Risk Assessment of Printed Wiring Board Alternative Finishes

Jimmy R. Reed
Raytheon Systems Company
Austin, TX
February 1, 2000

Table of Contents

ABSTRACT **3**

INTRODUCTION **4**

ALTERNATED FINISHES TEST PLAN **5**

SURFACE INSULATION RESISTANCE (SIR) AND DENDRITIC GROWTH TESTING 5
SOLDERABILITY TESTING 7
FUNCTIONAL RELIABILITY TESTING 9
Diesel Fuel (DF) and Hydraulic Fluid (HF) Exposure Protocol 13
Temperature/Humidity (85/85) and Thermal Shock (TS) Potocol 14
Condensing Atmosphere and Thermal Shock Protocol 15
Branch Water (BW) and Salt Fog (SF) Protocol 17

DATA AND DISCUSSION **19**

SURFACE INSULATION RESISTANCE AND DENDRITC GROWTH 19
SOLDERABILITY 33
FUNCTIONAL TEST 37

CONCLUSIONS **42**

SIR AND DENDRITIC GROWTH 42
SOLDERABILITY 42
FUNCTIONALITY 42

SUMMARY **43**

REFERENCES **44**

Abstract

The Circuit Card Assembly and Material Task Force (CCAMTF), an ad hoc industry group, has worked for the last 5 years on a series of experiments to determine the producibility and reliability of several alternate (non solder) finishes. The CCAMTF's work is a “follow on” of the National Center of Manufacturing Sciences (NCMS) Surface Finishes Team which did much of the screening work and issued its final report in 1995 [1].

This paper will address Solderability, Age Resistance, Dendritic Growth, Solder Joint Reliability, and Cost risks for the top contenders to replace solder as the premier final surface finish for Printed Wiring Boards (PWB).

Immersion Silver is recommended as a “drop in” replacement for reflowed tin-lead or Hot Air Solder Leveled (HASL), particularly when soldering low pitch devices (< 0.020") and BGA.

The issue of wire bondability is not addressed, though others [2] have researched this possibility and found Immersion Silver to be bondable.

Introduction

There is a sense in the electronics industry that environmental pressure alone will force us to remove the lead from component interconnections. I do not agree! What will force change is economics. There may be several acceptable solutions depending on the business environment, but In the end, the consumer will define what finishes will be used.

This data is evaluated from a High Reliability DOD or Commercial Avionics point of view. Consequences of changing the PWB surface finish are discussed for this target group.

The NCMS-Surface Finishes Team (NCMS_SFT) started its work in 1990. The goal was to find a tin lead replacement for the PWB surface finish. Eleven alternate finishes (see Table 1) were evaluated and the use of progressive environmental stressing solderability test specimens to determine relative finish performance was validated. The companies that participated in the work are shown in Table 2. The team completed its work and issued it final report in 1996. The final conclusion was that of all the finishes evaluated none would replace solder based on Cost, Performance, and Availability.

Table 1 NCMS Board Finishes

1. Tin/Lead Hot Air Solder Level
2. Tin/Lead Plate and Reflow
3. Immersion Tin/Lead
4. Organic Solderability Preservative
5. Electroless Palladium over Electroless Nickel
6. Electroless Palladium over Copper
7. Electroplated Palladium over Nickel
8. Immersion Gold over Electroless Nickel
9. Electroless Gold over Electroless Nickel
10. Electroplated Gold over Nickel
11. Castin™ - Hot Air Solder Level

Table 2 NCMS Board Finishes Participation

1. Texas Instruments
2. Lucent Technologies
3. Hamilton Standard
4. Sandia National Laboratory
5. International Business Machine
6. Digital Equipment Corporation

In 1995, after completing the NCMS-SFT work, a group of interested companies came together to define areas of common interest so the cost of developing new capabilities would be reduced for all. The team list is in Table 3

. Two development activities were defined as mutually beneficial. They were:

1. Reduction in the use of conformal coatings and reduction of Volatile Organic Carbon (VOC) in the conformal coatings required.
2. Continuation of the NCMS-SFT work on additional finishes and functional evaluation of solder joints with the best contenders.

In this paper, I will focus on the results relative to alternate board finishes.

Table 3 Members of the Circuit Card Assembly and Materials Task Force

Manufactures	***Consultants***	***Government***
Raytheon Systems Co.	Southwest Technology Consultants	USAF
Honeywell	Robisan Laboratory, Inc	U.S. Army Missile Command
Hughes Space & Communications Co.	Contamination Studies Laboratories, Inc	Naval Air Warfare Center,
Motorola: Semiconductor	NCMS	Wright-Patterson AFB
VIA Systems	American Competitiveness Institute	Current Technologies Corp. (CTC)
Lucent Technologies	Les Hymes Associates	
Alliant Techsystems		
Lockheed Martin		
AlliedSignal		
GTE		
SEHO U.S.A., Inc		
Rockwell Collins		

In 1997 representatives from all of the military services reviewed our preliminary solderability data and evaluated the functional test plan. They recommended modifications and the final plan was approved in 1998. Due to the addition of specific tests, the Services agreed to pay part of the cost of running the test and CTC was set-up to facilitate drafting the Joint Test Protocol (JTP) [3] and handle disbursement of the approved government funds.

This report will cover 30% of the functional test data, all solderability, and all SIR test results for alternative surface finishes. The final data and report are expected in 2000.

Alternated Finishes Test Plan

In addition to a functional reliability test, all surface finishes were evaluated for Surface Insulation Resistance (SIR), dendritic growth, and solderability under a series of environmental and mechanical stress conditions. Three different test vehicles were used and they will be described in for each test method. Surface finish fabrication was done at the same time for all surface finishes and test vehicles.

Three test methods will be discussed in the following order.

- Surface Insulation Resistance and Dendritic Growth
- Solderability
- Functional Reliability

Surface Insulation Resistance (SIR) and Dendritic Growth Testing

This SIR test used the IPC-B24 coupon as shown in Figure 1. All comb patterns were measured independently by coupon. Four coupons were run at each test condition with two test methods, IPC-TM-650 method 2.6.14 and Bellcore GR-78-Core issue 1 Sept 1997 Method 13.1.4. See the following for the test conditions.

SIR Test Conditions		
STRESS VARIABLE	**TEST METHOD**	
	IPC	***Bellcore***
Bias Voltage	10 vdc	10 vdc
Temperature	85 °C	65 °C
Relative Humidity	90 %	85 %
Stress Exposure Time	0 &168 hr.	96 & 596 hr.

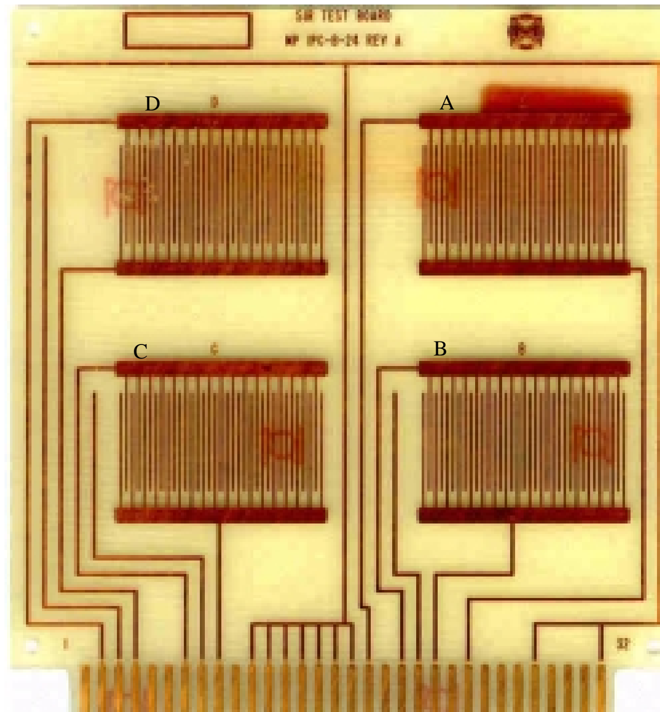

Figure 1 Surface Insulation Resistance Test Vehicle

SIR testing was reported by Reed [4] in 1997 on “as fabricated” specimens with and without solder mask and bias voltage indicated only minor differences in SIR due to surface finish. There were 4 surface finishes tested.

1. Benzimidazole on copper (OSP)
2. Hot Air Leveled Solder (HASL)
3. Immersion Silver on copper (Imm Ag/Cu)
4. Immersion Gold over electroplated palladium on copper (Imm Au/Pd/Cu)

As a result of this test, we decided to deliberately contaminate some of the specimens in an attempt to increase the test’s discrimination for surface finish. Standard HCl solutions and low residue flux were used as the contamination source.

Two methods of contaminating the specimens were used.

- Immersion – Complete immersion of the coupon into the solution. After 1 minute the specimens were removed and allowed to evaporate to dryness in a vertical rack.

- Drop – A single drop of standard solution was applied to the center of each comb pattern on each specimen. The contaminated specimens were allowed to air dry in a horizontal orientation.

After all solutions had dried, the specimens were individually packed in unsealed plastic bags and shipped to a contract laboratory for SIR testing.

In the contaminated SIR testing discussed in this report was done on the following surface finishes.

- Reflowed Solder Plate (RSP)
- Copper with no additional finishing (Cu)
- OSP on copper (OSP)
- Immersion Silver on copper (Imm Ag/Cu)

After the SIR testing was complete and all data collected, each specimen was visually inspected for evidence of dendritic growth or electromigration. This evaluation was done at 10X magnification with back lighting. Each comb pattern was given a “pass” or “fail” attribute for dendritic growth. Other observations were noted and will be discussed in the data section.

Solderability Testing

We found that the solder thickness [4] variation with HASL was much greater on the 1.0” X 2.0” solderability specimens (Figure 2) than on the board itself. This resulted in solderable parts being characterized as unsolderable via the wetting balance test.

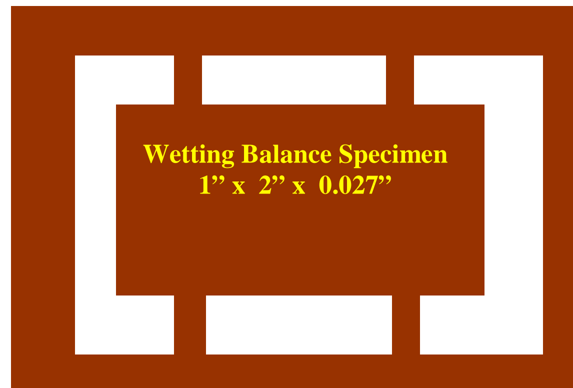

Figure 2 Wetting Balance Solderability Specimen

The improved signal/noise ratio of the wetting balance data from the large specimen was considered essential for proper characterizations of all surface finishes, so Plated & Reflowed Tin Lead was used to control the solder thickness issues and as the baseline for all solderability tests. Hot Air Solder Leveled (HASL) was used as the baseline for all functional parts.

All Solderability testing was conducted on a Multicore Mustmate 100 on an all copper specimens (Figure 2). forty-four coupons were chemically milled into a half-hard copper 12” x 18” sheet 0.025” thick. This panel was processed to give the surface finish as shown in Table 4.

Table 4 Solderability Surface Finishes

1. Hot Air Solder Leveled on copper (HASL)
2. Benzimidazole on copper (OSP)
3. Immersion Gold over electroplated palladium on copper (Imm Au/Pd/Cu)
4. Immersion Silver on copper (Imm Ag/Cu)

The coupons were cut from the panel and stressed according Table 5.

Table 5 Solderablity Stress Conditions

1. No stress “as received”
2. Simulated reflow in nitrogen
3. Simulated reflow in air
4. Bake for 8 hrs 105 °C and simulated reflow in nitrogen
5. Bake for 8 hrs 105 °C and simulated reflow in air
6. Storage for 168 hours at 50 °C and 85 relative humidity
7. Steam Aged 8 hours @ 92 °C

After stress the specimens were tested in a Multicore - Mustmate 100 wetting balance tester. The specimens were immersed vertically on the 1.0” side (Figure 2) using the following set up.

- Flux Actiec 2
- Specimen 1.0" X 2.0" X 0.025" copper stock
- Immersion Depth 3 mm
- Immersion Speed 20 mm/s
- Sampling Period 5 s
- Solder Alloy Sn63
- Solder density 8.15 mg/mm3
- Solder Temperature 245°C

Plated and reflowed tin lead was used as the “base case” instead of HASL due to improved coating thickness control on the wetting balance coupon.

Five specimens were averaged to represent the solderability of each finish and stress condition. Three values were collected from each wetting balance graph. They are…

1. Time to zero Force T0
2. Force at 2 Seconds F2
3. Time to 2/3 Max. Force T2/3

Figure 3 is a typical wetting balance curve with these data points identified. Due to past experience we focused on the F2 variable although the same overall results can be obtain using the other responses.

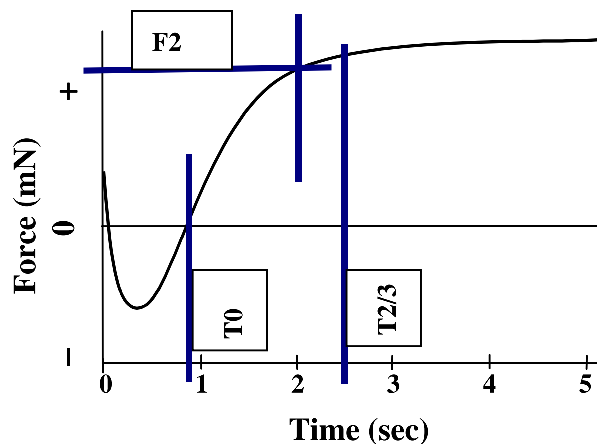

Figure 3 Typical Wetting Balance Curve

Functional Reliability Testing

The overall test plan for the CCAMTF is diagramed in Figure 4. The team selected the major surface finishes for evaluations based on the NCMS-SFT report. These finishes were subjected to additional solderability and SIR tests in an effort [4] to reduce the size and cost of the

The screening test for surface finishes was conducted independently of the conformal coating tests.
Table 6 contains a complete list of the surface finishes evaluated during the screening phase.

Table 6 Alternate Finishes Evaluated During Screening

1. HASL (baseline)*
2. Benzimidazol
3. Imidazol
4. Immersion Gold on Electroless Nickel
5. Immersion Silver on Copper
6. Electroplated Palladium on Copper
7. Immersion Gold on Electroplated Palladium

* Note: Baseline was changed to reflowed solder plate because of thickness control problems on the wetting balance specimens with HASL.

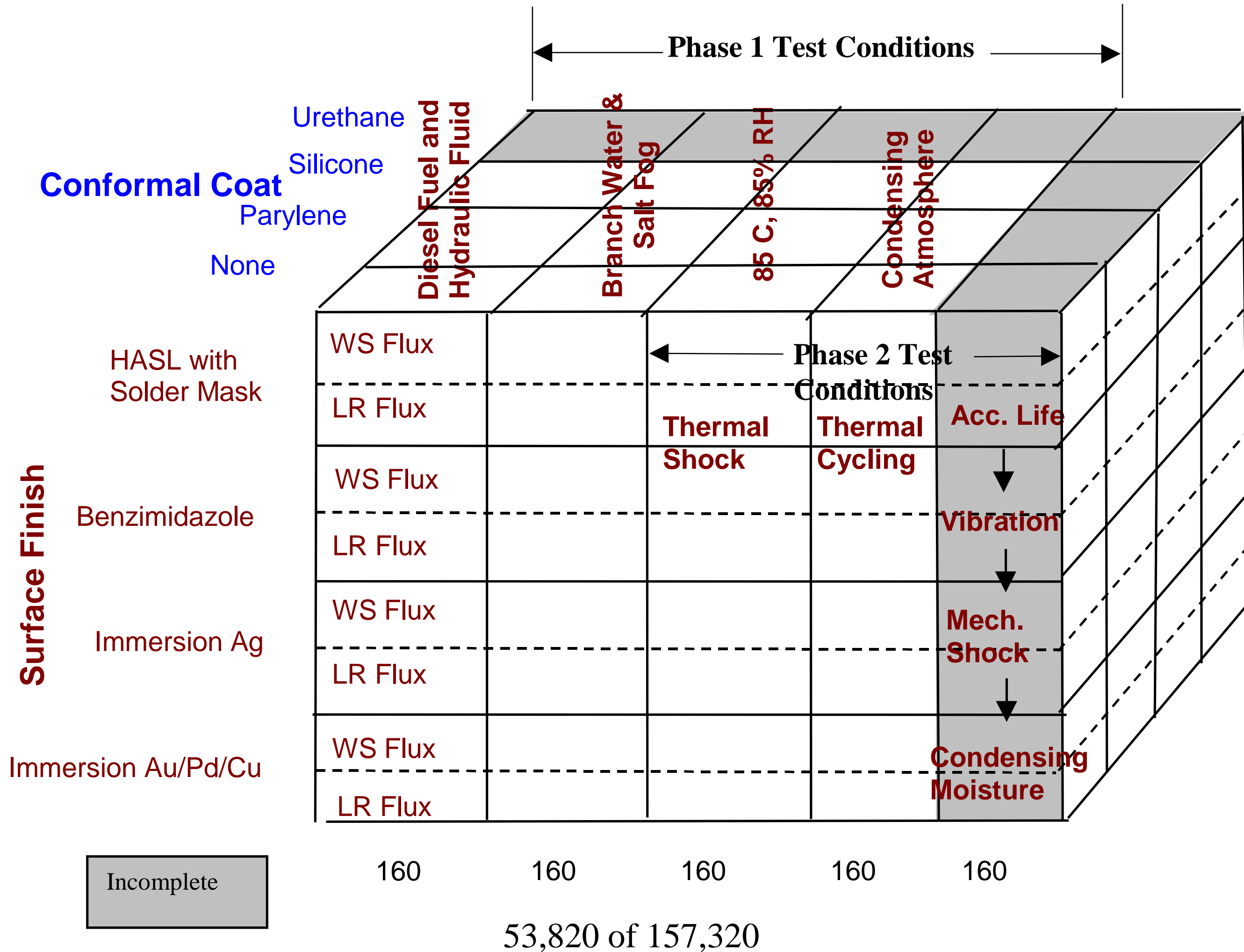

Figure 4 Three-Dimensional Representation of the CCAMTF Phase 1 & 2 Test Plan

After the surface finish screening [5], four surfaces finishes were down selected for Phase 1 and Phase 2 functional test evaluations. The finishes select are in Table 7.

Table 7 Phase 1 and 2 Surface Finishes

1. HASL with Solder Mask
2. Benzimidazole
3. Immersion Silver
4. Immersion Gold on Electro-Plated Palladium.

The test vehicle used for Phase 1 and 2 functional testing was developed by the Low Residue Soldering Task Group and adopted “as is” by the CCAMTF (see Figure 5).

`

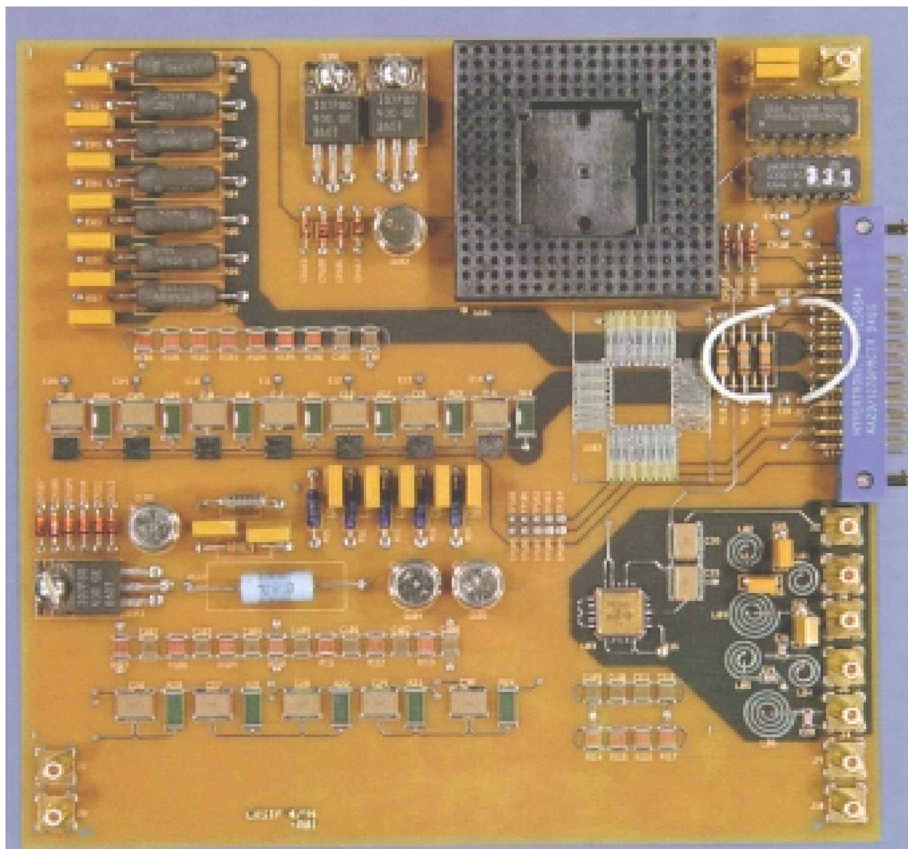

Figure 5 LRSTF PWA Used for Functional Tests

The PWBs were all fabricated at the Raytheon, Austin, TX facility. All components were purchased as a block and all terminations were tin lead coated. No testing was preformed to verify solderability of components. Boards and components were soldered at the American Competitiveness Institute (ACI).

The conformal coatings were applied at various facilities according to local capability and capacity. Each conformal coating material was applied at same time and at only one facility.

After coating, all assemblies were shipped to various facilities for the environmental and mechanical stressing. Several facilities were used based on capability and capacity. Table 8 gives a listing of the Phase 1 environment and
Figure 4 gives a 3D veiw of the overall Phase 1 and 2 test plan. Each box represents a single coating, flux type, surface finish, and stress condition. Data from 5 assemblies are reported in each box. There are 80 sets of boards and 12 stress conditions resulting in 480 unique observation cells.

Table 9 gives the conditions for the Phase 2 mechanical testing.

Table 8 Phase 1, Functional Environmental Tests

1. Exposure to Diesel Fuel and then Hydraulic Fluids
2. Branch Water Test and then Salt Fog
3. Exposure to 85°C, 85% RH for 3 weeks
4. Condensing Atmosphere

Figure 4 gives a 3D veiw of the overall Phase 1 and 2 test plan. Each box represents a single coating, flux type, surface finish, and stress condition. Data from 5 assemblies are reported in each box. There are 80 sets of boards and 12 stress conditions resulting in 480 unique observation cells.

Table 9 Phase 2, Functional Mechanical Shock Tests

1. Thermal Shock
2. Thermal Cycling
3. Accelerated Life
4. Vibration
5. Mech. Shock

Forty of the 160 PWAs shown in the test matrix in Figure 4 for Phase 1 &2 are coated with urethane. These 40 PWAs were added to the test matrix too late to be tested at the same time as the remaining 120 PWAs. Thus, this report contains results only for 120 PWAs.

- 40 PWAs without coating,
- 40 PWAs coated with Parylene, and
- 40 PWAs coated with silicone.

To keep the number of specimens to a managable level, we agreed to use the same set of boards for more than one stress evaluation. Consideration was given to the possiblity of cathicstrofic failures and interactions between the stress factors. No 100% agreement was ever reached, but the following indicate the way the boards were grouped for testing.

- Diesel Fuel followed by Hydraulic Fluid Exposure
- Branch Water followed by Salt Fog
- 85°C/90% Relative Humidity (RH) followed by Thermal Shock
- Condensing Atomsphere followed by Thermal Cycling
- Accelerated Life followed by Vibration, Mechanical Shock, and another Condensing Atomsphere.

Only compeleted test sets are reported. They are…

- Diesel Fuel followed by Hydraulic Fluid Exposure
- Branch Water
- 85 °C/90% Relative Humidity (RH) followed by Thermal Shock
- Condensing Atomsphere followed by Thermal Cycling.

The remainder of the tests are in work now and are expected to be complete in 2000.

Five circuit types were evaluated (Table 10) on each PWA on an Automatic Test System (ATS) built especially for this purpose at Raytheon in McKinney, TX.

Table 10 Electrical Circuit Types

High Current Low Voltage	(HCLV)
High Voltage Low Current	(HVLC)
High Speed Digital	(HSD)
High Frequency Low Pass Filter	(HF-LPF)
High Frequency Transmission Line Coupler	(HF-TLC)
Other Networks—Leakage	(ON)
Stranded Wire	(SW)

Each cell in Figure 4 contains the results from 5 identical PWAs for each of 23 circuits.

Table 11 defines all of the test measurements taken and the acceptance level of each. Each measurement is associated with only one of the circuit types in Table 10.

Table 11 Electrical JTP Responses for the LRSTF PWA

Test No.	***Test Description***	***Accept Criteria***	***Units***	***Comments***
	High Current Low Voltage			
1	HCLV PTH	<0.50 VDC	voltage	Baseline Pre-test
2	HCLV SMT	<0.50 VDC	voltage	Baseline Pre-test
	High Voltage Low Current			
3	HVLC PTH	mA< X< mA	current	
4	HVLC SMT	mA< X< mA	current	
	High Speed Digital			
5	HSD PTH	< 20% increase	Prop delay	Baseline Pre-test
6	HSD SMT	< 20% increase	Prop delay	Baseline Pre-test
	High Frequency Low Pass Filter			
7	HF PTH 50 MHz	±5dB	loss	HASL LR Parylene average
8	HF PTH f(–3dB)	±50MHz	freqency	HASL LR Parylene average
9	HF PTH f(–40dB)	±50MHz	freqency	HASL LR Parylene average
10	HF SMT 50 MHz	±5dB	loss	HASL LR Parylene average
11	HF SMT f(–3dB)	±50MHz	freqency	HASL LR Parylene average
12	HF SMT f(–40dB)	±50MHz	freqency	HASL LR Parylene average
	High Frequency Transmission Line Coupler			
13	HF TLC 50 MHz	±5dB	forward response	Baseline Pre-test
14	HF TLC 500 MHz	±5dB	forward response	Baseline Pre-test
15	HF TLC 1GHz	±5dB	forward response	Baseline Pre-test
16	HF TLC	±50MHz	Reverse Null Frequency	Baseline Pre-test
17	HF TLC	< 10dB increase	Reverse Null Response	Baseline Pre-test
	Other Networks—Leakage			
18	ON 10 mil Pads	>7.7 $\log_{10}$ohms	Resistance	
19	ON PGA “A”	>7.7 $\log_{10}$ohms	Resistance	
20	ON PGA “B”	>7.7 $\log_{10}$ohms	Resistance	
21	ON Gull Wing	>7.7 $\log_{10}$ohms	Resistance	
	Stranded Wire			
22	Stranded Wire 1	< 0.356 VDC	Voltage	Baseline Pre-test
23	Stranded Wire 2	< 0.356 VDC	Voltage	Baseline Pre-test

Twelve stress conditions were applied to the various specimens. The description of each stress follows. For the sake of simplicity only the Pass/Fail data to the JTP criteria in Table 11 are discussed. If the reader wishes a more in depth statistical and graphic presentation, he is directed to Iman [6] for additional information.

Diesel Fuel (DF) and Hydraulic Fluid (HF) Exposure Protocol

One hundred twenty LRSTF PWAs exposed to diesel fuel (DF) and hydraulic fluid (HF). Following Pre-test, these PWAs were twice dipped in DF, dried, and re-tested. Next, they were twice dipped in HF, dried, and retested. The test protocols for fluid exposure are as follows.

Diesel Fuel

1. Perform Pre-test
2. Mask all connectors
3. Equilibrate the DF at room temperature
4. Dip the PWA into the DF and soak for 10 min
5. Record the fluid temperature, ambient temperature, and relative humidity
6. Remove the PWA from the DF and let it drip dry for 30 min
7. Remove any remaining fluid by wiping with a lint free cloth
8. Repeat steps 4-7 with fresh fluid
9. Remove masking
10. Air dry for 24 hr
11. Record the electrical performance from the CCAMTF ATS
12. Go to the Hydraulic Fluid Procedure

Hydraulic Fluid

1. Mask all connectors
2. Equilibrate the HF at room temperature
3. Dip the PWA into the HF and soak for 10 min
4. Record the fluid temperature, ambient temperature, and relative humidity
5. Remove the PWA from the HF and let it drip dry for 30 min
6. Remove any remaining fluid by wiping with a lint free cloth
7. Repeat steps 3-6 with fresh fluid
8. Remove masking
9. Air-dry for 24 hr
10. Record the electrical performance from the CCAMTF ATS

Temperature/Humidity (85/85) and Thermal Shock (TS) Protocol

One hundred twenty PWAs were submitted to the 85/85 and TS test sequence. It consisted of three weeks exposure in an environmental chamber followed by a 200-cycle thermal shock test.

Temperature/Humidity

The 120 PWAs were exposed to an environment of 85° C and 85% relative humidity (85/85) for up to 3 weeks. All tests were conducted "As Received" (Pre-test), after 1 Week, after 2Week, and after 3 Week (Post-test) environmental exposures.

This test was proceeded the thermal shock test below.

Pre-Test. In the "Pre-test" the electrical measurements were compared to the acceptance criteria given in Table 11 at each test time. Note that the acceptance criteria in Table 11 require a comparison to a previous test for 11 of the 23 electrical circuits (#'s 1, 2, 5, 6, 13-17, 22, 23). Hence, comparisons to the JTP acceptance criteria were not made at Pre-test for these circuits.
Week 1. After 1 week of exposure to 85/85 environment, the PWAs were removed and functionally tested at Raytheon McKinney, TX. In this case there was a result from all circuit types.
Week 2. After 2 total weeks of exposure to 85/85 environment, the PWAs were again removed and tested in McKinney, TX.
Week 3 (Post-test). At the conclusion of the 85/85 test, the PWAs were removed and tested one final time. This Post-Test became the Pre-test for the Thermal Shock test.

Thermal Shock

The 120 PWA's from the 85/85 Post-test were introduced into a thermal shock chamber. Here all PWAs were moved between two chambers one set at -50°C (cold) and the other at 120°C (hot). The complete test was 200 cycles.

During a single cycle, the PWAs are in one chamber for 30 minutes then are automatically relocated into the other chamber for 30 min. The profile is shown graphically in Figure 6.

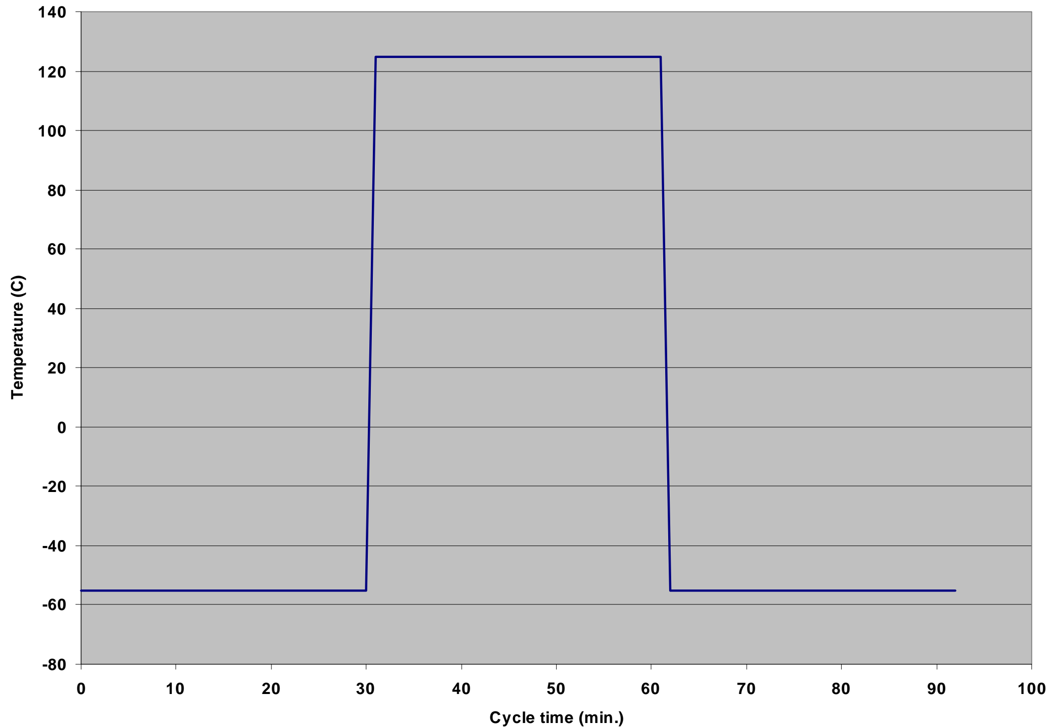

Figure 6 Temperature and Humidity Profile for One Cycle of the Thermal Shock Test

100 Cycles of Thermal Shock. After completing 100 cycles all PWAs were tested on the Automatic Test System (ATS) at Raytheon, McKinney, TX. The circuits requiring previous test data (#'s 1, 2, 5, 6, 13-17, 22, 23) were compared to the 85/85 Post-test.

200 Cycles of Thermal Shock. Electrical measurements were taken at the end of 200 thermal shock cycles. The PWAs were packaged and stored for future failure analysis

Condensing Atmosphere and Thermal Shock Protocol

In this test, 120 PWAs were subjected to 10 cycles in the Condensing Atmosphere environment followed by 200 thermal shock cycles.

Condensing Atmosphere

1. Apply electrical bias to the PWAs.
2. Begin with PWAs at 20°C and 40% RH
3. Lower the temperature to -10°C over a period of 7 min—when the temperature reaches -10°C,
4. Discontinue the humidity
5. Stabilize the PWAs at -10°C and 0% RH for 15 min
6. Warm the PWAs to 20°C over a period of 3 min
7. At 0°C, turn humidity on to 99% to ensure maximum wetness
8. Test the PWAs at 20°C over a period of 25 to 30 min
9. Discontinue the humidity
10. Lower the temperature to -10°C over a period of 7 min
11. Steps 3 to 8 are repeated 10 times (see Figure 7).
12. Electrical performance measurements are recorded during cycles 1, 4, 7, and 10

All functional tests were conducted during maximum wetness conditions. Figure 7 gives a graphich presentation of one cycle.

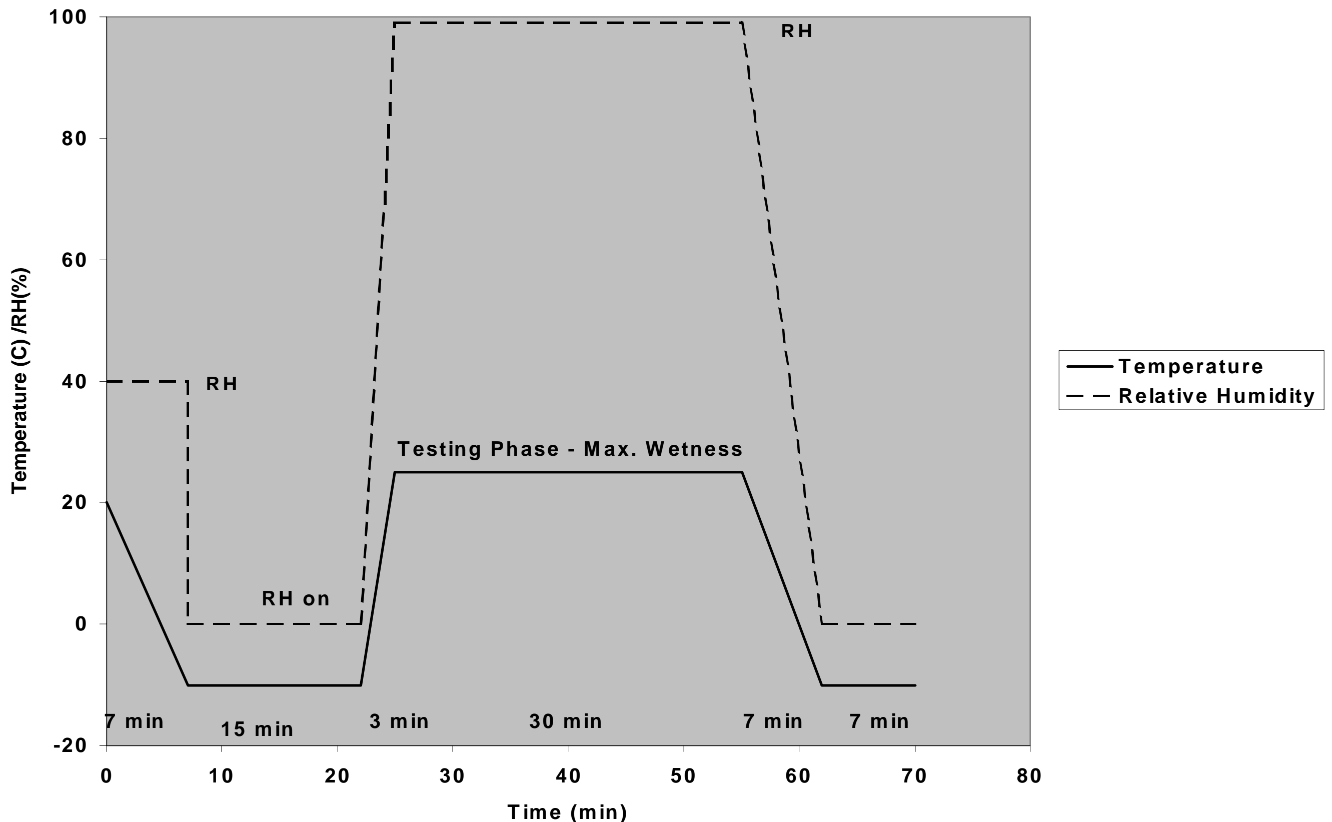

Figure 7 Temperature and Humidity Profiles for One Cycle of the Condensing Atmosphere Test

Thermal Cycling

One complete thermal cycle takes 122 min. The PWAs were functionally tested after 250 and 500 cycles. The following is the protocol used.

1. Receive dried parts from the Condensing Atmosphere Test
2. Lower the chamber temperature to -55°C at a rate of 5°C/min
3. Maintain the temperature at -55°C for 30 min
4. Raise the temperature to 100°C at a rate of 5°C/min
5. Maintain the temperature at 100°C for 30 min
6. Steps 1 to 4 are repeated 500 times
7. Test after 250 and 500 cycles

Figure 8.shows the temperature profile for one thermal cycle (TC).

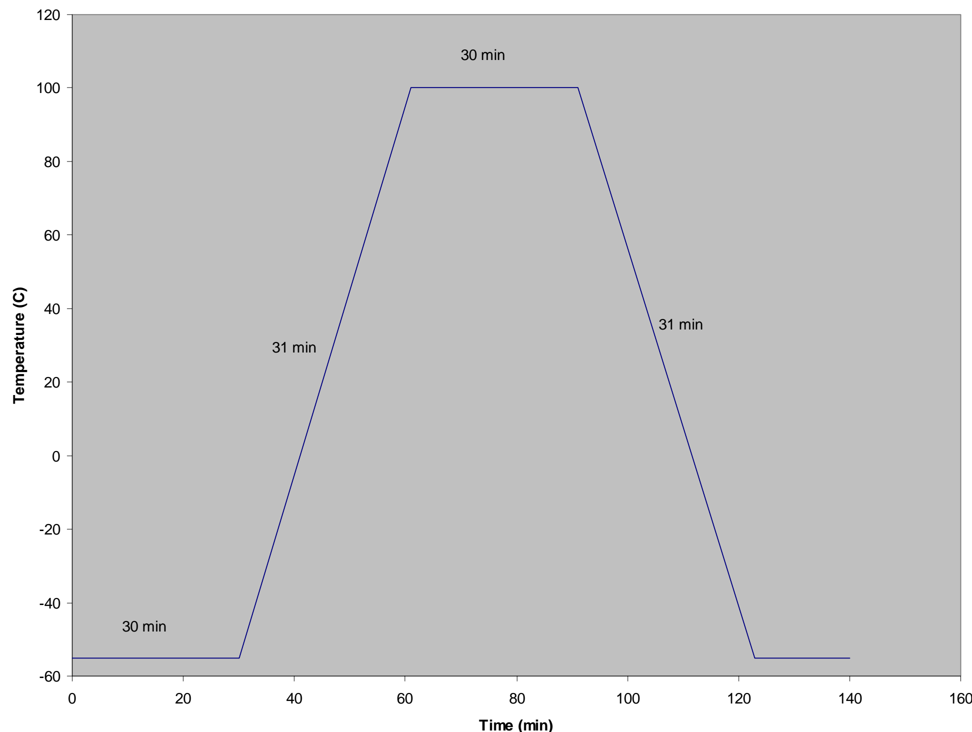

Figure 8 Temperature Profile for the Thermal Cycle Test

Branch Water (BW) and Salt Fog (SF) Protocol

These tests simulate the severe environmental stresses experienced by some of our electronic assemblies. The Branch Water test was run first followed by Salt Fog, because we assumed that the Salt Fog test would result in multiple hard failures.

Branch Water

The BW test uses tap water having a conductance of 1000 400 micromho with one *ml* of concentrated liquid dish washing detergent added to a liter of solutions to reduce the surface

tension. The test was developed at Hughes to evaluate the integrity of the conformal coating process.

The detergent solution is sprayed on the PWA at three different times during the BW test. The electrical functionality of the PWA is tested while the specimen is wet with the mixture,

The following test procedures were used by the BW test.
1. Test and record the electrical performance of the PWAs in the ATS without any stress.
2. Place the PWA in a vertical position in the CCAMTF ATS.
3. Spray the detergent solution uniformly over both sides of the PWA until a continuous film is visible over the entire PWA. Allow the solution to penetrate around the components and run downward for 3 ±0.5 *mi*n.
4. Test and record the electrical performance in the “Vertical” position of the PWA
5. Spray the PWA with approximately 20-ml of deionized water to remove the detergent solution.
6. Remove the PWA from the CCAMTF ATS and dry it with any mechanism that will not contaminate it.
7. Replace the PWA in the CCAMTF ATS and test and record its electrical performance (Post).
8. Place the PWA in a horizontal position in the CCAMTF ATS with the backside up. Spray the detergent solution only on the uppermost face (backside) of the PWA until a continuous film is visible over this face.
9. Allow the solution to penetrate for 3 ±0.5 *mi*n.
10. Test and record the electrical performance in the “Backside” position of the PWA
11. Spray the PWA with approximately 20-ml of deionized water to remove the detergent solution. Remove the PWA from the CCAMTF ATS and dry it with any mechanism that will not contaminate the PWA.
12. Replace the PWA in the CCAMTF ATS and test and record its electrical performance (Post).
13. Place the PWA in a horizontal position in the CCAMTF ATS with the component side up. Spray the detergent solution only on the uppermost face (component side) of the PWA until a continuous film is visible over this face. Allow the solution to penetrate around the components for 3 ±0.5 *mi*n.
14. Test and record the electrical performance in the “Comp.” position of the PWA
15. Spray the PWA with approximately 20-ml of deionized water to remove the detergent solution. Remove the PWA from the CCAMTF ATS and dry it with any mechanism that will not contaminate it.
16. Replace the PWA in the CCAMTF ATS and test and record its electrical performance (Post).
17. Go to the Salt Fog Test.

Salt Fog

The SF test is used to determine the resistance of a conformal coating film to accelerated, deleterious effects of exposure to a sulfur dioxide/salt fog. This test was performed in accordance with ASTM G 85-85 *(Standard Practice for Modified Salt Spray (Fog) Testin*g, March 1990), but with modifications and additions listed in the following test protocol.

The Salt Fog data were not available in time to get them into this report, but they will be reported in 2000.

Salt Fog procedures

1. Set the fog chamber to 123ºF ±3ºF. Set the bubble tower to 138ºF ±2ºF. Prepare a salt solution using one part by volume of ASTM D 1141-95 *(Standard Specification for Substitute Ocean Wate*r, February 2, 1990) solution in 10 parts distilled water.
2. Generate the fog discontinuously: each cycle consisted of five hours with fog generation and one hour without fog generation

3. Start the sulfur dioxide flow 15 *min* prior to cessation of the salt fog generation and continue it for 15 *min* into the non-generation period during each cycle for a total of 30 *min* of sulfur dioxide exposure during each cycle
4. Place MIL-I-46058C “Y”-coupons representing each surface finish/conformal coating combination into the test chamber
5. Perform the salt fog exposure for 56 cycles (336 *h*r)
6. At the completion of the 56th cycle, remove all coupons and perform the dielectric withstanding voltage and insulation resistance tests.
7. Select the five LRSTF PWAs that have been exposed to the BW test for each surface finish/conformal coating combination that passes the MIL-I-46058C “Y”-coupon test. Test and record the electrical performance of these PWAs on the CCAMTF ATS.
   Note: the electrical performance in Step 16 of the BW was used for this evaluation.
8. Place the LRSTF PWAs selected from Step 7 into the salt fog chamber.
9. Perform the salt fog test described above for 56 cycles (336 *h*r)
10. At the completion of the 56th cycle, remove all PWAs from the salt fog chamber. Evaluate on ATS and record their electrical performance.

Data and Discussion

Surface Insulation Resistance and Dendritc Growth

Figures 9-15 give a graphic presentation of the SIR test results. Figure 9 is the “non contaminated” control for both sets of data. Figures 10-12 display information on “immersion” contamination for both IPC and Bellcore conditions and Figure 13-15 show “drop” contamination results from the Bellcore method only. Insufficient specimens were built to complete all tests. We decided to omit the IPC test for “drop contamination”.

The results were so similar between the IPC and Bellcore data that they are presented together. The Bellcore data are from 96 and 596-hour tests and IPC are 0 and 168 hours data.

All uncontaminated (0 hours) specimens in Figure 9 had almost identical “as received” SIRs. It is apparent that the biggest factor affecting SIR is exposure to the test environment and bias voltage. There is little difference between any of the surface finishes or the test time and conditions.

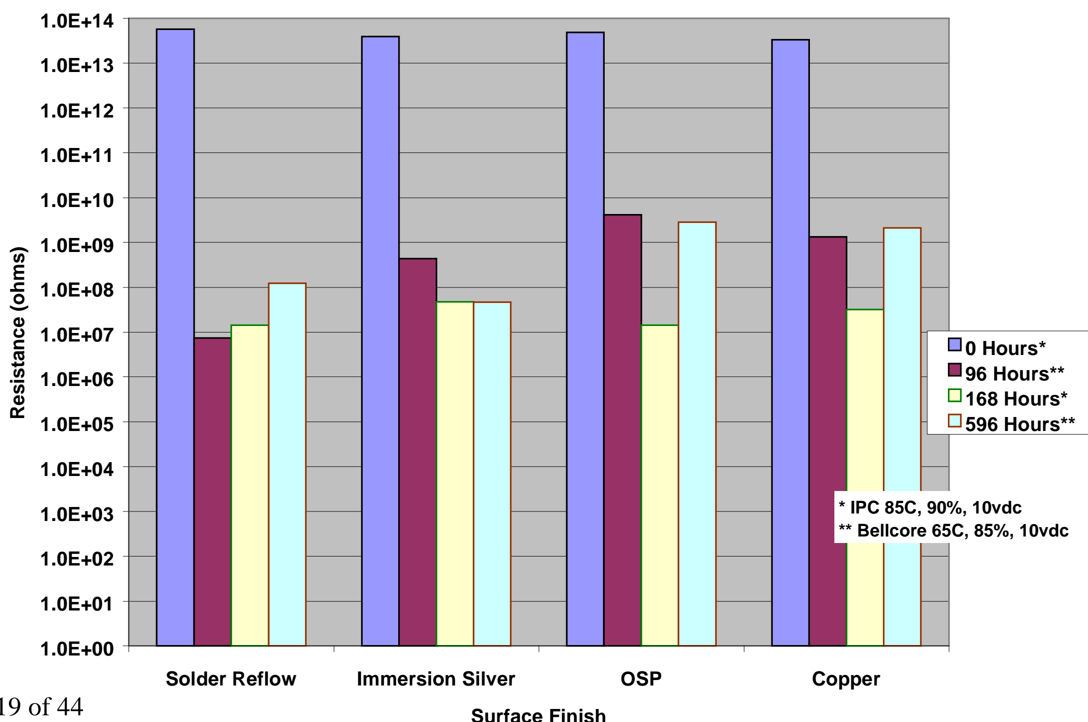

Figure 9 SIR with No Contamination

The SIR (Figure 10) is slightly lower after contamination with 0.01M HCl by immersion than the "non-contamination" result (Figure 9). After exposure to the test environment there is little or no difference between surface finishes.

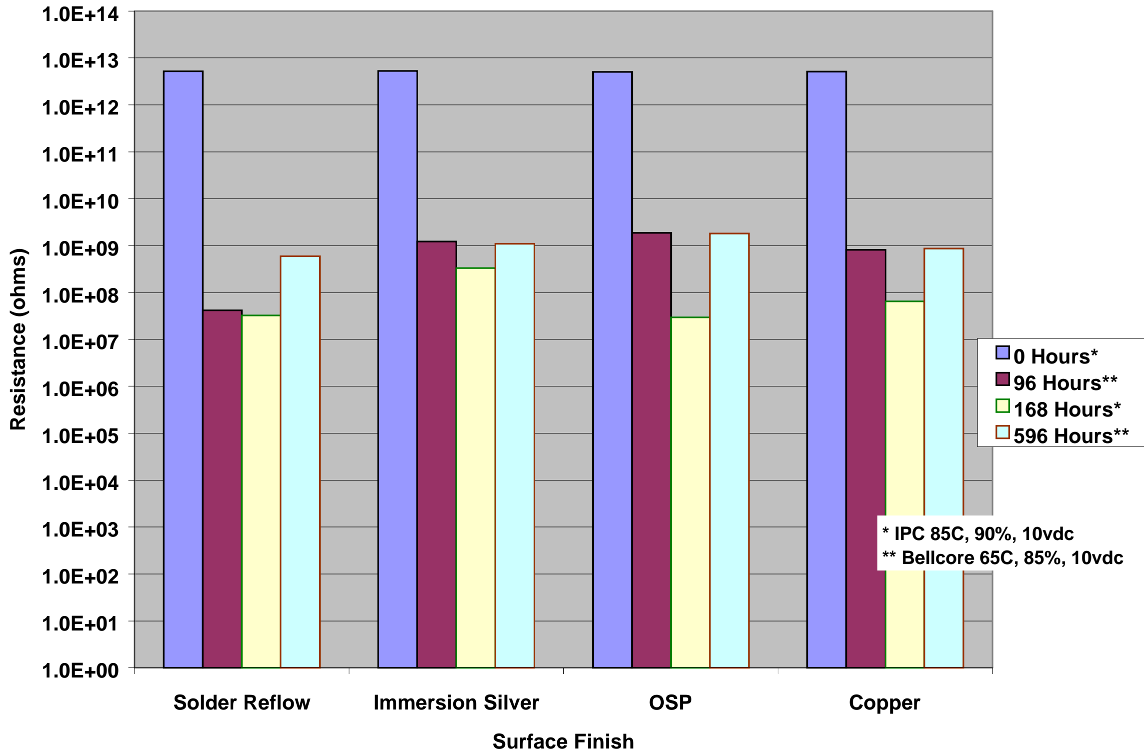

Figure 10 SIR after Contamination w/ 0.01 N HCl Immersion

The same behavior is exhibited after contamination with 0.1 M HCl and Low Residue Flux. (Figure 11 and 12). This was unexpected and may indicate a flaw in the contaminating media.

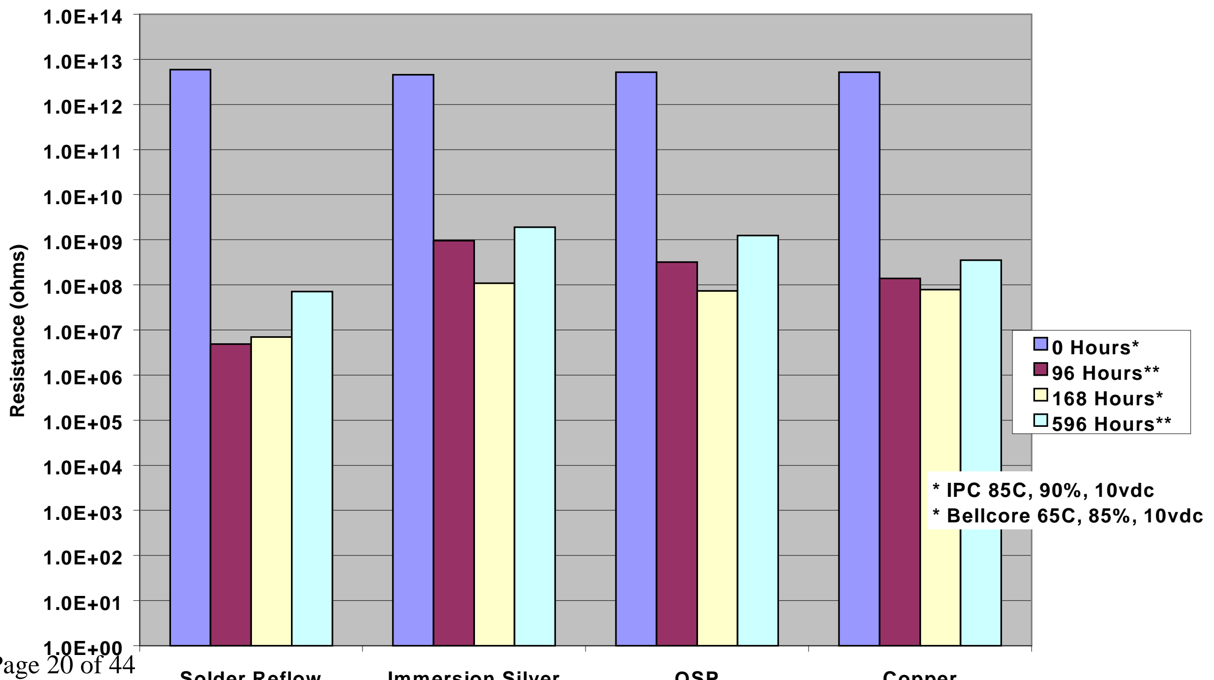

Figure 11 SIR after Contamination w/ 0.1 N HCl Immersion

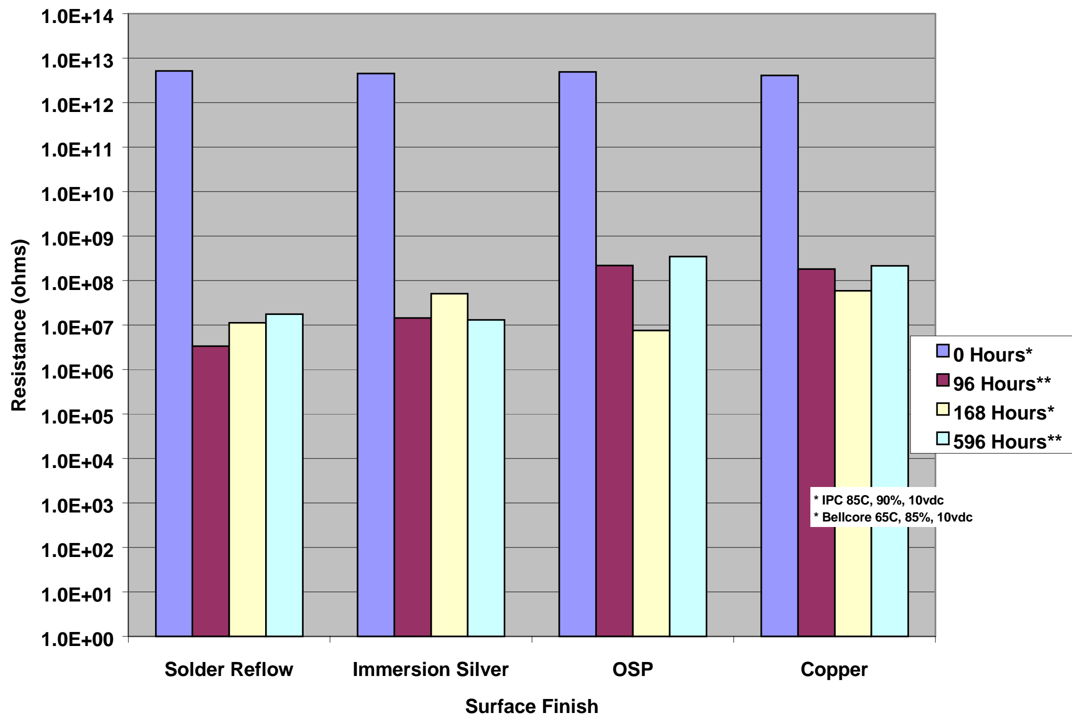

Figure 12 SIR after Contamination w/ Flux Immersion

Since the IPC test was the only method, which required an "as received" specimen, there are no 0-hour data for the "drop" test after contamination. However, since the "non-contaminated" specimens were from the same production group (Figure 9), we can assume that the contamination results started at about the same point. The final SIR is approximately equal between the "drop" and the "immersion" tests; therefore, the results from the "as received" specimens after "drop" contamination should also be very similar.

Figure 13-15 illustrates the effect of the "drop" contamination on SIR for the surface finishes evaluated in this study. The difference between the "immersion" and the "drop" contamination method is small compared to the effect of the test itself.

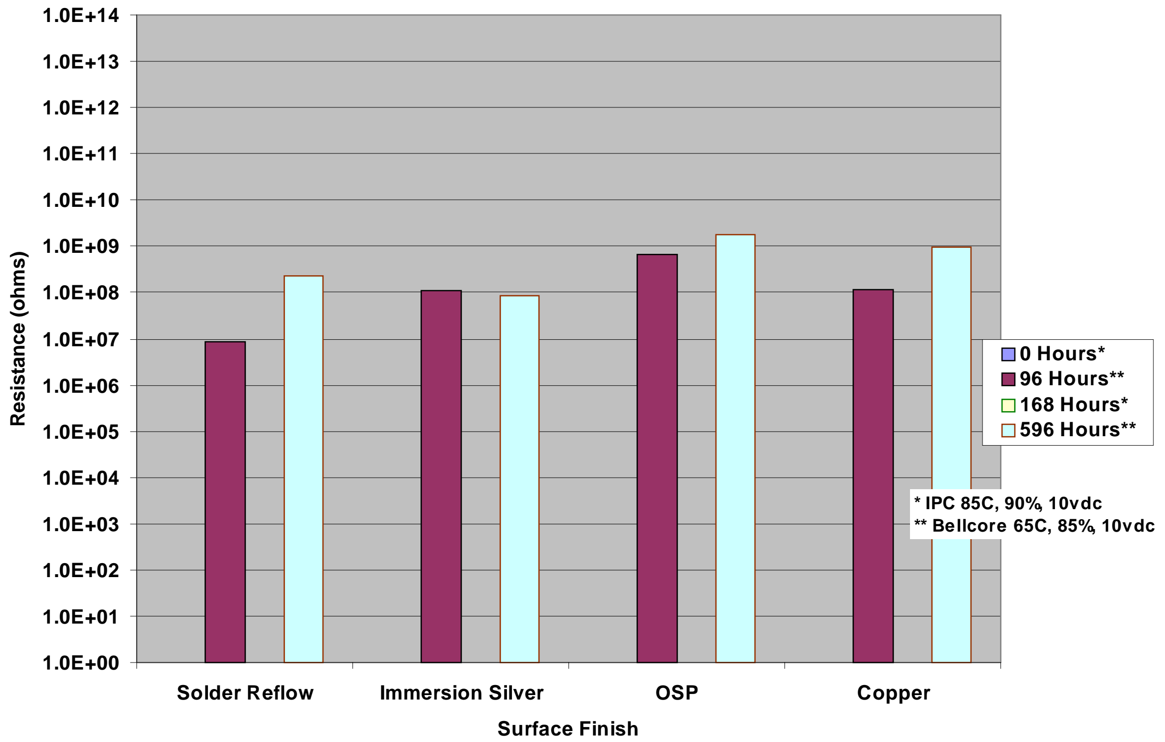

Figure 13 SIR after Contamination w/ 0.01 M HCl Drop

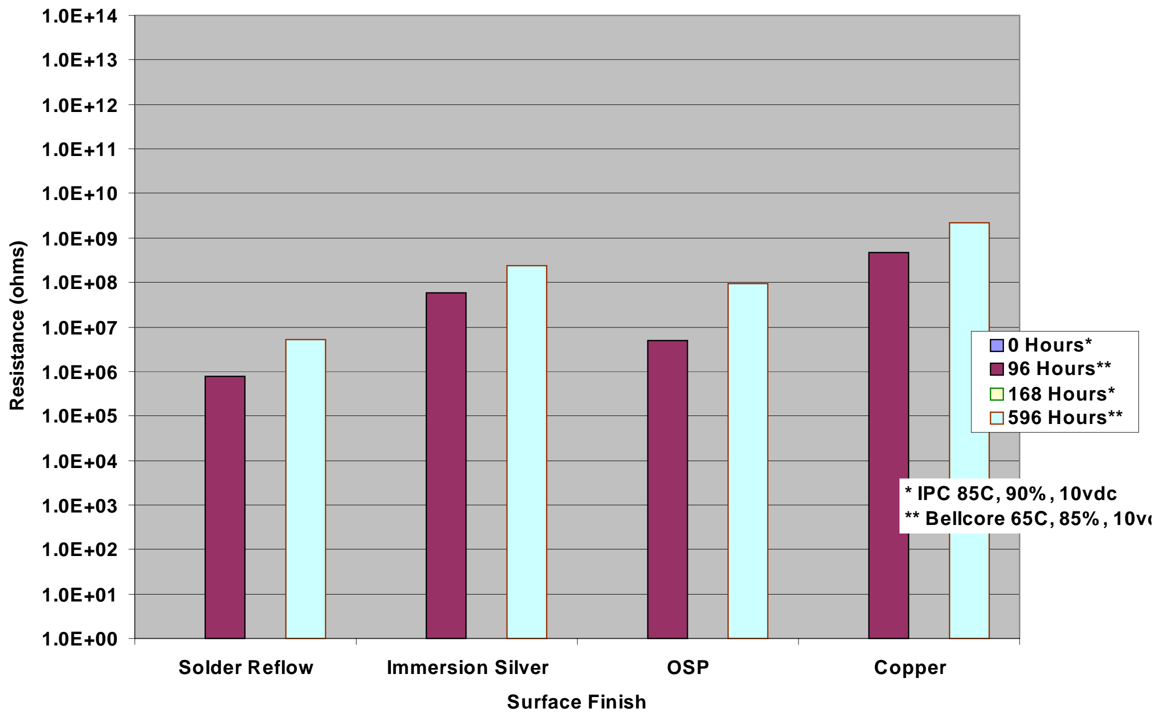

Figure 14 SIR after Contamination w/ 0.1 M HCl Drop

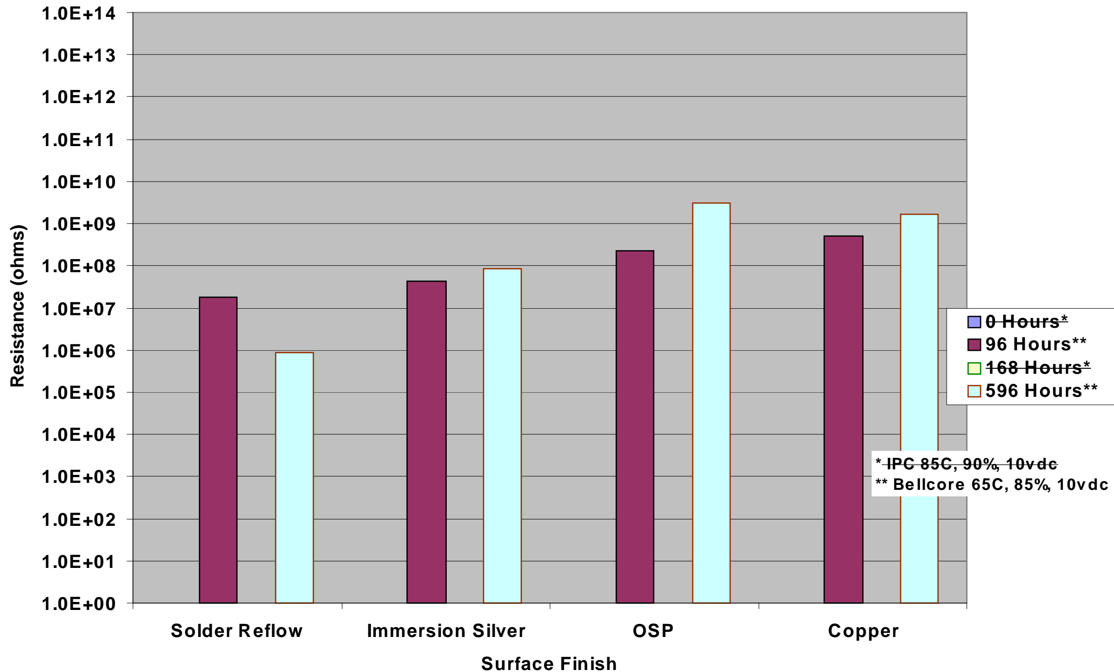

Figure 15 SIR after Contamination w/ Flux Drop

Figure 16 illustrates the average effect of Immersion contamination on SIR results. All surface finishes are averaged together since the impact of surface finish was minimal. The results indicated there is a 1-decade drop in the SIR due to contamination. All contamination levels had approximately the same impact.

When the test was done after exposure to the temperature, humidity, and voltage all specimens dropped 4 or 5 decades and stayed there regardless of the test time. There may be a slight difference between the IPC and Bellcore results due to the change in temperature and humidity.

From least to the greatest effect for the immersion contamination method (Figure 16) the Bellcore method produced the following tendencies. The IPC method agrees well except for the “as received” specimens.

1. As Received
2. 0.01M HCl
3. 0.1M HCl
4. LR flux

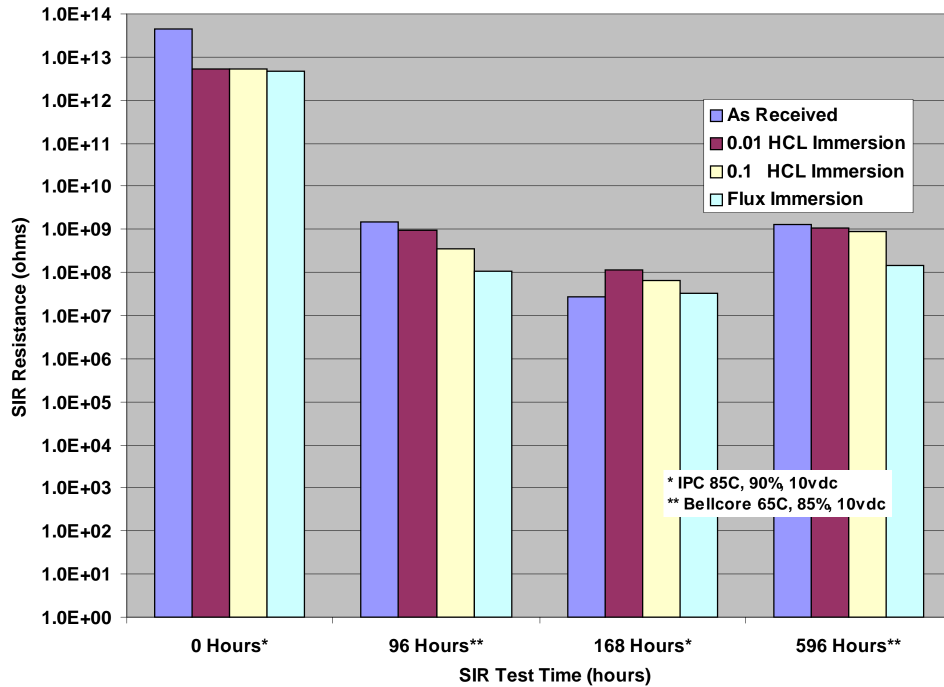

Figure 16 Impact of Contamination on SIR Results, all Surface Finishes

The following photographs were taken at 50X magnification. Metal dendrites should look like Figure 17, but many, particularly "drop" contaminations, looked like Figures 18 and 19.

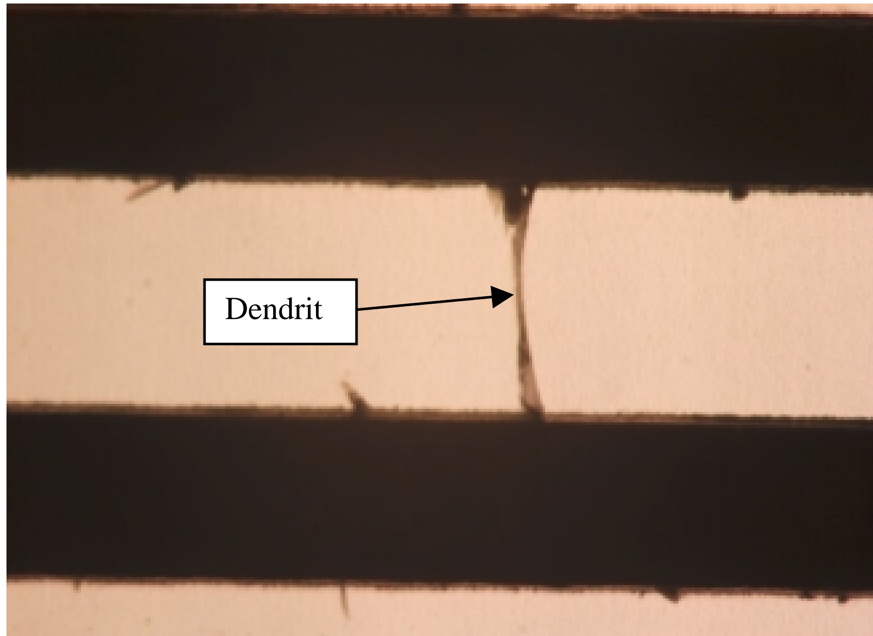

Figure 17 Typical Dendritic Failure Tin Lead Reflow 0.1 M HCl Immersion (100X mag.)

In many cases the "dendrites" were not the typical metallic dendrites, but a result of a crystalline compound formation during or after the contamination process.

The red crystals present on Bare Copper samples 9-12 (Figure 18) were noted only on those samples. They appear to be a chemical reaction between the material contaminate placed on the combs not normal metallic filament growth.

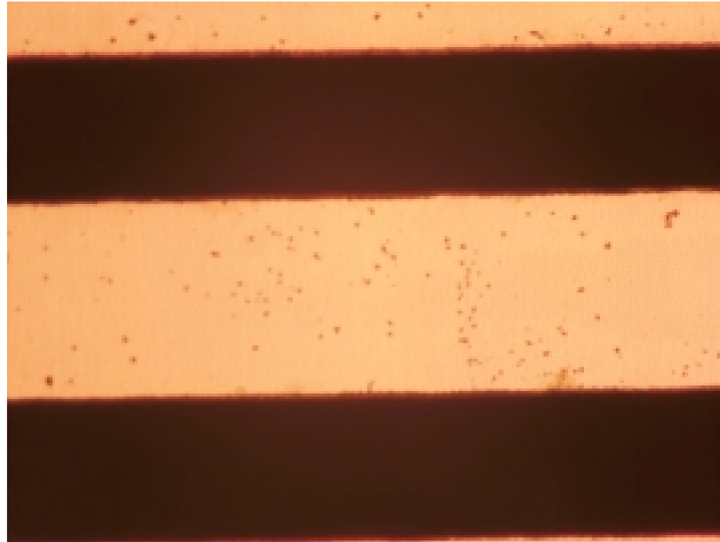

Figure 18 Bare Copper (0.01 M HCl Immersion) after 595 hours at 65ºC/85% RH

On most of the "drop" contamination, (Figure 19) the effects were noted on the edge of the drop and not within the center of the drop. Surface corrosion of the conductor traces is responsible for many of the edge effects noted.

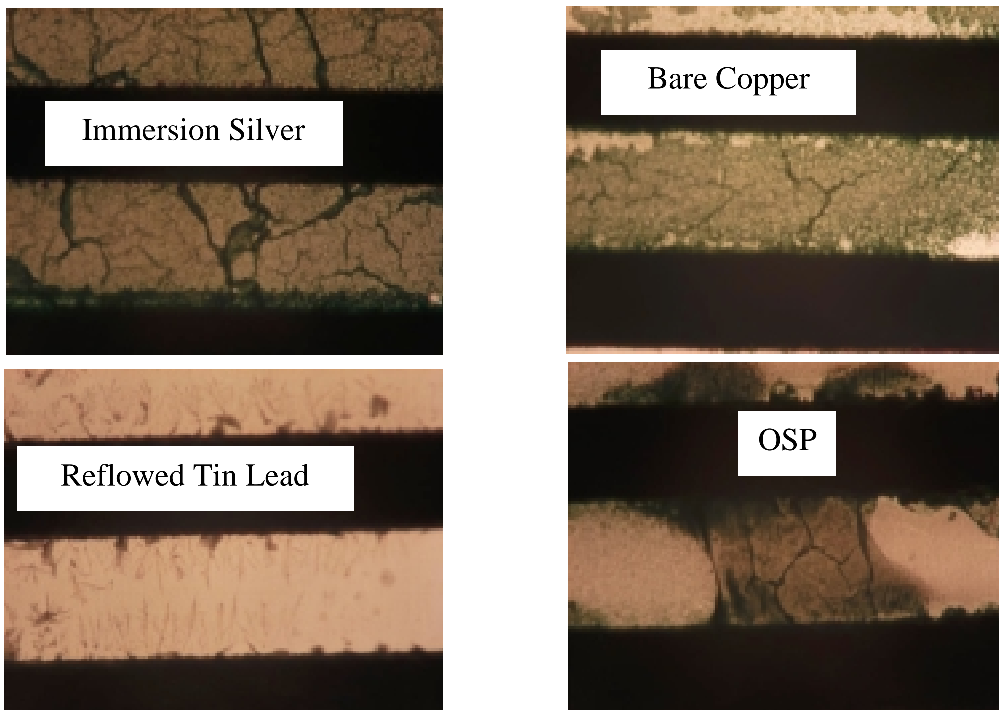

Figure 19 Typical Drop Contamination Results for Each Surface Finish

The 0.1 M acid and the LR flux appear to have reacted chemically with the surface treatments or circuitry and produced a variety of compounds rather than acting solely as surface contaminants for metal migration.

Table 12 shows the test lab's observations after a detail the visual inspection of the SIR specimens run via the Bellcore test method. Table 13 gives the same treatment for the IPC method. The "drop" contamination data were not collected due to lack of samples.

Each comb on each specimen was examined and reported separately. Shading of any block in Table 12 or Table 13 indicate that no combs failed for dendritic growth. Other observations were recorded, but were excluded from the dendritic growth evaluation.

The No Dendrite results indicate that all 4 comb patterns passed. If one specimen was good for dendritic growth then all 4 specimens were very likely to be good as well. This is particularly true in the case of the 0.01 M HCl immersion contamination. It was also noted that many of crystals reported on the specimens were the result of HCl reactions with copper and not the normal formation of metal dendrites

Table 14 and Table 15 are a summary of the visual inspections (dendritic growth) taken after the SIR testing. There are 4 comb patterns on each test specimens and 4 specimens per test, so 16 values are averaged to give the numbers in the tables

Observations…

1. There is good agreement between IPC and Belcore methods based on visual results except for the IPC-OSP Copper data, which is 26% lower than the Bellcore data. This data may be the result of some unintended contamination.
2. The drop contamination method is not a very discriminating procedure due to the excessive failure rates. Future testing will not include this contamination method.
3. Of the 0.01M HCl immersion data, only 2 of the 64 combs inspected had any dendritic growth reported.
4. The 0.01M HCl was an effective immersion-cleaning agent rather than a contaminant for all specimens.
5. Of the surface finishes, only reflowed tin lead had large number dendritic growth failures from the 0.01 and 0.1 M HCl immersion. Failure of the "as received" specimens suggests problems with the fabrication process for the reflowed tin lead specimens.
6. Immersion in Flux resulted were similar to the 0.1M HCl immersion.
7. While the standard HCl solutions resulted in some dendrites (Figure 9), it failed to produce classical dendritic growth. This may be due to evaporation of the ionic species. In future work, standard NaCl or KCl will be used as the contaminating agent.

Table 12 Detail Visual Observations from the Bellcore SIR Test

Test Conditions	Coupon Identification	Bare Copper Observations	Immersion Silver Observations	Reflowed Tin Lead Observations	OSP Copper Observations
Bellcore Test method					
As Fabricated	1	NO DENDRITES	NO DENDRITES	LUMPS ON C; A, B AND D OK	NO DENDRITES
As Fabricated	2	“	“	“	“
As Fabricated	3	“	“	LUMPS ON D; A, B AND C OK	“
As Fabricated	4	“	“	ALL OK	“
0.01 M HCl Immersion	5	NO DENDRITES	NO DENDRITES	GROWTH ON C; A, B AND D OK	NO DENDRITES
0.01 M HCl Immersion	6	“	“C” HAS SHORTS	NO DENDRITES	“
0.01 M HCl Immersion	7	“	NO DENDRITES	“	“
0.01 M HCl Immersion	8	“	“	“	“
0.1 M HCl Drop	9	GREEN AT EDGES OF DROP	GREEN AT EDGES OF DROP; NO DENDRITES	DENDRITES AT EDGES OF SPOT	FILM BETWEEN CONDUCTORS; DENDRITES
0.1 M HCl Drop	10	GREEN AT EDGES OF DROP; SMALL DENDRITE ON D	GREEN AT EDGES OF DROP; CRYSTALLINE DENDRITES	DENDRITES AT EDGES OF SPOT	FILM BETWEEN CONDUCTORS; DENDRITES
0.1 M HCl Drop	11	GREEN AT EDGES OF DROP; CRYSTALS WITHIN DROP	GREEN AT EDGES OF DROP; CRYSTALLINE DENDRITES	DENDRITES AT EDGES OF SPOT	FILM BETWEEN CONDUCTORS; DENDRITES
0.1 M HCl Drop	12	GREEN AT EDGES OF DROP; CRYSTALS WITHIN DROP; DENDRITE D	GREEN AT EDGES OF DROP; NO DENDRITES	DENDRITES AT EDGES OF SPOT	FILM BETWEEN CONDUCTORS; DENDRITES

Table 12 Detail Visual Observations from the Bellcore SIR Test (con't)

Bellcore Test method					
Test Conditions	Coupon Identification	Bare Copper Observations	Immersion Silver Observations	Reflowed Tin Lead Observations	OSP Copper Observations
0.1 M HCl Immersion	13	GREEN CORROSION CRYSTALS	FILM ON LAMINATE – NO DENDRITES	CRYSTAL GROWTH – CRYSTAL DENDRITES	FILM ON LAMINATE
0.1 M HCl Immersion	14	GREEN CORROSION CRYSTALS	FILM ON LAMINATE – NO DENDRITES	CRYSTAL GROWTH – CRYSTAL DENDRITES	FILM ON LAMINATE
0.1 M HCl Immersion	15	GREEN CORROSION CRYSTALS	FILM ON LAMINATE – NO DENDRITES	CRYSTAL GROWTH – CRYSTAL DENDRITES	FILM ON LAMINATE
0.1 M HCl Immersion	16	GREEN CORROSION CRYSTALS	FILM ON LAMINATE – NO DENDRITES	CRYSTAL GROWTH – CRYSTAL DENDRITES	FILM ON LAMINATE
0.1 M HCl Drop	17	DENDRITES WITHIN CRYSTALS	DENDRITES	CRYSTAL DENDRITES	DENDRITES WITHIN FILM ON LAMINATE
0.1 M HCl Drop	18	DENDRITES WITHIN CRYSTALS	DENDRITES	CRYSTAL DENDRITES	DENDRITES WITHIN FILM ON LAMINATE
0.1 M HCl Drop	19	DENDRITES WITHIN CRYSTALS	DENDRITES	CRYSTAL DENDRITES	DENDRITES WITHIN FILM ON LAMINATE
0.1 M HCl Drop	20	DENDRITES WITHIN CRYSTALS	DENDRITES	CRYSTAL DENDRITES	DENDRITES WITHIN FILM ON LAMINATE
Alpha 310M low residue flux Immersion	21	ALL OK	VERY TINY DENDRITES (FUZZY)	CRYSTALLINE DENDRITES	ALL OK
Alpha 310M low residue flux Immersion	22	ALL OK	VERY TINY DENDRITES (FUZZY)	CRYSTALLINE DENDRITES	ALL OK
Alpha 310M low residue flux Immersion	23	ALL OK	VERY TINY DENDRITES (FUZZY)	CRYSTALLINE DENDRITES	ALL OK

Table 12 Detail Visual Observations from the Bellcore SIR Test (con't)

Test Conditions	Coupon Identification	Bare Copper Observations	Immersion Silver Observations	Reflowed Tin Lead Observations	OSP Copper Observations
Bellcore Test method					
Alpha 310M low residue flux Immersion	24	ALL OK	VERT TINY DENDRITES (FUZZY)	CRYSTALLINE DENDRITES	ALL OK
Alpha 310M low residue flux Drop.	25	FUZZY	ALL OK	CRYSTALLINE DENDRITES	FUZZY
Alpha 310M low residue flux Drop.	26	FUZZY	ALL OK	CRYSTALLINE DENDRITES	FUZZY
Alpha 310M low residue flux Drop.	27	FUZZY	ALL OK	CRYSTALLINE DENDRITES	FUZZY
Alpha 310M low residue flux Drop.	28	FUZZY	ALL OK	CRYSTALLINE DENDRITES	FUZZY
Acceptable		43%	61%	11%	43%

Table 13 Detail Visual Observations from the IPC SIR Test

Test Conditions	Coupon Identification	Bare Copper Observations	Immersion Silver Observations	Reflowed Tin Lead Observations	OSP Copper Observations
IPC Test Method					
As Fabricated	41	PUDDLING AROUND EDGES	ALL OK	DENDRITES	ALL OK
As Fabricated	42	PUDDLING AROUND EDGES	HAIR ACROSS C. A, B, AND D OK	DENDRITES	ALL OK
As Fabricated	43	NO DENDRITES	ALL OK	DENDRITES	ALL OK
As Fabricated	44	DENDRITE ON C. A, B, AND D OK	ALL OK	DENDRITES	ALL OK
0.01 M HCl Immersion	29	ALL OK	ALL OK	ALL OK	ALL OK
0.01 M HCl Immersion	30	ALL OK	ALL OK	ALL OK	DENDRITES ON C – CONTACTS SHORTED
0.01 M HCl Immersion	31	ALL OK	ALL OK	ALL OK	ALL OK
0.01 M HCl Immersion	32	ALL OK	ALL OK	ALL OK	ALL OK
0.1 M HCl Immersion	33	ALL OK – GREEN "PUDDLES"	1 TINY DENDRITE ON D. ALL OTHERS OK	CRYSTALS – NO DENDRITES	CRYSTALS
0.1 M HCl Immersion	34	ALL OK – GREEN "PUDDLES"	ALL OK	DENDRITES AND CRYSTALS	CRYSTALS
0.1 M HCl Immersion	35	ALL OK – GREEN "PUDDLES"	DENDRITES ON D; ALL OTHERS OK	CRYSTALS – NO DENDRITES	CRYSTALS
0.1 M HCl Immersion	36	ALL OK – GREEN "PUDDLES"	ALL OK	CRYSTALS – NO DENDRITES	CRYSTALS

Table 13 Detail Visual Observations from the IPC SIR Test (con't)

Test Conditions	Coupon Identification	Bare Copper Observations	Immersion Silver Observations	Reflowed Tin Lead Observations	OSP Copper Observations
IPC Test Method					
Alpha 310M low residue flux Immersion	37	FURRY	FURRY	FURRY GREEN EDGES	GREEN EDGES
Alpha 310M low residue flux Immersion	38	FURRY – DENDRITES	FURRY	FURRY GREEN EDGES	GREEN EDGES
Alpha 310M low residue flux Immersion	39	FURRY	FURRY	FURRY GREEN EDGES	GREEN EDGES
Alpha 310M low residue flux immersion	40	FURRY	FURRY	FURRY GREEN EDGES	GREEN EDGES
IPC Acceptable		69%	56%	38%	69%

Table 14 Summary Visual Observations from the Bellcore SIR Test

Bellcore Test method…Immersion				
Test Conditions	Bare Copper % Acceptable	Immersion Silver % Acceptable	Reflowed Tin Lead % Acceptable	OSP Copper % Acceptable
As Fabricated	100%	100%	88%	100%
0.01 M HCl	100%	100%	94%	100%
0.1 M HCl	0%	100%	0%	100%
Low residue flux	100%	0%	0%	100%
Bellcore Acceptable Immersion	75%	75%	45%	100%
Bellcore Test method…Drop				
0.01 M HCl	0%	50%	0%	0%
0.1 M HCl	0%	0%	0%	0%
Low residue flux	0%	100%	0%	0%
Bellcore Acceptable Drop	0%	50%	0%	0%

Table 15 Summary Visual Observations from the IPC SIR Test

Test Conditions	Bare Copper % Acceptable	Immersion Silver % Acceptable	Reflowed Tin Lead % Acceptable	OSP Copper % Acceptable
IPC Test Method…Immersion				
As Fabricated	94%	94%	0%	100%
0.01 M HCl	100%	100%	100%	94%
0.1 M HCl	100%	88%	94%	100%
Low residue flux	0%	0%	0%	0%
IPC Acceptable Immersion	73%	70%	48%	73%

Solderability

While 3 wetting balance parameters were recorded, only one will be presented in this report. Force at 2 seconds (F2) has been a very reliable point of reference for this author in the past and will be uses exclusively in this report.

Figure 20 represents the “as received” (no stress) result. Surface finish solderability should be at its best in this condition. For that reason, they are used as baseline values for each surface finish.

The two RSP (reflowed solder plate) are considered to be completely solderable. The relatively low F2 (0.11 - 0.13 µN) is due to excess solder from the specimen draining into the solder pot when it is immersed. We were looking for changes in solderability due to stress and not a specific number.

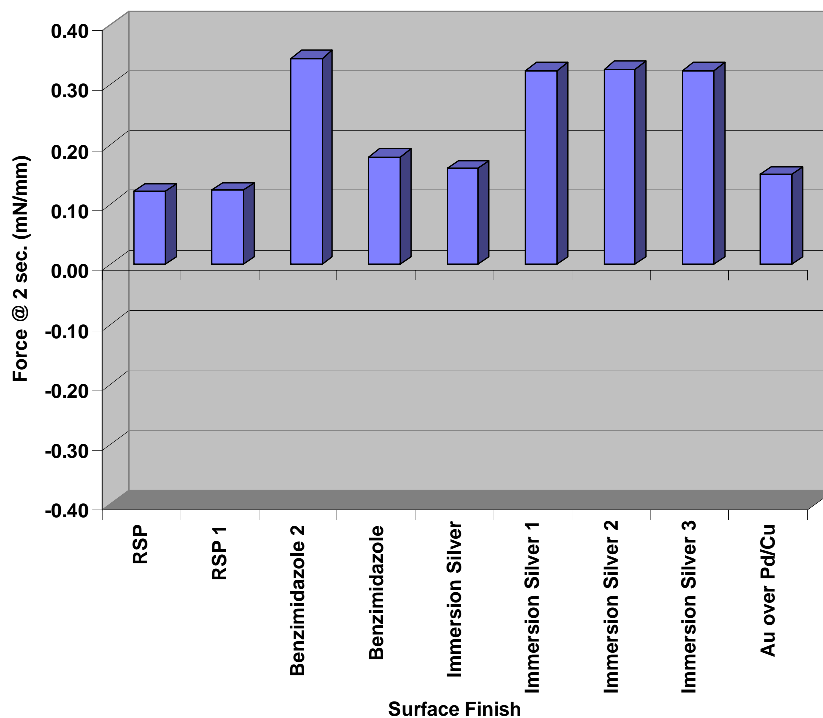

Figure 20 Force @ 2 sec. As Received

Benzimidazole and Benzimidazole 2 show significant variability “as received”. The low results are associated with non-optimum surface prep before the surface finish was applied. The same is true of the first “Immersion Silver” data point.

The 4 immersion silver data points are from multiple suppliers and processes. Only one set of readings were taken from the Immersion Gold on Electrolytic Palladium.

The first and least damaging stress level is the simulated IR reflow in nitrogen (Figure 21). At this stress RSP, Imm. Ag, and Au/PD solderabilities remain unchanged. However, both OSP samples had negative (wetting angles > 90 °) wetting.

Figure 22 shows that simulated IR reflow in air also results in very large changes for the OSP samples while all others finishes are relatively unaffected.

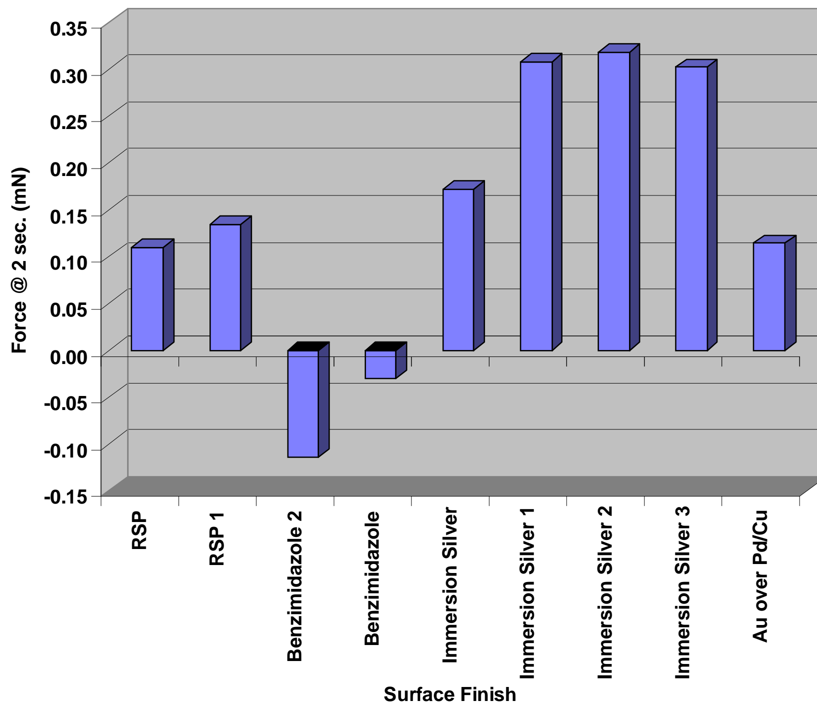

Figure 21 Force @ 2 sec. After Simulated Reflow in Nitrogen

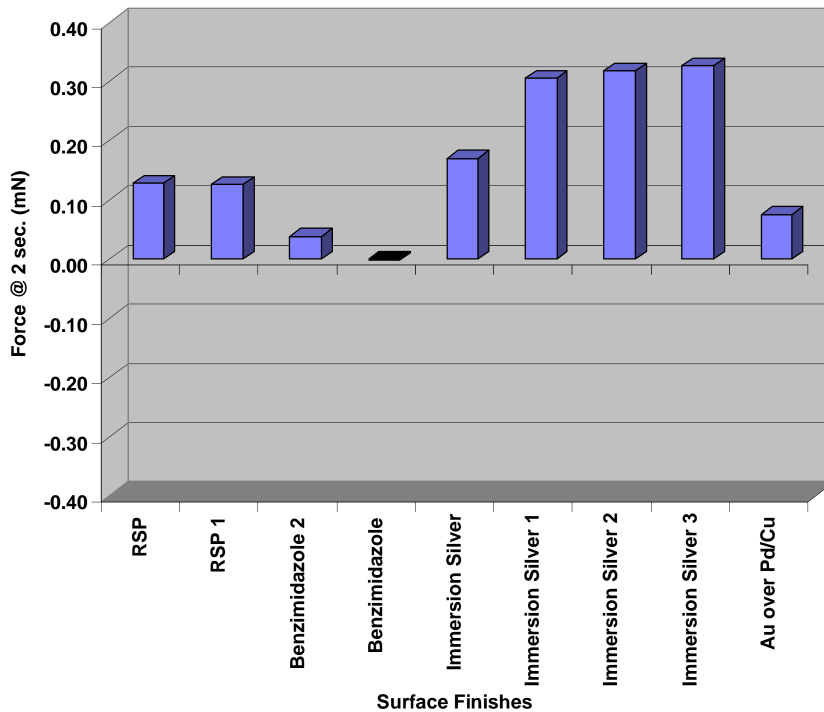

Figure 22 Force @ 2 sec. After Simulated Reflow in Air

Figures 23 and 24 are 8-hour bake at 105ºC plus a Simulated IR reflow in nitrogen and air respectively. The results are almost identical and show the OSP doing very poorly while the other finishes remain relatively constant.

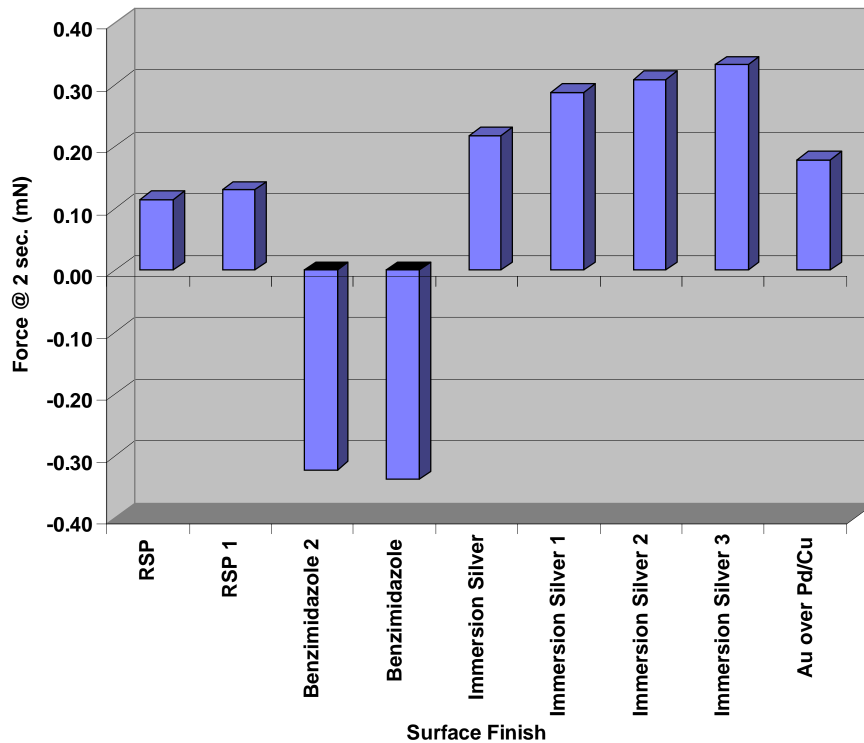

Figure 23 Force @ 2 sec. After 8 hr. Bake and Reflow in Nitrogen

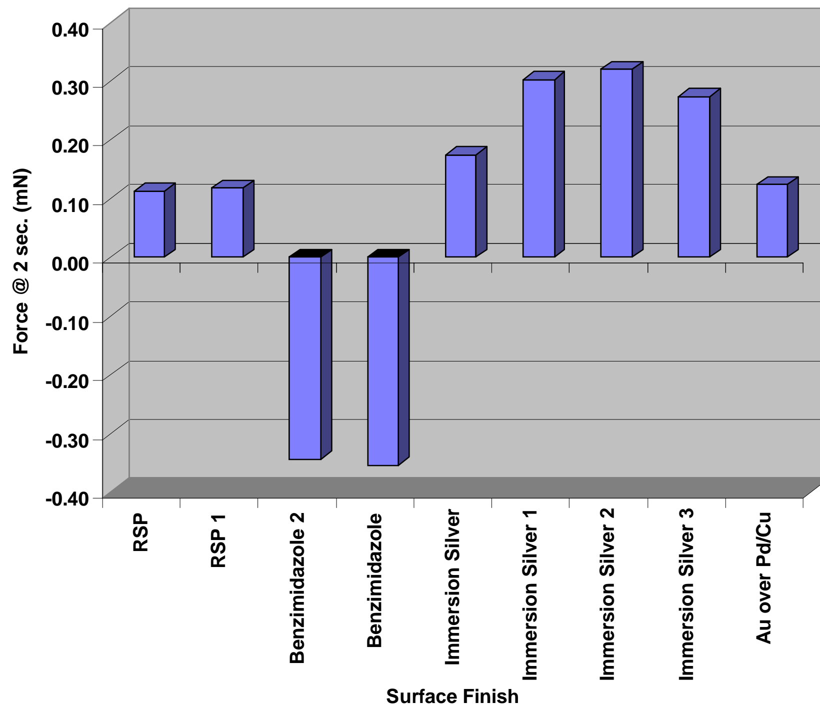

Figure 24 Force @ 2 sec. After 8 hr. Bake and Reflow in Air

Figure 25, is a storage test of 168 hours in a 50 °C/85 % RH environment. Two unexpected results were seen here. First, the OSP now has a positive wetting force equal to or greater than its baseline. Second, there is a definite drop in the F2 results for virtual all of the other finishes.

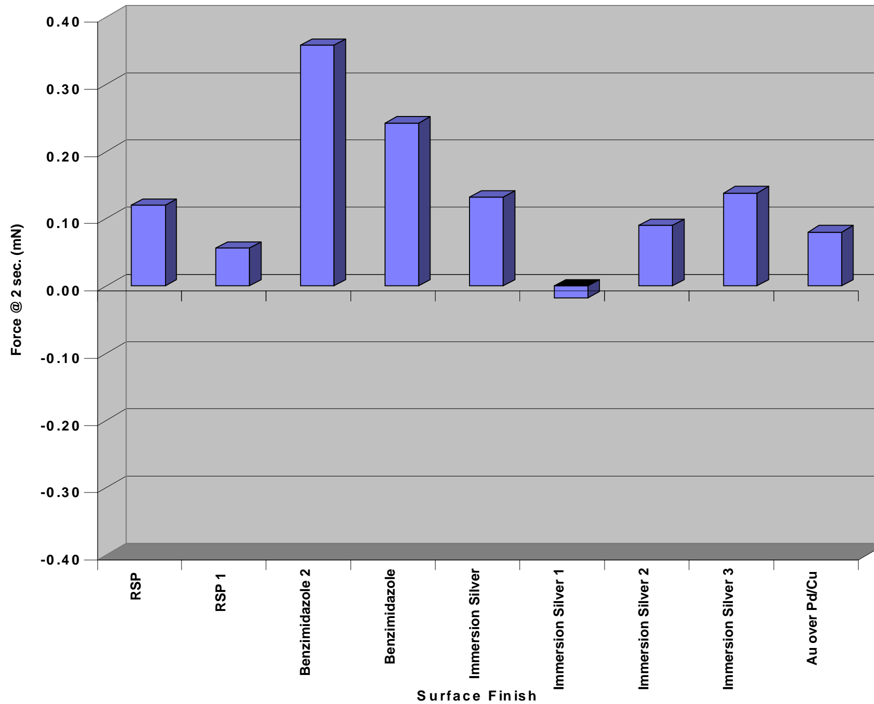

Figure 25 Force @ 2 sec. After 168 hr. Storage @ 50 ºC/85 % RH

The Steam Aging results shown in Figure 26 are the maximum stress applied to the surface finishes. After 8 hours exposure to a 100% RH environment at 92°C, all finishes were

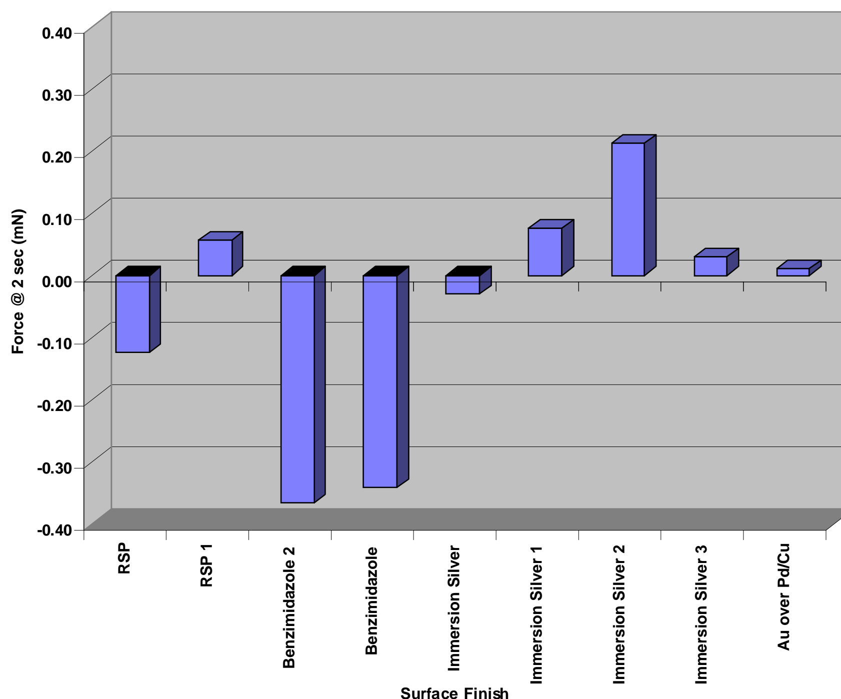

Figure 26 Force @ 2 sec. After 8 hr.Steam Aging

significantly affected. Even the RSP shows some negative wetting. It should be noted that the immersion Ag and Imm Au/Pd are roughly equivalent to RSP even after Steam Aging.

Observations
1. Benzimidazole – is solderable “as received”, but any reflow processing will drive the wetting force negative.
2. Reflowed Solder – provides a stable baseline for solderability comparisons.
3. Immersion Sliver and Immersion Gold on electroplated Palladium were equal to the solderable endurance of Reflowed solder plate.

Functional Test

The Functional data being reported here represents approximately 54,000 data points. When complete, the data set will include more than 157,000 data points. Iman, et.al.. [6] has done an exceptional job with statistical and graphic analysis of the functional data. In this report, I will confine my comments to the attribute data that are based on Table 11 criteria.

Table 16 summarizes the % acceptable based on the criteria in Table 11 by circuit type. Please note that Diesel Fuel (DF) is done before Hydraulic Fluid (HF) exposure, so the HF data come from PWAs, which were also exposed, to the DF conditions. The same is true for 85°C / 85% Relative Humidity (85/85) – Thermal Shock (TS) and Condensing Atmosphere (CA) – Thermal Cycle (TC) stressing.

There is a large variation in percent acceptable depending on circuit type in Table 16. Note the sensitivity of the HVLC and ON circuit types for CA exposures. At 85/85 and TS the HSD circuits are most sensitivity. For the DF – HF sequence percent acceptable is relatively constant (compared to other protocols) for all circuit types.

The Thermal Cycling (TC) stressing is preceded by the Condensing Atmosphere (CA) exposure, but the acceptance levels after TC are much better than the post CA test. This would suggest that most of the defects created by CA were not present after the PWA was dried.

Table 16 Percent Acceptable after Each Testing Sequence by Circuit Type

Circuitry	DF →	HF	85/85 →	TS	CA →	TC
HCLV	99.2%	100.0%	100.0%	100.0%	100.0%	100.0%
HVLC	98.3%	100.0%	96.7%	96.3%	**64.6%**	99.2%
HSD	100.0%	97.1%	**92.9%**	**91.3%**	98.8%	96.7%
HF LPF	98.9%	98.9%	99.7%	98.9%	99.9%	98.2%
HF TLC	99.7%	99.7%	100.0%	100.0%	93.7%	98.8%
ON	100.0%	100.0%	100.0%	99.8%	**62.3%**	98.1%
SW	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Total	99.3%	99.4%	99.0%	98.6%	88.8%	98.6%

Table 17 summarizes percent acceptable by surface finish. Note that the Condensing Atmosphere data are approximately 3% lower than the other conditions. Also, there does not appear to be a BAD surface finish for any the particular stress test.

Table 17 Percent Acceptable after Each Testing Sequence by Surface Finish

Finish	DF →	HF	85/85 →	TS	CA →	TC
HASL	99.9%	99.7%	99.5%	99.7%	95.9%	99.7%
OSP	99.8%	99.8%	99.7%	99.8%	97.0%	99.7%

IMM. AG	99.5%	99.8%	99.1%	99.6%	96.0	99.7%
IMM. AU/PD	99.9%	99.9%	99.6%	99.3%	96.2%	99.6%
Total	99.7%	99.8%	99.5%	99.6%	96.3%	99.1%

Table 18 summarizes all data taken for the Branch Water test. Three groups of data were collected for all PWAs related to the orientation of the board when the solutions were sprayed on them (Vertical, Back {backside}, and Comp. {component side). All PWAs were tested wet. Post-test results indicate the boards are rinsed with DI water and dried prior to testing.

As with the Condensing Atmosphere results, (Table 16) the acceptability of the test result is very dependent on the circuit type. The most obvious differences are highlighted in Table 18. Note that all of the large variances occurred during wet testing and that the averages of the wet tests relatively constant. After the boards are rinsed and dried (Post) the defects disappear and so does the sensitive to Circuit Type.

The PWAs from this test are in Salt Fog testing now, but the data are not available. Remember that the same parts will be used in the Salt Fog test.

Table 18 Percent Acceptable after BW by Major Circuit Group

Circuitry	Vertical	Post	Back	Post	Comp.	Post
HCLV	99.6%	100.0%	100.0%	100.0%	99.6%	100.0%
HVLC	**10.8%**	97.1%	**34.2%**	97.1%	**8.3%**	97.9%
HSD	**7.5%**	97.5%	97.5%	97.5%	97.5%	97.5%
HF LPF	99.8%	99.7%	91.9%	98.9%	99.0%	99.6%
HF TLC	44.7%	99.8%	**34.3%**	98.0%	85.8%	97.0%
ON	31.0%	99.6%	**37.9%**	99.2%	**20.2%**	96.9%
SW	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Total	59.8%	99.1%	66.9%	98.7%	74.6%	98.3%

Table 19 summarizes the data by surface finish after Branch Water testing. As in Table 18 there is a negative effect of testing wet, but there is no indication that these rejects are associated with the surface finish.

Table 19 Percent Acceptable after BW by Surface Finish

Finish	Vertical	Post	Back	Post	Comp.	Post
HASL	58.8%	98.4%	67.7%	98.8%	75.1%	98.4%
OSP	60.3%	99.3%	67.8%	99.4%	74.9%	98.8%
IMM. AG	60.9%	99.4%	67.2%	98.8%	75.1%	98.4%
IMM. AU/PD	59.1%	99.4%	65.7%	98.4%	74.2%	98.4%
Total	59.8%	99.1%	67.1%	99.1%	75.8%	98.5%

Test failures from the Diesel Fuel and Hydraulic Fluid sequence were investigated to identify the cause. Table 20 lists the number of anomalies and the number of PWAs reviewed by surface finish, coating status, and flux type. Note that the Urethane coating data were Not Available (NA) for this report.

There were so few rejects in DF/HF group that there were no clear differences for surface finish, coating status, or flux type.

Table 20 Anomalies after Completion of the Diesel Fuel & Hydraulic Fluid Sequence

Surface Finish	Anomalies	PWAs	Coating Status	Anomalies	PWAs	Flux Type	Anomalies	PWAs
HASL	4	2	**None**	5	3	**Low Residue**	1	1
OSP	2	1	**Parylene**	2	1	**Water Soluble**		
Imm. Ag	0	0	**Silicone**	0	0			
Imm. Au/Pd	1	1	**Urethane**	NA	NA			

Table 21 lists the results of our failure analysis on the anomalies found after Diesel Fuel and Hydraulic Fluids sequence (Table 20). Only the HSD circuits failed and it was related to electrical overstress and had nothing to do with finish, coating, or flux.

Table 21 Failure Analysis Summary after Completion of theDiesel Fuel & Hydraulic Fluid Sequence

Circuit Type	Failure Count	Cause
HCLV	0	NA
HVLC	0	NA
HSD	7	Electrical Overstress
HF LPF	0	NA
HF TLC	0	Open Trace
ON	0	NA
SW	0	NA

The anomalies detected after completion of the 85/85 and Thermal Sequence are shown in Table 22. As you can see no of the tested parameters stand out as have a big effect.

Table 22 Anomalies after Completion of the 85/85 & Thermal Shock Sequence

Surface Finish	Anomalies	PWAs	Coating Status	Anomalies	PWAs	Flux Type	Anomalies	PWAs
HASL	8	6	**None**	16	12	**Low Residue**	17	9
OSP	6	4	**Parylene**	12	6	**Water Soluble**	22	14
Imm. Ag	9	6	**Silicone**	11	5			
Imm. Au/Pd	16	7	**Urethane**	ND	ND			

The cause of the anomalies in are reported in Table 22. As was found in the DF/HF testing (Table 21) the anomalies, which were investigated, were caused by problems with Design, Fabrication, and Assembly. More importantly, the data do not support any change associated with the tested parameters.

Table 23 Failure Analysis Summary after Completion of the 85/85 and TS Exposures

Circuit Type	Failure Count	Cause
HCLV	0	NA
HVLC	9	Open PTH resistor, Open trace.
HSD	21	Electrical Overstress
HF LPF	8	Open VIAs, Unsoldered Cap.
HF TLC	0	NA
ON	1	Arcing at input
SW	0	NA

The Condensing Atmosphere reject rate was so high it was decided to look at them before the Thermal Cycling test. As you can see in Table 24 the rate was extremely high relative to the other tests and clearly more Uncoated PWA were rejected and with more anomalies per unit than coated specimens. Parylene and Silicone conformal coatings gave about the same protection on all surface finishes.

Table 24 Anomalies after 10 Cycles in Condensing Atmosphere

Surface Finish	Anomalies	PWAs	Coating Status	Anomalies	PWAs	Flux Type	Anomalies	PWAs
HASL	70	17	**None**	**188**	**40**	**Low Residue**	136	35
OSP	45	13	**Parylene**	21	11	**Water Soluble**	96	30
Imm. Ag	56	17	**Silicone**	23	14			
Imm. Au/Pd	61	18	**Urethane**	ND	ND			

Table 25 should be contrasted with Table 24. It represents the reject rate after the Condensing Atmosphere boards are dried and Thermal Cycled 500 times. Also note that there is no “standout” problem with surface finish, coating status, or flux type.

Table 25 Anomalies after Exposure to Condensing Atmosphere and Thermal Cycle Sequence

Surface Finish	Anomalies	PWAs	Coating Status	Anomalies	PWAs	Flux Type	Anomalies	PWAs
HASL	7	4	**None**	13	10	**Low Residue**	14	8
OSP	6	4	**Parylene**	6	4	**Water Soluble**	15	11
Imm. Ag	7	5	**Silicone**	10	5			
Imm. Au/Pd	9	6	**Urethane**	ND	ND			

Table 26 shows the results of the failure analysis of the anomalies after completing the CA/TC test sequence. All anomalies were associated with Design, Fabrication, or Assembly of the parts and not with the surface finish, coating status, or flux parameters. Also remember that all of these boards when through the condensing Atmosphere test which revealed clear problems with

uncoated boards. Therefore, the anomalies were transient and did not show-up after the boards were dried.

Table 26 Failure Analysis Summary after Exposure to Condensing Atmosphere and Thermal Cycle Sequence

Circuit Type	Failure Count	Cause
HCLV	2	Failure not duplicated.
HVLC	2	Arc over.
HSD	8	Broken pin P1, Electrical overstress.
HF LPF	5	Open VIAs
HF TLC	7	Open VIAs.
ON	5	Arc over.
SW	0	NA

Table 27 summaries the importance of the parameters for the completed tests based on the criteria in Table 11. Only the coating status was a factor in any of the tests completed to date. It was only important for two tests Condensing Atmosphere and Branch Water tests. Both test require functional evaluation while in water filmed condition.

Table 27 Important Parameters Based on Acceptance Criteria

	DF →	HF	85/85→	TS	CA →	TC	BW
Finish							
HASL	NOT	NOT	NOT	NOT	NOT	NOT	NOT
OSP	NOT	NOT	NOT	NOT	NOT	NOT	NOT
IMM. AG	NOT	NOT	NOT	NOT	NOT	NOT	NOT
IMM. AU/PD	NOT	NOT	NOT	NOT	NOT	NOT	NOT
Coating							
None	NOT	NOT	NOT	NOT	**YES**	NOT	**YES**
Parylene	NOT	NOT	NOT	NOT	NOT	NOT	NOT
Silicone	NOT	NOT	NOT	NOT	NOT	NOT	NOT
Urethane	NA	NA	NA	NA	NA	NA	NA
Flux							
LR	NOT	NOT	NOT	NOT	NOT	NOT	NOT
WS	NOT	NOT	NOT	NOT	NOT	NOT	NOT

Conclusions

SIR and Dendritic Growth

1. The standard HCl solutions used as the contamination source should be changed to either sodium or potassium chloride solutions.
2. The "Drop" application method should be eliminated. The results for dendritic growth were all bad.
3. While some dendrites were found, there was no correlation to surface finish.
4. There were only minimal differences in the results between the IPC and Bellcore SIR methods. Unfortunately, neither was well correlated to the contamination level. Using NaCl instead of HCl might have given a different result.

Solderability

1. Eight hours of Steam Aging significantly damaged the solderability of all Surface Finish.
2. OSP is the least expensive finish tested, but it does not handle high temperature bakes well at all. It should be used for single pass applications and/or with more active fluxes.
3. Immersion Silver and Immersion Gold on Palladium were equal to tin lead at all stress levels. Either could be used as a "Drop In" for HASL or reflowed solder plate.
4. Several suppliers are available for the Immersion Silver process, but the supply chain for the Immersion Gold on Palladium is not as good. We had significant problems getting the correct plating on the specimens evaluated.

Functionality

1. In most cases, the biggest factor influencing functional results was the test environment. Condensing or high humidity conditions consistently resulted in poorer than average performance.
2. All Surface Finishes were acceptable based on these SIR, Solderability, and Functional test.
3. The only big factors identified in the functional tests were from uncoated assemblies in high humidity environments. It is apparent that these stress are really looking at the effect of the conformal coating process.
4. The variation in the Functional testing from the high humidity tests (BW, and CA) for coated specimens is due to lack of coverage during the coating process rather than the material or surface finish.
5. Even the water-soluble flux (water washed) was not a driver when compared to low residue (leave on flux). Please take this result with some caution due to the lack of a RMA cleaned flux control.

Summary

1. Several surface finishes are compatible with SN63 solder joining and are commercially available to replace the tin lead finish in board fabrication.
2. Immersion Sliver and Immersion Gold on Palladium are “drop-in” replacements for solder at assembly; though, the Silver process is more available.
3. OSPs are not applicable for direct solder conversions. It should be used when only one solder joining process is required or when more aggressive fluxes and pre-heat conditions can be used. All OSPs are very inexpensive.
4. Don’t perform electrical functional test under condensing environments without good conformal coatings!

References

1. Kokas, J., et al, “Surface Finishes Team Final Report”, National Center for Manufacturing Sciences, Inc. (NCMS), Oct., 1996
2. Brunner, B. Gordon, R., Marr S., “Evaluation of Immersion Silver as a reliable PWB Finish for Soldering and Wire Bonding”, Proceedings from the IPC Summit on PWB Surface Finishes and Solderability, Austin, TX, Sept, 1998.
3. Iman, R., Koon, J., et al, “Joint Test Protocol CC-P-1-1 for Validation of Alternatives to Lead-Containing Surface Finishes, for Development of Guidelines for Conformal Coating Usage, and for Qualification of Low-VOC conformal Coatings”, Joint Group on Acquisition Pollution Prevention (JG-APP), DOD, 1998.
4. Reed, J., "Immersion Silver as a Replacement for Solder Finish”, IPC/SMIA Electronic Assembly EXPO Proceedings, Oct 1998.
5. Iman, R. L., Koon, J. F., et al, “Screening Test Results for Developing Guidelines for Conformal Coating usage and for Evaluating Alternative Surface Finishes”, CCAMTF Report, June 1998.
6. Iman, “Update on Current Circuit-Card Assembly and Materials Task Force Results”, IPC Electronic Assembly EXPO ’99. Proceedings, March 1999.