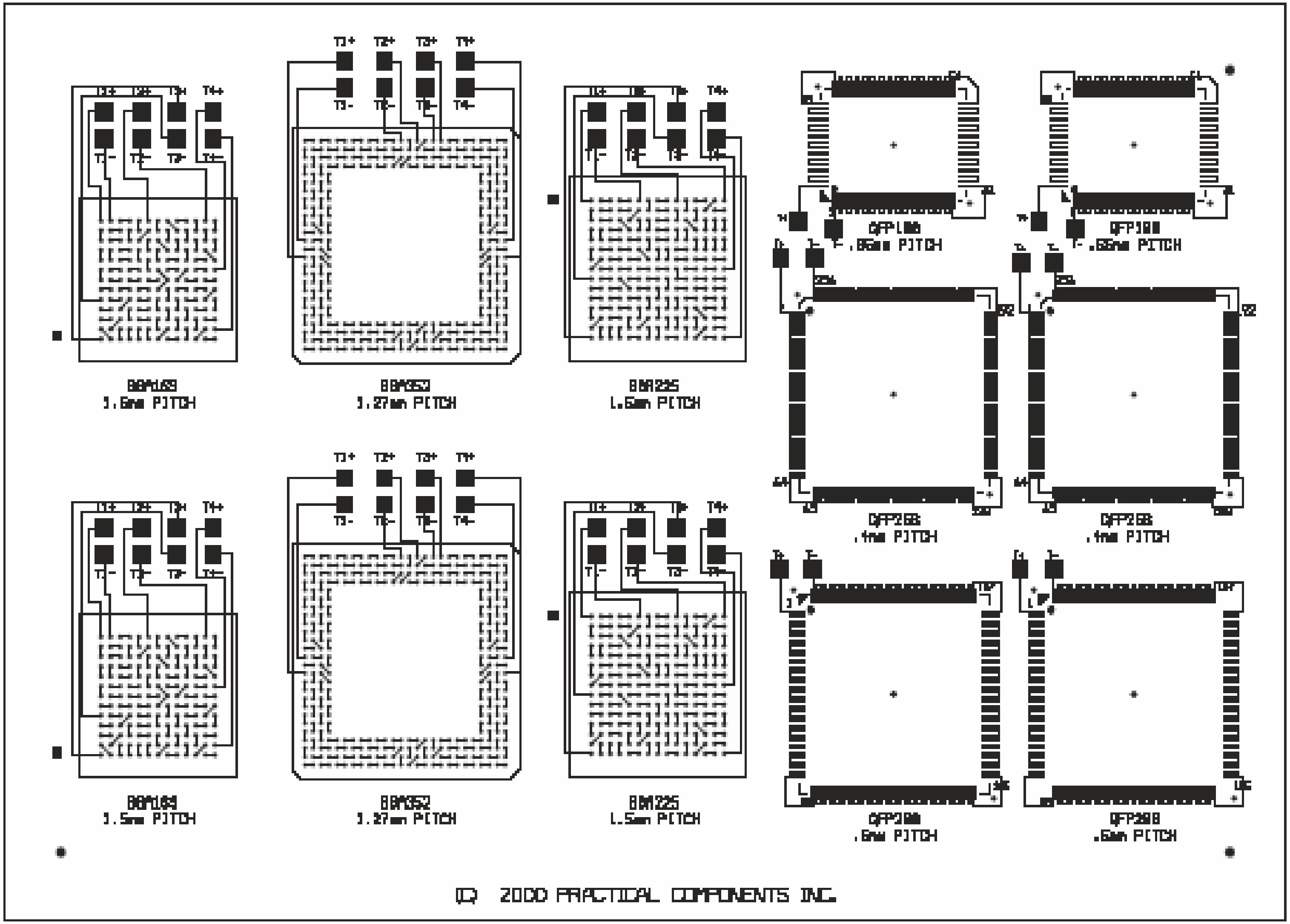
Standard finish is Immersion Silver (also available with OSP or ENIG finish).

Top view—actual board size is 5.5" x 8".

JDSU

Test Coupon (Bottom Side)

The following schematic shows the package types mounted on the bottom side of PCB.



Bottom view— actual board size is 5.5" x 8".

Summary of Test Matrix for PCBA Qualification

The following is the test matrix used to qualify each contract manufacturer to assemble lead-free PCBAs

Test	Conditions	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
First Article Review	IPC-610, class 2	SS=3	SS=3	SS=11	SS=3	SS=3	SS=3
Inspection of Solder Joints	IPC-610, class 2	SS=3	SS=3	SS=11	SS=3	SS=3	SS=3
SEM 1000x + SEM dot maps of cross-section material boundaries	SEM imaging	SS=3					
Cross-section analysis of solder joints	IPC-TM-650	SS=3					
Mechanical Strength of solder joints: lead pull strength	• IPC-TM-650 • 10 N for non-cycled leads • 5 N for cycled leads		SS=3	SS=3, Post TC			
Electrical measurement	Functional Testing or ICT			SS=11	SS=3	SS=3	SS=3
Mechanical Impact	200g, 1.33ms, 5 pulses, 6 directions				SS=3		
Vibration - Sinusoidal	5-50Hz, 0.1oct/min, 0.5g and 50-500 Hz, 0.25oct/min, 3g				SS=3		
Vibration - Random	Mil-810-e Random, 10-40Hz @0.015 (g^2/Hz), 40-500Hz from 0.015 to 0.00015 linear (g^2/Hz), Duration = 1hr per axis, total = 3hrs				SS=3		
Temperature Cycle	• Use ETS4-1SW Thermal shock chamber • Soak= -40°C/125°C • Precool / preheat = -40°C/80°C • Cold Dwell=20min • Hot Dwell = 30min Measurements at 24, 48, 100, 500 & 1000 cycles.			SS=11			
Damp Heat	85°C /85% RH, 1000 hours. Measurements at 168, 500 &1000 hrs.					SS=3	
Whisker Growth	60°C /93% RH, 4000 hours. Measurements at 168, 500 & 1, 2, 3, 4000 hrs.						SS=3
Electrical Measurement	Functional Testing or ICT			SS=11	SS=3	SS=3	SS=3
Cross-section of solder joints	IPC-TM-650			SS=8	SS=3	SS=3	SS=3

Summary of Test Matrix for PCBA Qualification

The following is the test matrix used to qualify each contract manufacturer to assemble lead-free PCBAs

- Additional test added to test matrix:
  - Whisker Growth Temp Cycling:
    - Total = 1500 cycles
    - -40C/85C
    - 10 minute dwells
    - PCBAs to be inspected every 500 cycles for Sn whiskers.

- 4000 hrs High Temp Storage Whisker Growth test is the more revealing of the two tests. Condition was 60C/93%, the new conditions according to JEDEC 201, March 2006 is now 55C/85%.

Summary of results - Initial IPC-A-610-D Inspection

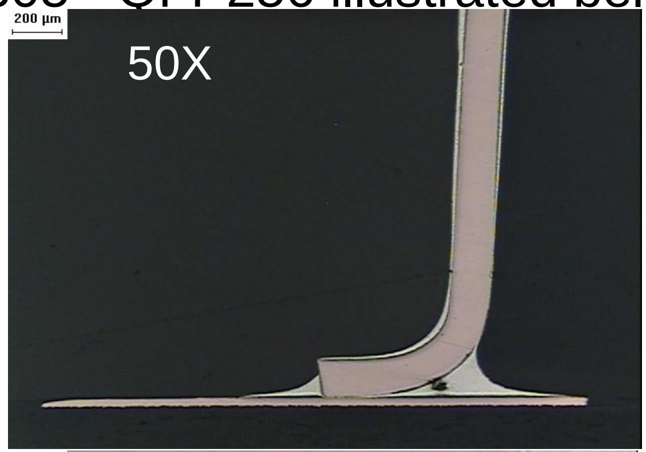
- All boards inspection at incoming according to IPC-A-610-D, class 2.

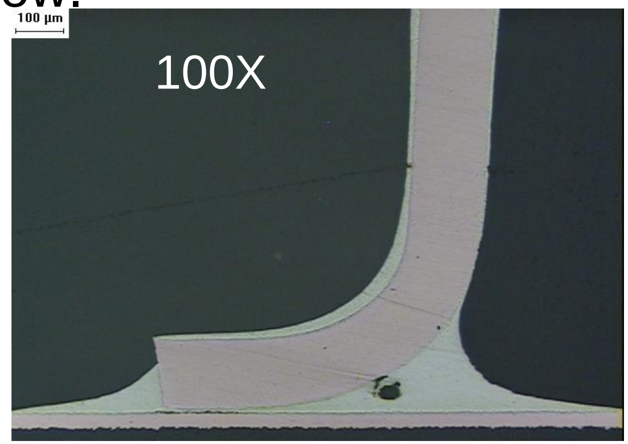
The following pass/fail criteria was used during each test.

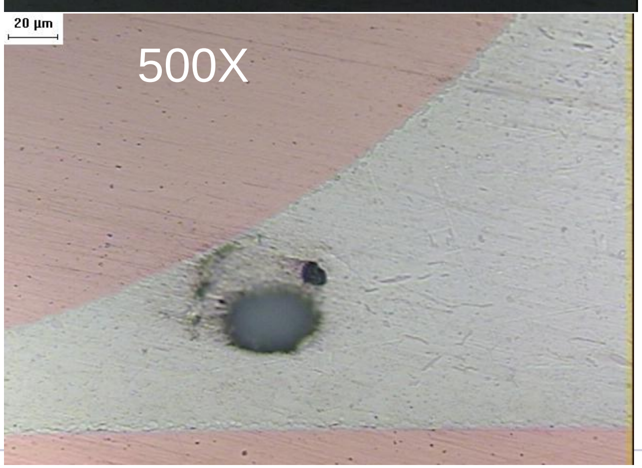
Criteria	Attribute
Inspection	As per IPC-A-610D
Cross-section	▪ voiding (less than 25% of joint) ▪ good heel wetting ▪ good toe wetting ▪ intermettalics (evidence of good wetting) ▪ intermettalics (less than 10um thick) ▪ silver plating (completely consumed in solder joint)

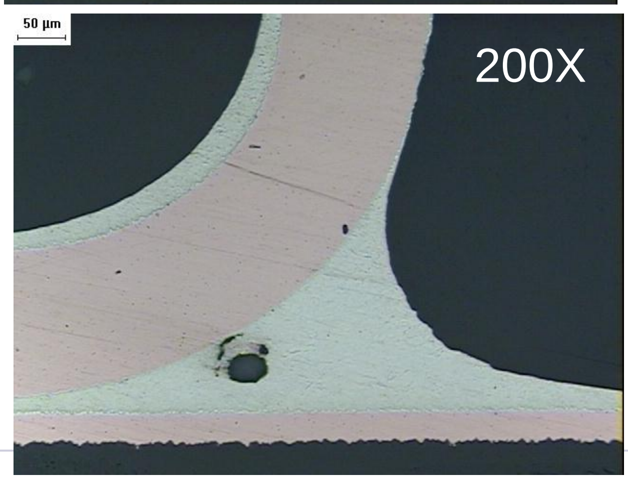
Summary of results - Cross-sectional Analysis of Joints

- 3 boards from incoming and Post Temp Cycling were analyzed.
- 0402, PLCC68, SO14, BGA225, BGA352, QFP256, QFP100 components were analyzed.
- SAC 305 - QFP256 illustrated below.



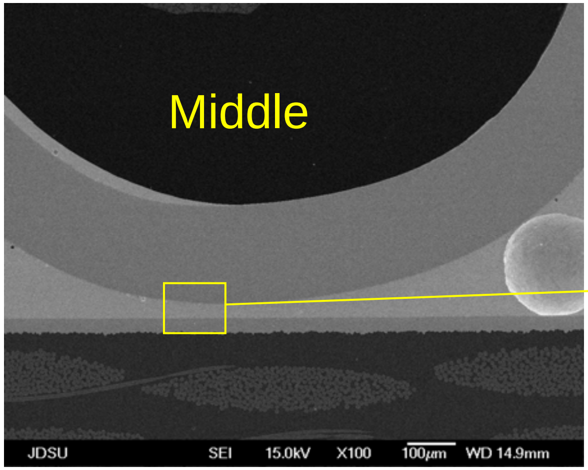


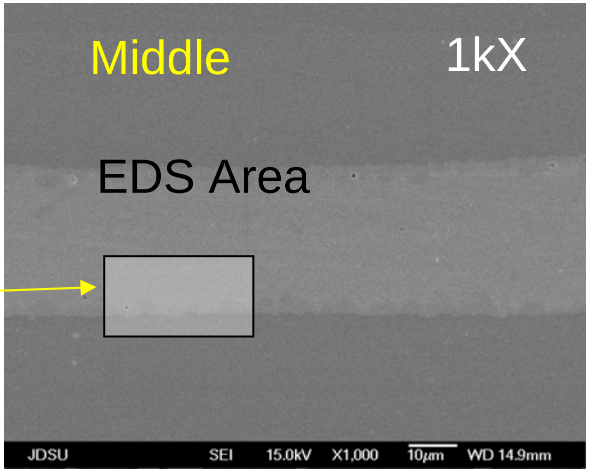


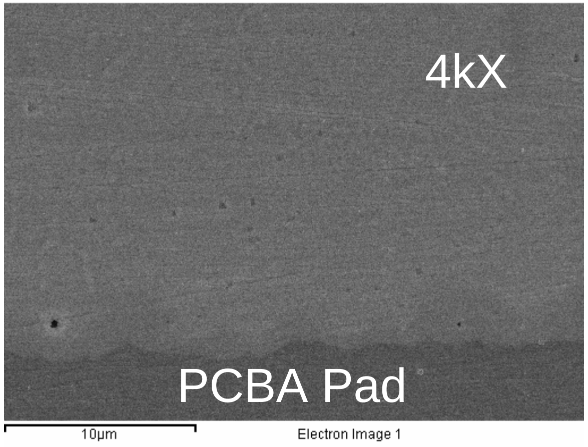


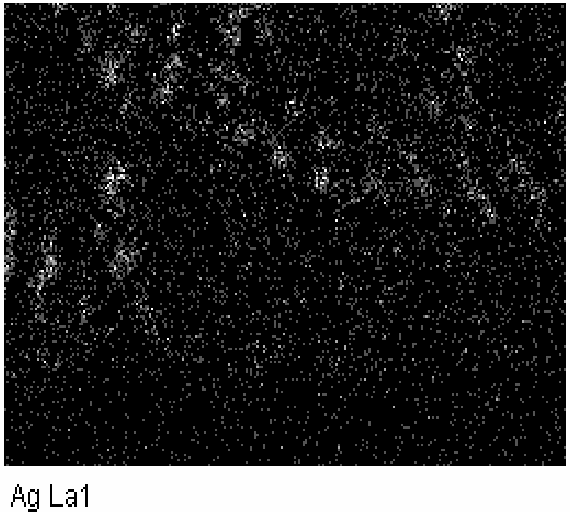
Summary of results - Optical, SEM 1000x and EDX Dot Map imaging of Material Boundaries

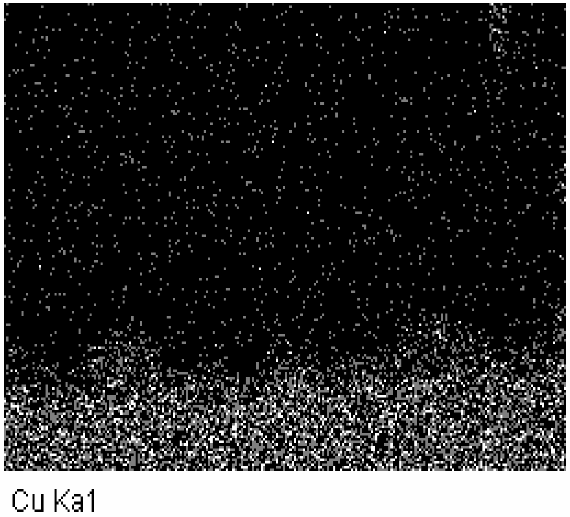
- One PLCC68 component from each group analyzed.





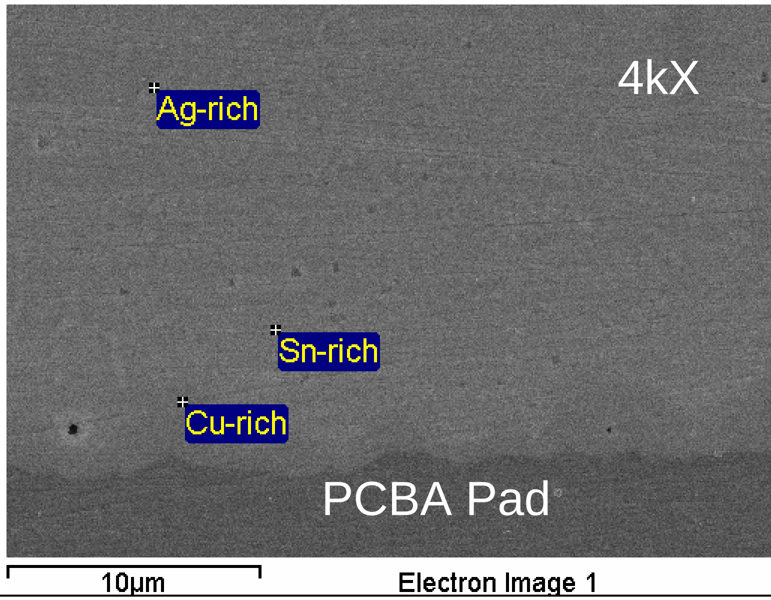






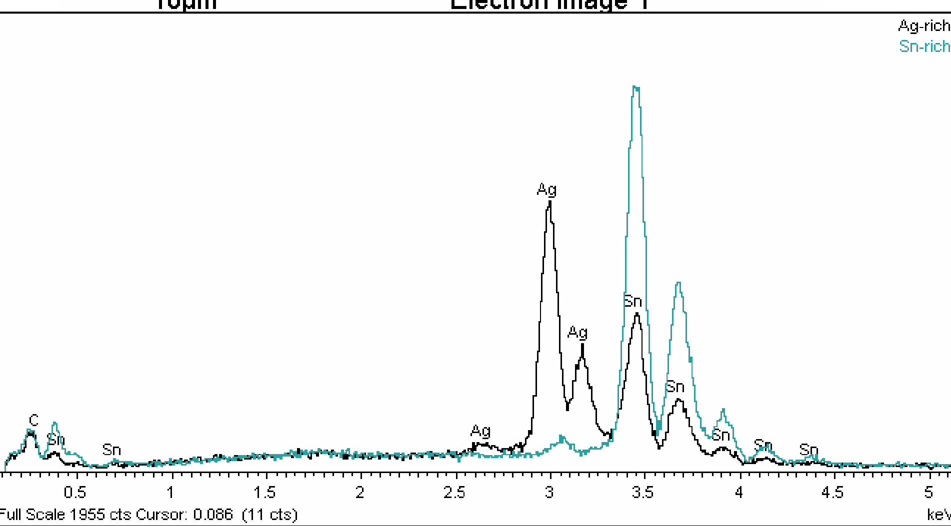
Summary of results - Optical, SEM 1000x and EDX Dot Map imaging of Material Boundaries

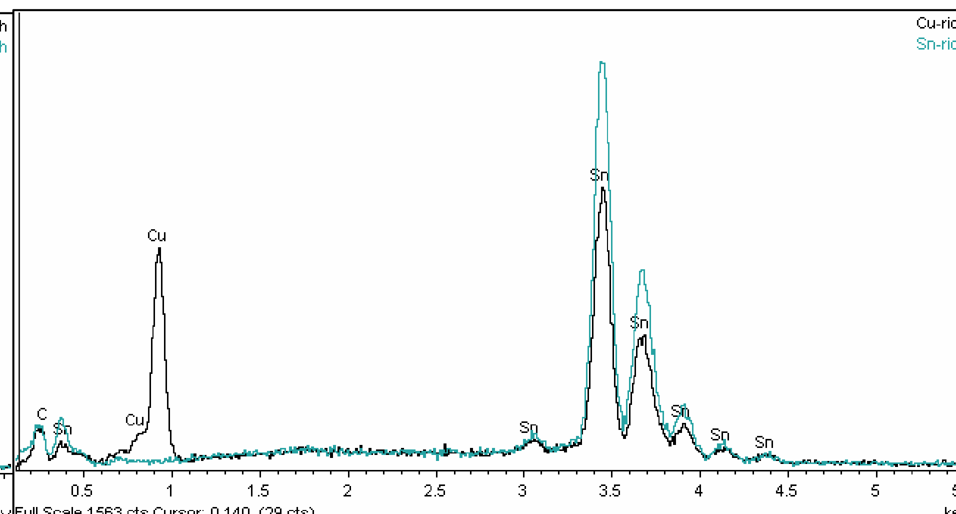
- One PLCC68 component from each group analyzed.



Left: SEM images of solder joint middle.

Below: EDS spectra of the Ag-rich, Sn-rich and Cu-rich regions.





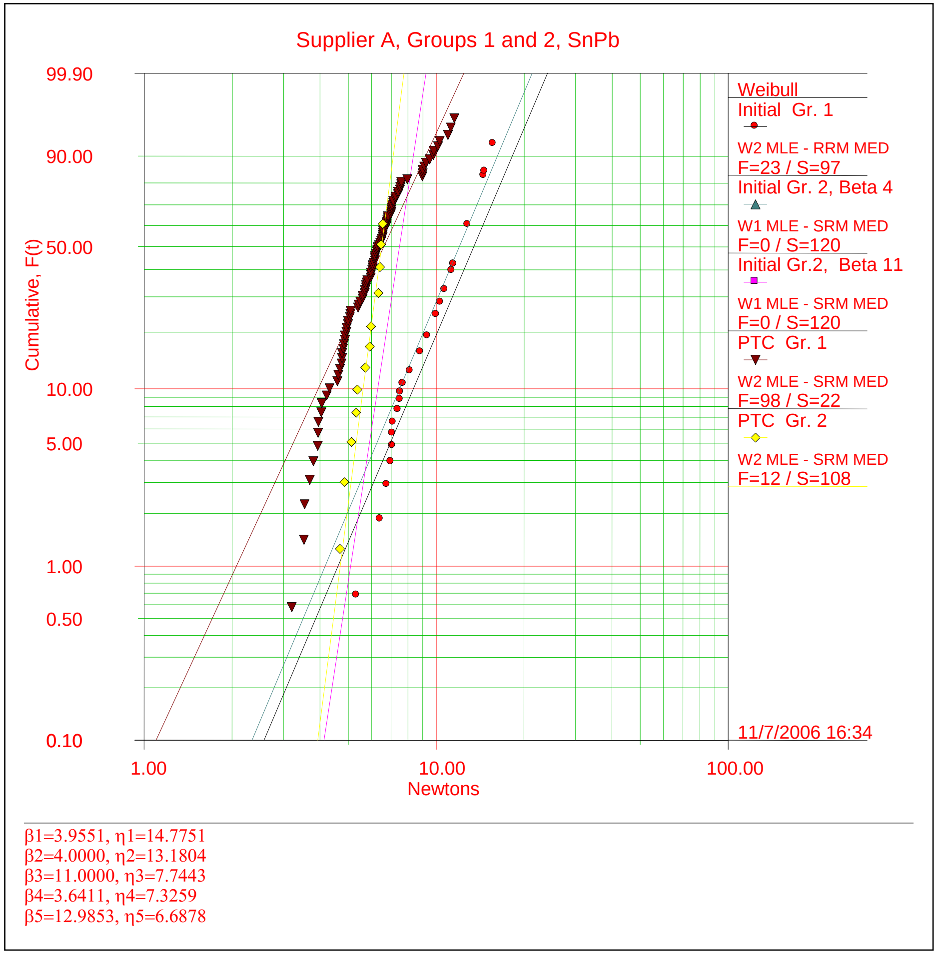
Summary of results - Lead-Pull Test – SnPb – Supplier A

- **3 boards from incoming and Post Temp Cycling were analyzed.**
- **QFP256 component analyzed.**
- **10 pins from each edge of the QFP256 were pulled. 40 pins per component, 120 pins total per supplier.**
- **Both SnPb and SAC boards were analyzed.**
- **Cumulative distribution function of Strength (N) was plotted.**

- **Data analyzed to reveal:**
  - **SnPb vs. SAC strength**
  - **Uniformity of reflow amoung the pins**
  - **Consistency of aging as revealed by post Temp Cycling data also demonstrates reflow uniformity.**

Summary of results - Lead-Pull Test – SnPb – Supplier A

- **Lead pull data of QFP256, SnPb, supplier A, test group 1 and 2**



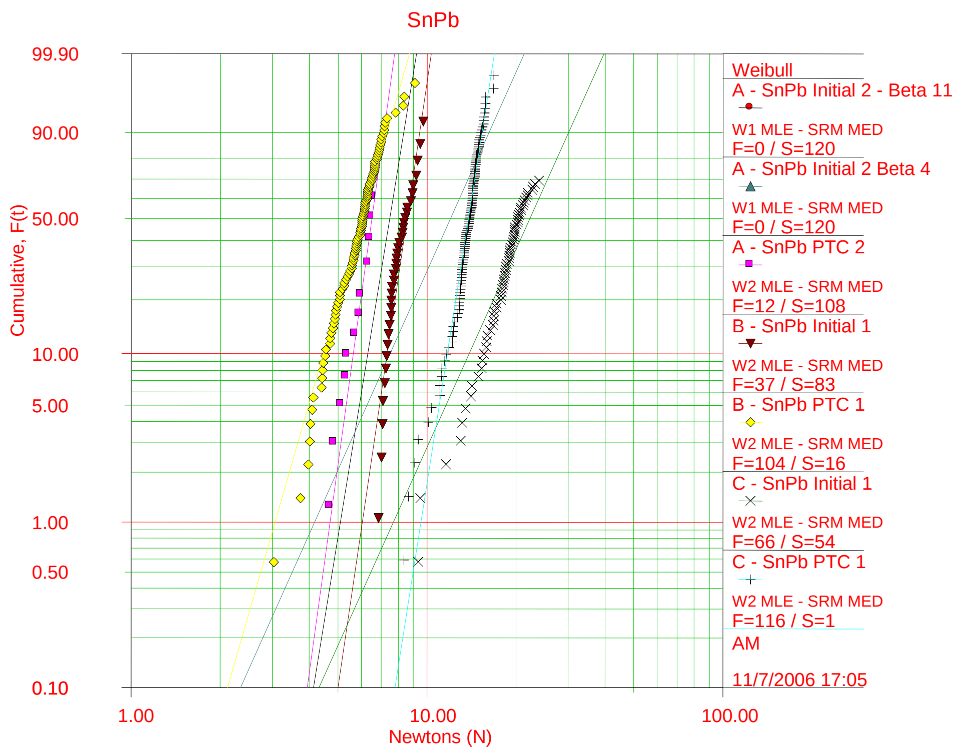
Supplier A	Groups	Slope (β)	Eta (η)
Initial	1	3.95	14.77
	2	4*	13.18
	2	11*	7.74
Post Temp Cycling	1	3.64	7.32
	2	12.98	6.68

- Gr 1 bad reflow.
- Gr 2 good reflow.
- Gr 2 tighter distribution, therefore more uniform and consistent reflow across all pins vs. GR 1.
- High eta, low Beta for GR 1 means some pins really good others really bad…no uniformity.

*Slope was set at 4 and 11 for comparison. No significant change in eta when the slope was varied from 9 and above. So eta for this set of data is around 7.7N. We can see from the PTC results that this INITIAL data slope is closer to 12 than 4.

Summary of results - Lead-Pull Test – SnPb - All Suppliers

- **Lead pull data of QFP 256**, SnPb, all suppliers.**



β1=11.0000, η1=7.7443
β2=4.0000, η2=13.1804
β3=12.9853, η3=6.6878
β4=12.1163, η4=8.8300
β5=6.2306, η5=6.4150
β6=3.9857, η6=24.4204
β7=11.4393, η7=14.2778

** Sup.C data for QFP160 component with a lead thickness that was twice the QFP256 lead thickness of the PC008 test coupons.

Supplier	Supplier	Slope (β)	Eta Force (η)
Initial	A	4*	13.18
	A	11*	7.74
	B	12.11	8.83
	C**	3.98	24.42
Post Temp Cycling	A	12.98	6.68
	B	6.23	6.41
	C**	11.43	14.27

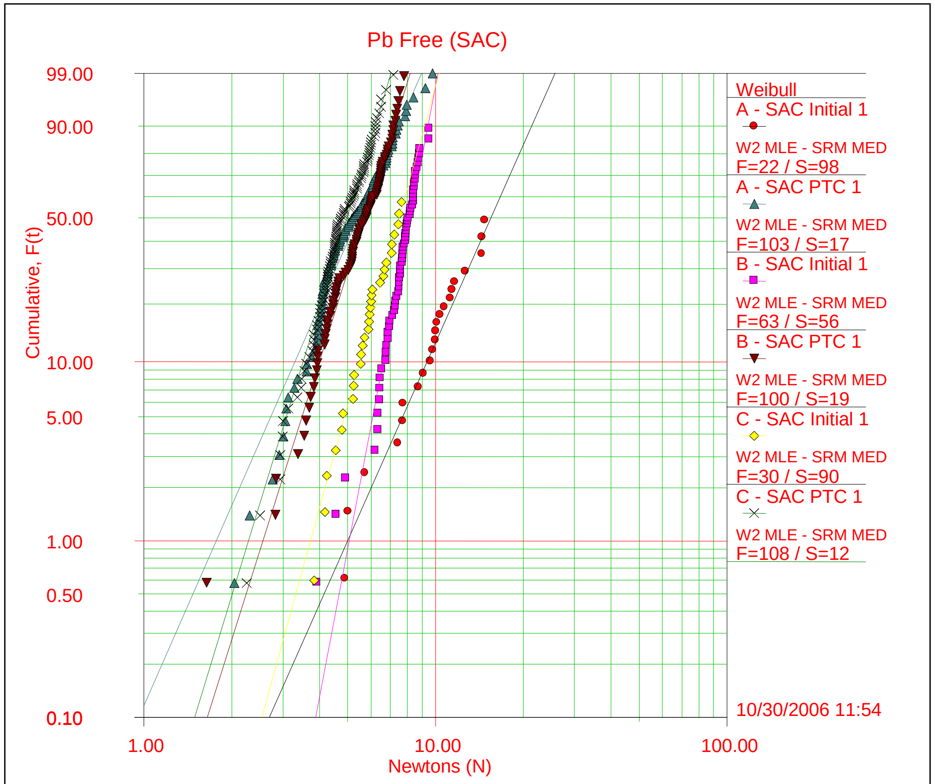
- Sup. A data, uniform solder joint strength with a similar beta pre and PTC light uniform aging of the joints with a drop in eta from 7.74 to 6.68.

- Sup. B data, similar beta and eta numbers as sup. A, but PTC beta was half of initial value. Joints were not completely uniform and some joints aged more than others.

- Sup. C, was the opposite of supplier B. It had a low initial beta, and so low initial uniformity of the solder joints, but a very high beta after temperature cycling, suggesting the joints all aged in a similar way.

Summary of results - Lead-Pull Test – SAC - All Suppliers

- **Lead pull data of QFP 256, SAC, all suppliers.**



$\beta 1=3.7366, \eta 1=17.0884$
$\beta 2=3.7758, \eta 2=5.9879$
$\beta 3=8.7467, \eta 3=8.5551$
$\beta 4=5.2566, \eta 4=6.1316$
$\beta 5=6.0276, \eta 5=7.9930$
$\beta 6=5.4403, \eta 6=5.3080$

Supplier	Supplier	Slope (β)	Eta (η)
Initial	A	3.73	17.08
	B	8.74	8.55
	C	6.02	7.99
Post Temp Cycling	A	3.77	5.98
	B	5.25	6.13
	C	5.44	5.30

- Sup. A was the worse performing. Lower initial beta and higher eta and a large drop in post temperature cycling eta suggest a large variation in solder joint quality. Not surprising as initial inspection of these boards showed many leads with blotchy and unsmooth reflow.

- Sup. B and C demonstrated very similar lead-pull data. The betas and eta of both suppliers are similar for both pre and post stress suggesting uniform aging across leads and so uniform reflow.

Summary of results - Lead-Pull Test – SnPb / SAC – Comparison.

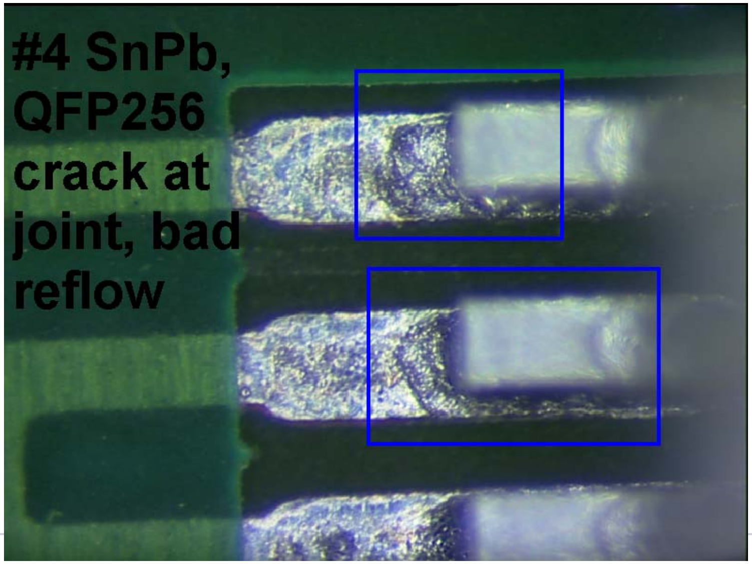
- **SnPb / SAC Comparison:**

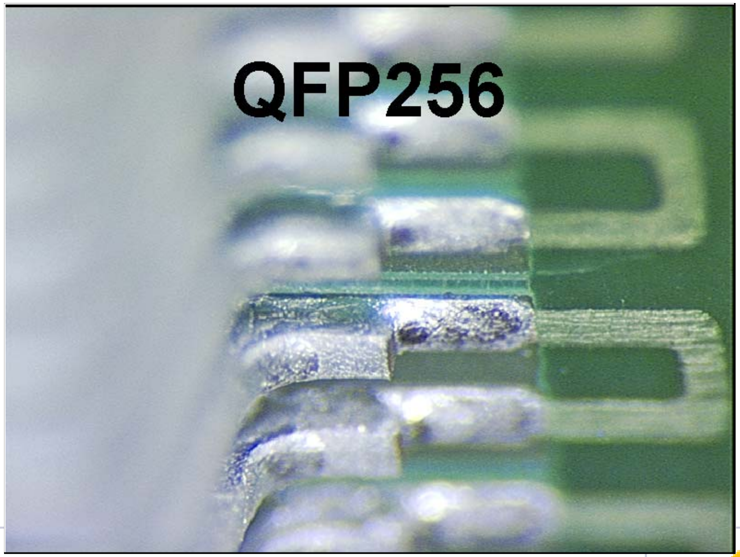
•Looking at supplier B data and comparing the SnPb and SAC lead-pull results, we see that the post temperature cycling data for the SnPb and SAC are very similar. This suggests that when boards are assembled with good solder joints, the aging of the joints will be similar.

Supplier B	Supplier	Slope (β)	Eta (η)
Initial	SnPb	12.11	8.83
	SAC	8.74	8.55
Post Temp Cycling	SnPb	6.23	6.41
	SAC	5.25	6.13

Summary of results - Temperature Cycling

- 11 boards were Temp Cycling (-40/125C, 1000cycles).
- Pictured below, post 1000 cycles temperature cycling optical pictures of SnPb QFP256. Although the SnPb solder case is pictured, same applies to SAC solder. Supplier A, set 1 and set 2.
- If the SAC reflow was blotchy as in the first picture, cracks were found at the joint post Temp Cycling. Excellent reflow as pictured on the right, passed 1000 cycles with no visible cracks.
- A ski slope type fillet with 50% height at the toe at incoming inspection guaranteed an excellent performance of the joint in this test and the whole qualification.

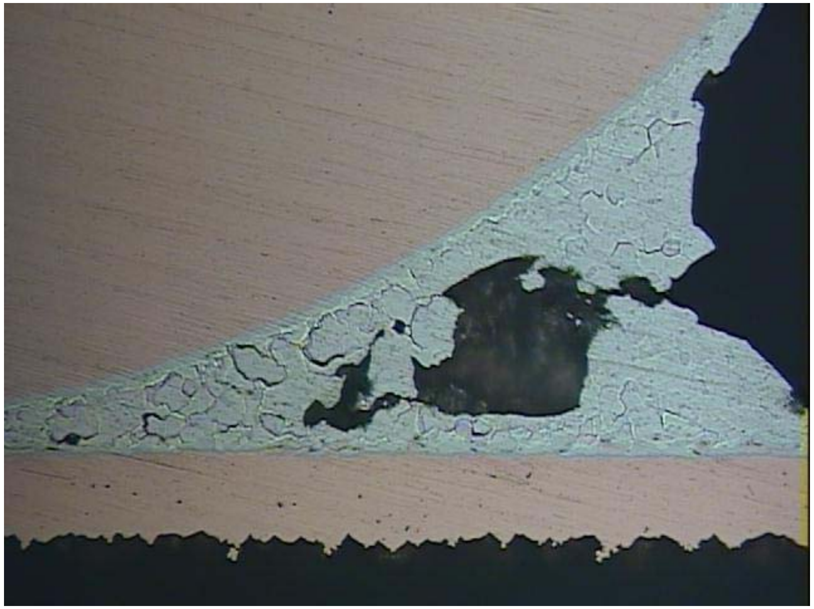


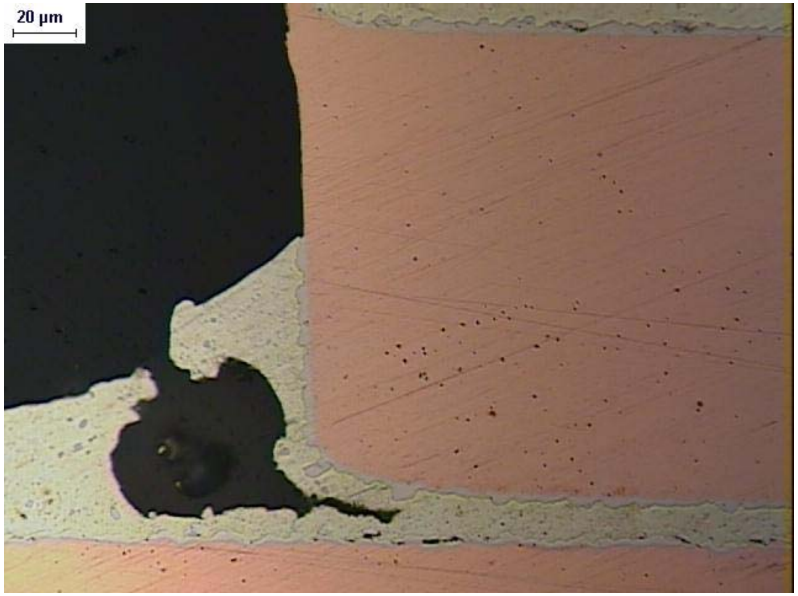


Summary of results - Temperature Cycling

- **Voiding: Excessive voiding in the SAC joint acted as a nucleation site for crack formation and propagation. Pictured below.**
- **Pass criteria for voiding was set at no more than 25% of joint area. It was found this level provided a reliable joint.**

- **Post temperature cycling cross-sections of SAC QFP256**





Summary of results - Mechanical Test

- Random Vibration as per Mil-810e
- Sine Vibration as per GR-63-CORE a telecom requirement.
- Impact as per GR-63-CORE a telecom requirement.

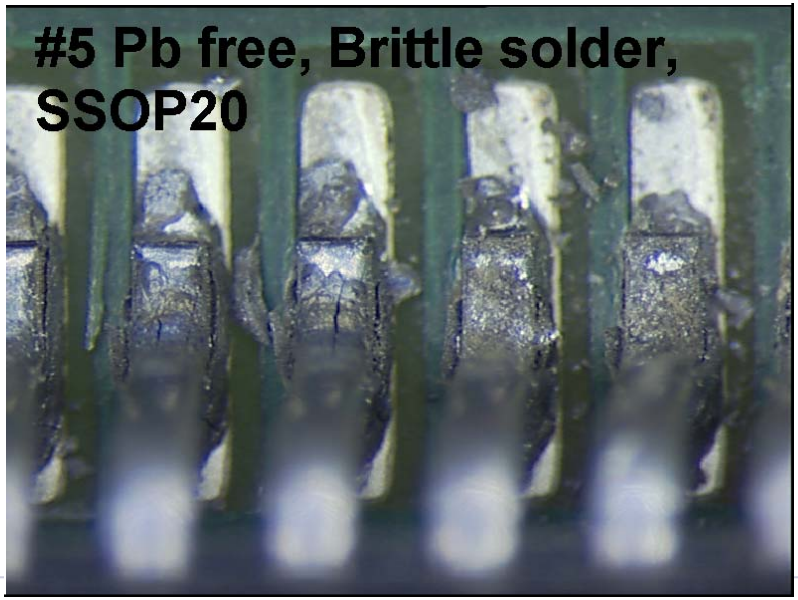
- No differences were found between SnPb and SAC.

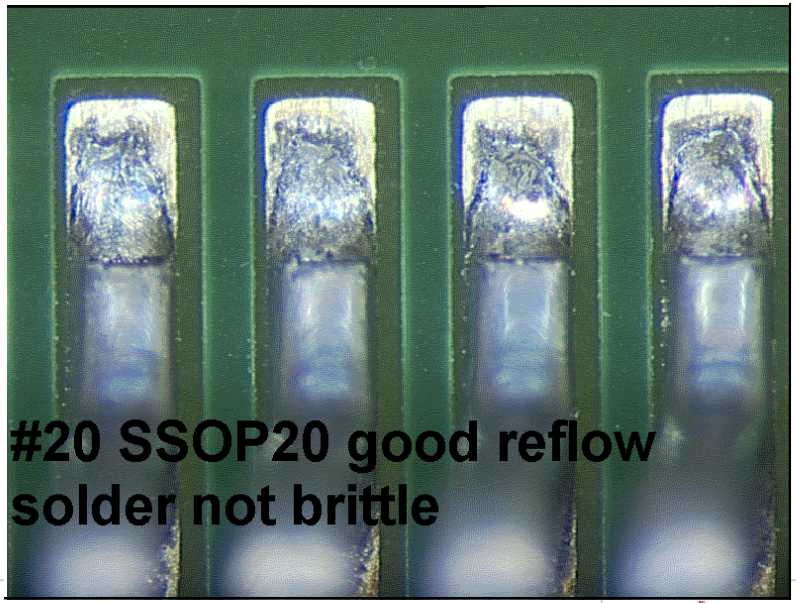
Summary of results - Damp Heat

- 1000 hrs @85C/85%RH, as per GR-1312-CORE, a telecom requirement.
- Test was used to evaluate whether fluxes used were corrosive and to evaluate the ability of supplier to ensure all flus residue is inactive.
- All PCBAs were inspected at incoming and post Damp Heat. A few BGA packages removed from PCBA to verify for corrosion underneath.
- No differences found between SnPb and SAC for evaluated suppliers.

Summary of results - Whisker Growth

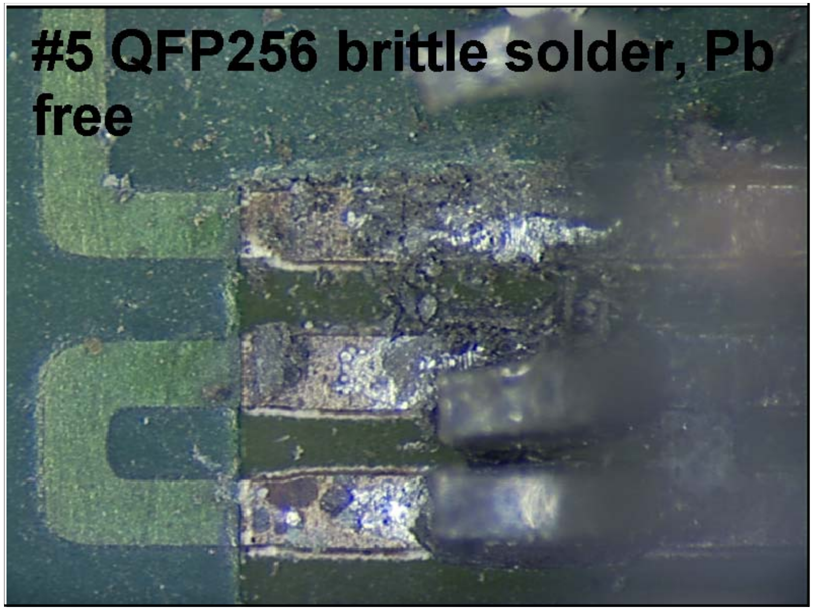
- 4000hrs @ 60C/93%
- All boards inspected with 50x magnification. Our imaging equipment was able to resolve whiskers <10um in length. None were found.
- Boards sent to external lab for SEM to see extent of Sn Whiskers that are smaller than 10um.
- Good solder reflow produces: no or very little whiskers.
- Bad solder reflow produces: Excessive Sn whiskers and joint brittleness.

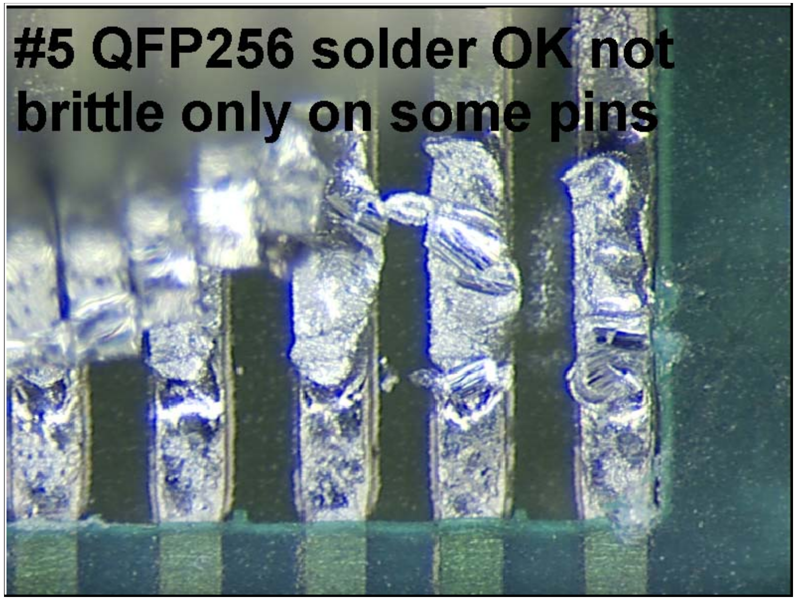




Summary of results - Whisker Growth

- Bad solder reflow produces:
  - Excessive Sn whiskers and joint brittleness.
- Pictured below, bad and reflow on the same component on the same PCBA.
- Rather disappointed……no whiskers observed





Summary Conclusion

- Good ski-slope type toe fillets are a good indicator as to whether a supplier performed a good reflow on a particular PCBA. Whisker growth and lead-pull data validates this need, particularly for lead free solders.
- Whisker growth data also suggests that in order to minimize whiskers and joint brittleness, a good ski-slope type toe fillet is needed for SAC based joints. It was found that leads with excellent reflow did not become brittle and did not grow any large (as seen under 50X magnification) whiskers. The whisker growth test was also a good indicator of reflow uniformity across a PCBA.
- From the temperature cycling test the added voiding sites seen in SAC solders act like nucleation sites for crack propagation. Although the cross-sectional images show this, when a good reflow was present, (looking at supplier B lead-pull data) this did not seem to be an issue for solder joint strength.
- From the lead pull data, when PCBAs are assembled with good solder joints, the initial distribution of lead-strengths is tighter for SnPb than for SAC but the eta is similar. Post aging or temperature cycling, both SnPb and SAC joints seem to age the same and the lead-pull strength distributions, beta, and eta become similar.
- No differences were found between SnPb and SAC solder joints after impact and vibration testing.
- No differences were found between SnPb and SAC solder joints after damp heat testing.

Summary Conclusion – On-going reliability

- Implement an on-going reliability test program when SAC PCBAs become a requirement.
- A test matrix based on a subset of tests:
  - random sampling of SAC based PCBAs
  - whisker growth, temperature cycling and lead-pull testing.
  - When suppliers can demonstrate a consistent performance on all three tests, the on-going reliability program requirements can be reduced.
    - For whisker growth, no brittle joints are to be present after 4000hrs. For temperature cycling no cracking of solder joints is to be present and for the lead-pull data initial and post stress betas and etas are to be similar.