

Determining the Reliability of Tacky Fluxes in Varying Soldering Applications

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Abstract

The use of tacky fluxes is common throughout the industry in applications such as ball attach, BGA repair and hand soldering. These applications employ different heating profiles, meaning that the fluxes are required to endure a wide range of time and temperature conditions, while not compromising long-term reliability.

Tacky fluxes are generally made from the same types of materials that comprise standard solder paste products designed for typical SMT applications. Therefore, the processability and reliability of tacky fluxes that are subjected to a standard SMT reflow profile are well understood. However, when the same tacky flux is subjected to a shorter heating cycle, such as a hand soldering application, it is not necessarily known if the flux residues will have the same reliability as expected when subjected to the typical SMT reflow profile. This paper examines the long-term reliability of no-clean tacky fluxes when subjected to a variety of processing conditions.

Introduction

Tacky fluxes, also known as paste fluxes or gel fluxes are commonly used in the electronics assembly industry in a variety of applications. These fluxes generally have a honey-like consistency and can be used for ball attach applications, BGA reballing and hand soldering applications. Although these fluxes have several uses within the electronics assembly industry, their most common usage is to be blended with solder powder in the production of solder paste. For this reason, many tacky flux products are simply fluxes that were originally designed for solder paste products but are not combined with metal powder.

Solder paste technology has changed in many ways over the past 10+ years¹. Table 1 below identifies many of the improvements that have been made in solder paste technology since the early 1990s.

Table 1 – Some Improvements in No-Clean Solder Paste Technology

	1990s	Current
Print Speed Window	0.5 to 2.0 in/sec	0.5 to 8.0 in/sec
Maximum Idle Time	10 to 20 minutes	60 to 120 minutes
Shear Thinning Resistance	Poor to Moderate	Much Improved
Reflow Profile Window	Typically Very Limited	Large Window
Ease of ICT	Causes Non-contact Failures	Very Compatible with ICT Process

These performance improvements have been created by chemical changes to the paste flux formulations. For example, in order to improve the idle time characteristic, the flux solvent chosen must have a slower evaporation rate at room temperature than traditional solder paste solvents. This generally means selecting a solvent with a higher boiling point and lower vapor pressure, resulting in a solder paste product that is far more stable in the printer than prior formulations. While this means that the paste will be improved in terms of stencil life and idle time, it also means that the solder paste must see a specific time-temperature profile in order to drive off all of the solder paste solvent during reflow. Profiles that are too short or too cool may not completely exhaust the flux solvents, leaving a residue that is more fluid than expected. If enough flux solvent remains entrapped within the flux residue, it could leave a residue that is more active than the solvent-free residue that would normally be expected². Furthermore, solder pastes have been modified to improve in-circuit testing yields, resulting in softer post-soldering flux residues. This can increase the ionic mobility and correspondingly result in poorer reliability behavior if the solder paste is not properly formulated.

With the modernization of flux chemistries to improve solder paste printing characteristics; this has also affected the accompanying tacky flux products in the same way. Flux solvents have higher boiling points and lower evaporation rates to improve printing consistency and stencil life in ball attach processes.

Since tacky fluxes are, in the most general sense, solder pastes without the metal, they are truly designed to be used in an environment with a time-temperature profile that is similar to those used for solder paste reflow. However, since tacky fluxes are used in applications that do not employ full reflow processing, the reliability properties of these fluxes are less understood. Hand soldering processes may result in a situation where the flux is over-applied and under-heated such that the reliability is far different than a full

reflow process. The purpose of this paper is to examine the reliability characteristics of tacky fluxes that have been processed in a variety of methods.

Methodology

Two no-clean tacky fluxes were selected for this experiment. Both were applied to IPC B-25 coupons via four methods in order to simulate typical applications for tacky fluxes that are common in industry. The simulated processes are characterized as follows:

- Standard reflow process
- BGA repair process
- Unheated
- Hand soldering process

For the standard reflow process, BGA repair process and unheated process, the tacky fluxes were stenciled onto IPC B-25 coupons with 2-mil thick stencils. After stenciling, the boards were subjected to various time-temperature profiles to simulate the various heating processes where tacky fluxes may be used in a production environment. The standard reflow profile was meant to simulate a lead-free process on the upper edge of the reflow profile window. The profile is shown in Figure 1:



Figure 1 -- Lead-free reflow profile

The BGA repair process had a peak temperature of 245 °C, was above liquidus for 45 seconds and the heating time was 2.8 minutes. This is a substantially shorter and cooler process than the reflow process described in Figure 1.

For the unheated simulation, the tacky flux was stenciled onto the coupons with a 2-mil stencil and stored at room temperature until the coupons were placed in the test chamber. The unheated condition was included in this experiment to simulate the worst-case scenario regarding the usage of tacky fluxes in a production environment. It is possible that tacky fluxes used in hand soldering applications could be over-applied in areas where the board does not see any heat. This would typically occur during a hand soldering process where too much flux is applied to a wide area but the soldering operation is performed at a single point. In such a condition, the residue near the solder joint would have seen a quick hand soldering profile while tacky flux that was applied further from the joint may not see any heat. In such cases, the solvent system, which has been designed to remain stable at room temperature, will not be completely evaporated during the soldering process.

The hand soldering process condition was simulated by hand dispensing the tacky flux onto the IPC B-25 test coupon in six locations and soldering with a soldering iron at 700 °F. Care was taken to dispense the tacky flux onto a very small area and to fully heat the entire area of dispensed flux.

Table 2 summarizes the differences in the four process conditions from a time and temperature standpoint.

Table 2 – Comparison of Time and Temperature Relationships Across All Processes

	Total Heating Time	Peak Temperature	Time above Liquidus
Reflow Process	330 seconds	260 °C	75 seconds
BGA Repair Process	165 seconds	245 °C	45 seconds
Hand Soldering Process	6 seconds	240 °C (approx.)	4 seconds
Unheated	None	Room Temperature	None

The testing was completed on three types of board finishes (Copper, Immersion Silver and Immersion Tin). Blank control coupons were included of each board finish type.

All of the test boards were subjected to an electrochemical migration test that applies a five-volt continuous bias over a 21-day period. The polarity of the bias was not reversed during the test. The test conditions were held at 50 °C and 90% RH throughout the duration of the test. Resistance measurements were taken at 10-minute intervals. The test method is identical to a Hewlett Packard test method³ for Electrochemical Migration (ECM) except that this experiment was conducted over 21 days instead of 28 days.

This type of electromigration test is considered to be a strenuous test from a flux reliability standpoint. Compared to standard IPC surface insulation resistance testing, this test method is more strenuous from a pass/fail standpoint. The longer duration, lower voltage and more frequent resistance measurement employed in this experiment all contribute to a higher likelihood of inducing dendritic failure than standard IPC surface insulation testing.

The requirements to pass this test are as follows:

- All control readings must be above 1000 Megaohms
- All specimen samples must stabilize above 100 Megaohms and within two decades of the control coupons
- Readings for specimen samples may be below 100 Megaohms (but above 1 Megaohm) during the first 96 hours provided that it recovers to above 100 Megaohms by the 96th hour (576th reading)
- After stabilization, the resistance values must not degrade by more than one decade throughout the duration of the test

Data

Across all three board finishes and both tacky fluxes, the typical resistance readings were significantly different for the various heating methods. Table 3 demonstrates the increase in resistance values with increased heat processing of Flux A. The table includes the average of all resistance values after the 96th hour.

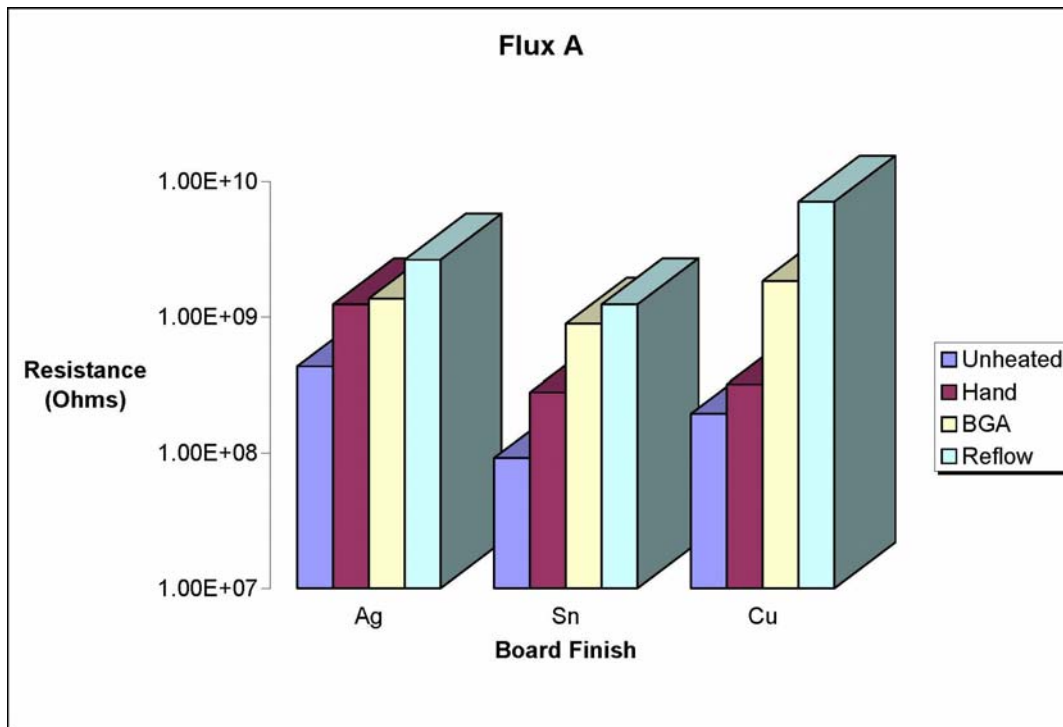


Figure 2 – Average Resistance Readings for Flux A Across All Board Finishes and Heating Conditions

Although taking averages of resistance values is not necessarily the best approach to evaluating pure reliability properties (because dendritic failures could be lost in the averaging process), Table 2 does demonstrate that longer heating processes of tacky fluxes will increase resistance values. Flux B demonstrated a similar pattern of increased resistance values with additional heating across all board finishes. Tables 4 through 7 show the readings over the entire 21 day period for the group of Tin finish boards for Flux A.

Flux A, Tin, Unheated

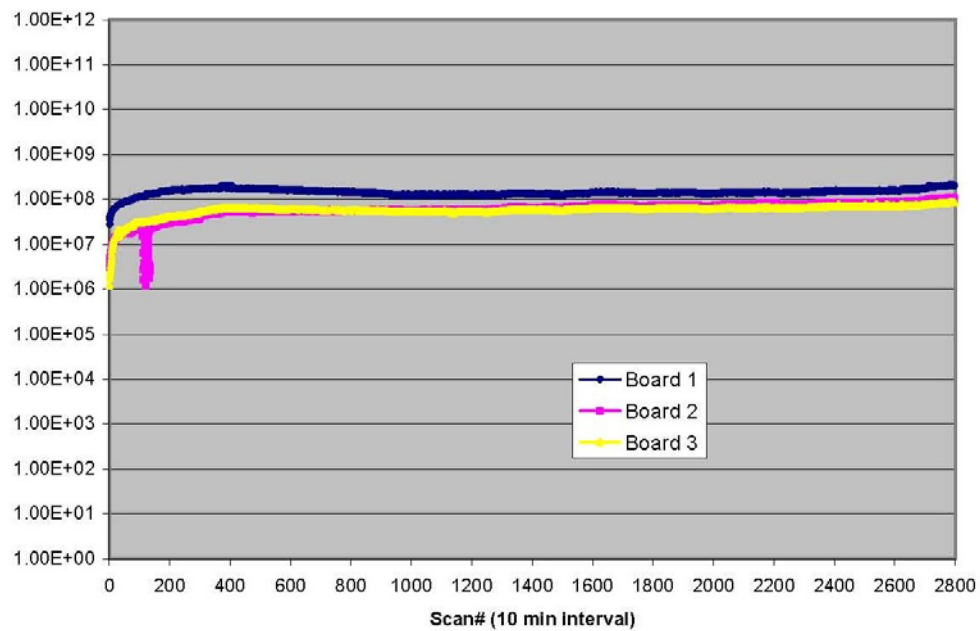


Figure 3 – Resistance data for Flux A on Tin coupons with unheated condition

As evidenced in Table 4, the readings for all three unheated coupons start below $1 \text{ E}+08$ and increase over the first few hundred readings before leveling off. Although one of the coupons reached and stayed above $1 \text{ E}+08$ prior to reaching 96 hours, the other two coupons never reached $1 \text{ E}+08$ until near the end of the 21-day run.

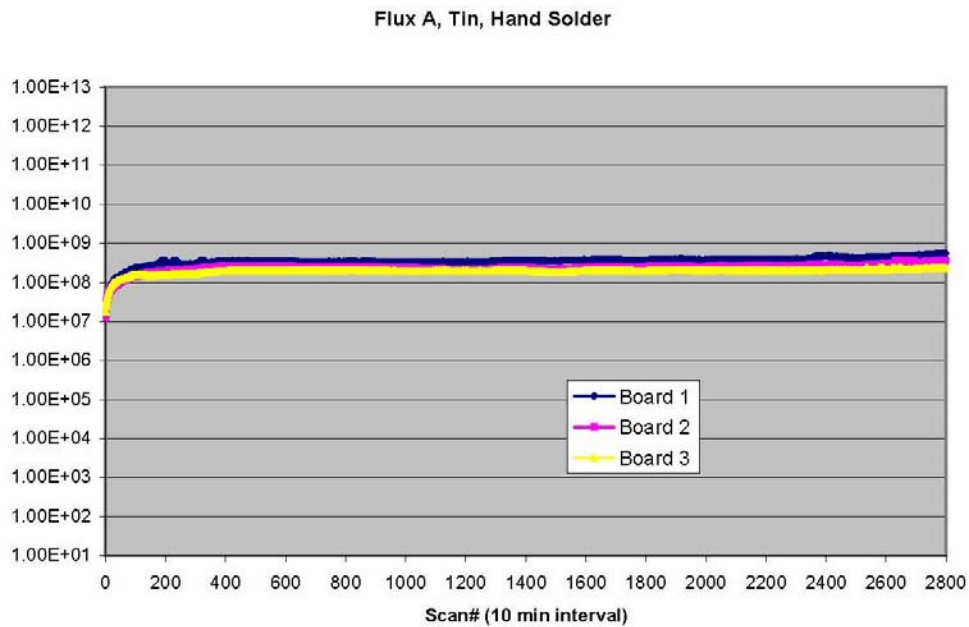


Figure 4 – Resistance data for Flux A on Tin coupons with Hand Soldered condition

The initial readings in the hand soldered condition also started below but recovered much sooner (<100 readings) and all three coupons leveled off above $1 \text{ E}+08$ for the duration of the test.

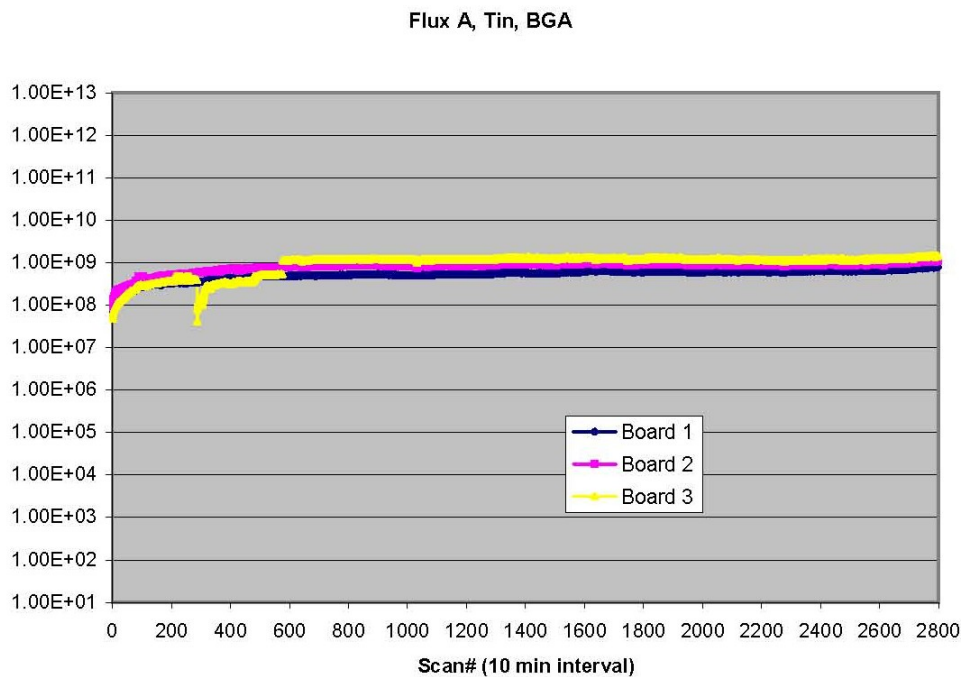


Figure 5 – Resistance data for Flux A on Tin coupons with BGA Reballing condition

The coupons processed with the BGA heating process started at approximately $1.0 \text{ E}+08$ and rose by one decade within the first 96 hours. After 96 hours, the resistance readings remained very stable for the duration of the test. The reduction in the resistance reading for Board 3 between 200 and 400 readings would indicate that something occurred on the boards to promote conductivity. These

types of quick reductions with slow recovery are often indicative of a small water droplet that condensed on the test pattern that dried off during the next several hours. No dendritic growth was observed on the Board 3 after the test was completed.

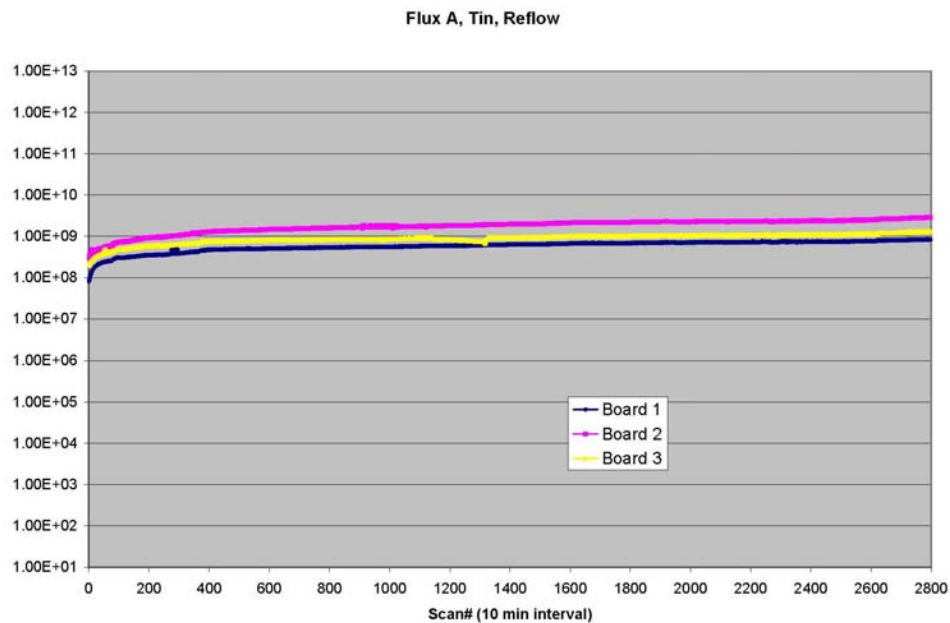


Figure 6 – Resistance data for Flux A on Tin coupons with Reflow condition

The reflowed coupons were the only grouping to have initial readings that exceeded $1.0 \text{ E}+08$. All readings from this group quickly increased by one decade and remained near $1.0 \text{ E}+09$ for the duration of the test.

Other combinations of flux and board finish showed a similar pattern in the data. The most significant difference in resistance values across the experiment was the heating conditions employed. There was some difference in resistance values as board finish was changed (see Table 2 above) but this was not nearly as significant as the simulated heating process. The differences between the two no-clean flux types were insignificant.

Discussion

The data indicates that the resistance readings decline with reductions in time and temperature processing conditions. Full reflow conditions provided the highest resistance readings; followed by BGA reballing, hand soldering and unheated conditions. Despite having the lowest resistance values, the unheated fluxes leveled off at resistance values that were just below the $1.0 \text{ E}+08$ requirement, so the failures were not of the catastrophic variety.

There was no evidence of dendritic growth across the entire experiment. Prior testing of other fluxes has evidenced dendritic growth in the unheated state. Remnants of dendrites formed during this testing can be found from visual analysis performed after the testing is completed. Additionally, this particular test procedure often shows evidence of dendrites via quick declines in the resistance value when the dendrite is formed and a quick increase when the dendrite breaks. Table 8 demonstrates an example of another flux that has evidenced dendritic failure during the test.

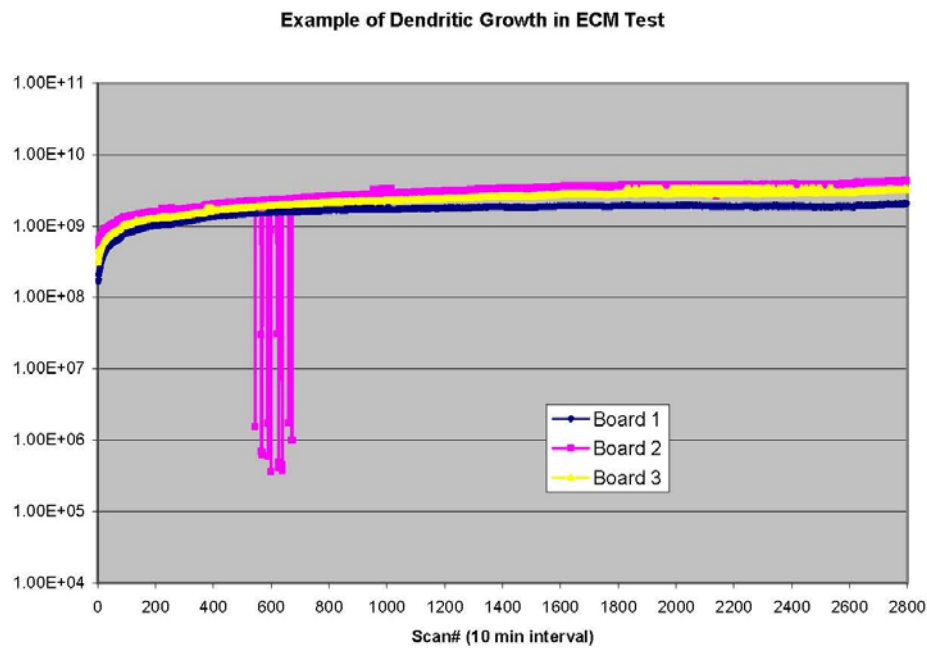


Figure 7 – Example of Dendritic Growth on Board 2

Board #2 in Table 8 shows the type of rapid drop and rise that would be consistent with dendrite formation and the subsequent burning up of the dendrite as it makes contact with another conductor. This type of dendritic failure behavior was not evidenced in any of the testing that was conducted as part of this experiment.

Both fluxes and all of the heating variations produced similar types of curves, all of which tended to increase approximately one decade during the first 200 – 600 readings (33 – 100 hours) of the testing. The increases in resistance in this part of the curve are largely derived from the solvents in the flux residues evaporating over time. Once the solvent loss reaches a steady state, the resistance values generally level off for the duration of the test.

The differences in steady-state resistance levels between various heating methods can be primarily attributed to the degree to which the activators in the tacky fluxes are reacted during the initial heating cycle. This explains why additional time and temperature during the heat process generates higher resistance values for both types of tacky fluxes.

Conclusions

The reliability behavior of no-clean tacky fluxes varies with the processing time and temperature. Standard reflow conditions result in a post-soldering residue that is benign and should be considered reliable. Typical BGA repair conditions also yield a reliable residue. Both of these processes provide enough time and temperature to the tacky flux to exhaust the flux solvents and also deplete the activity sufficiently such that excellent reliability results should be expected.

The hand soldering of tacky fluxes produces suspicious reliability results and these potential reliability issues should be considered prior to implementing a no-clean tacky flux for repair purposes. Although the test data for the hand soldering condition passed the ECM test, the results were extremely close to the pass/fail criteria. The resistance values for the hand soldering process were much lower at the onset of the test, indicating a short period of time where the flux residues still contained a great deal of unreacted activator and entrapped flux solvent. With time in the ECM test chamber, at 50 °C, the solvent started to evaporate and the resistance values climbed over the first 100 hours. However, if this is translated into a real production environment, hand soldering is often performed on areas of circuit boards that are not particularly well vented; such a scenario would entrap the flux solvents within the residue and maintain a higher level of conductivity over a longer period of time⁴. The use of tacky fluxes in hand soldering should be adopted only in well-vented areas of the board and performed by operators that understand the need to completely heat the flux in order to completely drive off flux solvents.

The reason that it is so critical to carefully implement tacky fluxes in a rework environment is represented by the results for the unheated condition in this experiment. The over-application and under-heating of tacky fluxes can result in portions of dispensed tacky flux that see little if any heat. The two no-clean tacky fluxes studied in this experiment failed to reach 1.0 E+08 ohms for the duration of the testing, indicating that such a situation could result in current leakage or even potentially dendritic growth in the long term. Although dendritic growth was not observed in this study, this does not mean that it wouldn't occur with other flux types, other

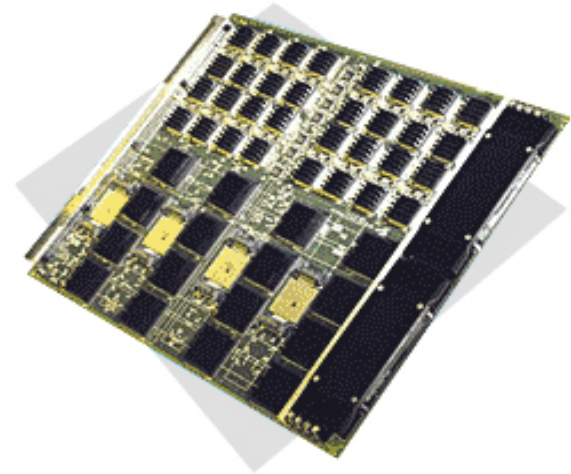
board finishes or on particular component finishes. For this reason, it is advised to fully ascertain the reliability of any no-clean tacky flux product before implementing it into a repair operation. The reliability testing should simulate the worst-case condition of repair fluxes, which would correspond to the unheated condition in this experiment. If a no-clean tacky flux is chosen for a repair process, operators should be carefully trained to be certain that the flux is fully heated during the repair process.

References

1. Smith, Brian "Recent Developments in No-Clean Solder Paste", SMT Magazine, November 1999
2. Watson, Bryce *et al* "Soldering Fluxes and the Repair Process", APEX Conference, March 2003
3. Holder, Helen *et al*, "HP Flux Electrochemical Migration (ECM) Test Method" (HP Document #EL-EN861-00) February 2006
4. Watson, Bryce *et al* "Soldering Fluxes and the Repair Process", APEX Conference, March 2003

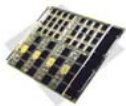
Determining the Reliability of Tacky Fluxes in Varying Soldering Applications

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APEX / February 2006



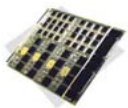
Background

- Tacky fluxes are solder paste without the metal powder
- Also known as:
 - Gel fluxes
 - Paste fluxes
- Commonly used for:
 - BGA ball attach processes
 - Flip chip attach processes
 - Hand soldering processes



Chemistry Changes

- Solder paste changes:
 - Longer stencil life
 - Longer tack time
 - Faster print speed
 - Softer post-soldering residue
 - Idle time

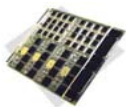


Chemistry Changes

Many of these solder paste performance improvements are related to solvent choice

- Boiling point
- Vapor pressure

The goal is to use a solvent that does not dry out quickly such that idle time, stencil life & tack time are all improved



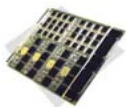
Tacky Flux Reliability

Given that solder pastes and tacky fluxes share the same chemistry, tacky fluxes are known to be reliable when subjected to a time-temperature profile that is similar to a typical reflow process.

But what about BGA reballing processes?

Or hand soldering processes?

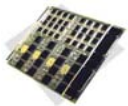
Many users assume that “no-clean” means that it can be used in any application without reliability consequences, but is this true?



Problem Statement

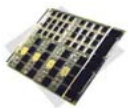
Tacky fluxes are used in a variety of soldering applications, but reliability information is usually only well-known for full reflow processes.

Users are employing tacky fluxes without being certain of reliability behavior given the heating process.



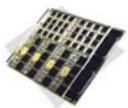
Goal

Determine the reliability behavior for no-clean fluxes when subjected to a variety of simulated processing conditions.



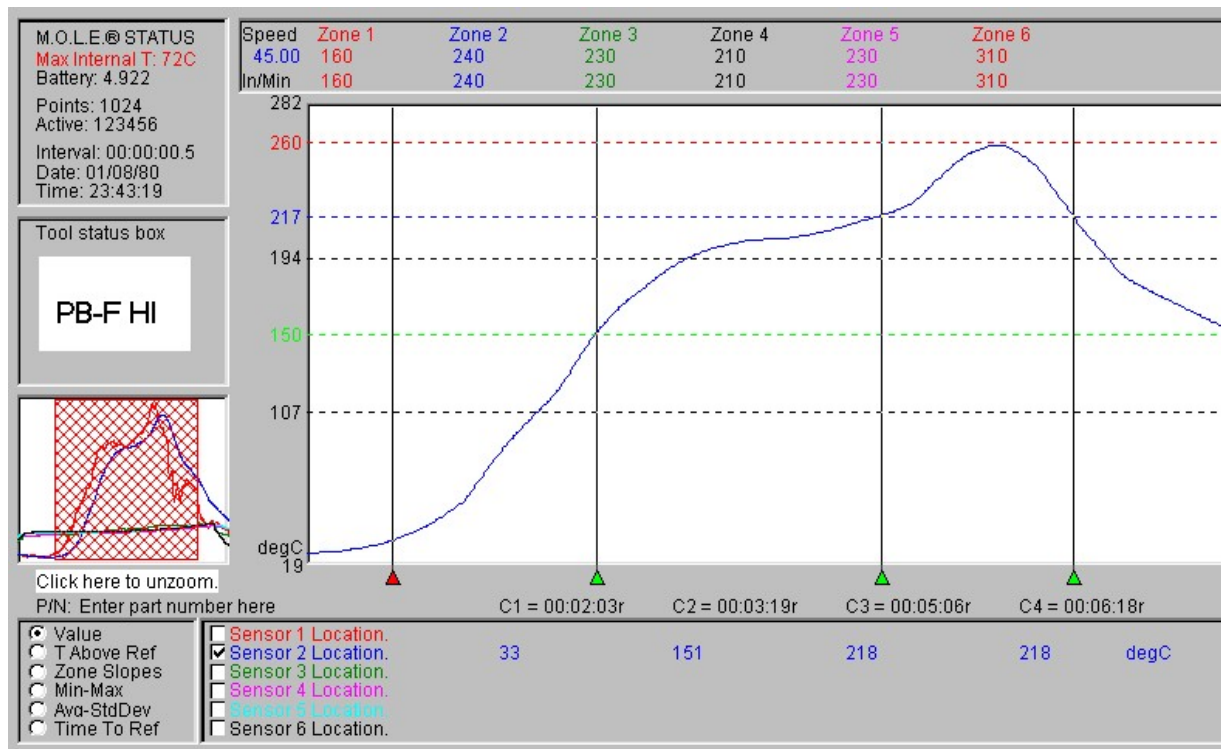
Experimental Design

- Two no-clean tacky fluxes
- Three board finishes (ENIG, Tin, Silver)
- Four simulated heating processes:
 - Full reflow
 - BGA reballing
 - Hand soldering
 - Unheated



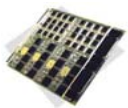
Sample Preparation

- Full reflow:
 - Apply 2 mils of tacky flux through a stencil onto an IPC B-25 coupon
 - Pass coupon through lead-free reflow profile:



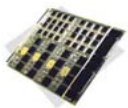
Sample Preparation

- BGA Repair:
 - Apply 2 mils of tacky flux through a stencil onto an IPC B-25 coupon
 - Heat coupon using a Weller hot air rework station
 - 2.8 minutes of heating time
 - Peak temperature of 245 C
 - 45 seconds above liquidus



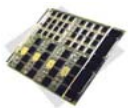
Sample Preparation

- Hand Soldering:
 - Apply a minimal quantity of tacky flux to 6 sites on each pattern on the IPC B-25 coupon.
 - Touch each of the 6 sites with a soldering iron set at 700 F
 - Total contact time: 8 seconds
 - Time above liquidus: 4 seconds
 - Peak temperature: 240 C (estimated)



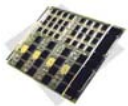
Sample Preparation

- Unheated:
 - Apply 2 mils of tacky flux through a stencil onto an IPC B-25 coupon
 - Hold at room temperature until the coupon is ready for temperature and humidity conditioning



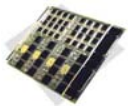
Test Method

- 50 C / 90% RH
- 5 volt bias (not reversed during the test)
- Resistance measured every 10 minutes for 21 days
- This is similar to the HP Electrochemical Migration test procedure
- Far more likely to produce failure than standard IPC SIR testing

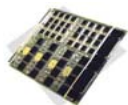
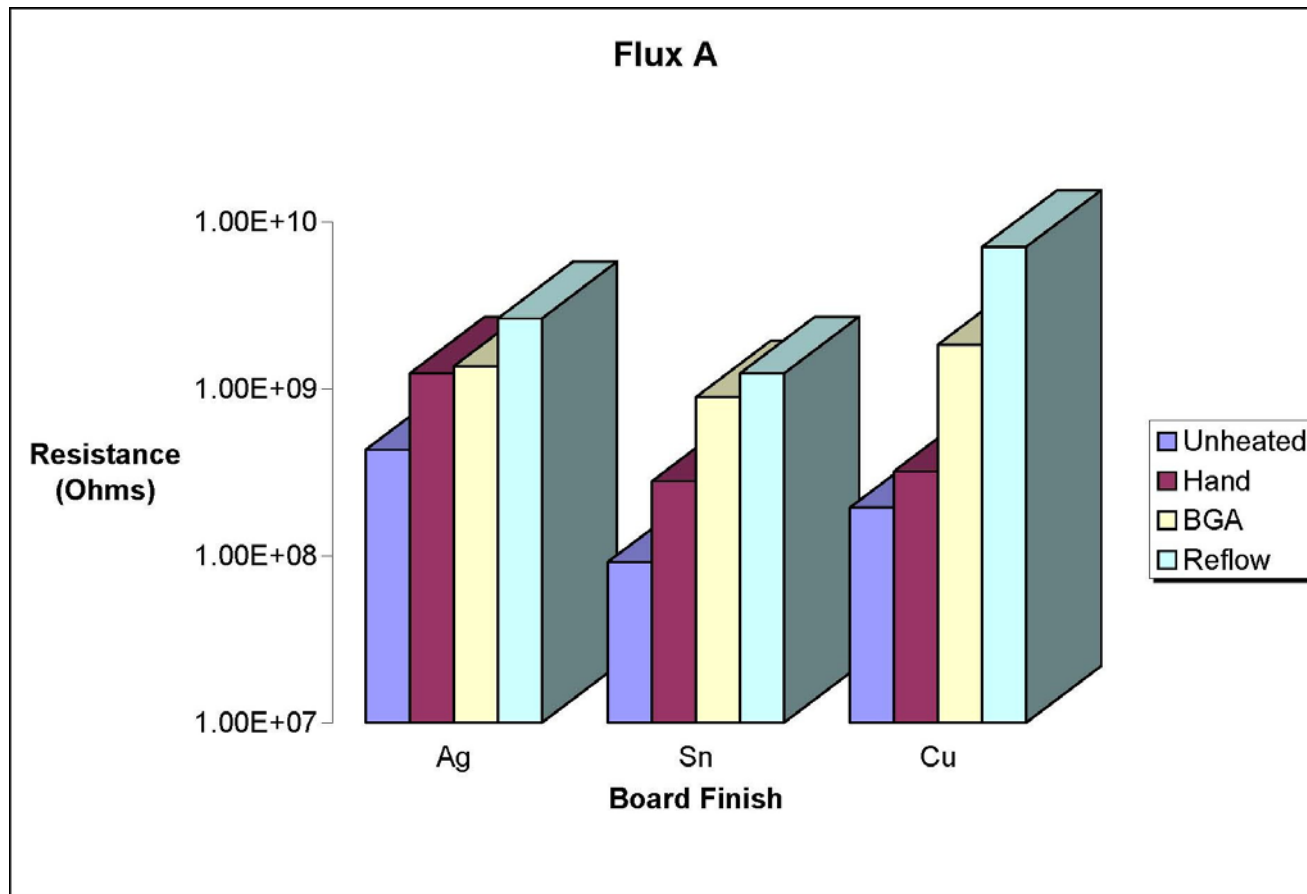


Test Pass/Fail Criteria

- All readings during first 4 days must be $> 1.0 \text{ E}+06$
- All readings during days 5 - 21 must be $> 1.0 \text{ E}+08$ and within 2 decades of control coupons
- Once stabilized, no reading may drop by a full decade during the duration of the test



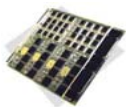
Data Overview



Includes all reading after 96 hours for Flux A

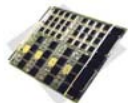
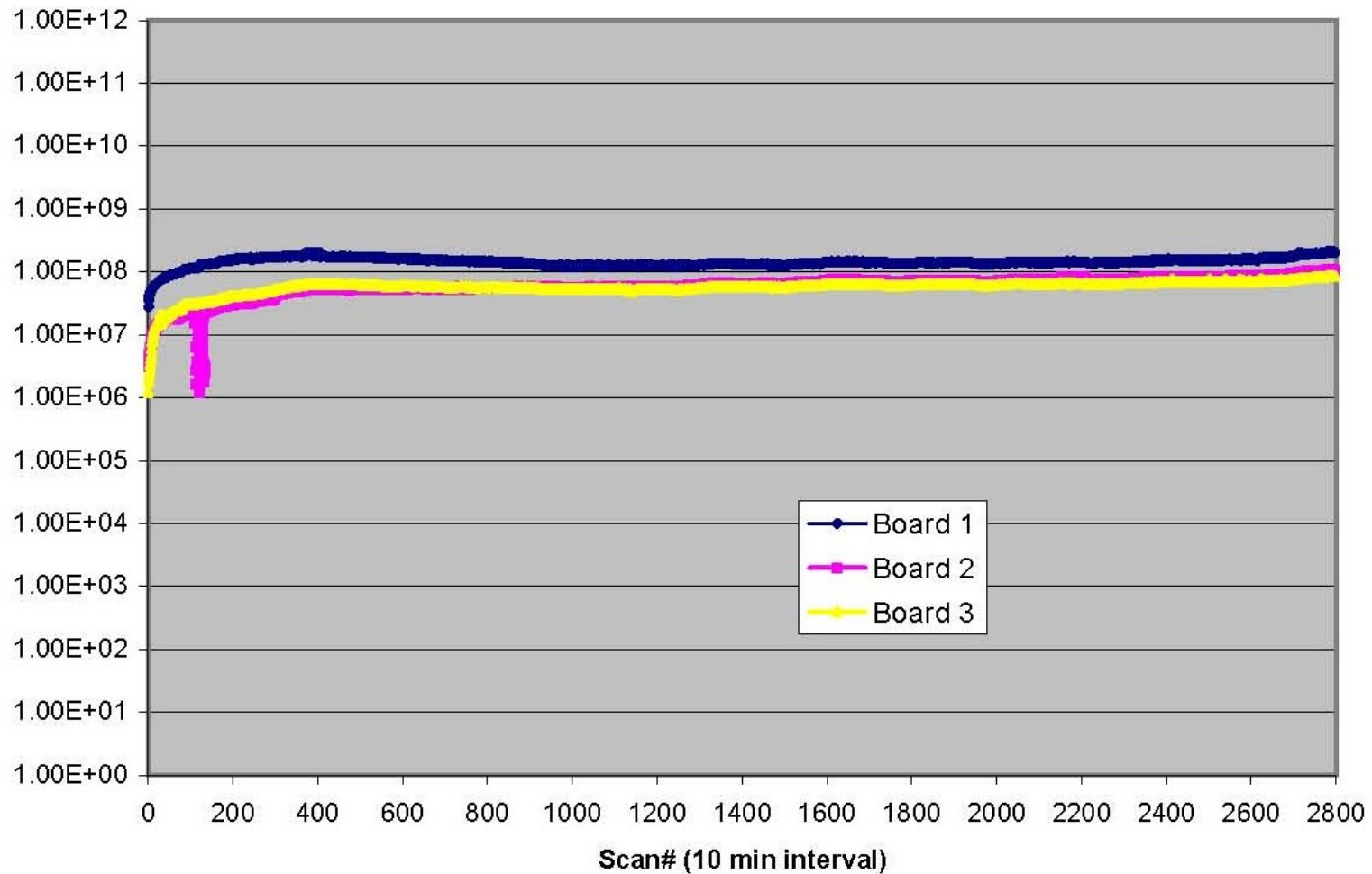
Data Overview

- Across both fluxes and all three board surfaces, resistance values increased with greater time and temperature in the heating process
- Resistance values:
 - Full reflow > BGA Repair > Hand Soldering > Unheated
 - Unheated processing resulted in some combinations that failed the pass/fail criteria



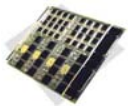
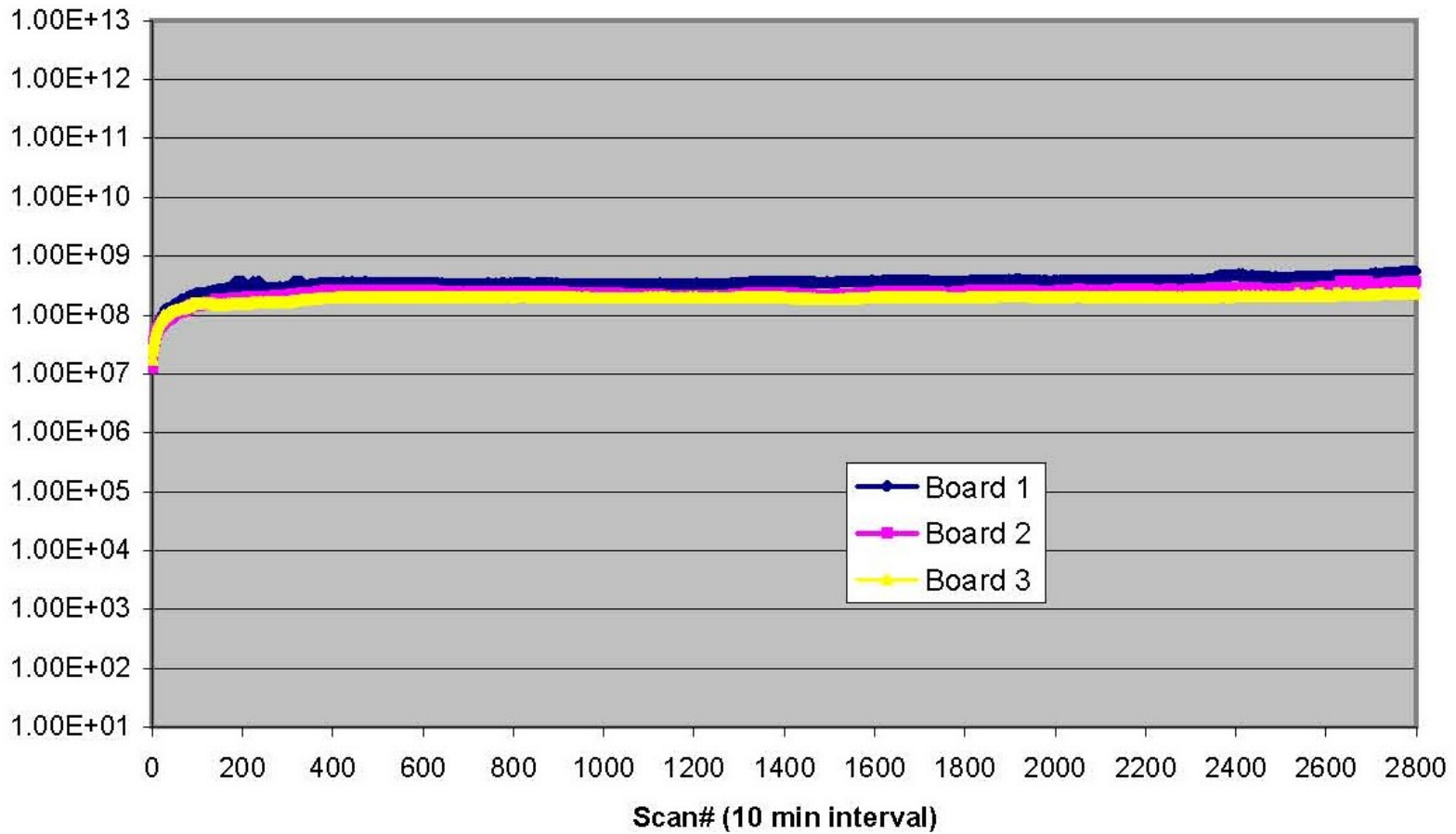
Sample Data Table (Unheated)

Flux A, Tin, Unheated



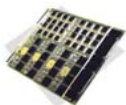
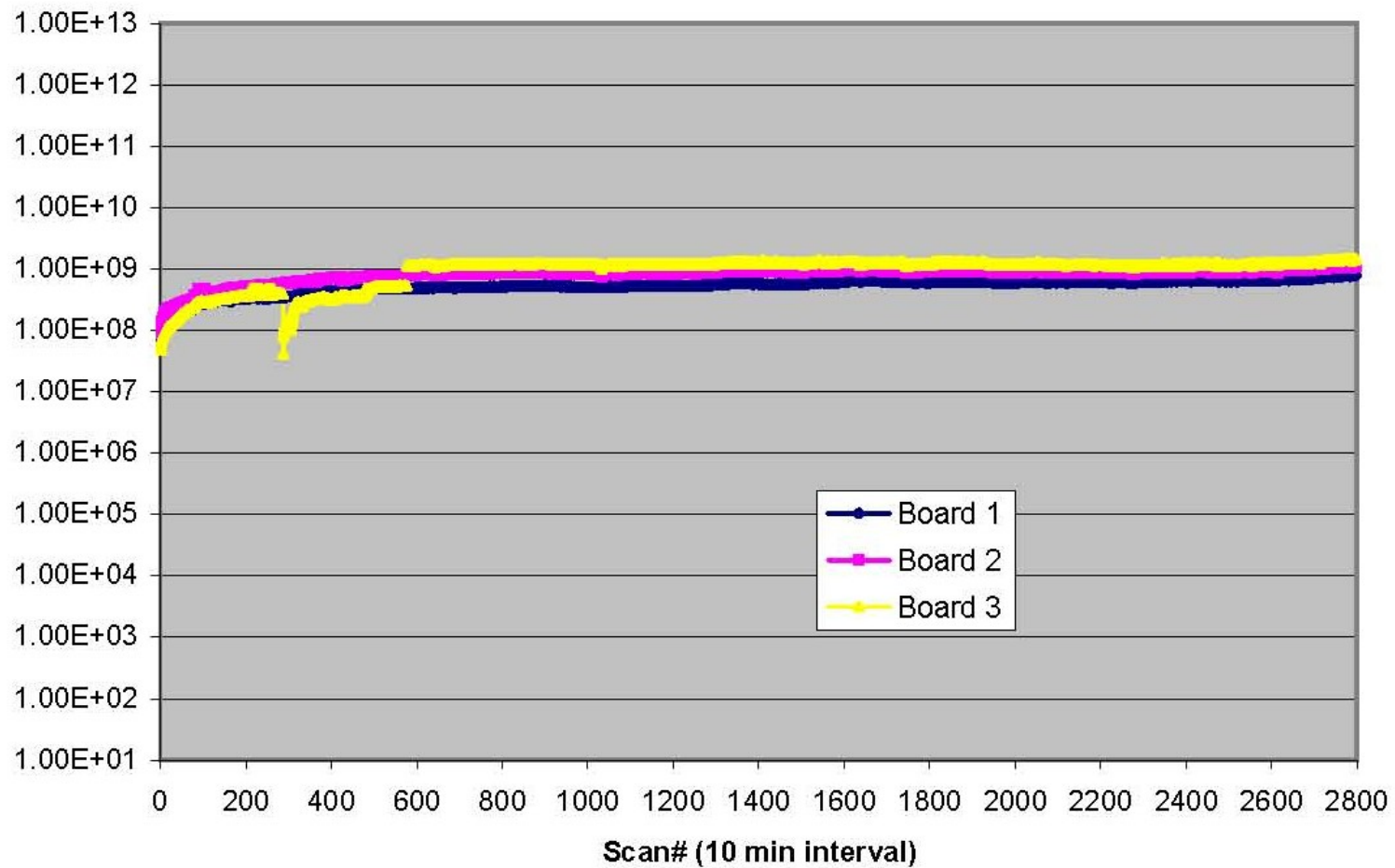
Sample Data Table (Hand)

Flux A, Tin, Hand Solder

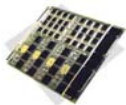
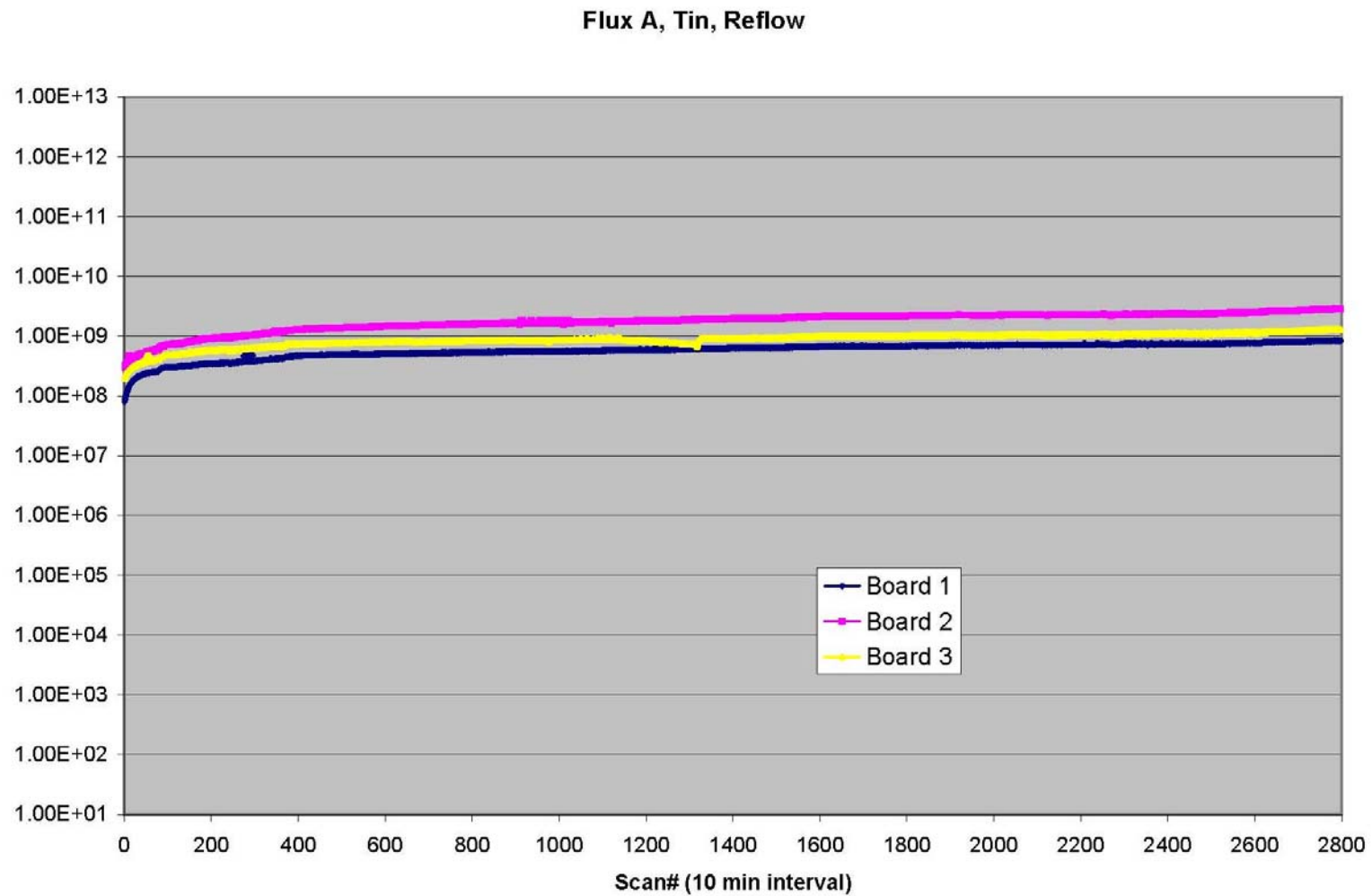


Sample Data Table (BGA Repair)

Flux A, Tin, BGA



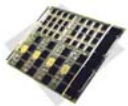
Sample Data Table (Reflow)



Discussion

Ramp-up

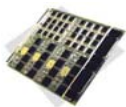
- Increase by ~ 1 decade during the first 200 - 600 readings (33 - 100 hrs)
 - Attributed to solvent dry-out at 50 °C



Discussion

Steady-state Resistance

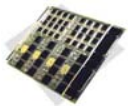
- More time / temperature increases resistance values in the steady-state (beyond first 200 - 600 readings)
- Attributed to amount of unreacted activator remains in the tacky flux residue



Discussion

Dendritic Failure

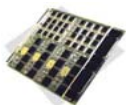
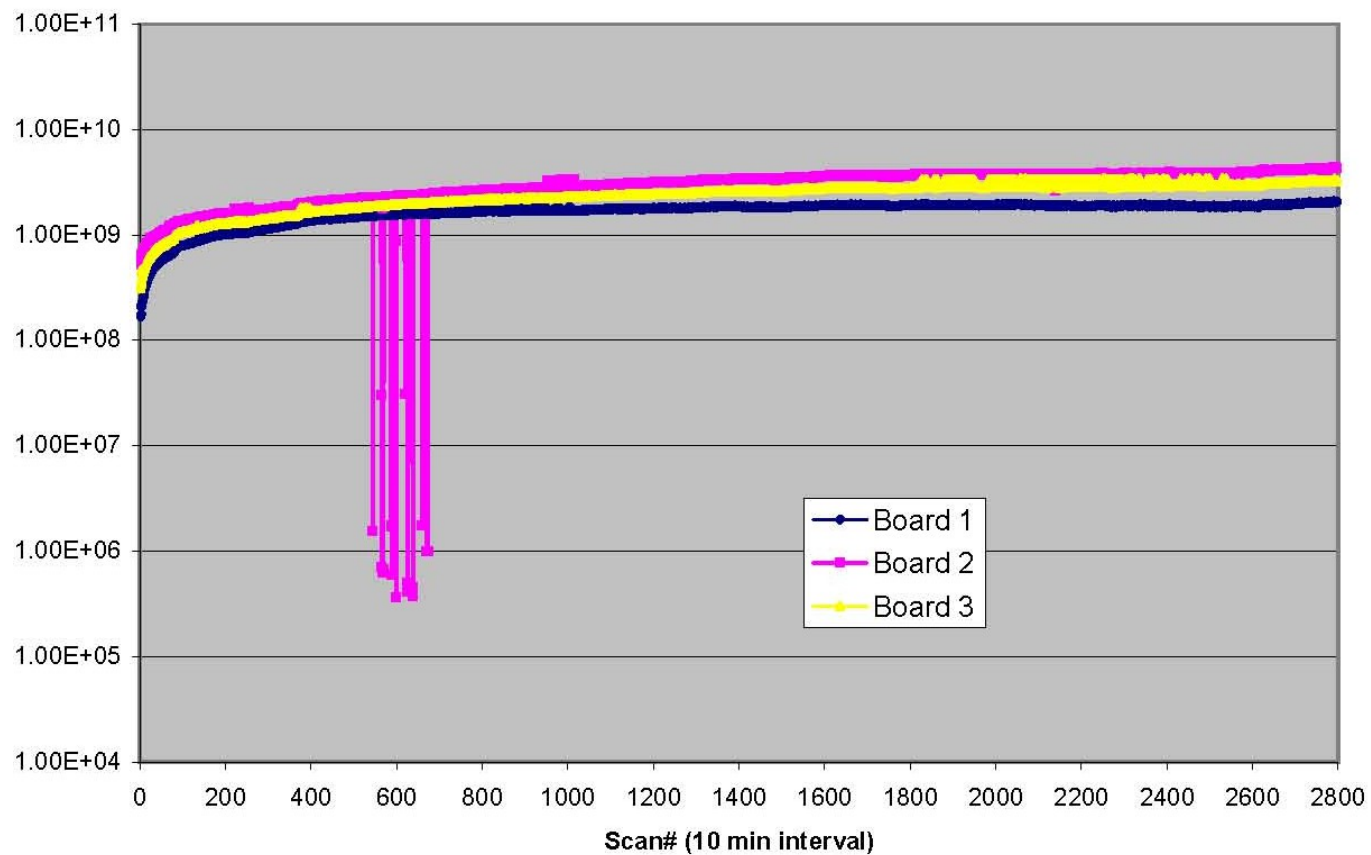
- This experiment did not produce any dendritic failure
 - Visual analysis
 - ECM testing with a 10-minute measurement pulse can “find” the dendrites being formed



Discussion

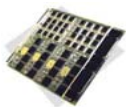
Example of Dendritic Failure

Example of Dendritic Growth in ECM Test



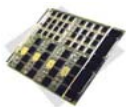
Conclusions

- Heating process does affect no-clean tacky flux reliability
- Full reflow > BGA repair > Hand Soldering > Unheated
- All heated processes passed the test, but the hand soldering condition was extremely close to the pass/fail criteria
- Unheated condition failed the test (low steady-state resistance)



Conclusions

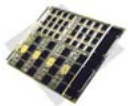
- All users should verify reliability of no-clean tacky fluxes in application-appropriate testing
- Users should consider not using no-clean tacky fluxes for hand soldering applications as unheated or entrapped tacky fluxes can present reliability issues
- If no-clean tacky fluxes are used for hand soldering, operators need to be trained on the heating requirements and reliability risks



Acknowledgements

The speaker would like to acknowledge co-authors Jennifer Allen and John Tuccy of Kester. Both were instrumental in conducting the experiment, collecting the data and reporting the data into meaningful format.

Brian Deram of Kester also provided insight regarding the appropriate experimental design.



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