Challenges Associated with Non-Clean Liquid Flux Selection to Meet Industry Standards

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Abstract
The selection of a liquid flux for use in wave soldering operations is extremely critical to both the manufacturing assembly process and the long term reliability of electronic assemblies. As in the case of VOC-free fluxes, suppliers have developed products that minimize their impact on the environment and meet IPC-J STD 004 Revision A requirements. Just over 4 years ago Revision B was released[1] with significant changes to the Surface Insulation Resistance testing including thermal profile, humidity targets, bias voltages, and measuring frequency requirements. These changes along with tighter halide limits have significantly restricted the VOC-free flux offerings, due to concerns of reliability test failures. Though harsh environments may have seen improvements in the field of reliability, correlation to field failure rate improvements has not been seen on typical environments since the option of Revision B release.

Smaller flux formulators are not always aware of the changes nor have re-classified their products. Testing has uncovered numerous VOC-Free products, which do not meet stated specifications. Even for fluxes claiming to pass the current standard, the lack of adequate method detail on how to execute the test and reporting of parameters used, introduces variation in results and interpretational errors.

In order to meet the IPC J-STD-004 standard Revision B requirements and design materials that can meet the thermal challenges of today's products, most liquid flux formulators increased or re-introduced rosin in the formulations. As a result, moving back to the use of alcohol fluxes is the primary option. This transition back to VOC containing materials conflicts with the majority of the environmental initiatives within manufacturing.

This paper details the challenges to be encountered by comparing results provided by flux manufacturers to that obtained in-house during verification testing. Comparison will also be made between laboratory testing and production results. Gaps and opportunities will be presented in the industry's current approach to flux development and selection.

Introduction
Soldering fluxes are used to stimulate wetting and assist with the proper formation of solder joints. The fluxes primary function is to remove the oxides from the surfaces to be soldered while protecting the cleaned surfaces against re-oxidation. It also helps to transfer the heat and remove the reaction products to allow good connection between the base metal and the solder.

The fluxes consist of active and wetting agents dissolved in a carrier, typically water or alcohol. After the application of the flux the carrier is evaporated leaving the active agent over the surfaces. The residues originated from flux vapors, heated flux, or non-heated flux may have effects that vary from just discoloration to a complete damage of the functioning of the product. Thus, design of an appropriate flux is a balance of two conditions: the efficacy of the flux to promote wetting and the impact of the flux residues on the soldered products long term reliability.

To assist the user in the selection of an appropriate flux, the industry has developed a classification of fluxes based upon corrosivity in IPC J-STD-004 (Table 1.) By determining the halide content and performing Corrosion, Copper Mirror, Surface Insulation Resistance (SIR), and Electro Chemical Migration (ECM) tests, fluxes are classified as Low (L), Medium (M), and High (H) activity and 0 or 1 for the halide content.

Table 1. Test Requirements for Flux Classification

Table 3-2 Test Requirements for Flux Classification

Flux Type	Copper Mirror	Corrosion	Quantitative Halide[1] (Cl-,Br-,F-,I-) (by weight)	Conditions for Passing 100 MΩ SIR Requirements [2]	Conditions for Passing ECM Requirements
L0	No evidence of mirror breakthrough	No evidence of corrosion	<0.05%[3]	No-clean state	No-clean state
L1			≥0.05 and <0.5%		
M0	Breakthrough in less than 50% of test area	Minor corrosion acceptable	<0.05%[3]	Cleaned or No-clean state[4]	Cleaned or No-clean state[4]
M1			≥0.5 and <2.0%		
H0	Breakthrough in more than 50% of test area	Major corrosion acceptable	<0.05%[3]	Cleaned	Cleaned
H1			>2.0%		

1. This method determines the amount of ionic halide present (see Appendix B-10).
2. If a printed circuit board is assembled using a no-clean flux and it is subsequently cleaned, the user should verify the SIR and ECM values after cleaning. J-STD-001 may be used for process characterization.
3. Fluxes with halide measuring <0.05% by weight in flux solids may be known as halide-free. If the M0 or M1 flux passes SIR when cleaned, but fails when not cleaned, this flux **shall** always be cleaned.
4. Fluxes that are not meant to be removed require testing only in the no-clean state.

Many modern electronic assemblies are designed to leave the fluxes residues on the boards in the field. This is being done to reduce manufacturing costs and support environmental goals. This design requirement drives the flux formulators to insure the remaining flux residues to be safe in the operating environment.

For the flux formulators, IPC J-STD-004 defines the required test methods to qualify a new flux formulation, to measure the production quality conformance and to verify the end use performance of fluxes as stated in Table 2. The two performance tests Spread test and Wetting Balance test attempt to assess the solderability of the material, but these tests do not typically represent the complex soldering of modern assemblies. Additionally, tests are optional and as such do not serve the industry well in validating the applicability of the materials.

Table 2. Qualification Requirements for Fluxes

Table 4-1 Qualification, Quality Conformance and Performance Testing for Flux

Test Method: Name	Test Method: IPC-TM-650 or Other Method	Reference Paragraph	Qualification	Quality Conformance	Performance
Copper Mirror	2.3.32	3.4.1.1	R		
Corrosion	2.6.15	3.4.1.2	R		
Quantitative Halides	2.3.28.1	3.4.1.3	R		
Surface Insulation Resistance	2.6.3.7	3.4.1.4	R		
	IEC 61189-5	3.5.2	O		
	Bellcore-GR-78-CORE, Section 13.1		O		
	ISO 9455-17		O		
Electrochemical Migration	2.6.14.1	3.4.1.5	R		
Flux Solids, Nonvolatile Determination	2.3.34	3.4.2.1	R		
Acid Value Determination	2.3.13	3.4.2.2	R	R	
Flux Specific Gravity Determination	ASTM D-1298	3.4.2.3	R	R	
Viscosity—Paste Flux	2.4.34.4	3.4.2.4	R	R	
Visual		3.4.2.5	R	R	
Qualitative Halides, Silver Chromate	2.3.33	3.5.1.1	O	O	
Qualitative Halides, Fluoride Spot	2.3.35.1	3.5.1.2	O	O	
Fungus	2.6.1	3.5.3	O		
Wetting Balance[1]	2.4.14.2	3.7.1	O		O
Spread Test, Liquid Flux[1]	2.4.46	3.7.2	O		O

R = Required
O = Optional
1. For these tests to be used to gauge performance, testing must be performed initially and when a reassessment of performance is necessary. Initial and retest results should be compared.

It is possible to effectively define proper conformance quality limits that insure consistent soldering performance of the materials, when the formulator performs an effective limits study and tightly controls the supply chain of the formulation constituents. For no-clean products, the most significant challenge is meeting the qualification requirement of J-STD-004. This is especially true when testing is confounded by other assembly materials and constituents carried onto the products from the Printed Circuit Boards (PCBs) and components. As a result, the identification of acceptable materials must go well beyond a mere review and classification per J-STD-004.

Modern Selection Process
The selection process of modern materials must consider all aspects of the business, product and end customer risk. Although this process must start with fluxes that meet the J-STD-004 requirements, a proper selection must include the Printed Circuit Board (PCB) challenges, material combinations, component technologies, soldering alloy requirements, and environmental restrictions.

The primary factors used to select a non-clean flux are its ability to solder simple and complex assemblies and to provide long term reliability. Other considerations are the cosmetic aspect of the flux residue. Finding a flux that meets all requirements has turned out to be challenging and time consuming. Abundant testing is required to find the perfect candidate.

The methodology to find a new material consisted in that shown in Figure 1:

Figure 1. Methodology for Flux Selection

Paper Study
We began the evaluation by conducting a paper study where critical to quality (CTQ) parameters are defined. Batteries of requirements that start from product characteristics to product reliability are turned into qualitative and quantitative measures. Some CTQ parameters are:

a) Flux classification (L0 for No-Clean processes)
b) Flux J-STD-004 latest revision reliability data
c) Flux compatibility to solder alloys (tin lead and lead free alloys)
d) Flux appearance (Clear, cohesive, low tackiness)
e) Flux process window (Preheat times, dwell times, peak temperature, etc)

Many of the formulators contacted, lacked adequate information to complete the paper study. This was mainly observed in smaller flux suppliers. The biggest eye-opening was the lack of information on changes in the IPC standards. As a result many did not have data supporting their products meet the current standards and when testing was conducted, the qualification standard or material classification could not be met. In addition, there was little understanding on the product process window. Their Technical Data Sheets (TDSs) provided information that did not always match current manufacturing practices for simple and thermally challenging assemblies.

Since the TDSs are reviewed by the customers in the selection process, marketing influences drive the broadest statements of soldering performance and reliability performance. The reality was that in testing many did not have the stated capabilities as per their TDSs. The over stated capabilities of the TDS also create regulatory compliance challenges for the assembler. In other cases, the TDS becomes a cut and paste from previous formulation and are found with error. The challenge to the assembler using the material is with the regulatory auditor's interpretation of the TDS as the governing body of work. Even when comprehensive studies showing the performance and interoperability of the material sets are presented, findings still get issued to the assembler for being in violation of the TDS.

Nowadays, the complexity of products continue to increase, hence thermally challenging boards are not uncommon. These assemblies require the following in order to achieve acceptable through hole fill:

- Higher pot temperatures (i.e. greater than 270°C for lead free alloys)
- Longer dwell times (i.e. longer than 10 seconds)
- Higher preheat temperatures (i.e. greater than 130°C)

Since the J-STD-004 performance tests have not kept up to match these process requirements, many of the flux suppliers' TDSs recommend temperatures and times that are not wide enough to ensure that the fluxes will work well at higher preheat and pot temperatures and dwell times.

Solder:	SnAgCu or SnCu
Pre-heat temp:	100 - 110°C at soldering side
Solder temp:	250 - 260°C
Dip time:	5 - 7 sec (total time of first and 2nd wave)

Figure 2. Example of Typical Process Window for a Flux from a TDS

Through an effective CTQ matrix and detailed investigation with a supplier, many formulations and suppliers were eliminated from the evaluation. From the 18 fluxes used in this study, more than 50% dropped or were eliminated. The remaining materials and their characteristics are provided in Table 3.

Table 3. List of Fluxes Tested

Flux	Type	IPC Class	Solid Content (%)
A	VOC Free	ORL0	5.86
B	VOC	ORL0	4.05
C	VOC	ROL0	7.2
D	VOC	ORL0	6.0
E	VOC Free	ORL0	5.05
F	VOC	ROL0	3.9
G*	VOC Free	ORL0	3.7
H*	VOC	ROL0	5.77

*Added latter on to the test

Laboratory Solderability Testing

To further the qualification of the materials, the next step was to assess the solderability based on how well the fluxes make the surface wettable. The complicated nature of solderability makes it difficult to perform solderability tests in the laboratory that are fully representative of what will happen in actual soldering practice. Wetting balance and spread testing are the most common and are stated in J-STD-004 as optional testing for flux qualification.

Wetting Balance is used to measure the rate of wetting. The test method is described in TM650 2.4.14.2. The test measures the forces of the surface tensions of the materials over time. Three points in the curve were used the rank the fluxes.

a) Time at which the force acting on the specimen is equal to the calculated buoyancy, which is the initiation of the wetting, known as wetting time
b) The force at 5 seconds
c) The force at 10 seconds

To most accurately simulate the soldering environment the sample preparation is critical. Copper coupons were thermally profiled in a batch oven to achieve a preheat profile similar to the production process (120 seconds at 110°C). This was to assure proper activation of the fluxes. Three coupons per flux type were tested. For a baseline, coupons were run with the IPC Test Flux # 2. The data showed large variation among runs as per Figure 3 for all tested fluxes. The average of the 3 curves was used to rank the fluxes.

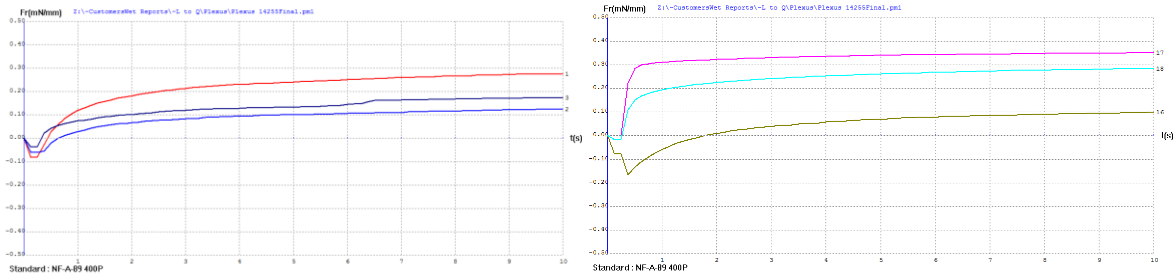

Figure 3. Examples of Wetting Balance Curve for IPC Test Flux #2 and Flux B

The following table shows the results of the experiment for 7 fluxes. Rapid wetting can be observed in cases of Flux A and B and poor wetting in Flux E and F (i.e. Time to cross zero). Slight increase in force was observed for all fluxes after 10 seconds. The highest number was given to fluxes with fast wetting and higher force. Note that the results here are averages as the variation amongst test runs was often significant.

Table 4. Wetting Balance Results

Flux	Time to Cross Zero (sec)	Force at 5 Sec (mN/mm)	Force at 10 Sec (mN/mm)	Rank
A	0.314	0.3	0.31	6
B	0.293	0.22	0.24	5
C	0.732	0.17	0.2	4
D	2.866	0.03	0.04	3
E	9.491	-0.02	0	2
F	Did not cross	-0.14	-0.12	1
IPC Test Flux #2	0.443	0.16	0.19	N/A

Spread Testing was conducted as per TM650 2.4.46. This test was performed on both copper and brass coupons. Coupons were flattened and cleaned with steel wool. Rings of SAC305 solid wire were placed on the center of the coupons to control the volume of available solder. A controlled volume of flux was placed in the center of the ring just before placing the coupons into a profiled preheating process (130^{0}C for 1 minute). Samples were placed onto the surface of a solder bath until the solder melted, completing the flux preheating process. The coupons were given a 5 seconds wetting time. A total of 8 coupons per flux type were tested.

The area of spreading was measured using an optical CMM (See Figure 4). Greater spreading was observed on the copper rather than on the brass coupons. Visual inspection showed that some of the fluxes wet the surface very easily whereas others did not. Some fluxes interact with the copper changing the color of the surrounding areas to black and/or green.

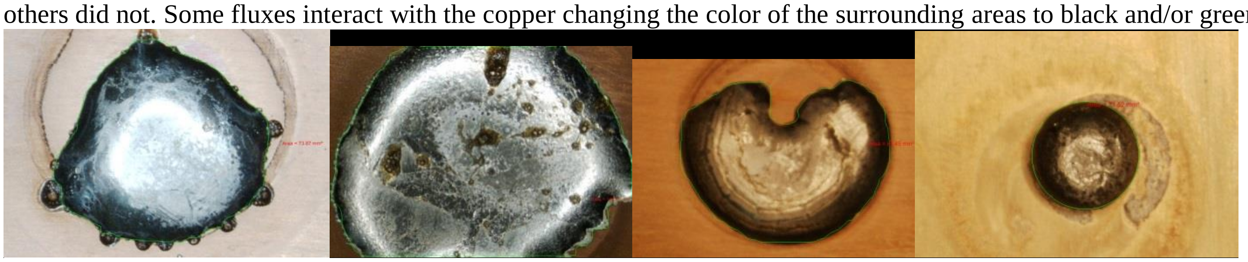

Figure 4. Pictures of solder spreading using various fluxes

The spreading measurements showed that Flux D had the highest degree of wetting on copper coupons. One way ANOVA at 95% confidence interval showed that Flux D followed by Flux C performed better than the rest. The worst performers were fluxes F and A.

For the brass coupons, opposite performance was observed. One way Anova at 95% confidence interval showed that the best performer was fluxes A, B, and F. The worst performers were fluxes C and D.

This result is conflicting for the assembler since the soldering processes have to support a wide variety of base materials. Since these tests are not part of the current standard, formulators are not challenged with optimizing the formulations to support all the challenges.

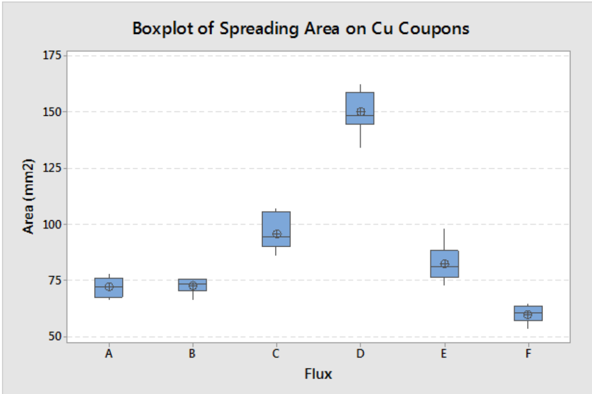

Figure 5. Spreading Results on Cu and Brass Coupons

The highest rank was given to the largest spreading area. The surrounding area of copper coupons with Flux A turned black and green in every single coupon. Therefore it was eliminated as it was identified to be a corrosive by-product whereas in the case of Flux D the green was determined to be copper abietate. The latter being a non-corrosive and non-conductive reaction by- product of rosin and copper oxide.

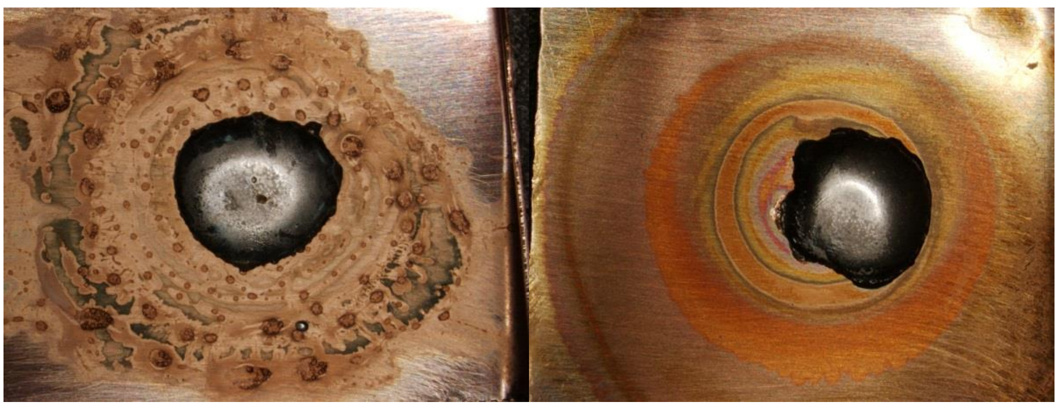

Figure 6. Coupons when using Flux A and Flux F

Table 5. Spread Test Results on Copper and Brass

Flux	Average Area on Cu (mm^2)	Visual Inspection	Rank for Cu	Average Area on Brass (mm^2)	Visual Inspection	Rank for Brass
A	72.1	Green/Black	2 (Eliminated)	65.1	No issue	6
B	72.5	No issue	3	60.0	No issue	5
C	95.6	No issue	5	22.9	No issue	2
D	150.1	No issue	6	19.9	No issue	1
E	82.6	No issue	4	56.2	No issue	3
F	60.0	Green	1	57.8	No issue	4

Table 6 shows a summary of the lab test results. The best performer was flux B followed by C. The worst performance was shown by flux F.

Table 6. Composite Laboratory Solderability Testing Results

Flux	Wetting Balance	Cu Spread	Brass Spread	Total Points	Comment
A	6	2	6	14	Eliminated due to discoloration
B	5	3	5	13	
C	4	5	2	11	
D	3	6	1	10	
E	2	4	3	9	
F	1	1	4	6	Poorest Lab test soldering flux

It is interesting to observe that Wetting Balance and Spread testing results did not align. This is not necessarily surprising. Wetting balance testing focuses on speed of wetting and the ability to wet-out (up) vertically, whereas spread testing characterize the ability of a solder to spread out horizontally over a maximum period of time. These performance properties are not necessarily provided by a single activator, but more often than not by a blend of 2 or more. Some flux manufacturers select these better than others and often selected (intentionally or un-intentionally) for a specific and narrow process window that may not fit all applications.

Reliability Testing
The test vehicle used was 62-mil-thick made of FR4 material, LPI Green solder mask with an ENIG finish. Side B of the board has the two standard IPC B24 test patterns and is free of solder mask. Image of side B is as follows.

SIR testing was conducted via current IPC J-STD-004B requirements:

- Test chamber temperature 40 ± 1 °C
- Test chamber humidity 90 ± 3% R.H.
- Applied bias near 25 V/mm. Due to limitations of the equipment 10V was applied, which is an applied bias of 19.7 V/mm
- Measurement cycle is every 20 minutes
- Test Duration 168 hours
- Test Criteria:
    - No cycle test reading < 1*10E8 past 24 hours at required temperature and humidity
    - No visual evidence of dendritic growth
    - No visual evidence of corrosion or discoloration

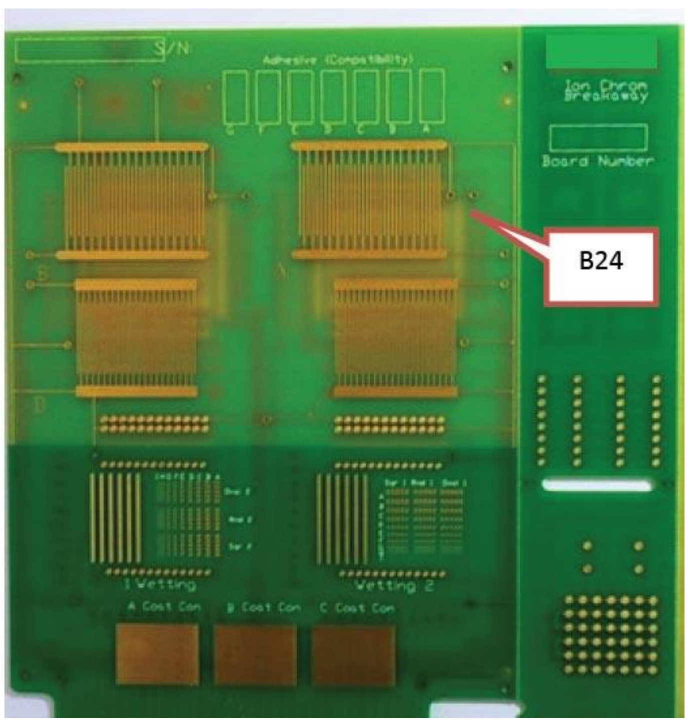

Figure 7. Company TV12 Test Vehicle

The sample preparation should consider the intended operating window. A cold, short profile with high flux deposits provides the most challenging conditions for SIR. The combination of operating parameters that provided the most severe wave soldering conditions were determined to be the following**:**

Table 7. Process Parameters for TV12

Parameters	Condition Used
Solder Alloy	Sn/Pb & SAC 305
Alloy Temperature	255ºC & 265ºC
Flux Deposition	1200 microgram/inch^2
Topside Preheat	90ºC
Dwell Time in solder wave	4 seconds
Use of Wave Pallets	Yes

These parameters reflected the lowest preheat temperatures and maximum amount of flux as per the fluxes TDS. The maximum amount of flux was limited to its saturation point where no drips were observed when fluxing the test vehicle. Boards were sent through the wave machine using selective pallets to create entrapment points and areas where the flux will not see the liquid soldering temperatures.

Boards were placed in the SIR chamber at different times due to capacity and availability. For each cycle, a bare board was tested as a control. As shown in Table 8, for both the tin lead and lead free alloys only 40% of the materials passed and when analyzed across the alloys, only one material passed both alloy conditions. Thus the TDS and supplier supplied data was not a strong predictor of actual performance.

SIR testing was considered to be amongst the highest of CTQ's. The presence of dendrites on SIR patterns was cause for immediate disqualification. This therefore eliminated many of the fluxes, leaving only 1 solid contender remaining (flux F). This was troublesome as the laboratory soldering testing ranked flux F low. Therefore, a second paper study was conducted and 2 additional fluxes for the SIR study were added (flux G and H). Final results showed that flux H passed the SIR testing whereas flux G still failed the test. This left fluxes F and H remaining for future consideration.

Table 8. SIR Results

Flux ID	Solder Alloy	% Patterns Passing Electrically	Dendritic Growth	Evidence of corrosion	Pass/Fail
E	Sn/Pb	15	*Yes*	None	Fail
D	Sn/Pb	93	*Yes*	None	Fail
B	Sn/Pb	29	*Yes*	None	Fail
F	Sn/Pb	100	*None*	None	Pass
C	Sn/Pb	100	*None*	None	Pass
E	SAC 305	80	*Yes*	None	Fail
D	SAC 305	100	*None*	None	Pass
B	SAC 305	50	*Yes*	None	Fail
F	SAC 305	100	*None*	None	Pass
C	SAC 305	75	*Yes*	None	Fail

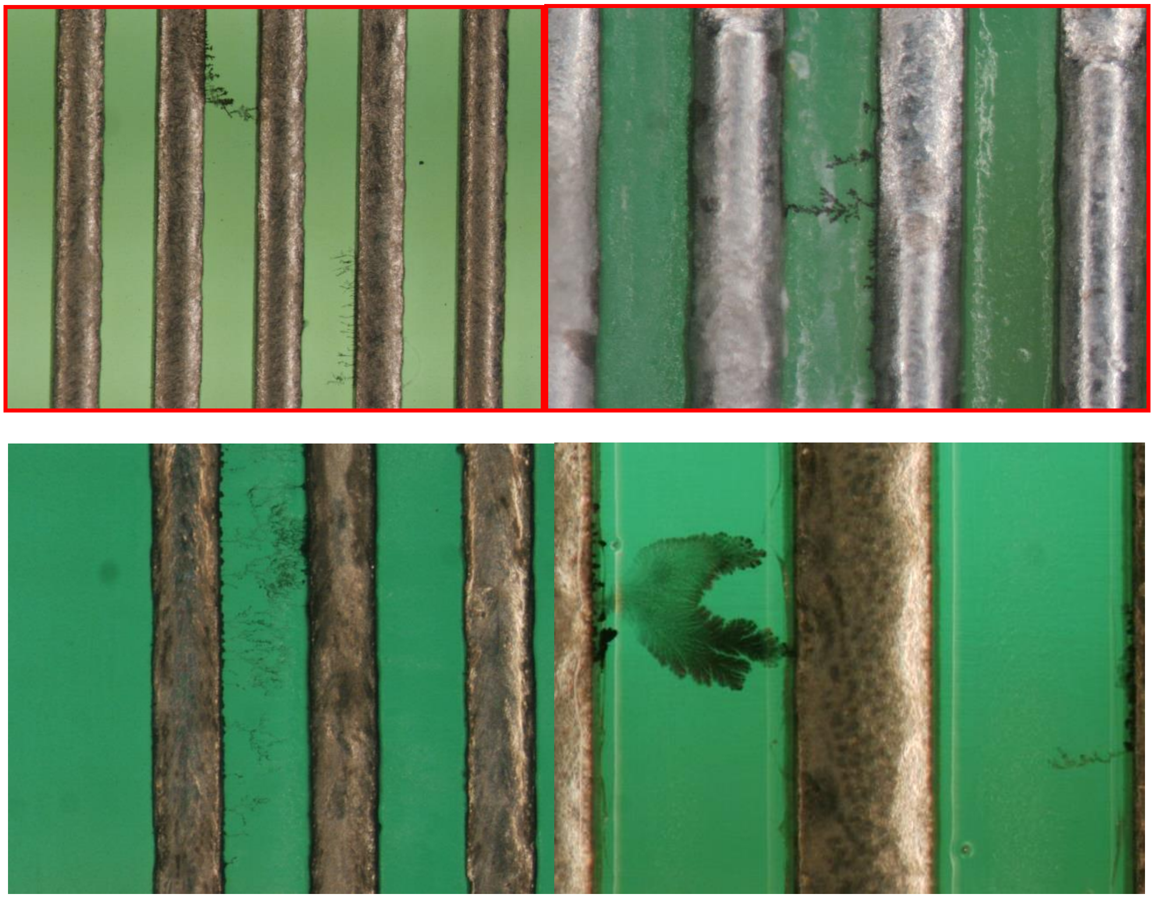

Figure 10: Typical SIR Failures

Table 9. SIR Results of Added Fluxes

Flux ID	Solder Alloy	% Patterns Passing Electrically	Dendritic Growth	Evidence of corrosion	Pass/Fail
H	Sn/Pb	100	*None*	None	Pass
G	Sn/Pb	0	*Yes*	None	Fail
H	SAC 305	100	*None*	None	Pass

The only materials that meet the SIR testing were alcohol based fluxes. For the electronic manufactures this creates environmental challenges. More diligent adherence to compliance standards for every site local government regulation on air pollution would be required as well as additional training of personnel along with stricter controls on flux application. Flammable storage solutions would be required and additional fire prevention measures during processing. As a consequence, it was well understood that a larger investment would be required to create a safe environment. Significant investment to comply with the latest SIR requirement was accepted being a requirement in moving forward.

Solderability Testing

Solderability testing follows the selection process. The final remaining 2 down selected fluxes were used: flux F and flux H using the TV-18 test board to assess the hole fill and soldering capabilities of the fluxes. This test vehicle is a 93-mil-thick board with Cu OSP finish and different hole designs (connection to layers, pin to hole ratio) that creates thermal and static pressure challenges for the range of typical products. Furthermore, a selective solder wave pallet was used to simulate modern assembly processes.

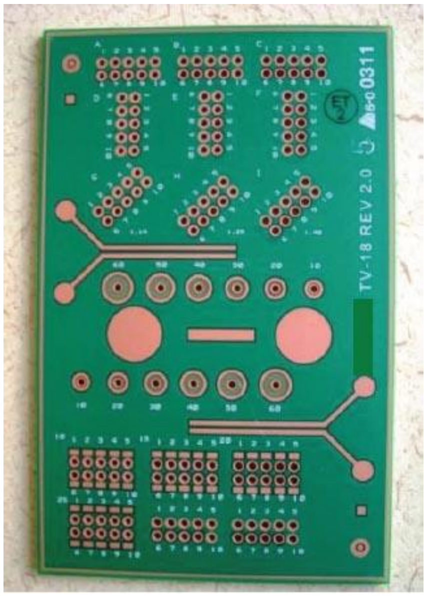

Figure 11. Company TV18 Test Vehicle

Process Methodology and Design of Experiments

The boards were pre-conditioned by sending them twice through a standard lead free reflow profile. The following parameters and levels based on current production demands were used to run a full factorial design with middle points.

When developing the process window for the fluxes, it is observed that frequently there is a large disagreement with their respective TDS. One of the biggest differences is the amount of flux necessary to yield best soldering performance. TDS often calls for large quantity of flux which can cause reliability problems, cosmetic issues, and/or wave machine maintenance concerns. The reason for the difference is the absence of a standard process of how flux should be measured. For this study, a clean plate is sprayed through production equipment with the flux, remove the plate from the machine, and weight the flux. Then, the flux amount is calculated by:

$$Flux\ Amount = \frac{Flux\ Weight\ x\ \ Flux\ Solid\ Content}{Area}$$

Table 10. Design of Experiment

Parameters	Units	Level 1	Level 2	Middle
Flux Amount	µg/in2	700	1200	950
Topside Preheat Temperature	ºC	90	145	118
Dwell Time	Sec	4	10	7

The following factors were kept constant and 3 replicates per condition were run, for a total of 27 boards

Pot temperature = 270ºC

Solder Alloy = SAC305

The boards were placed onto pallets, and then the headers were inserted by hand onto the board. Boards were then run through the wave machine. The output of the experiment were soldering defects and hole fill.

Inspection Results

Each board was visually inspected and defects were recorded. Two defects most commonly observed were bridging and blow holes. Flux H had a significant amount of bridging while Flux F presented few cases of blow holes. The number of bridges was determined by counting the total number of pins involved in a bridge.

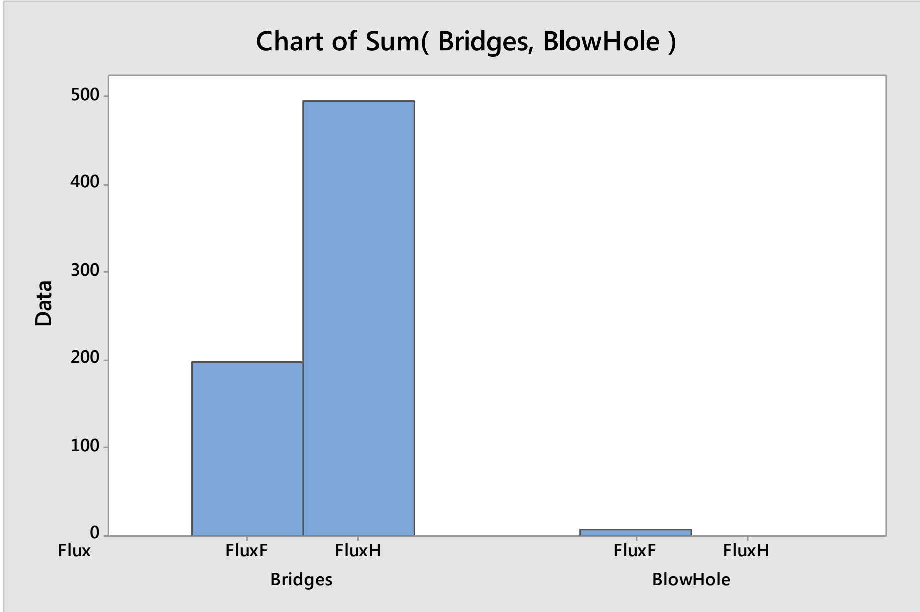

Figure 12. Soldering Defects

The post wave residues were also characterized. Large amounts of residue was observed with flux H than flux F when applying the same amount. The residue for flux H was yellow and it was tacky when it was warmed while flux F residue was clear and shiny and not tacky. Both fluxes contain rosin so it was expected to observe residue on the boards. The tackiness of the flux was of concern as it can entrap Foreign Object Debris (FOD), pallets would be required to be washed more often, and machine fluxer will require higher maintenance.

Figure 13. Flux Residue for Flux H and Flux F

X-ray was used to characterize the hole fill of all the solder joints. Then for each flux, the process window was optimized by targeting a minium of 75% hole fill. Given the range of products and challenges, a material with the largest profile is desireable. It was determined that flux F performed best with cooler preheat temperatures while flux H works best with hotter preheat temperature.

When comparing the data at their optimal process windows, it indicated that flux F had better hole fill than flux H. One way ANOVA at 95% confidence interval clearly favored flux F. On average, flux F had 8% better hole fill than flux H. However, the data also indicated that flux F had a narrower process window for preheat temperature, which it is an important factor for thermally challenging boards. Thermogravimetric Analysis (TGA) was performed on flux F. The data indicated that at 140 ºC the flux starts degrading. Therefore, the preheat process window for this flux would be limited to 135ºC bottom side preheat temperature.

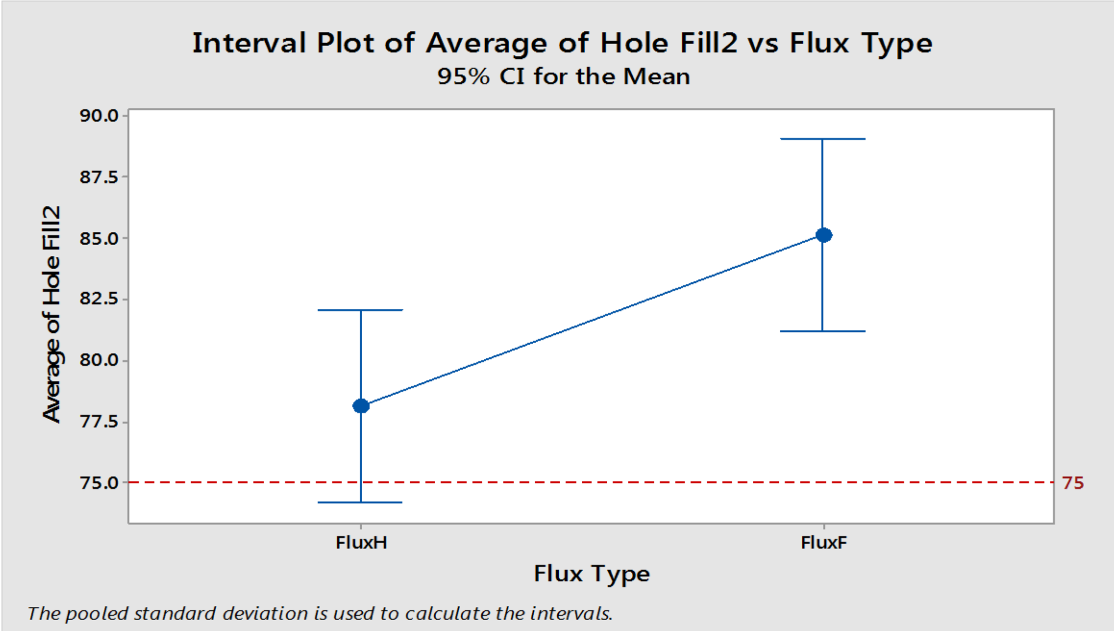

Figure 14. Hole Fill Comparison between Flux H and F

Summary

The evaluation was successful in identifying a non-clean liquid flux that meets industry reliability requirements and still provides acceptable hole-fill. The last step in our evaluation is to test this new flux in combination with other soldering assembly materials such as solder paste, hand soldering flux etc. The residues left by other materials in combination with the flux residue can create an adverse effect on the reliability. This testing is on-going.

Ongoing Work/ Call for Industry Action

Flux development and selection always presents the flux manufacturer and user with the classic balancing dilemma of flux activity versus residual safety. Namely, the desire is to get optimal wetting and hole fill while still maintaining a lack of corrosiveness of the flux residues. Changes to IPC specifications which have made SIR testing more stringent while also requiring higher hole fill have greatly narrowed the suitable flux selection window. Newer SIR requirement has eliminated VOC free fluxes from the market and increase our collective environmental impact. The industry has operated successfully under the previous SIR standard which enabled VOC free fluxes for decades with low reliability risk and limited challenges traced back to proper qualification and processing of the materials.

The above points make the development and identification of a flux very challenging to say the least for both the flux manufacturer and user. It is not impossible to have a flux that meets all stipulated IPC reliability testing for a class and yet having poor solderability. The later point is true because flux developers typically have a narrow scope of in-depth field testing which they can perform often relying heavily on a limited number of customers providing the bulk of the feedback prior to release to the general market. This leaves some customers sifting through a broad spectrum of offerings in order to identify a flux that is suitable for a majority of their applications.

The above is presented as an industry gap, namely that current flux specifications focus heavily on reliability without any requirement for consideration of soldering performance. Furthermore, the reliability standards need to focus more heavily on the sample preparation and ties to processing conditions so correlation exists between the published results and risk in the field and the material is optimized to handle the modern electronic assemblies. Without this change, the industry will continue to experience costly qualifications and continue to experience field reliability challenges.

Acknowledgements

The authors of this paper would like to acknowledge our colleagues Chee-Kiat Tan, CW Ooi, Mark Voss, Sue Ziegler, Chris Smith, Thomas Shoaf, Zoltan Szoke, Stephen Mainwaring, and Denis Jean for their contributions to the success of this project.

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Problem Statement

- J-STD 004 Revision B changes:
  - Method for Calculation of Halides
  - Surface Insulation Resistance
- As a result, changing the classification of some fluxes and eliminating VOC-free flux offerings due to reliability concerns.
- The industry is moving back to the use of rosin-alcohol based fluxes, which conflict with the majority of environmental activities of reducing VOC from the air

Changes Halide Content

J-STD-004 A	J-STD-004 B
Spot Test For Chlorides and Bromides	Ion Chromatography
Qualitative Test	Quantitative Test
Spot test was sensitive to about 3000 ppm. Fluxes with halide up to 0.3% will pass the test and be considered Halide Free	

Halide Free fluxes contain < 500 ppm (0.05%) of chlorides and bromides.

Why is this important? Because the amount of halides contained in flux relates to the corrosivity of the flux residue

The re-classification is optional for current products

Changes on SIR

	J-STD-004A	J-STD-004B
Temperature (C)	85	40
Humidity (%RH)	85	90
Voltage Bias	48	25
Time	7 days	7 days
Resistance Measurement	24 hours, days 4, and 7	Every 20 minutes
Min Resistance (MΩ)	100	100

- Test Criteria:
  - No resistance < 1*10E8 past 24 hours
  - No visual evidence of dendritic growth
  - No visual evidence of corrosion or discoloration

Changes on SIR

- Lower temperature and higher humidity affect VOC free fluxes
- Lower temperature does not decompose the flux fast
- Higher humidity causes flux to absorb moisture
- Lower bias slows the self destruction of dendrites and they are captured by the more frequent monitoring of the resistance

Flux Selection Process

Paper Study

- Critical To Quality
  - Product Characteristics
    - Classification as L0
    - Meet J-STD-004B
  - Process Characteristics
    - Compatibility with Lead Free and Tin Lead
    - Flux Process window (Preheat Time, Dwell Time, Peak Temperature etc)
  - Documentation/Test Results
    - SIR results

18 Fluxes were proposed from different suppliers around the globe

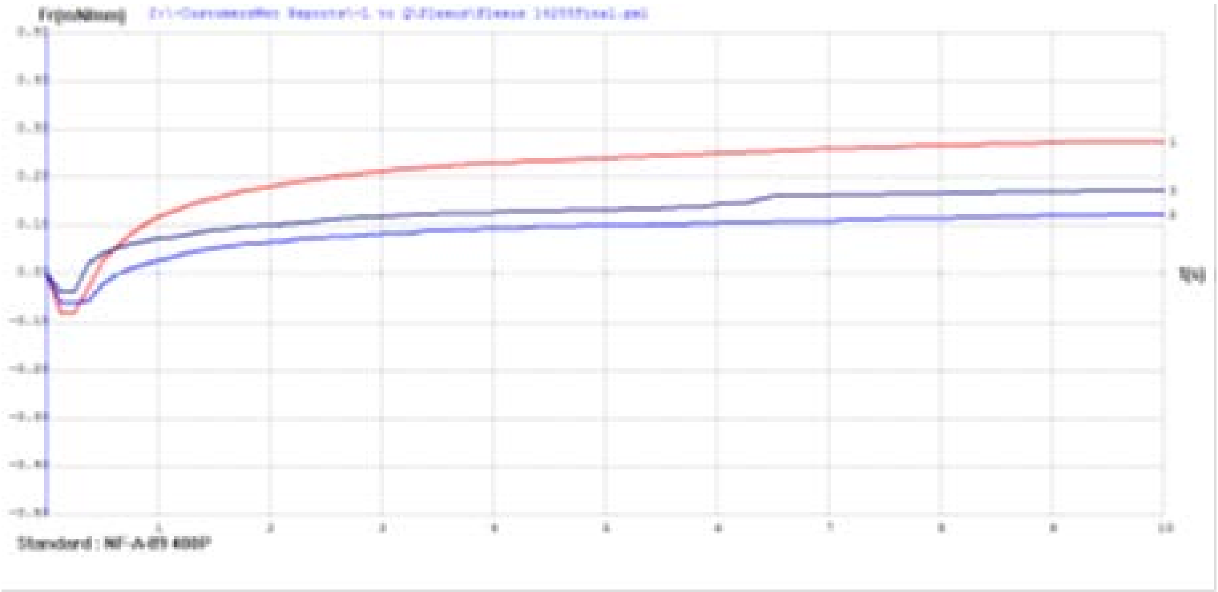
Paper Study

- More than 50% of the fluxes were eliminated
  - Unaware of new SIR requirements
  - Fail to pass new SIR testing
  - Lack of resources to perform SIR testing
  - Unknown process window; TDS do not represent current manufacturing practices

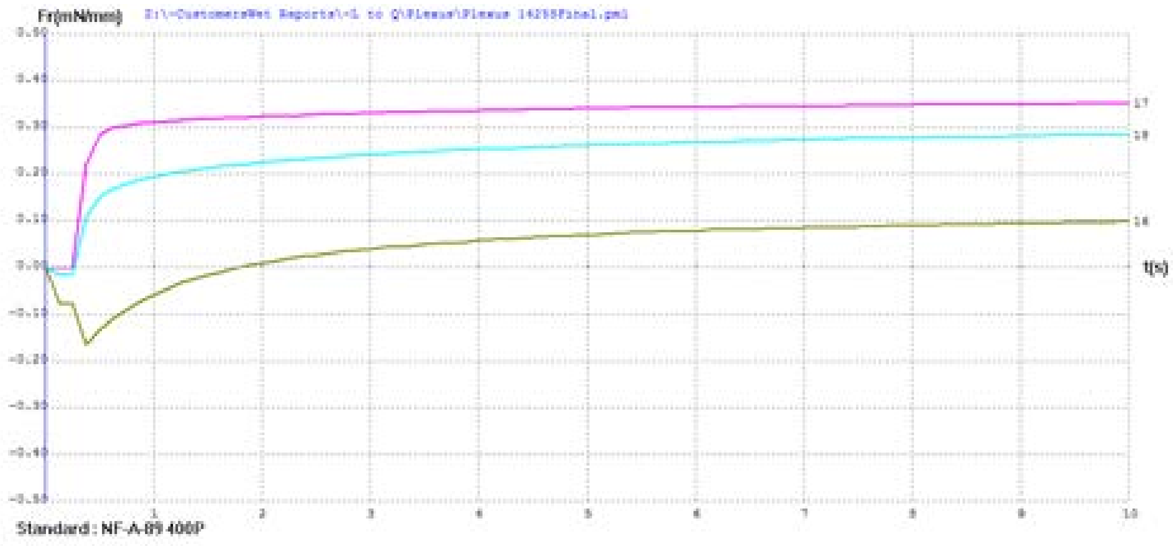
Flux	Type	IPC Class	Solid Content (%)
A	VOC Free	ORL0	5.86
B	VOC	ORL0	4.05
C	VOC	ROL0	7.2
D	VOC	ORL0	6.0
E	VOC Free	ORL0	5.05
F	VOC	ROL0	3.9
G*	VOC Free	ORL0	3.7
H*	VOC	ROL0	5.77

*Added latter on to the test

Wetting Balance



IPC Test Flux #2



Flux B

Measures the rate of wetting. Method is described in TM650 2.4.14.2
Large variation among runs, which was problematic. The average of 3 curves was used to rate the fluxes

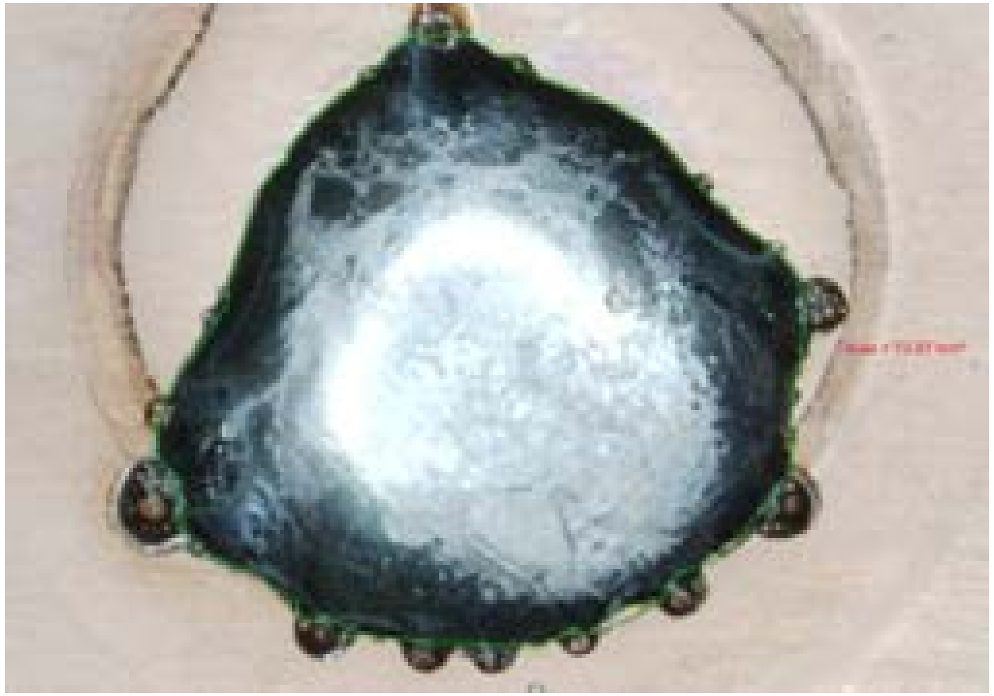
Wetting Balance Results

Flux	Time to Cross Zero (sec)	Force at 5 Sec (mN/mm)	Force at 10 Sec (mN/mm)	Rank
A	0.314	0.3	0.31	6
B	0.293	0.22	0.24	5
C	0.732	0.17	0.2	4
D	2.866	0.03	0.04	3
E	9.491	-0.02	0	2
F	Did not cross	-0.14	-0.12	1
IPC Test Flux #2	0.443	0.16	0.19	N/A

Rapid wetting was observed in flux A and B and poor wetting on flux E and F
The faster the wetting and force the higher the rank.

Optional Testing as per IPC J-STD-004

Spread Testing

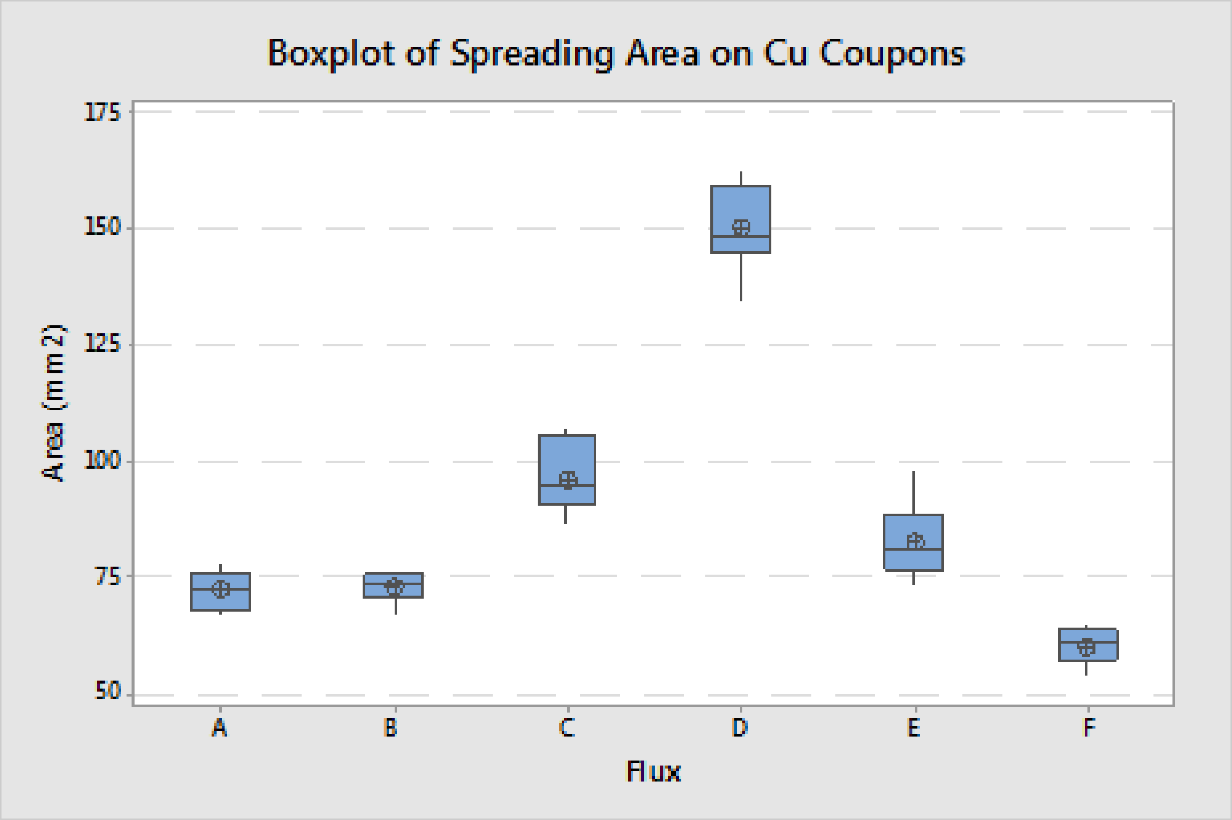


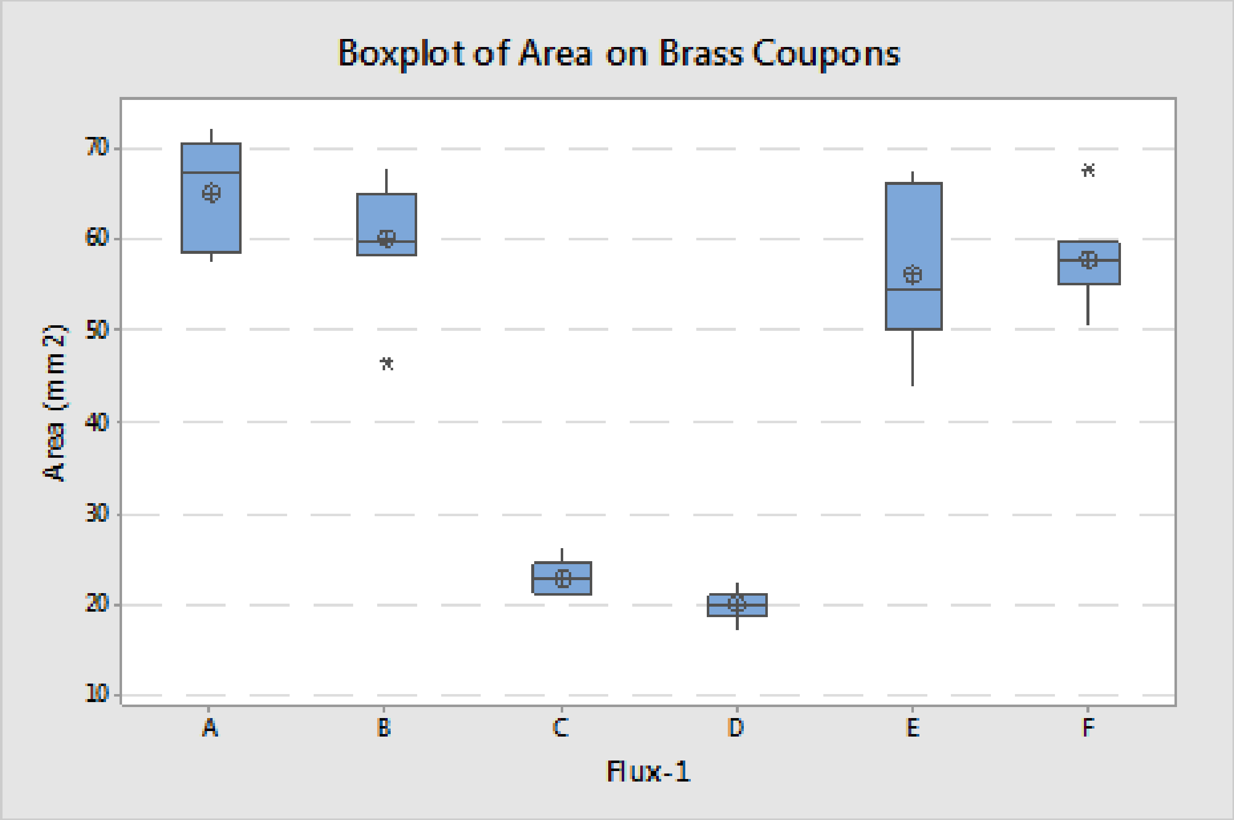
Spread Testing was conducted as per TM650 2.4.46

Copper and Brass coupons were used in the experiment

Optional Testing

Spread Testing





Larger areas were observed in Copper coupons. Flux D had the highest spread followed by flux C. For brass, the best performed were flux A, B, and F

Spread Testing

Visual Inspection showed cases where the surface discolored.

For flux A, the surrounding area turned black/green in every coupon. This flux was eliminated from the testing

Spread Testing

Flux	Average Area on Cu (mm^2)	Visual Inspection	Rank for Cu	Average Area on Brass (mm^2)	Visual Inspection	Rank for Brass
A	72.1	Green/Black	2 (Eliminated)	65.1	No issue	6
B	72.5	No issue	3	60.0	No issue	5
C	95.6	No issue	5	22.9	No issue	2
D	150.1	No issue	6	19.9	No issue	1
E	82.6	No issue	4	56.2	No issue	3
F	60.0	Green	1	57.8	No issue	4

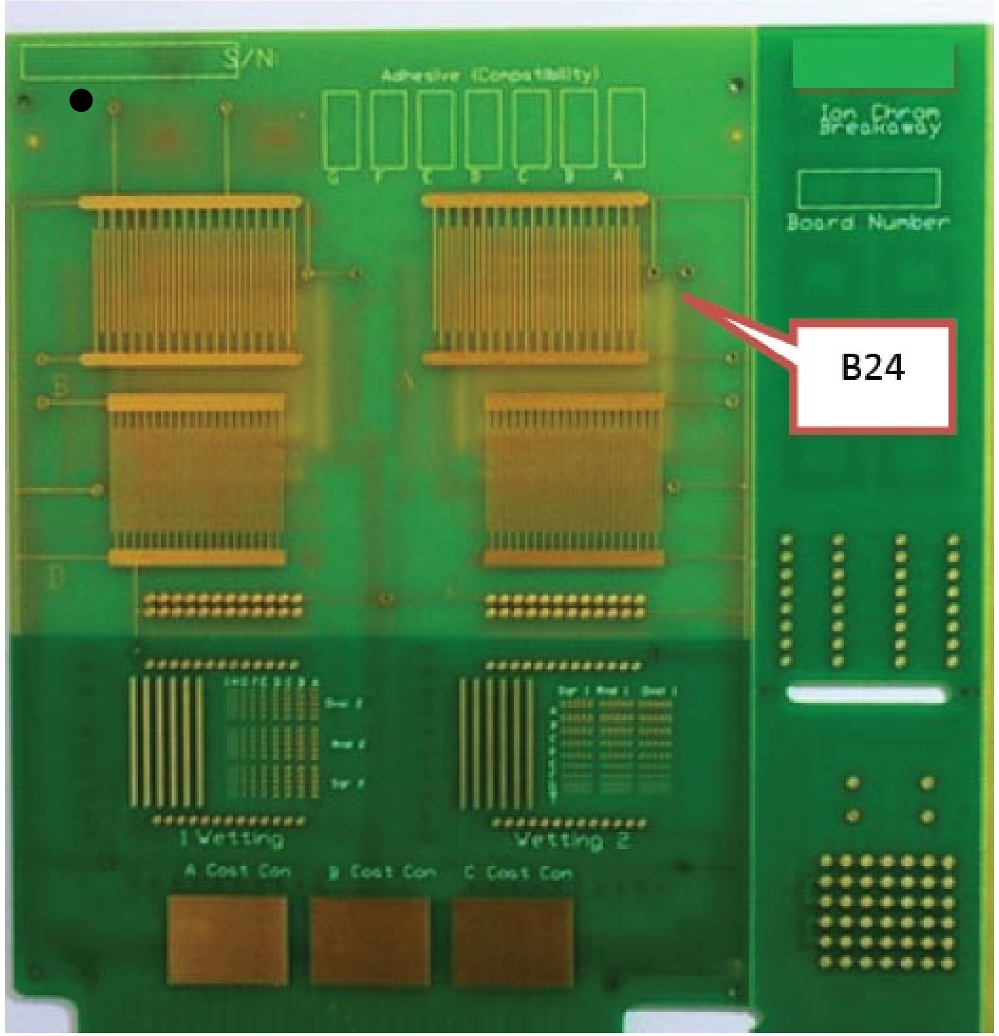
Opposite results were observed in Cu and Brass coupons, which is problematic as the soldering process needs to support a variety of base materials

Summary of Lab Testing

Flux	Wetting Balance	Cu Spread	Brass Spread	Total Points	Comment
A	6	2	6	14	Eliminated due to discoloration
B	5	3	5	13	
C	4	5	2	11	
D	3	6	1	10	
E	2	4	3	9	
F	1	1	4	6	Poorest Lab test soldering flux

Wetting Balance and Spread Testing results did not align.
Wetting Balance focuses on speed of wetting and the ability to wet out vertically whereas Spread testing characterizes the ability of a solder to spread out horizontally. These properties are not necessarily provided by a single activator in the flux. Some flux manufacturers select these better than others.

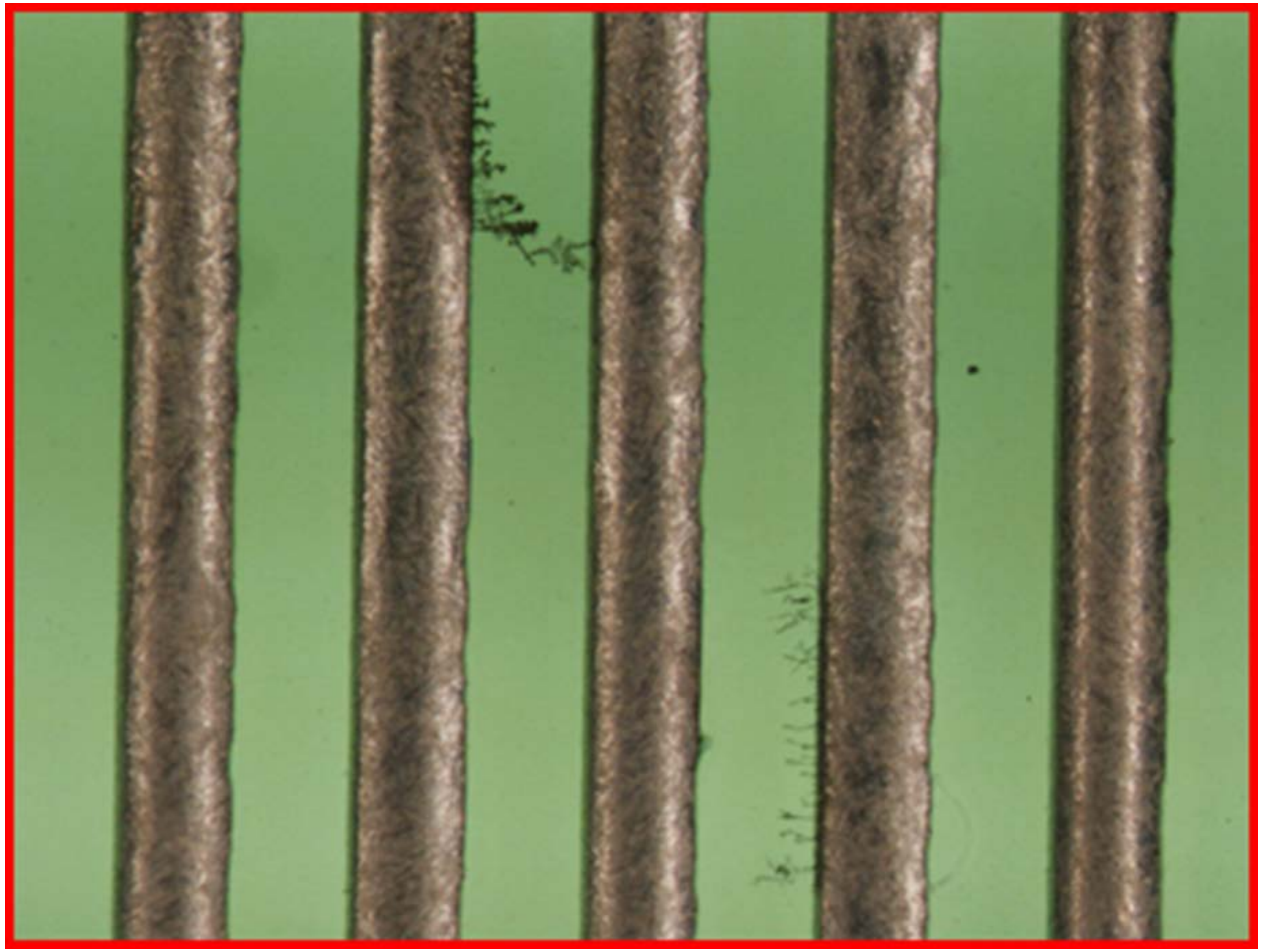
Reliability Testing

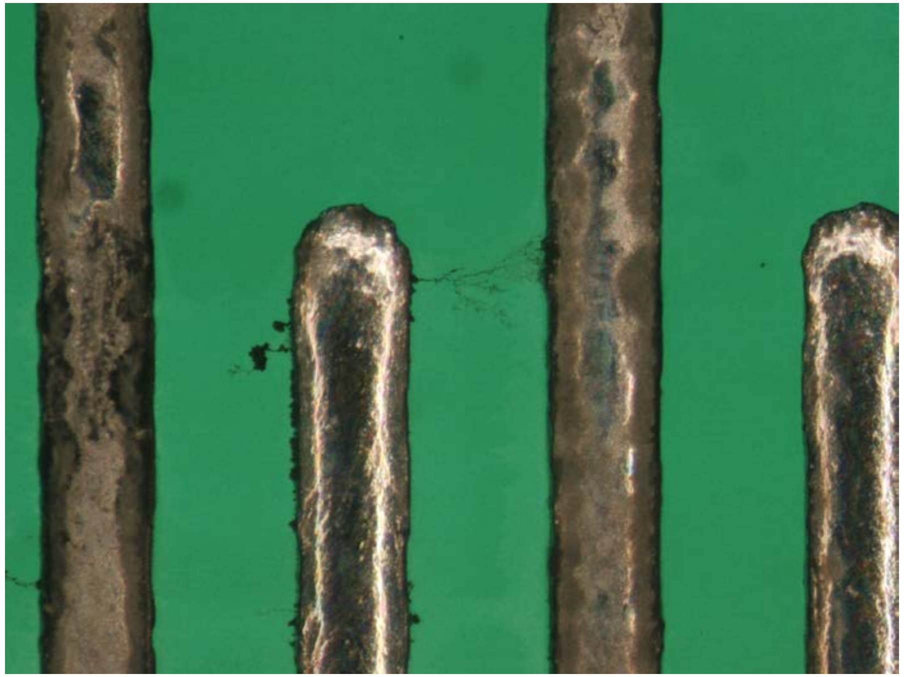


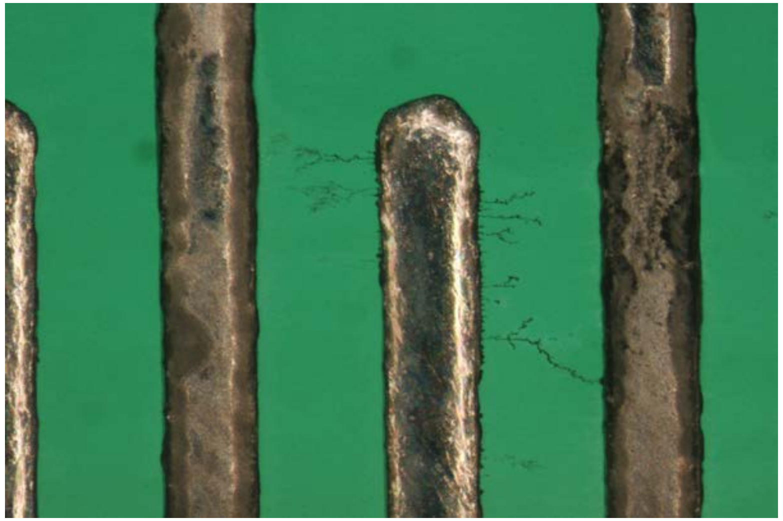
Parameters	Condition Used
Solder Alloy	Sn/Pb & SAC 305
Alloy Temperature	255^{o}C & 265^{o}C
Flux Deposition	1200 microgram/inch^{2}
Topside Preheat	90^{o}C
Dwell Time in solder wave	4 seconds
Use of Wave Pallets	Yes

These parameters represent the lowest preheat temperatures and max amount of flux as per TDS. The max amount of flux was limited to its saturation point

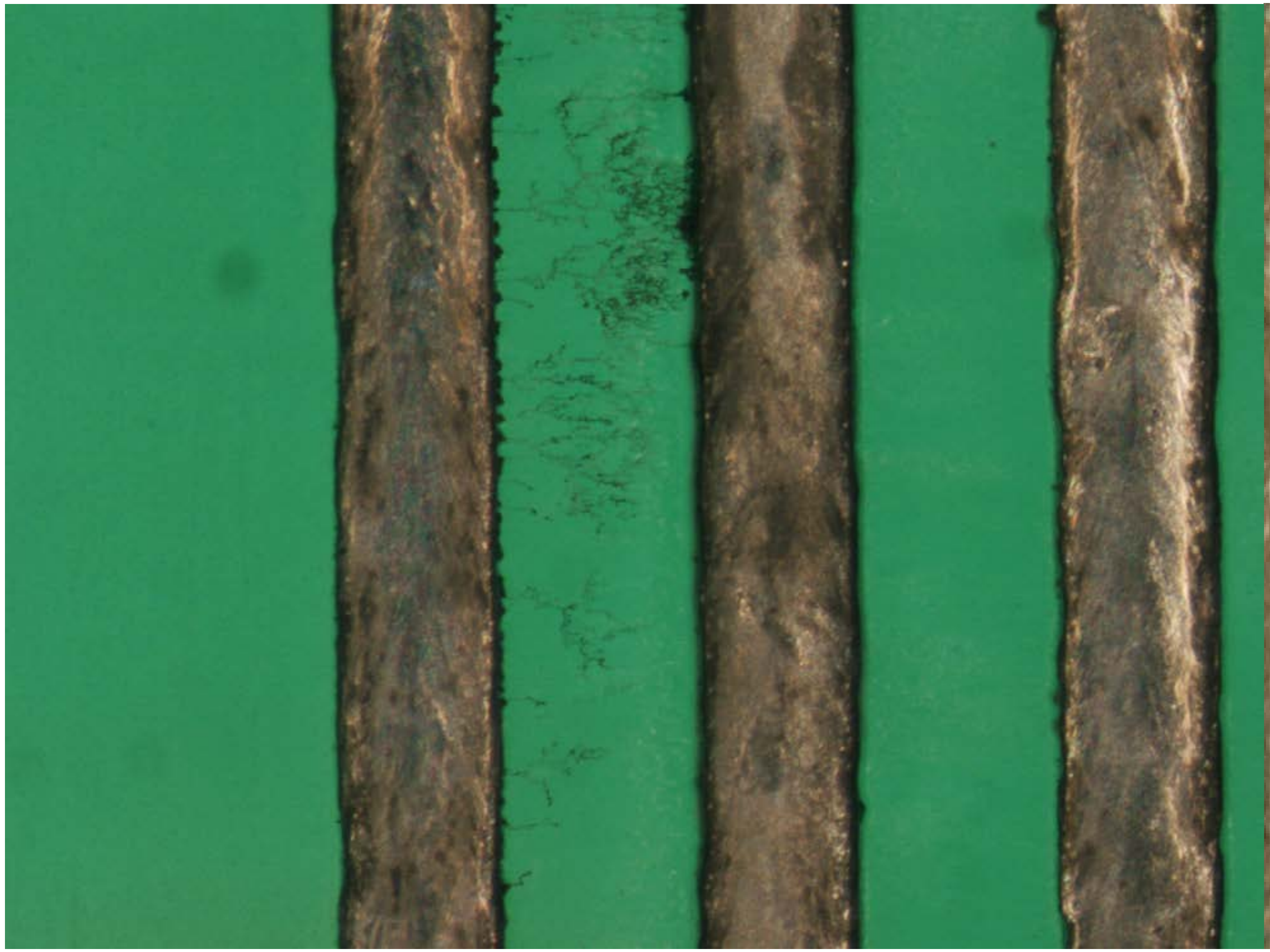
SIR Results







SIR Results



SIR Testing

Flux ID	Solder Alloy	% Patterns Passing Electrically	Dendritic Growth	Evidence of corrosion	Pass/Fail
E	Sn/Pb	15	Yes	None	Fail
D	Sn/Pb	93	Yes	None	Fail
B	Sn/Pb	29	Yes	None	Fail
F	Sn/Pb	100	None	None	Pass
C	Sn/Pb	100	None	None	Pass
E	SAC 305	80	Yes	None	Fail
D	SAC 305	100	None	None	Pass
B	SAC 305	50	Yes	None	Fail
F	SAC 305	100	None	None	Pass
C	SAC 305	75	Yes	None	Fail

Flux F only flux that passed the test. This was troublesome as the laboratory testing ranked Flux F with the lowest score.

Second paper study was conducted and 2 additional fluxes were added to the test.

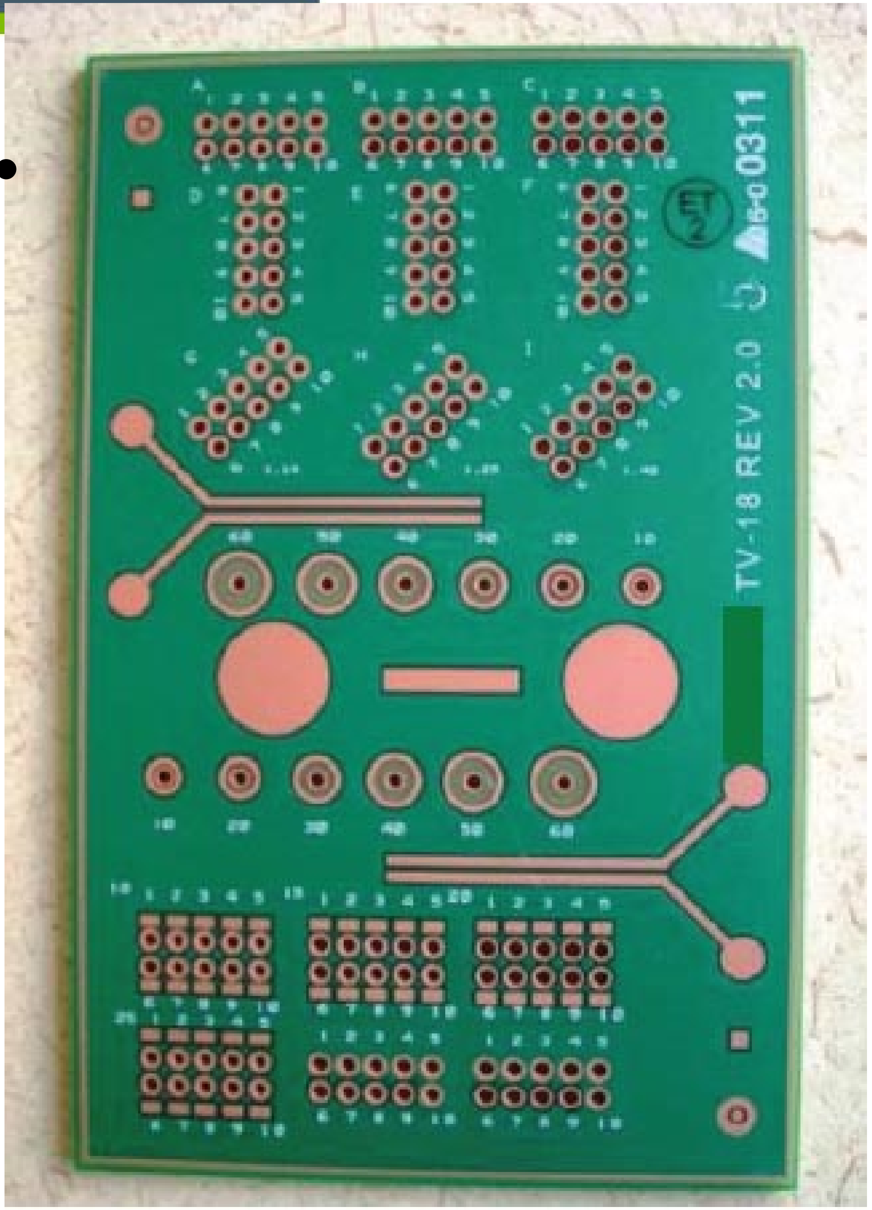
All these fluxes passed SIR as stated from the manufacturer
What is the difference? The method

SIR Testing

Flux ID	Solder Alloy	% Patterns Passing Electrically	Dendritic Growth	Evidence of corrosion	Pass/Fail
H	Sn/Pb	100	None	None	Pass
G	Sn/Pb	0	Yes	None	Fail
H	SAC 305	100	None	None	Pass

Flux H passed the SIR testing. Leaving Flux F and H for further consideration

Solderability Testing



- TV18
- 93 mil thick board
- Cu OSP surface finish
- Diff. Pin to Hole Ratio and Orientation

Solderability Testing

Parameters	Units	Level 1	Level 2	Middle
Flux Amount	µg/in2	700	1200	950
Topside Preheat Temperature	^{o}C	90	145	118
Dwell Time	Sec	4	10	7

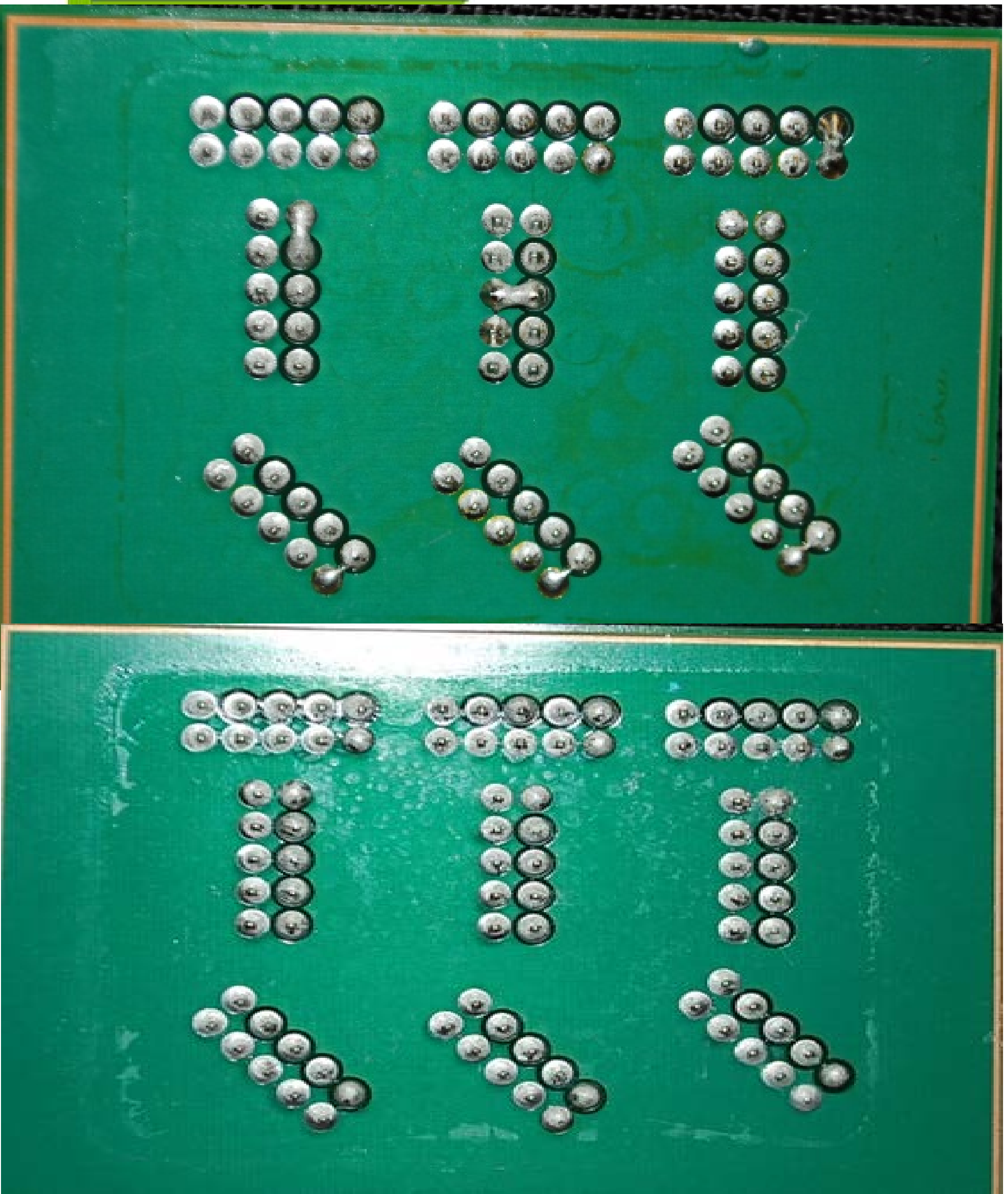
Constant Factors
Pot Temperature = 270C
Solder Alloy = SAC305

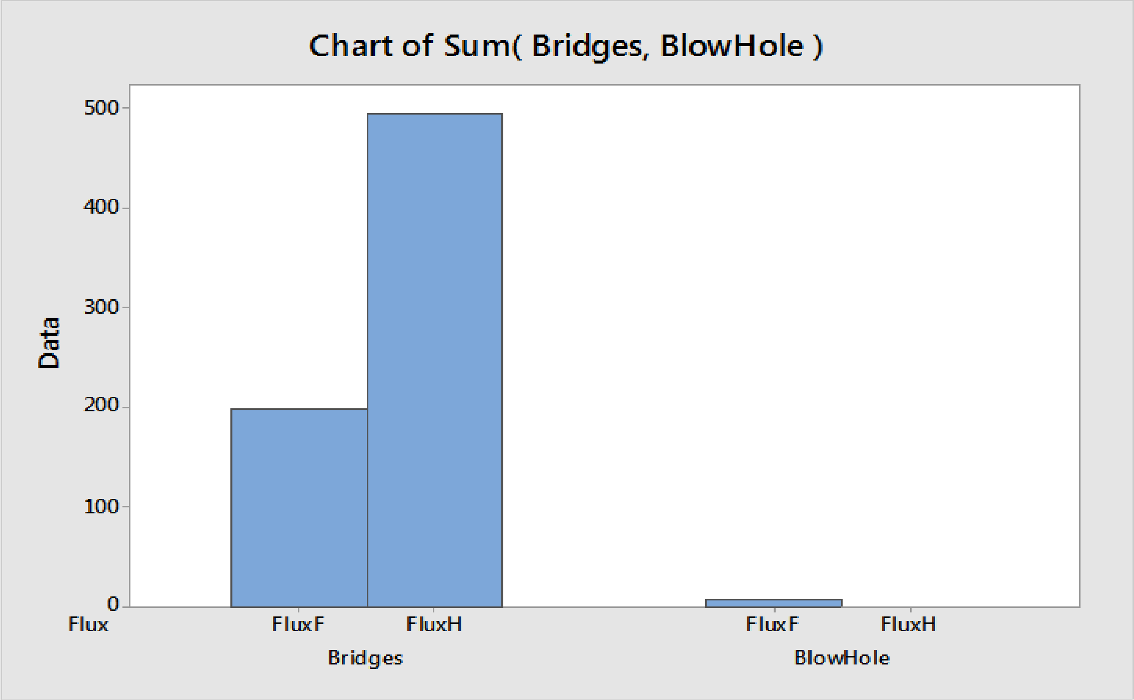
Boards were pre-conditioned = 2 reflow profiles
Wave pallets were used

3 replicates per condition for a total of 27 boards

The DOE represent parameters used for standard and thermally challenging assemblies

Solderability Testing





Visual Inspection: Flux H had significant amount of solder bridging while Flux F had few cases of Blow Holes.

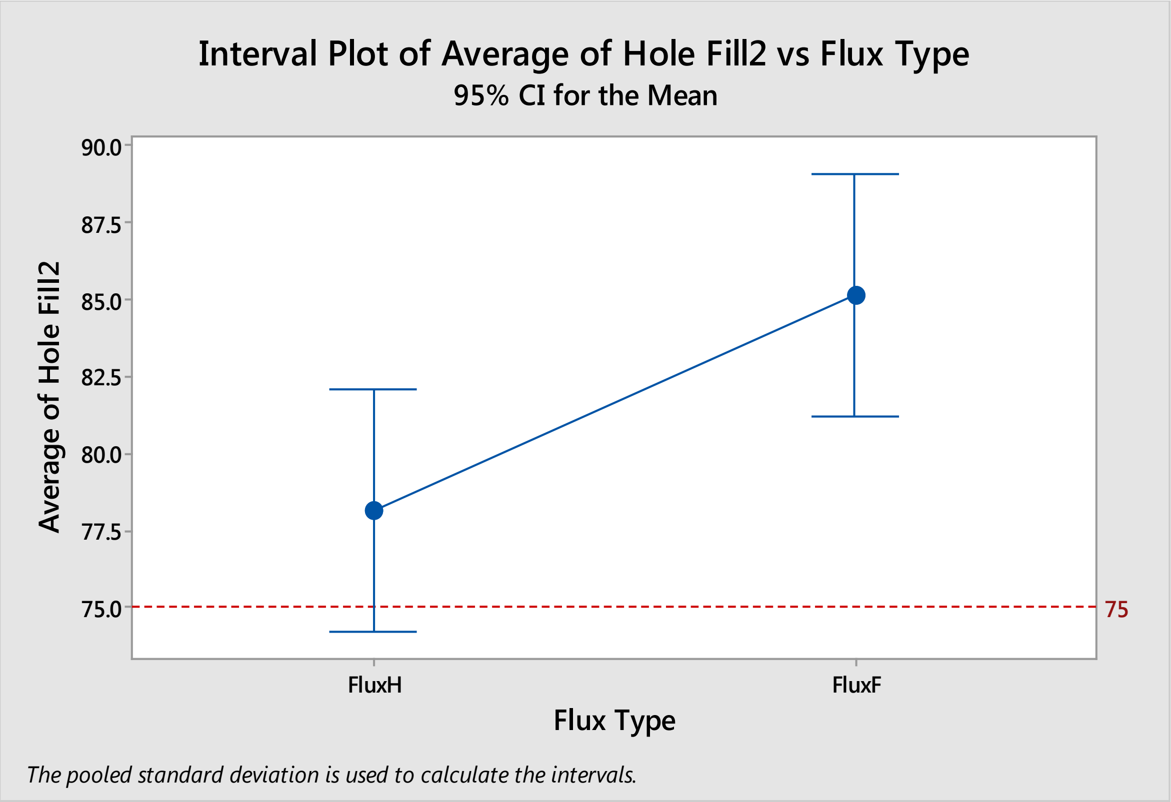
Post-wave residues:

Flux H - large amount of residue, yellow and tacky when warm

Flux F - residue was clear and shiny but not tacky

Solderability Testing

Hole Fill was characterized using X-ray. For each flux the process window was optimized by targeting min. 75% hole fill.



Flux F had 8% more hole fill than flux H. But Flux F had a narrower process window for preheat temperature which is an important factor for thermally challenging boards.

TGA analysis was used to identify the max. preheat temperature

Summary

- The evaluation was successful in identifying a non-clean liquid flux that meets industry reliability requirements and still provides acceptable hole fill.
- Process was long and expensive.
- Next step, evaluation of flux F with other soldering materials. The residue left by other materials in combination with the flux residue can create an adverse effect on reliability.

Call to Industry Action

- Dilemma
  - Flux activity versus residual safety
- Changes to IPC specification on SIR and hole fill requirements have greatly narrowed the flux selection window
- VOC free materials have been eliminated and increase environmental impact
- The industry has operated successfully under previous SIR requirements, which enable VOC-free fluxes for decades with low risk of reliability risk

Call to Industry Action

- The industry gap is that current flux evaluation requirements focus heavily on **reliability**, without any requirement for consideration on **soldering** performance.
- Reliability standards need to focus more heavily on **sample preparation** that **ties to manufacturing processing** conditions. So correlation exists between published results and risk in the field.
- Without these changes the industry will continue to experience costly qualifications and experience field reliability challenges.

Acknowledgements

Chris Smith – Neenah, WI
Jodie Lemoine – Neenah, WI
Thomas Shoaf – Neenah, WI
Zoltan Zsoke – Kelso, UK
Stephen Mainwaring – Kelso, UK
Chee-Kiat Tan – Penang, Malaysia
CW Ooi – Penang, Malaysia
Mark Voss – Neenah, WI
Sue Ziegler – Neenah, WI
Denis Jean – Neenah, WI