

Investigation of Process Feasibility / Compatibility and Solder Joint Reliability of Tin-Lead Dippable Solder Paste Ball Grid Array (BGA) Component Rework/Repair

David Hillman, Douglas Pauls, Andrew Steinmetz
Rockwell Collins
Cedar Rapids Iowa

Abstract

This paper is an examination of the process feasibility, solder joint reliability, and materials/process compatibility of a dippable solder paste material for an area array component rework/repair process. The Ball Grid Array (BGA) components in this investigation were reworked according to typical production procedures and a new dipping procedure using the AirVac Onyx 29 BGA rework machine. The components were tested for thermal cycle solder joint reliability and flux process compatibility. The thermal cycle and flux process compatibility test results demonstrated that the dippable solder paste material and BGA rework process were acceptable for IPC Class 3 High Performance products.

Background

BGA components are traditionally reworked by removing an existing BGA component, the pads redressed and the solder mask inspected for damage, applying solder paste to a replacement BGA component with a stencil, and soldering the balled component to a printed wiring assembly using a BGA hot gas rework machine. A custom stencil is made for each component which fits the solder ball grid, allowing solder paste to coat the solder balls. An alternative method is to apply tacky flux to the printed wiring assembly pads, place the component on the pads and reflow solder with hot air. The stencil process is the optimum procedure because it adds solder volume to each joint which improves solder joint reliability.

Dippable solder paste offers a more versatile method of applying solder paste. A BGA component can be dipped into this material and each solder ball will be coated with a thin, uniform layer of solder paste. This method eliminates the need for custom stencils and replaces them with wells of different depths which can each be used for a variety of part sizes and ball array configurations. This method can be performed using standard BGA rework machines, allowing for a more accurate dipping and placement process.

The material evaluated was Heraeus Printable Solder Paste BD72SN63-80-5 (hereafter “dippable paste”). This was a Type 5, no clean, low residue paste. Solder balls were made of Sn63/Pb37 alloy and Heraeus BD72 series flux was used. The metals content of the paste was 89% (+/- 1.5%) and the paste must be stored at 5-12°C. The paste flux used in this evaluation was Alpha Metals UP-78M, a bromine-activated, J-STD-004 classification ROL1 paste flux (hereafter “tacky flux”). Figure 1 shows a solder ball covered partially with the dippable paste material (the frosty appearance on the bottom).

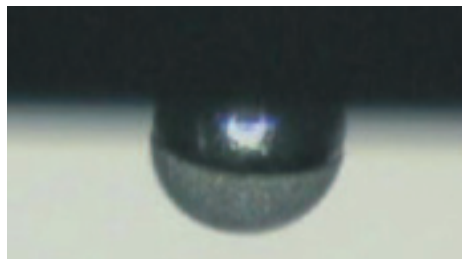


Figure 1 Heraeus Dippable Solder Paste Applied to an Individual Solder Sphere¹

Study Objectives

The objectives of the investigation were: (1) Determine whether the dippable paste process could be used to create reliable solder joints; (2) demonstrate that the process could be adapted for use on a BGA rework machine; (3) show that the flux in the dippable paste was compatible with a typical production process; and (4) determine what residues were present on the processed test vehicles.

Test Approach

The evaluation was split into two phases. Phase 1 was designed to answer the question of solder joint reliability. Phase 2 was designed to examine the compatibility of the dippable paste flux with other fluxes/processes.

Phase 1: Solder Joint Reliability Investigation

There were two processes considered for Phase 1: (1) use of dipdable paste alone and (2) use of dipdable paste with the addition of tacky flux. Flux is necessary to clean a soldering surface of oxidized metal; therefore, the condition where a component is soldered without tacky flux and without the dipdable paste (which contains flux) would not work and was not considered for the evaluation.

The test was set up to answer two primary questions for Phase 1:

1. Does dipdable paste create a solder joint that is as reliable as directly soldering the component using tacky flux only?
2. Is it necessary to apply tacky flux to a board before using dipdable solder paste or is the flux in the dipdable paste sufficient to create a reliable solder joint?

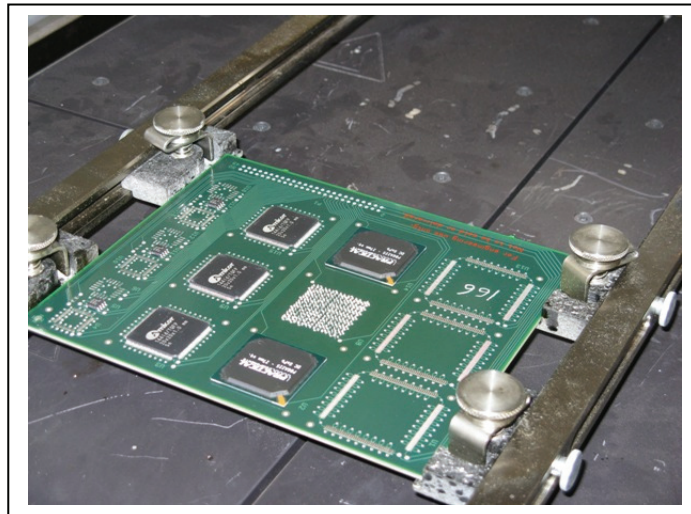


Figure 2. Phase 1 Test Vehicle

Three treatment conditions were used in this experiment. Five test vehicles (see Figure 2) were used for each treatment condition, each holding three BGA components. In total, 44 BGAs were tested on 15 test vehicles. All components on any particular test vehicle were reworked in the same manner. The rework treatments are outlined below.

1. **Tacky Flux Only (15 Components):** Tacky flux was applied to the printed wiring board pads before soldering and the components were soldered to the pads without the application of solder paste to the printed wiring board pads.
2. **Solder Dipped and Fluxed (15 Components):** These components were dipped in the dipdable solder paste and tacky flux was applied to the printed wiring board pads before soldering.
3. **Solder Dipped Only (14 Components):** The components were dipped in the dipdable solder paste and the components were soldered to the board without the application of tacky flux to the printed wiring board pads.

Phase 1 Test Sample Processing

Solder Paste Well

The solder paste well used for dipping the BGAs was made using aluminum stock. The depth of the well was approximately half the height of a solder ball with a well height/width designed to easily accommodate the solder ball (see Figure). This allowed for some room for x-y placement error during the dipping process.

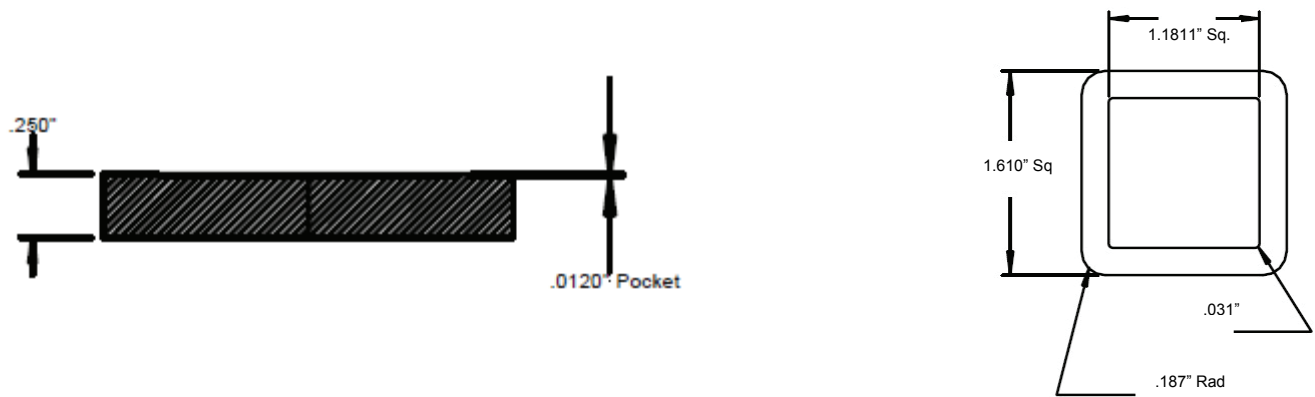


Figure 3 Solder Paste Dipping Fixture

BGA Rework with Dippable Solder Paste

1. The dippable paste was removed from cold storage and allowed to come to room temperature before use. At least one hour was allotted for this warm up period any time the paste was removed from refrigeration.
2. A thermal profile for the BGA was created on an AirVac Onyx 29. The thermocouple for this process was placed under the BGA to record the temperature at the solder joints. High temperature tape was placed over the part to secure the part and thermocouple during the profiling process (see Figure 4). This profile was saved for use during the removal and soldering steps.

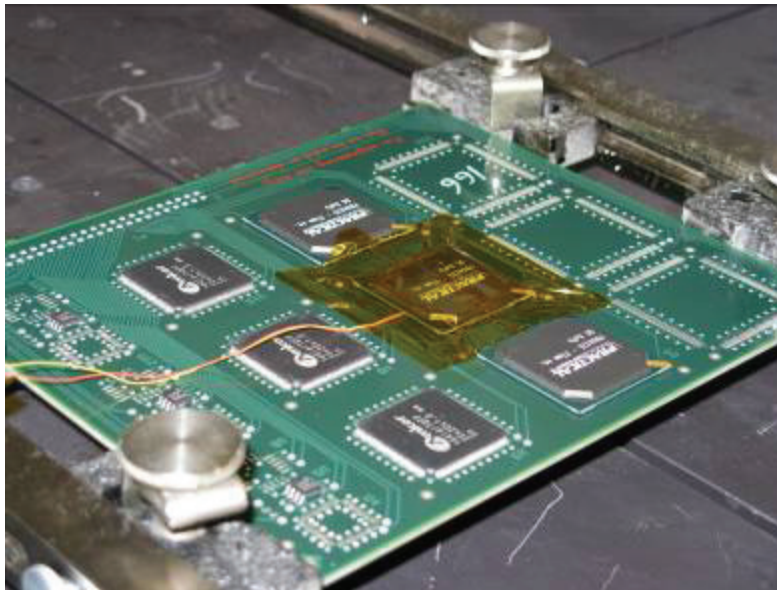


Figure 4 Creating the Thermal Profile

3. The BGA component was removed and site-cleaned using the Onyx 29.
4. At this point, if no dippable paste was being used, the solder well preparation and component dipping steps were skipped. The soldering program was run with the procedure resumed at Step 10.
5. Before beginning the soldering process, the solder well was prepared by first spreading dippable solder paste over the well with a craft stick. The paste completely covered the surface and was pushed into the corners. The well did not require much paste because it was extremely shallow, but some excess was added to ensure a complete fill.

6. A razor blade was then used to level the paste and wipe away excess, making as smooth a surface as possible. The blade was held at approximately a forty-five degree angle to avoid flexing in the middle and creating a non-coplanar surface. Figure 5 illustrates the solder well leveling process.

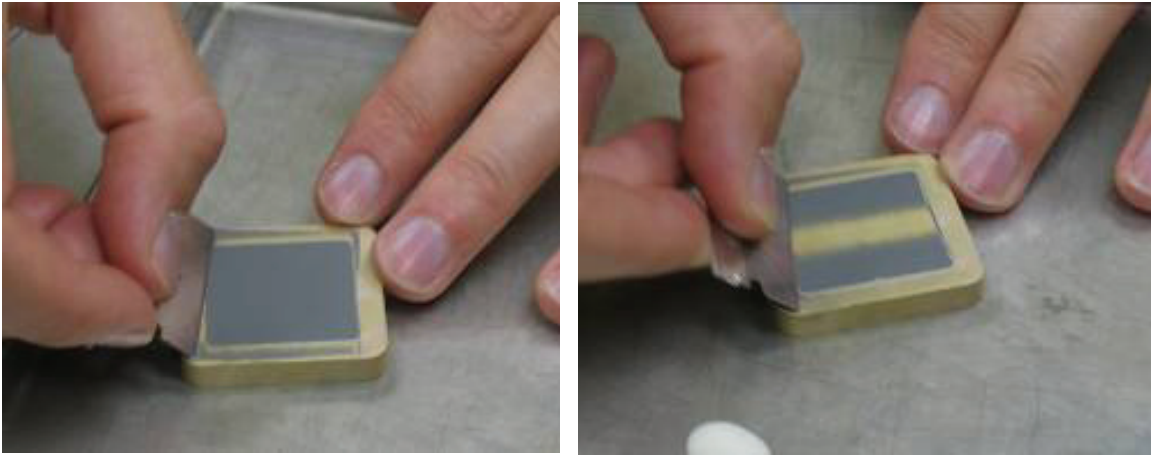


Figure 5 Solder Wells Leveled correctly (left) and incorrectly (right)

7. Solder remaining along the edge of the well was wiped away using a sponge tipped swab.
8. After the solder well was prepared, the soldering portion of the Onyx 29 program was run. The Onyx 29 has a function called Dip Fluxing which performs exactly the same motion required to solder dip. When the prompt appeared on screen to prepare the Dip Fluxer, the loading tray was removed from the presentation table and replaced with the leveled solder well, as shown in Figure 6.



Figure 6 Solder Well on Presentation Table

9. When the dipping process was completed, the solder paste in the well was visually checked to confirm that the BGA left a full footprint and had not been mishandled during dipping (see Figure 7).

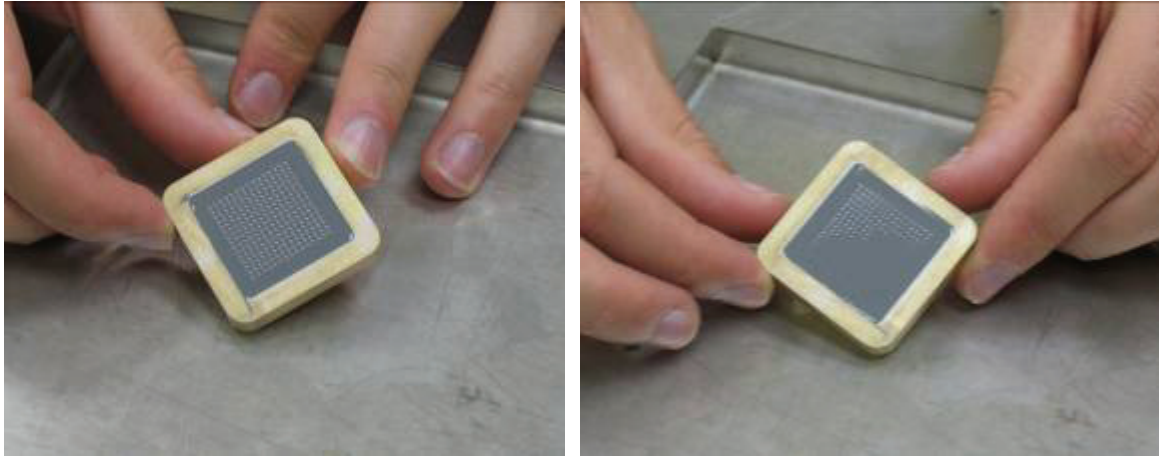


Figure 7 Complete BGA Footprint (left) and Partial BGA Footprint (right) in Solder Well

10. At this point a prompt appeared in the program to apply flux to the site. If the test samples were to receive the additional tacky flux, the flux was added here.
11. After the component was soldered and allowed to cool, a sponge swab with Petroform Bioact SC-10 was used to clean any flux residue, followed by a sponge with isopropyl alcohol. The test vehicle was allowed to air dry in most cases, but where excessive amounts of alcohol or BioAct existed, a dry sponge swab was used to remove the excess liquid.
12. The solder well was refilled by adding a small amount of solder paste to the area where the BGA component had left a footprint. This was then leveled with a razor and excess solder paste wiped away with a sponge. The solder well was not cleaned completely between each part. Any time a new part was not being placed immediately; however, the solder well was cleaned to avoid drying of the solder paste.
13. The above process was repeated from Step 3 with the refilled well to apply another component.
14. To clean the well, a paper towel was used to wipe away the majority of the paste. Then a sponge swab with isopropyl alcohol was used to clean residual paste and get into the corners of the well depression. Afterwards, the fixture was dried with a paper towel (see Figure 8).

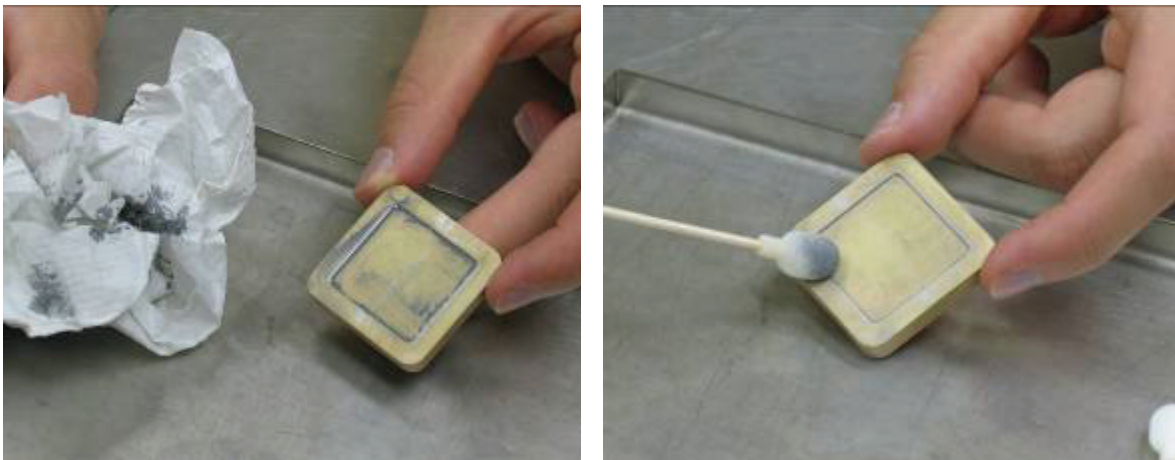


Figure 8 Solder Well Cleanup –Right: Wiping with Paper Towel, Left: Sponge Swab with Alcohol

15. After all components were soldered to the boards, they were sent to aqueous cleaning to remove flux residues and foreign object debris.
16. It should be noted that for all cleaning in this evaluation, the aqueous cleaning was performed in an Austin America Technology MicroJet Mach 3 in-line aqueous cleaner, using a heated saponifier and deionized water rinsing.

Thermal Cycle Parameters and Methodology

At Rockwell Collins, solder joint reliability is evaluated using thermal cycling while monitoring resistance across the solder joint. The temperature cycle range chosen for this investigation was -55°C to +125°C with a 15 minute minimum dwell at both temperature extremes. A maximum temperature ramp of 10°C/minute was used in the testing. The BGA component solder joints were continuously monitored throughout thermal cycle testing with an event detector in accordance with the IPC-9701 specification. An 'event' was recorded if the resistance of a channel exceeded 300 Ω for more than 0.2 μ sec. A failure was defined when the daisy-chained 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.

BGA components that were identified as failures were electrically removed from the continuity loops for 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 using a temperature acquisition unit. The profile exhibited tight control over board temperatures, especially over the cold range of the cycle. The heating phase shows some minor spread in temperatures due to airflow distribution within the chamber. Figure illustrates the thermal cycle temperature profile for the -55°C to +125°C testing.

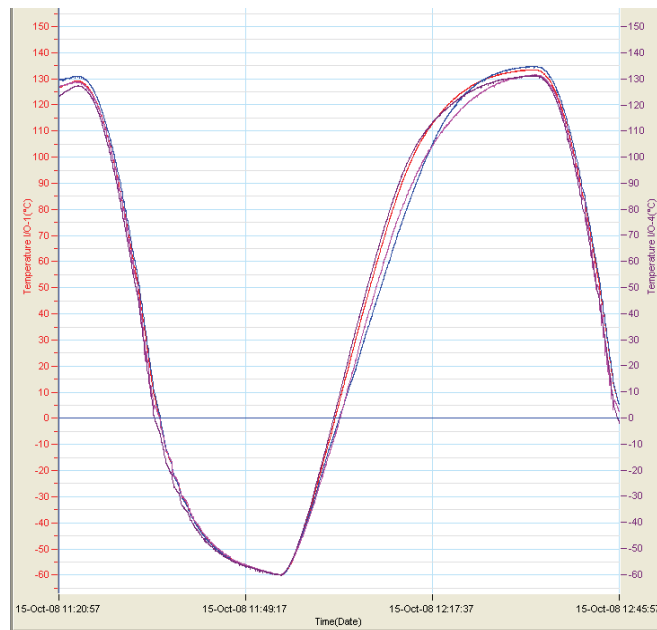


Figure 9 Test Vehicle Thermal Profile

Statistical Analysis

Normally, a statistical/Weibull analysis would be done on the failure data to determine the first failure and failure distribution. However, none of the solder joints in the evaluation exhibited any failures. All 44 BGA components, representing all three test processes, passed 2000 thermal cycles with no recorded failures.

Failure Analysis

One BGA component representing each of the investigation categories; (1) tacky flux only, (2) dippable solder paste only, and (3) tacky flux and dippable solder paste combined, were randomly selected for metallographic cross-sectional analysis. No anomalies in the BGA solder joint geometries, wetting angles or solder joint microstructures were observed. Figures 10-12 illustrate representative metallographic cross-sectional results.

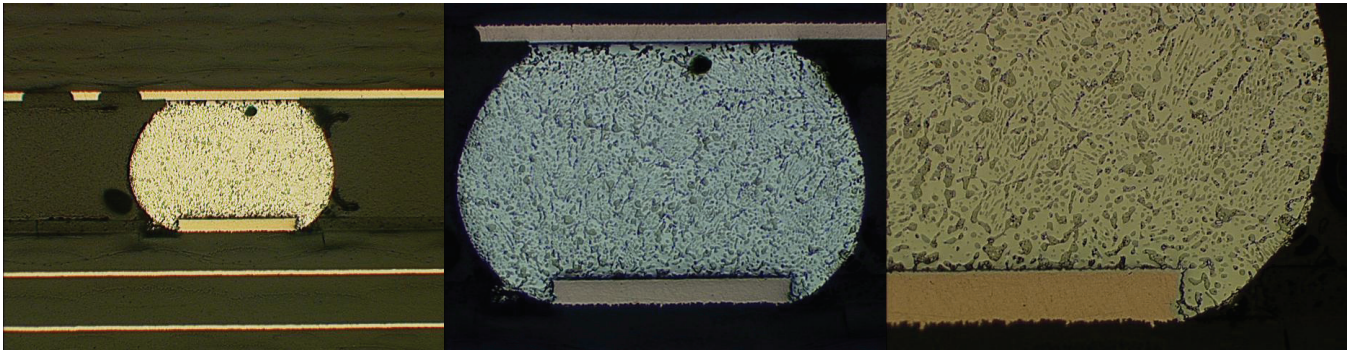


Figure 10 Tacky Flux Only BGA Component Cross-section Set

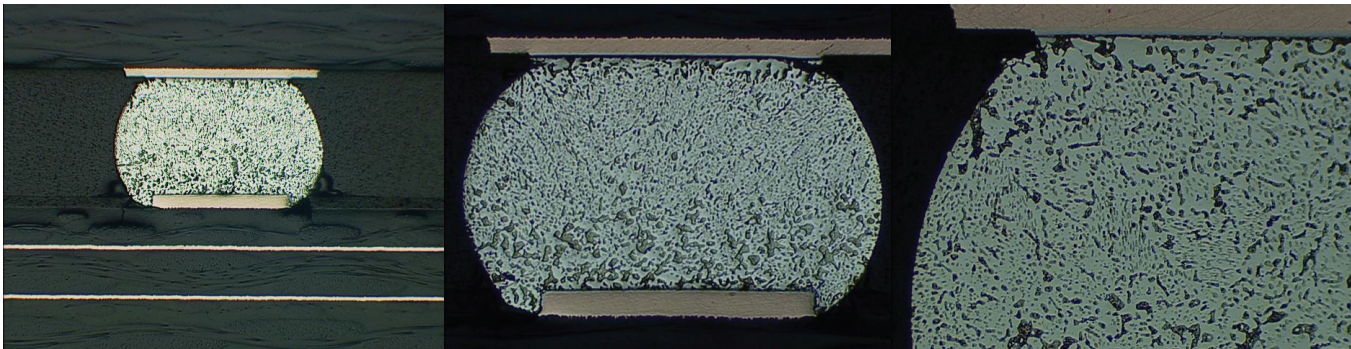


Figure 11 Solder Dipped Only BGA Component Cross-section Set

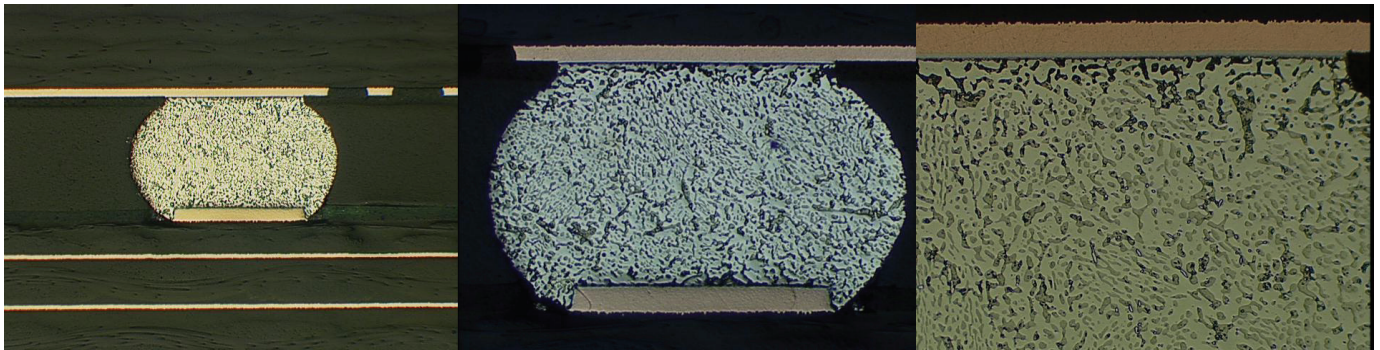


Figure 12 Solder Dipped and Tacky Flux Combination BGA Component Cross-section Set

Phase 2: Flux Material Compatibility Qualification Investigation

An analysis of residues in a Materials Compatibility Study should always be made in two parts: (1) a chemical analysis of what residues are present and in what amounts; and (2) an assessment of the effects of those residues on electrical performance under humid conditions. By examining the change in residues and the change in effects, the compatibility of materials throughout a manufacturing process can be assessed. While chemical characterization and electrical impact can be assessed by a number of valid methods, the two most applicable methods for this study were ion chromatography (IC) for chemical analysis and surface insulation resistance (SIR) for electrical characterization.

The test vehicle chosen for this phase of the study was the IPC-B-52 standard test assembly, shown in Figure 13. This figure also shows the location of the two BGAs. The B-52 is one of the qualification vehicles for IPC-J-STD-001 and contains provisions for both ion chromatography and SIR tests. The BGA for the B-52 test board was a 256 I/O, 1 mm pitch, full array BGA device.

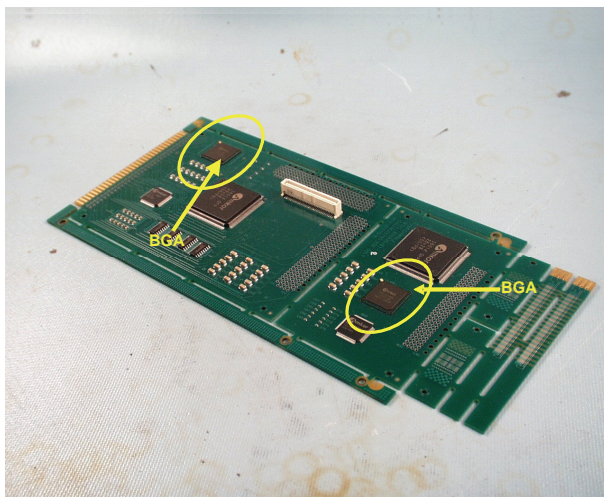


Figure 13 IPC-B-52 Standard Test Assembly.

The B-52 assemblies had been previously manufactured using the standard Rockwell Collins assembly materials and processes. As such it was considered to be representative of most Rockwell Collins products. These assemblies had been sealed in clean, virgin plastic (Kapak) bags. A total of nine IPC-B-52 test assemblies were used in this project.

Test Sample Processing for IPC-B-52

The test samples were processed in three sets as follows.

1. An AirVac Onyx 29 rework station was used for all test vehicle processing.
2. The existing BGAs were removed from both the SIR board and the IC coupon, using the Onyx 29.
3. All rework areas were site cleaned after BGA removal and preparation for new BGA attach.
4. Three IC coupons (SN1, 2, 3) and three SIR coupons (SN11, 12, 14) were subjected to in-line aqueous cleaning. These six coupons represented the baseline cleanliness condition prior to any BGA re-attachment processes.
5. Three IC coupons (SN4, 5, 6) and three SIR coupons (SN13, 15, 16) were processed with BGAs dipped in the Heraeus paste and reflowed with the Onyx 29. These coupons were then subject to cleaning. These six coupons represented the condition of using the dipdable paste only.
6. Three IC coupons (SN7, 8, 9) and three SIR coupons (SN17, 18, 19) were processed with a combination of the dipdable paste and tacky flux applied to the rework site prior to BGA placement. The BGA was then reflowed with the Onyx 29 and subjected to aqueous cleaning. These six coupons represented the condition of using both the dipdable paste and the tacky flux.
7. All samples were stored in clean, virgin (Kapak) bags until testing could be performed.

It should be noted that the extract solution used in this evaluation is different from the industry norm of 75% isopropanol and 25% deionized water, as found in IPC-TM-650 method 2.3.28. Previous research at Delco Electronics, Trace Laboratories, and Rockwell Collins, presently unpublished but discussed in IPC committees, has shown that the 10% isopropanol / 90% deionized water often is gentler on the electronics, while just as sensitive for ionic extraction. Rockwell Collins has been using this extract solution for all of our research for over eight years.

Residue Analysis – Ion Chromatography

1. Table 1 shows the specifics of the Rockwell Collins ion chromatography system.

Table 1. Ion Chromatography System Specifics

Parameter	Anions	Cations
<i>Chromatograph</i>	Metrohm 761 Compact IC	Metrohm 761 Compact IC
<i>Method</i>	Suppressed Anions	Non-Suppressed Cations
<i>Eluent</i>	1.4 mM Carbonate / 2.8 mM Bicarbonate	8.0 mM d-Tartaric Acid / 0.75 mM dipicolinic acid
<i>Column</i>	Metrohm ASUPP5-250 with guard	Metrohm Cation 2 – 250 with guard
<i>Sample Loop</i>	20 µL	20 µL
<i>Run time</i>	34 minutes	18 minutes
<i>Control Ions</i>	F, Cl, NO ₂ , NO ₃ , Br, PO ₄ , SO ₄	Li, Na, NH ₄ , K, Ca, Mg
<i>Suppressor</i>	Metrohm MSM	None
<i>Regenerant</i>	100 mM sulfuric acid	

- Each of the processed test samples was placed into a clean 3M Scotchpak Kapak bag. These are heat sealable polyester film bags which have very low extractable ionics.
- A solution of 10% anhydrous isopropyl alcohol and 90% deionized (DI) water (18 megohm-cm) was prepared. A volume of 100 mL of this extract solution was introduced into each Kapak bag.
- One bag was filled with the same amount of extract solution, but no test sample. This was a bag blank and its function was to benchmark any ionic material extracted from the bag material itself.
- Each bag was suspended in an 80°C water bath for a total of one hour. After one hour, the bags were removed from the water bath and the test samples removed from the extract solution. The extract solution was allowed to cool to room temperature.
- Prior to any analytical runs, the IC system was allowed to warm up and eluent run through the system until a stable baseline was attained.
- A four-point calibration method was run and covered the range of 0.2 – 20 parts per million (PPM) concentration for all anions and cations in the control groups.
- A sample of 20 microliters of each candidate solution was analyzed.
- The generated chromatograms were reviewed. If any chromatograms showed unstable baselines, the sample was re-run.
- The sample information, extract information, and resultant PPM values were entered into an Excel spreadsheet and converted to a normalized figure of micrograms per square centimeter.

Ion Chromatography Test Results

- Figure 14 shows a sample chromatogram. Each chromatogram was a record of the measured solution conductivity as a function of flow time through the column (in minutes). Results were expressed in parts per million, based on the calibration standards.

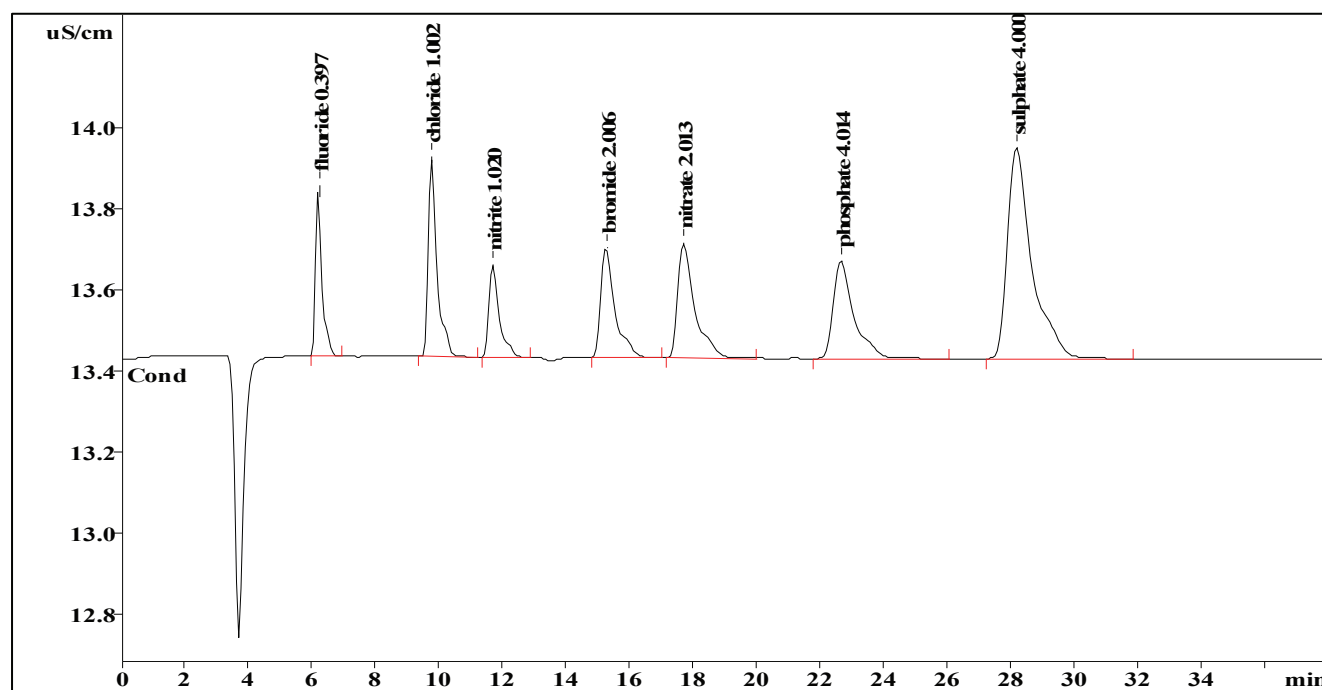


Figure 14 Sample Chromatogram

Table 2 shows the levels of extractable anions (negatively charged ions) from the test samples. Table 3 shows the levels of extractable cations (positively charged ions) from the test samples. These values were converted from the parts per million (PPM) values of the chromatograms using this formula:

$$\text{Value } (\mu\text{g}/\text{cm}^2) = [\text{PPM value of chromatogram}] * [\text{Extract Volume (in mL)}] / [\text{extracted surface area}]$$

Table 2. Anion Residues in Micrograms Per Square Centimeter

Description	Extract Volume	Surface Area (cm ²)	Fluoride	Chloride	Nitrite	Bromide	Nitrate	Phosphate	Sulfate
No BGA in Place									
B-52 Coupon SN 1	100.00	132.00	0.00	0.20	0.00	0.00	0.00	0.00	0.23
B-52 Coupon SN 2	100.00	132.00	0.00	0.21	0.00	0.00	0.00	0.00	0.27
B-52 Coupon SN 3	100.00	132.00	0.00	0.19	0.00	0.00	0.00	0.00	0.25
		Mean	0.00	0.20	0.00	0.00	0.00	0.00	0.25
BGA with Paste Only									
B-52 Coupon SN 4	100.00	132.00	0.00	0.21	0.00	0.00	0.00	0.00	0.25
B-52 Coupon SN 5	100.00	132.00	0.00	0.25	0.00	0.00	0.00	0.00	0.26
B-52 Coupon SN 6	100.00	132.00	0.00	0.24	0.00	0.00	0.00	0.00	0.27
		Mean	0.00	0.23	0.00	0.00	0.00	0.00	0.26
BGA with Paste and Flux									
B-52 Coupon SN 7	100.00	132.00	0.00	0.22	0.00	0.00	0.00	0.00	0.30
B-52 Coupon SN 8	100.00	132.00	0.00	0.17	0.00	0.00	0.00	0.00	0.28
B-52 Coupon SN 9	100.00	132.00	0.00	0.28	0.00	0.00	0.00	0.00	0.30
		Mean	0.00	0.22	0.00	0.00	0.00	0.00	0.29
Bag Blank	100.00	132.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 3. Cation Residues in Micrograms Per Square Centimeter

Description	Extract Volume	Surface Area (cm ²)	Lithium	Sodium	Ammonium	Potassium	Calcium	Magnesium
No BGA in Place								
B-52 Coupon SN 1	100.00	132.00	0.00	0.00	0.00	0.00	0.00	0.00
B-52 Coupon SN 2	100.00	132.00	0.00	0.00	0.00	0.00	0.00	0.00
B-52 Coupon SN 3	100.00	132.00	0.00	0.00	0.00	0.00	0.00	0.00
		Mean	0.00	0.00	0.00	0.00	0.00	0.00
BGA with Paste Only								
B-52 Coupon SN 4	100.00	132.00	0.00	0.00	0.00	0.00	0.00	0.00
B-52 Coupon SN 5	100.00	132.00	0.00	0.00	0.00	0.00	0.00	0.00
B-52 Coupon SN 6	100.00	132.00	0.00	0.00	0.00	0.00	0.00	0.00
		Mean	0.00	0.00	0.00	0.00	0.00	0.00
BGA with Paste and Flux								
B-52 Coupon SN 7	100.00	132.00	0.00	0.00	0.00	0.00	0.00	0.00
B-52 Coupon SN 8	100.00	132.00	0.00	0.00	0.00	0.00	0.00	0.00
B-52 Coupon SN 9	100.00	132.00	0.00	0.00	0.00	0.00	1.52	0.00
		Mean	0.00	0.00	0.00	0.00	0.51	0.00
Bag Blank	100.00	132.00	0.00	0.00	0.00	0.00	0.00	0.00

Discussion of Ion Chromatography Results

- Both anion and cation residues give insights on the chemical interactions taking place on the test substrates.
- In this evaluation, there was only one test sample (SN9) that showed any cation residues. Typically, cation residues are mostly related to solder mask materials and solder mask developing processes. These coupons had been through several cleaning processes prior to this test study, so it was not surprising that there were no discernable cation residues using the control cations used. There were some unidentified cation peaks that did not correspond to the control cations. From

past developmental work at Rockwell Collins, these unidentified peaks were related to the cleaning saponifier used in the aqueous cleaning process. Only trace amounts of the saponifier were present.

3. Of greatest interest in a cleanliness evaluation is that of the anion species present. Anions have been linked by several authors to electrochemical failures, such as electrolytic corrosion, electrochemical migration (dendritic growth) and electrical leakage under humid conditions. The primary ions of interest are the monovalent ions of chloride (Cl⁻) and bromide (Br⁻). While other authors have varied in the recommended maximums for these ions, Rockwell Collins has found that a 1 microgram / cm² upper limit on chloride, and a 3 microgram / cm² upper limit on bromide to be good target limits. Another ion of concern was sulfate (SO₄⁻²), with a recommended maximum of 3 micrograms / cm².
4. We can see that the chloride, bromide, and sulfate residues were all well below the levels recommended.
5. It should be noted that the values reported for sulfate are not exclusively sulfate ions. Because of the chromatographic method used, and the eluents used, the weak dicarboxylic acid flux activators in the low residue fluxes come out (elute) in the same range as sulfate. As most flux activators in low residue fluxes are a combination of several dicarboxylic acids (e.g. succinic acid, glutaric acid, maleic acid), there is no traceable standard for “flux”. It is generally a very in-depth effort to determine the exact concentrations of the acids present, which is seldom done. No industry research has been presented to date linking the amounts of individual dicarboxylic acids to failure mechanisms.
6. For the chromatographic methods used, it should be noted that when measurable amounts of flux are present, a secondary peak, occurring 1-2 minutes of retention time after the sulfate peak, will be present. In all of the chromatograms for this study, this secondary peak was not present. The overall conclusion was that there was no significant amount of flux present after the standard manufacturing cleaning process.
7. The conclusion from this portion of the study was that the aqueous cleaning process used at Rockwell Collins was fully adequate to remove all of the harmful flux residues from both the dipplable paste and the combination of the dipplable paste and tacky flux.

Residue Assessment – Surface Insulation Resistance Testing

Knowledge of the kinds of ionic residues and residue amounts is desirable; however, a more important consideration is the effect that residues have under humid conditions and an electrical bias. This is generally the end use environment for most aerospace electronics.

The SIR test methodology chosen was IPC-TM-650, method 2.6.3.7, which was the most current SIR test method for the evaluation of the effects of manufacturing residues on insulation resistance. Table 4 shows the SIR test parameters used.

Table 4. SIR Test Parameters

Parameter	Description
Test Equipment	Gen 3 Systems AutoSIR 256
Test Environment	85°C / 87.5% relative humidity
Ramp up	No Bias, condensation free
Test Duration	7 days
Bias Voltage	10 volts DC
Measurement Voltage	10 volts DC
Measurement Frequency	Every 60 minutes
Equilibration Time	3 hours

All of the test samples were first checked for electrical shorts using a digital multimeter. None of the test samples contained any electrical shorts. All test samples were then inserted into edge-card connector based fixtures, which had been previously verified with 100 gigohm (1E11 ohms) precision resistors. All samples were placed in a vertical position under a rain shield, parallel to the chamber air flow. All circuit paths (internal to the AutoSIR256) contained a 1 megohm current limiting resistor, so the minimum resistance measurement was always 1 megohm.

A set of initial resistance measurements was made at ambient (25°C/50% RH) conditions prior to the start of the test. A set of final resistance measurements was made within one hour of return to ambient conditions. During the ramp up from ambient to elevated conditions, no electrical bias was applied to the test patterns. The ramp up method first increased temperature to 85°C, maintaining lower (20-30%) relative humidity, over the course of 30 minutes. Humidity was then ramped up to 87.5% over the course of 30 minutes. This non-condensing ramp method was important because it prevented the condensation of a layer of liquid water on the test samples, which generally invalidates an SIR test. The first measurement at elevated conditions occurred three hours after the start of the ramp up process. This allowed the test samples to equilibrate for two hours before starting periodic measurements.

Test Results – SIR Testing

1. Figures 15-17 show the SIR results in graphs of the measured resistance, expressed in LogOhms, vs. time in test in hours. A LogOhm is the base 10 logarithm of the measured resistance (1×10^6 ohms = 1 megohm = 6 LogOhms). The high values at the start and end of each chart represent the initial and final measurements made at ambient conditions.
2. For this study, a pass-fail metric of 100 megohms (8.0 LogOhms) was chosen. This resistance level has been largely favored by the IPC committees as an acceptable discriminator between acceptable and unacceptable for the B-52 test board.

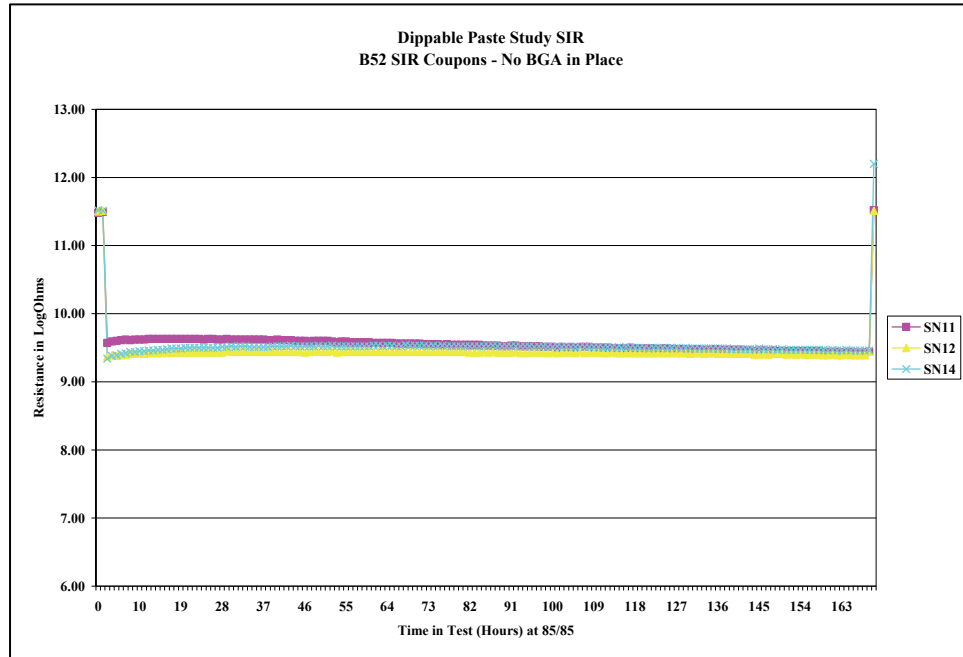


Figure 15 SIR Results for B-52 with No BGA in Place (Baseline)

3. Figure 15 shows the response of the B-52 test board BGA pattern with no BGA in place and no exposure to the candidate materials. The response shows that the test boards were in a clean and consistent starting condition. The difference between the three test board patterns would not be considered as significant in SIR testing.

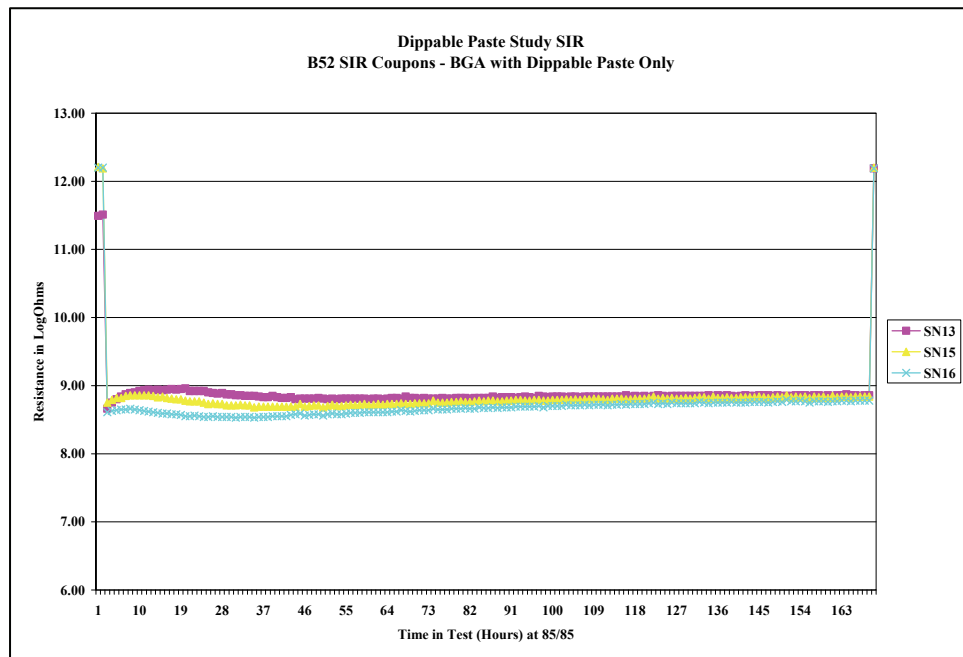


Figure 16 SIR Results for B-52 with Dippable Paste Only

4. Figure 16 shows results for the B-52 test board BGA pattern with a BGA component in place, soldered with the dippable paste only, followed by saponified aqueous cleaning (the standard Rockwell Collins process). The data shows some decrease in insulation resistance, compared with the data from Figure 15. This was not unusual in an SIR test, as most components will decrease SIR levels regardless of the attachment materials or process. The levels were always well above the 8.0 LogOhm criteria and were very consistent between the different test samples.

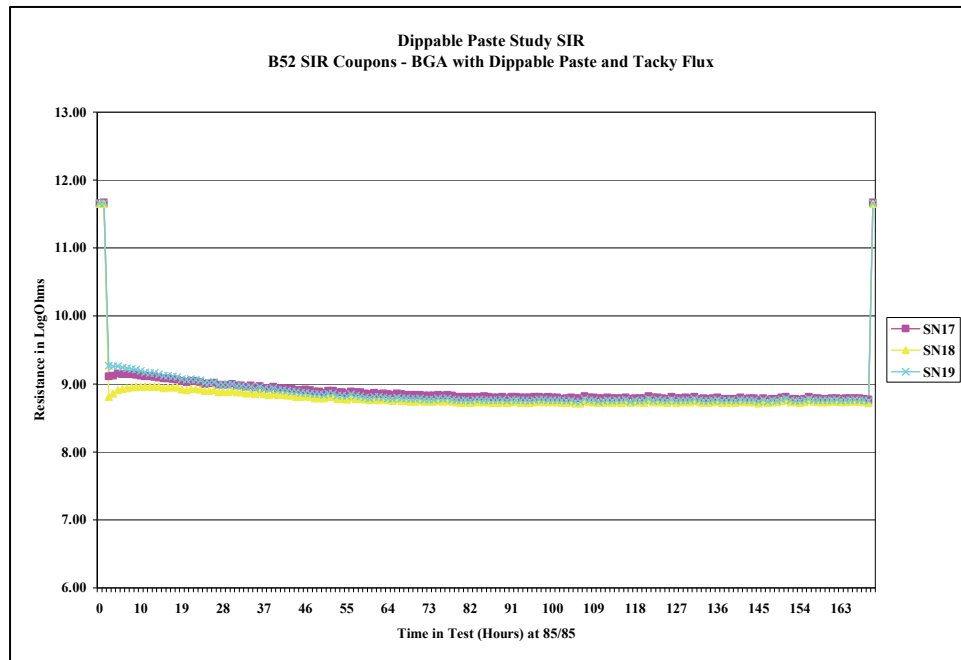


Figure 17 SIR Results for B-52 with Dippable Paste and Tacky Flux

5. Figure 17 shows the results for the B-52 test board BGA pattern with a BGA attached using a combination of the dippable paste and the additive tacky flux. As with the paste-only samples, the SIR levels were well above the 8.0 LogOhm level with good consistent result. These desirable results also show that there were no harmful effects of combining the flux residues from the dippable paste with the tacky flux residues, as can sometimes happen when fluxes from different vendors are combined.

Post SIR Visual Examination

Following SIR testing, each of the B-52 SIR boards was examined visually with magnification up to 10X. For the test samples containing BGAs, the BGAs were removed with an Onyx 29 hot gas rework machine without the addition of any flux. Both the board surface and the underside of the BGAs were examined to determine the presence of electrochemical migration (dendritic growth), electrolytic corrosion, or other visual phenomena indicating degradation.

Figure 18 shows the BGA SIR pattern on the board surface as well as the underside of the BGA component after removal from the test board. Figure 19 shows a close up image of both conditions. The white residue noted in the photos is residual low residue flux from the soldering operation. These images are from Board SN17, which was a combination of the flux from the dippable paste and the additive tacky flux. Similar white residues were found on the assemblies that had been processed with the dippable paste alone, though with a lesser degree of white residues. A check of other IPC-B-52 boards (previous study) from the same manufacturing run showed lower levels of white residues. The conclusion reached was that the white residues were remainders from the original manufacturing process, with minor addition from the dippable paste and more white residues from the additive tacky flux.

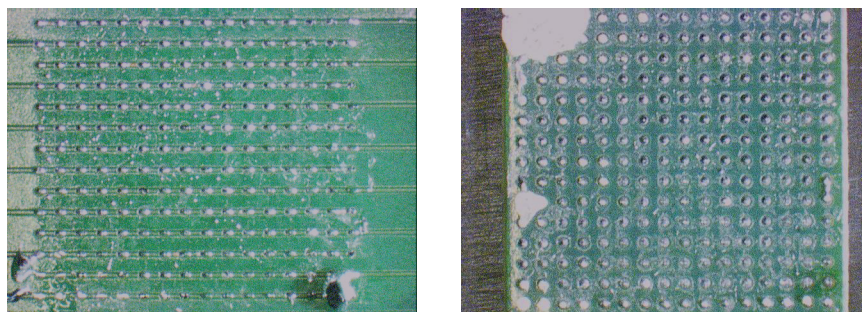


Figure 18 Board SN17 BGA Pattern (left), BGA Underside (right)

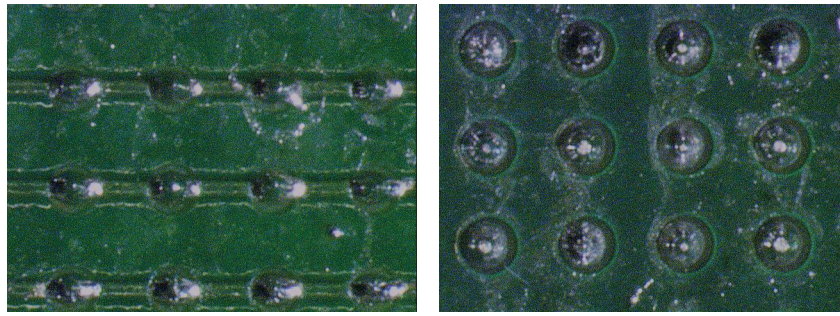


Figure 19 Closeups of Board (left) and BGA (right)

White residues from low residue (no clean) fluxes are relatively common. The residue itself is often either residual abietic acid from the rosin in the flux, or a weak dicarboxylic acid from the flux activator. Both of these materials will turn white after exposure to either aqueous cleaning or high humidity conditions (e.g. SIR testing).

The issue of white residues and their effects on circuit reliability have been debated extensively within the industry. Work by Dr. Karen Tellefsen², Alpha Metals, has shown that many of the residues we see on circuit boards are benign in nature. In the author's experience, white residues are purely cosmetic, when they exist in the "white haze" condition of Figure 19. White residues become an issue when they are present in a more substantial thickness, and then only when the flux has received inadequate thermal processing or absorption of other process chemicals. The lack of electrochemical migration, along with the favorable numbers in the SIR test demonstrate that these residues were benign and not a hazard to reliability.

Overall Conclusions

1. The use of dipdable solder paste is a new concept for BGA rework but is a widely established methodology in the electronics industry for wafer bumping and package-on-package technologies³. The use of dipdable solder paste in electronics assembly soldering processes such as repair/rework or area array assembly is a viable option, as demonstrated by this study.
2. The thermal cycle solder joint integrity and flux compatibility results were acceptable for IPC Class 3 High Performance products.
3. The residues from the BGA attachment process, both for the dipdable-paste-only and for the dipdable paste and tacky flux combination, were found to be desirably low, following saponified aqueous cleaning, as measured by ion chromatography.
4. When tested using standard SIR protocols and the IPC-B-52 test vehicle, the remaining residues did not show deleterious behavior when combined with an electrical potential in a hot and humid test environment. The lack of electrochemical failure mechanisms, such as dendritic growth or electrolytic corrosion, showed there were no harmful effects from the Heraeus dipdable paste residues and no harmful interactions between the Heraeus dipdable paste flux residues and the Alpha Metals UP-78M tacky flux.

Acknowledgments

Rockwell Collins has a very active college co-op program, in which bright, young engineers spend 8 months at Rockwell Collins learning materials science. The authors are indebted to Andrew Steinmetz and Nathan Marzen for their assistance and hard work in this project.

References

- ¹ From Heraeus Assembly Materials Bumping Products Brochure, November, 2007
- ² K. Tellefsen: "Green Residues and Electrical Reliability", Proceedings of the International Conference on Electronic Assembly: Materials and Process Challenges. Atlanta, GA. June 1998.
- ³ M. Dreiza, Amkor Package-on-Package Webinar Presentation, "Package on Package Applications, Requirements, Infrastructure and Technologies", IMAPs Lunch and Learn PDC Webinar Series, January, 2009.

Investigation of Process Feasibility / Compatibility and Solder Joint Reliability of Tin-Lead Dippable Solder Paste Ball Grid Array (BGA) Component Rework/Repair

Dave Hillman and Doug Pauls
Principal Materials and Process Engineers
Rockwell Collins
Cedar Rapids, IA USA



Agenda

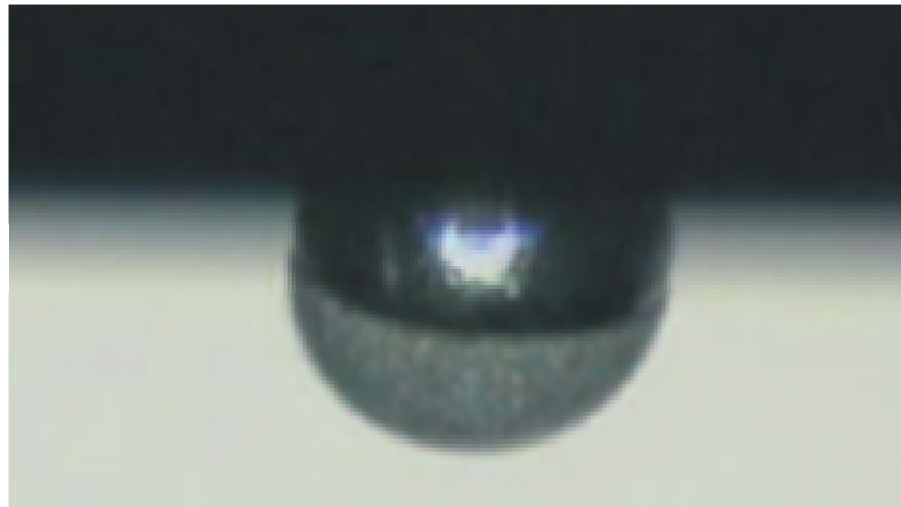
- Background
- Objectives
- Phase I: Solder Joint Reliability Phase
- Phase II: Flux Material Compatibility Qualification
- Conclusions

Background

- Background

- BGA components are traditionally reworked by removing an existing BGA component, applying solder paste to a replacement BGA component with a stencil, and soldering the component to a printed wiring assembly using a BGA hot gas rework machine
- An alternative method is to apply tacky flux to the printed wiring assembly pads, place the component on the pads and reflow solder with hot air
- The stencil process is the optimum procedure because it adds solder volume to each joint which increases solder joint reliability

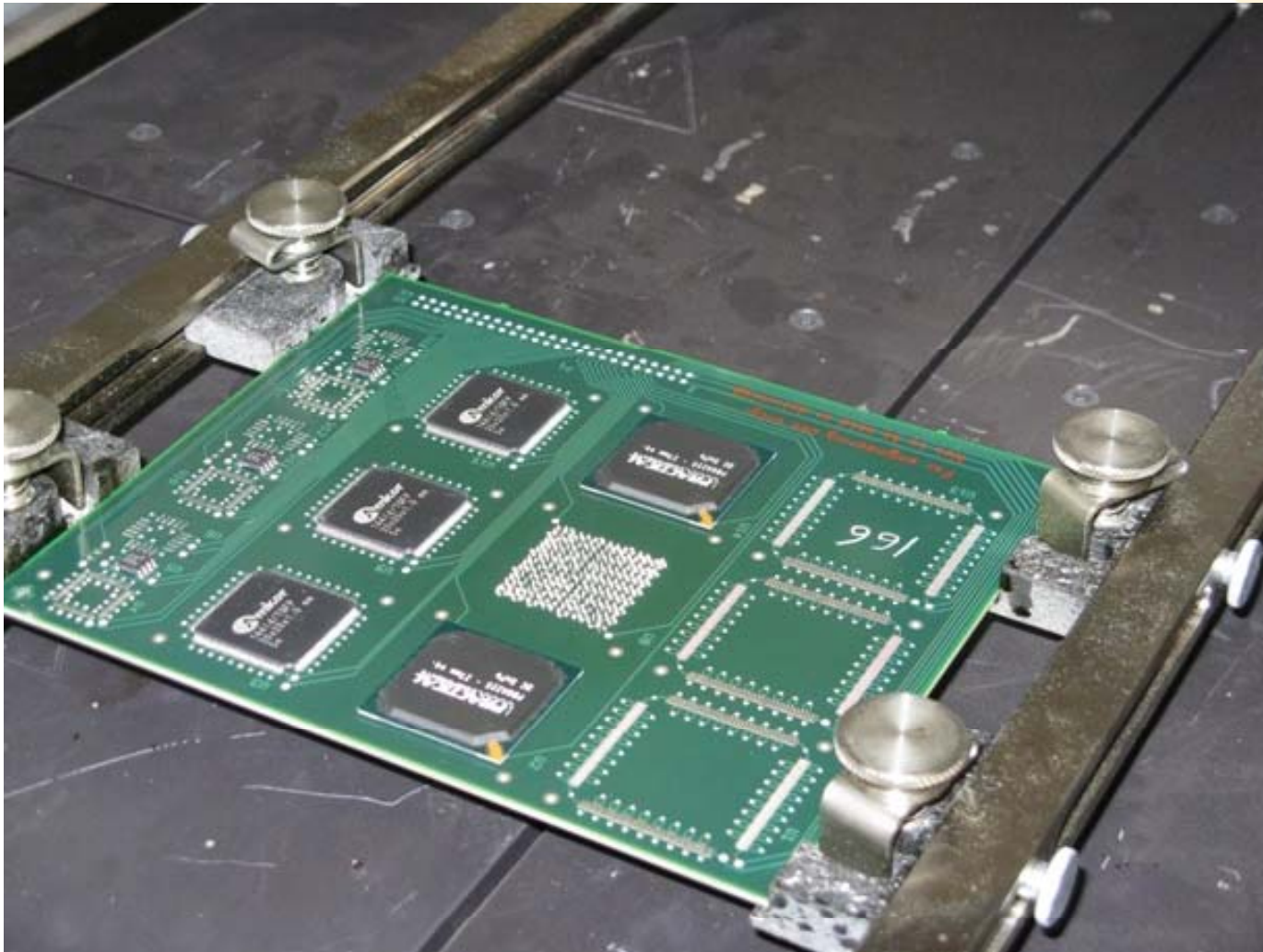
- Material Information:
 - Heraeus Printable Solder Paste BD72SN63-80-5 (“dippable paste”)
 - Type 5, no clean, low residue paste
 - Metals content of the paste was 89% (+/- 1.5%)
 - The tacky flux used in investigation:
 - Alpha Metals UP-78M, a bromine-activated ROL1 paste flux.



Study Objectives

- (1) Determine whether the dippable paste process could be used to create reliable solder joints
 - (2) demonstrate that the process could be adapted for use on a BGA rework machine
 - (3) show that the flux in the dippable paste was compatible with a typical production process
 - (4) determine what residues were present on the processed test vehicles
-
- Phase 1: Thermal Cycle Study
 - Phase 2: Process Compatibility Study

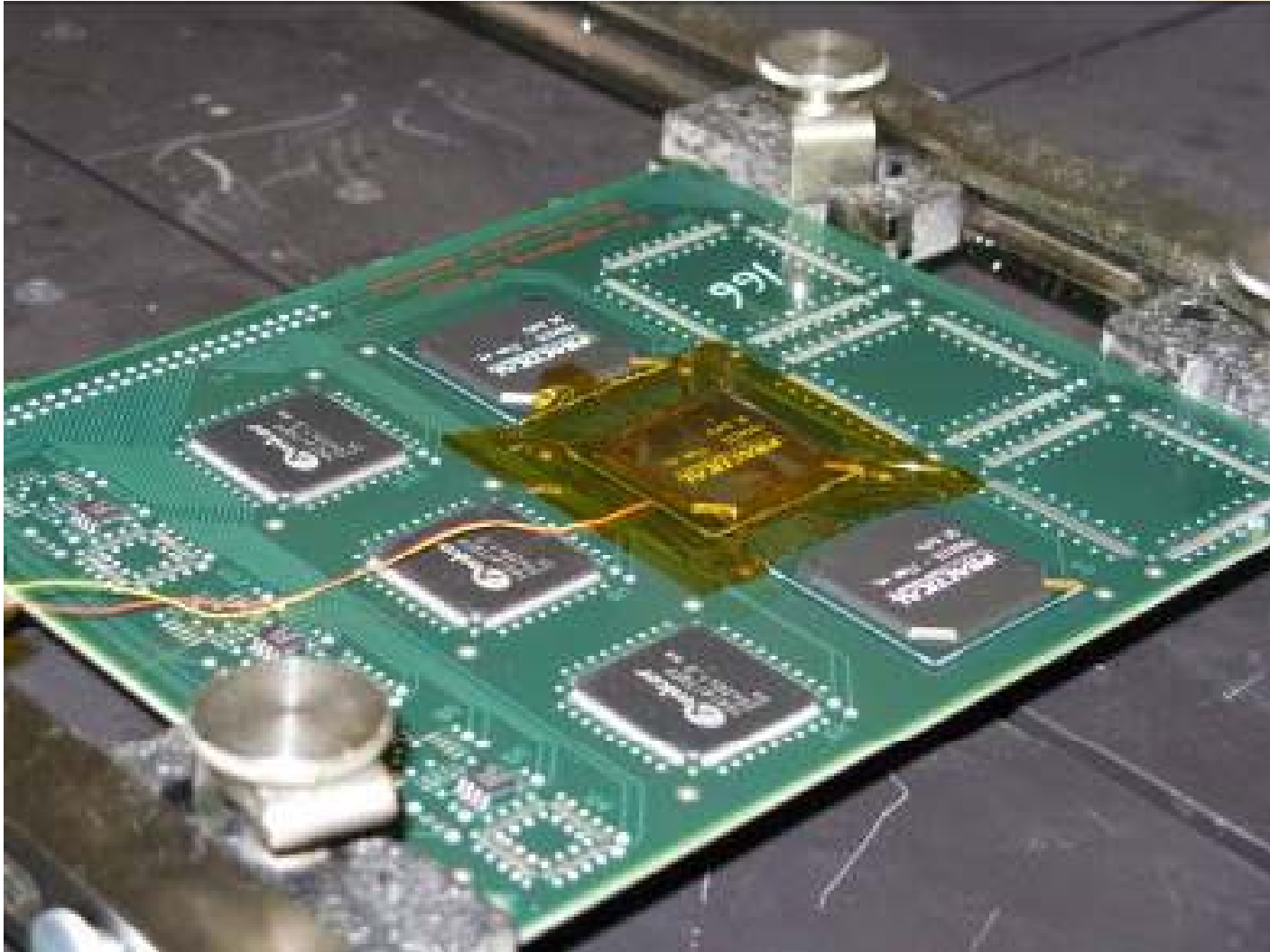
Test Vehicle



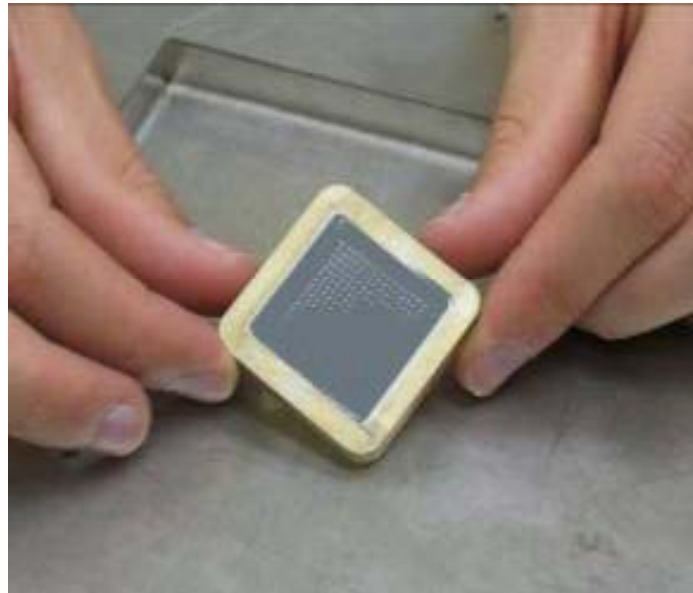
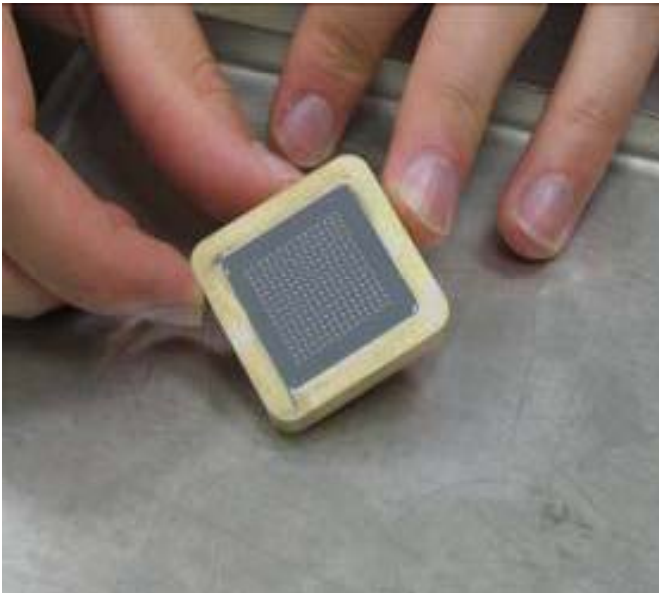
Test Classes

- **Tacky Flux Only (15 Components):** Tacky flux was applied to the printed wiring board pads before soldering and the components were soldered to the pads without the application of solder paste to the printed wiring board pads.
- **Solder Dipped and Fluxed (15 Components):** These components were dipped in the dippable solder paste and tacky flux was applied to the printed wiring board pads before soldering.
- **Solder Dipped Only (14 Components):** The components were dipped in the dippable solder paste and the components were soldered to the board without the application of tacky flux to the printed wiring board pads.
- All BGAs were internally daisy chained to correspond to daisy chaining on the board surface

Thermal Profiling



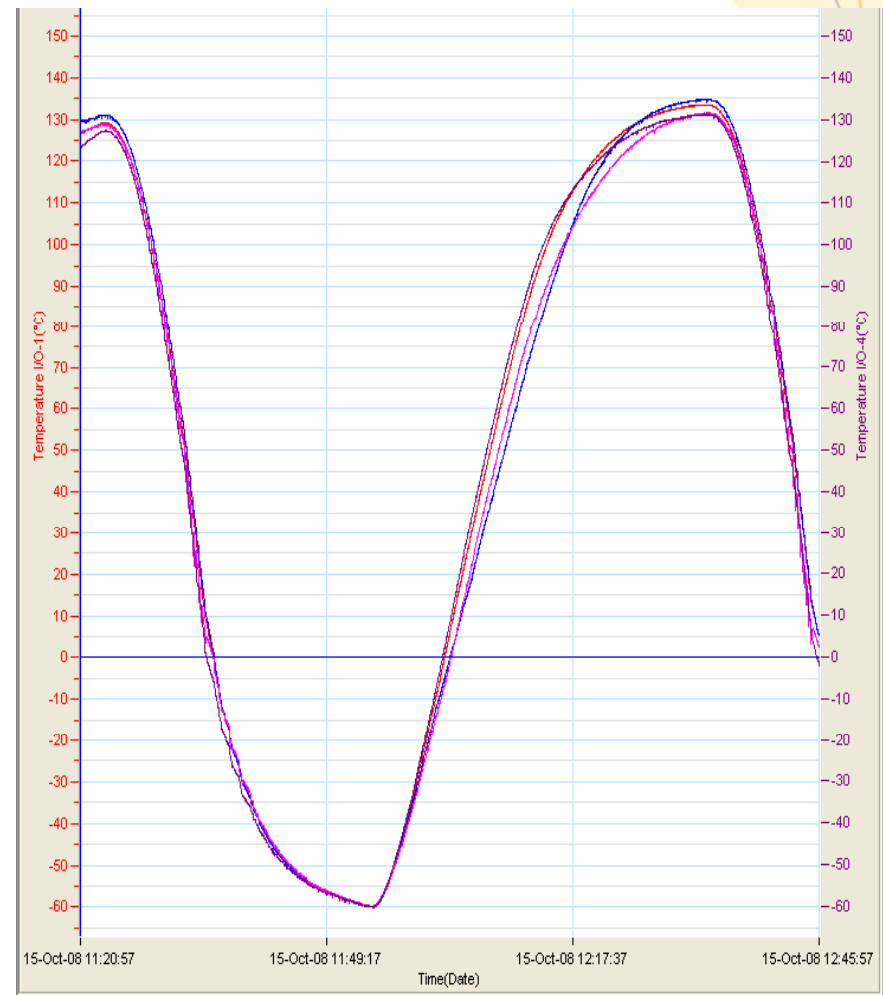
Paste Wells





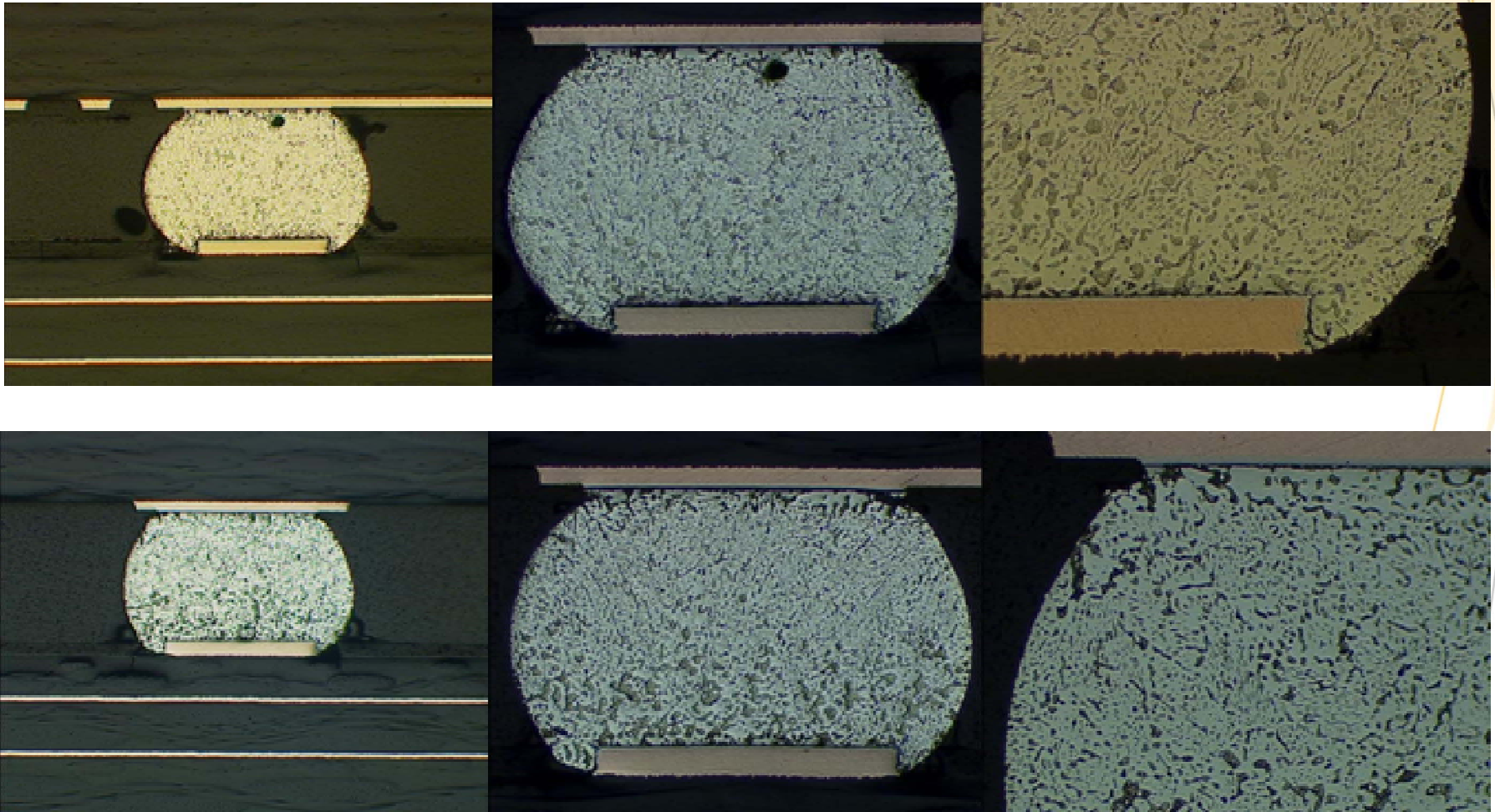
Thermal Cycle Profile

- 2000 cycles
- -55°C - +125°C
- 15 minute dwells at either extreme
- 8-10°C / min ramp rates
- Per IPC-9701
- Resistance Monitored
 - Recorded an event for 15 consecutive cycles,
 - Had five consecutive detection events within 10% of current life of test, or
 - Became electrically open.



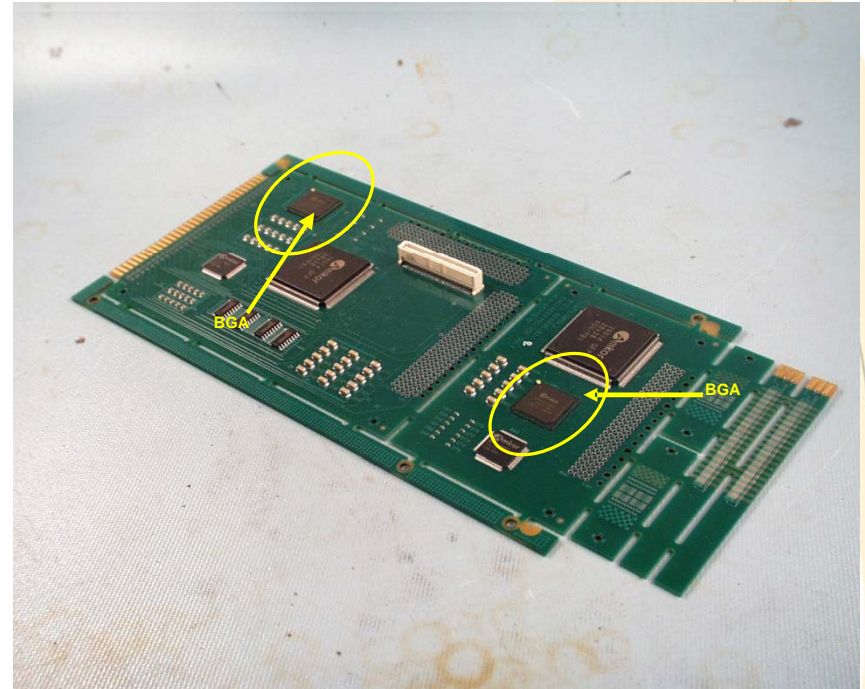
Phase 1 Results: Tacky Flux vs. Dippable Paste

- No failures in thermal cycling for any of the three test classes
- No anomalies in the BGA solder joint geometries, wetting angles or solder joint microstructures were observed.



Phase 2 Testing

- IPC-B-52 standard test assembly chosen for the testing
- One coupon for surface insulation resistance (SIR) testing – 9 samples
- One coupon for ion chromatography residue analysis – 9 samples
- No BGA
- BGA attached with dippable paste only
- BGA attached with dippable paste and tacky flux





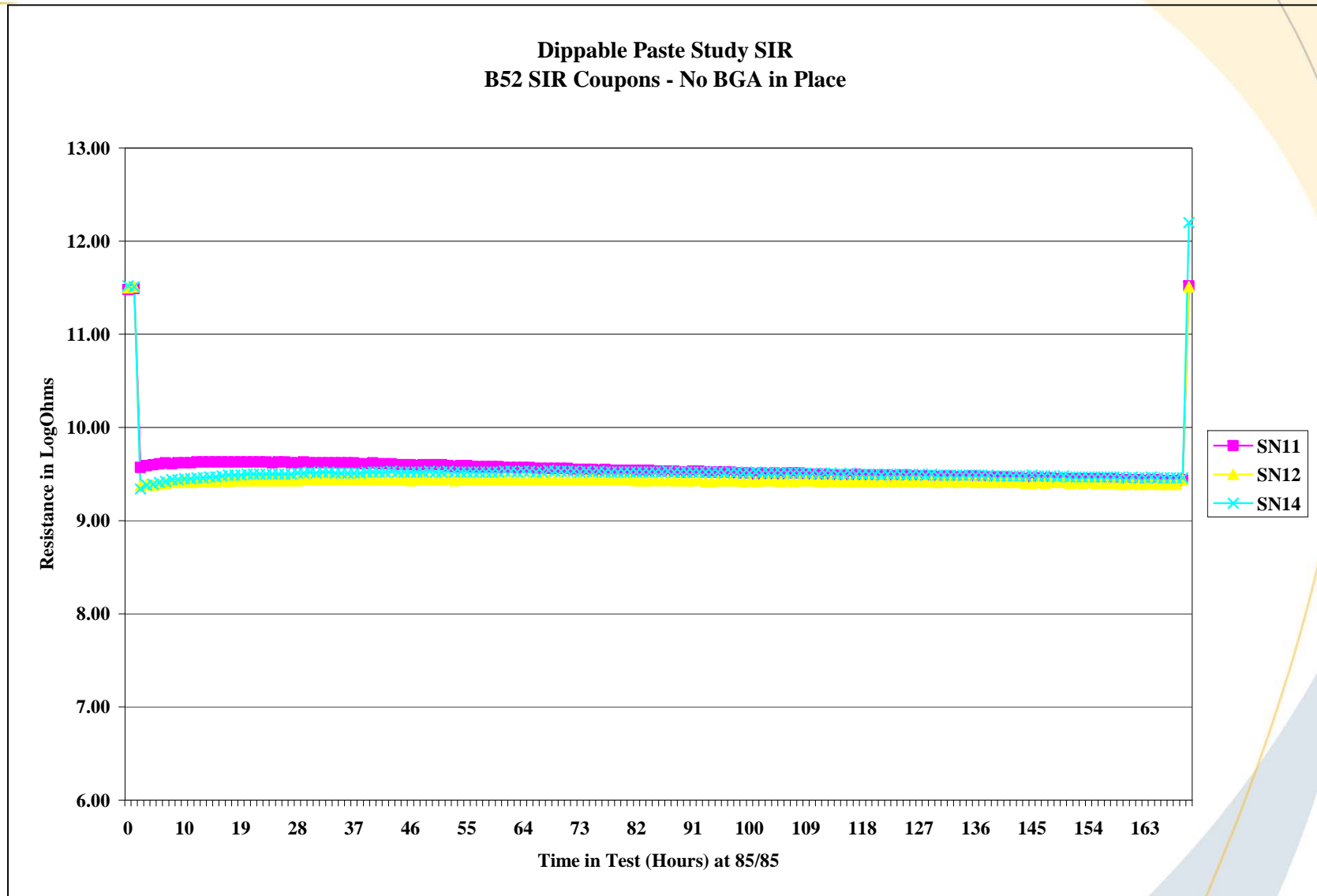
Chosen Metrics for Ionics

- 1 microgram / cm² upper limit on chloride
- 3 micrograms / cm² upper limit on bromide
- 3 micrograms / cm² upper limit on sulfate

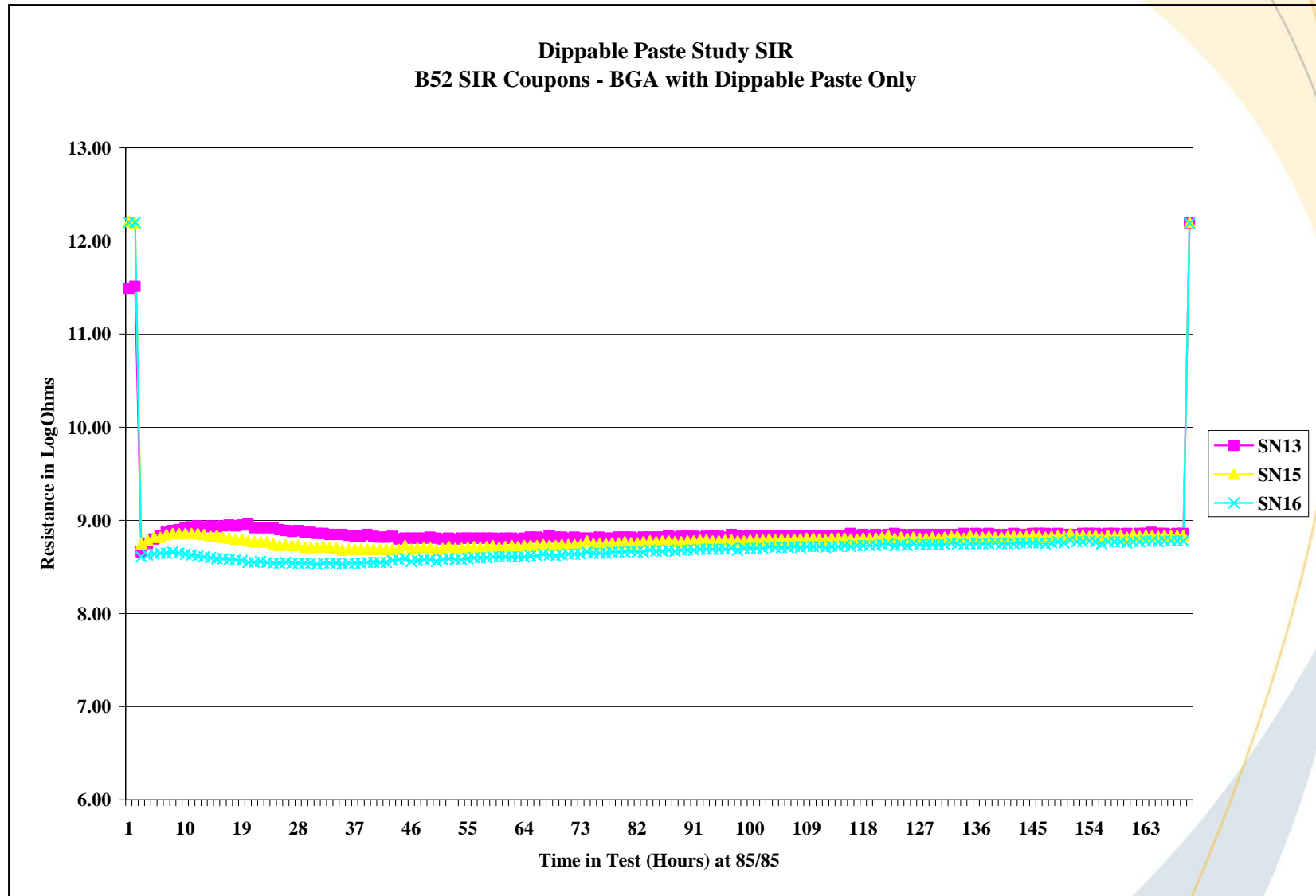
SIR Test Specifics

Parameter	Description
Test Equipment	Gen 3 Systems AutoSIR 256
Test Environment	85°C / 87.5% relative humidity
Ramp up	No Bias, condensation free
Test Duration	7 days
Bias Voltage	10 volts DC
Measurement Voltage	10 volts DC
Measurement Frequency	Every 60 minutes
Equilibration Time	3 hours

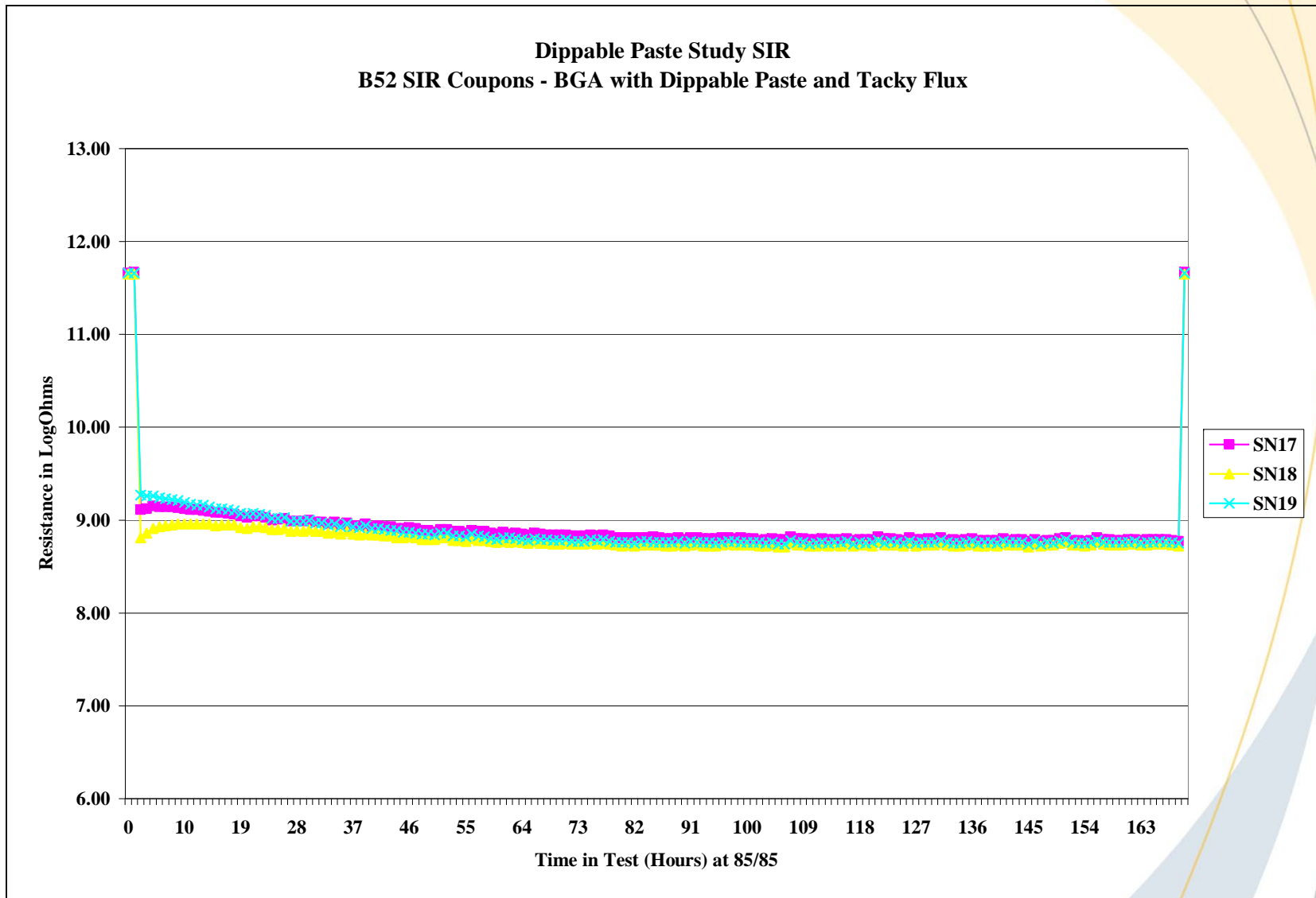
SIR Results – BGA Pattern Only



SIR – Dippable Only



SIR – Dippable + Tacky Flux



Overall Conclusions

- Yah Shure, dat dippable stuff verks purdy guud (translation - It works)
- No failures in thermal cycling
- Extra solder volume = improved reliability
- Acceptable residue levels after in-line saponified aqueous cleaning
- No harmful electrochemical effects as determined by SIR
- **Why would you put lots of flux down you don't intend to use and makes cleaning harder???**



CURIOSITY

SOME PLACES REMAIN UNKNOWN BECAUSE NO ONE HAS VENTURED FORTH.
OTHERS REMAIN SO BECAUSE NO ONE HAS EVER COME BACK.