Creep Corrosion of OSP and ImAg PWB Finishes

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Abstract

With increasing adoption of lead-free PWB surface finishes, along with increasing product deployments in more corrosive environments, the electronics industry is observing increased occurrences of corrosion-induced product failures. Particularly, creep corrosion on immersion silver has been observed to cause product failures after very short service periods in G2 and worse environments, in some cases less than one year. In our previous work (APEX 2009) [1], we demonstrated that creep corrosion of ImAg can be correlated to the presence of certain types of surface contamination (for instance residues left behind by organic acid fluxes). In this work, creep corrosion observed on OSP finished circuit boards will be reported. The effect of post-reflow cleaning process on creep corrosion will be discussed. A laboratory MFG test will also be discussed that replicates field creep corrosion. Comparison of creep corrosion susceptibility between OSP and ImAg PWB surface finishes will also be made.

1. Introduction

Creep corrosion is the mass transport process in which solid corrosion products (typically sulfide and chloride) migrate over a surface without the influence of an electric field. It was first reported by Egan and Mendizza for Ag_2S on an Au surface [2]. In their experiment, a silver substrate was used and one half of the Ag surface was coated with a thick Au layer (see figure 1). When the sample was exposed to a sulfur containing environment, silver sulfide was formed on exposed Ag. Furthermore, it was also observed that silver sulfide spilled over onto the Au surface and migrated away from the Ag-Au interface. This migration was called creep corrosion [2]. In figure 1, one can clearly see the leading edge of the creeping silver sulfide. Interestingly, when the experiment was repeated with a Ag-Rh or Ag-Pd interface, Ag_2S did not creep onto either the Rh or the Pd surface, even though heavy silver sulfide was formed on the exposed silver surface in both cases. Apparently, Ag_2S creep corrosion is highly surface specific and only happens on the Au surface but not on the Rh and Pd surfaces. This is a very important characteristic of creep corrosion. First, a site is required for creating corrosion product, for example an exposed Ag substrate in this case. Additionally, a surface is needed to support the creep of corrosion products. In this case, it is the Au surface. Rh and Pd, on the other hand, would not support the creep of silver sulfide.

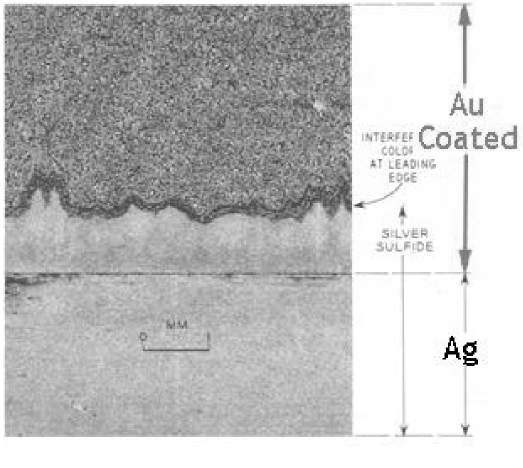


Figure 1 – Creep corrosion of silver sulfide on Au surface [2]

Creep corrosion is not only limited to metallic surfaces. It has also been observed on the plastic molding compound used for IC packages. In this case, the corrosion first takes place on the exposed lead-frame (Cu alloy) and the corrosion product (typically copper sulfide) migrates on to the adjacent encapsulated surface of the component and causes an electrical short circuit between the adjacent leads (see Fig.2) and product failures in the field. Zhao [3] has systematically studied creep corrosion on plastic encapsulated microcircuit packages with noble metal pre-plated lead-frames and found that Telcordia outdoor MFG testing is effective in producing creep corrosion on the plastic molding compound. As little as 5-day Telcordia outdoor MFG testing can induce creep corrosion over the mold compound. Battelle Class III testing is less effective but still capable of producing creep corrosion over the mold compound surface. Telcordia Indoor MFG testing, on the other hand, did not induce creep corrosion within the 30-day exposure.

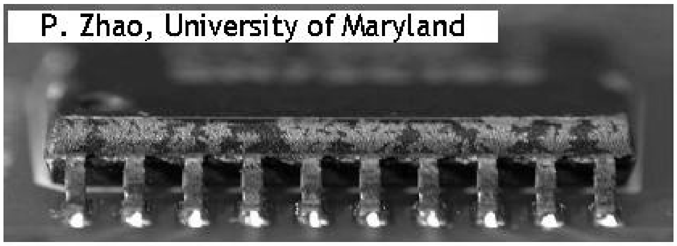


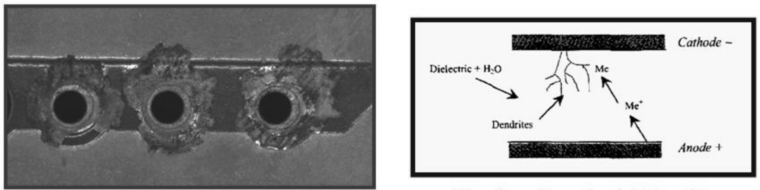
Figure 2 – Creep corrosion on molding compound for a DIP component [3]

In the last few years, product failures due to creep corrosion were reported for circuit boards with ImAg as the final finish [4-7]. Corrosion occurred first on the exposed ImAg pad (not covered by solder after assembly). Corrosion products (primarily copper sulfide) migrate onto the adjacent solder mask surface and eventually lead to a short circuit between the adjacent pads. In our previous work [1], we have systematically studied creep corrosion on ImAg finished circuit boards and found that creep corrosion on printed circuit boards is highly sensitive to the surface condition. Neither clean FR4 nor clean solder mask surfaces support creep corrosion. In general, circuit boards assembled with rosin wave soldering fluxes and solder paste containing rosin flux are also resistant to creep corrosion. Residues left on the solder mask surface by certain organic acid fluxes, on the other hand, form a "creepable" surface and are highly active for supporting creep corrosion of copper sulfides. The right choice of assembly flux can eliminate product failure due to the creep corrosion associated with ImAg plated circuit boards deployed in the global environment. In this paper, creep corrosion on circuit boards with OSP final finish will be reported. Furthermore, the effect of post-reflow cleaning process on creep corrosion will also be discussed.

1.1 Creep Corrosion vs. Electrochemical Migration and Whisker Formation

Creep corrosion needs to be distinguished from the well-studied electrochemical migration on printed circuit boards. Fig. 3 compares some of the key differences between creep corrosion and electrochemical migration (ECM). ECM requires electrical bias between the cathode and anode, whereby metal ions migrate from anode to cathode and form dendrites on the cathode. The migration is directional. Creep corrosion does not need electrical bias and typically will grow in all directions. ECM also requires a low-resistance electrolytic path between anode and cathode, which is typically supplied by a condensed water layer containing ionic species. In contrast to electrochemical migration, creep corrosion does not require an electrical bias and a low-resistance electrolytic path between the anode and cathode. Although humidity can accelerate the corrosion of base metals and likely creep corrosion, the presence of a condensed water layer is not required for the creep of corrosion products. Creep corrosion could also occur on a "dry" surface. However, creep corrosion is surface specific and needs certain chemical characteristics of the surface to support the creep of corrosion products. A given corrosion product can only migrate on a specific type of surface. For instance, Ag_2S creeps readily on gold surfaces but does not creep on rhodium and palladium surfaces [2]. Cu_2S does not creep on clean FR4 and solder mask surfaces but creeps readily on those surfaces with certain

	Creep Corrosion	Electrochemical Migration
Electrical Bias	No	Yes
Low-resistance electrolytic path between anode and cathode	No	Yes, supplied by condensed water layers
Sensitive to surface chemical characteristics	Strong	Weak



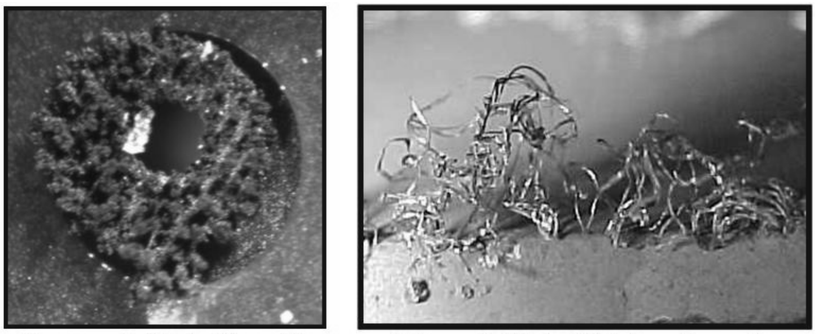
Creep Corrosion

Electrochemical Migration

Figure 3 – Key difference between creep corrosion and electrochemical migration

types of organic acid residues. ECM, on the other hand, is less sensitive to the surface characteristics. As long as there exists an anode and a cathode with an intervening condensed water layer, the characteristics of the surface between the anode and cathode have little impact for ECM.

Creep corrosion has a very different mechanism from that of whisker formation and dendritic growth. The latter two are driven by the compressive stress in the coating. Dendritic growth of corrosion products such as copper sulfide and silver sulfide is a consequence of the much lower density and higher specific volume of the corrosion products relative to their metal counterparts. When Cu or Ag are corroded to form copper sulfide or silver sulfide, there is a volume expansion in the original Cu or Ag metal films, leading to a compressive stress build up. As corrosion is typically not uniform and occurs preferentially at defect sites such as a grain boundary or porosity, this compressive stress can not be easily released and therefore initiates/drives the whisker formation and dendritic vertical growth of corrosion products out of the coating films. Fig. 4 shows typical images of corrosion product dendritic vertical growth (left) and whisker formation (right). Unlike creep corrosion, surface properties of areas surrounding the corroding sites are not important for whisker formation and dendritic growth.



Copper Sulfide Growth Silver Sulfide Whisker Growth

Figure 4 – Dendritic growth and whisker formation [8] driven by compressive stress

2. Experimental

Mixed flowing gas (MFG) testing has been widely used for simulating corrosive environments and performing accelerated testing on electronic devices and assemblies [9-16]. MFG testing severity should match the severity of the deployed environment . The expected product life will determine the test length sufficient to capture corrosion-related failures. Battelle and Telcordia have developed various MFG test conditions, mostly for simulating North American environmental conditions. For instance, the Cu corrosion rate in a Telcordia NEBS outdoor environment (275-360nm/day) would give one day to one year acceleration for a typical North American G1 environmental condition (<360nm/year) classified by ISA [11]. For simulating much more aggressive environments in the current worldwide marketplace, a new test condition was developed by Alcatel-Lucent (ALU) with significantly higher H_2S concentration. This increase of H_2S concentration takes two facts into consideration: 1) copper sulfide has been determined as the main component of the corrosion products in the field and 2) copper sulfide formation increases monotonically with increasing H_2S concentration to concentrations greater than our test conditions use. Table 1 compares the NEBS outdoor MFG condition with the ALU condition. The ALU condition has the advantage of shorter test time, but otherwise yields similar results.

Table 1. MFG Test Conditions

	H_2S	SO_2	NO_2	Cl_2
NEBS Outdoor	100 ppb	200 ppb	200 ppb	20 ppb
ALU International	1500-2000 ppb	200 ppb	200 ppb	20 ppb

The ALU MFG condition was used for the testing described in this paper. The temperature was 40^oC and the humidity was ~70% RH. The corrosion rate in the chamber was monitored using Cu coupon weight gain and was determined to be ~500-600 nm/day (equivalent copper sulfide thickness). Similar thickness of corrosion products has been observed for Cu coupons deployed for one year in some field locations [15-16] in the world. Thus, one year filed deployment of the equipment in those locations can be simulated by one day exposure in the MFG chamber.

Circuit boards with OSP final finishes were assembled using a halide free, water cleanable solder paste. The paste contains organic acid flux and has IPC classification of ORM0. According to paste supplier's specification, post reflow residue can be easily removed in warm DI water cleaning systems. A Trieber Aqua SMD Junior was used for the post-reflow cleaning and has one wash section, a rinse section and final rinse section. There is no rinse or air knife between the wash section and the rinse sections. Wash water is heated in the machine to 130°F. No saponifiers or de-foaming agents are added to the water. The surface cleanliness is monitored with an Alpha Metals Ionograph 500M. Typical readings are around 1ug/sqin, well below the 10 ug/sqin IPC limit.

3. Experimental results

Fig.5 compares optical images of circuit boards before (top two images) and after 5 days MFG test (bottom two images). As the two top images show, OSP-coated pads were not completely covered by the solder after reflow and the edges of the pads are exposed. This is more clearly seen in Fig.6, where SEM image of a pad and EDS analysis results at two locations are summarized. The left-upper corner in the top image is the end termination of the component. Most of the area of the Cu pad is covered by the solder and flux residues, as the EDS result on the left side shows. However, no solder is found on the edge of the pad (right-bottom). The EDS analysis on the edge of the pad (right side) shows a large Cu peak and two small O and C peaks, indicating an exposed Cu pad with OSP and possibly also some flux residues. When this sample is exposed to MFG, corrosion products will form on the exposed OSP/Cu edge. Furthermore, corrosion products creep on to the adjacent solder mask surface and causes short circuits between the adjacent components, as clearly shown in Fig.5.

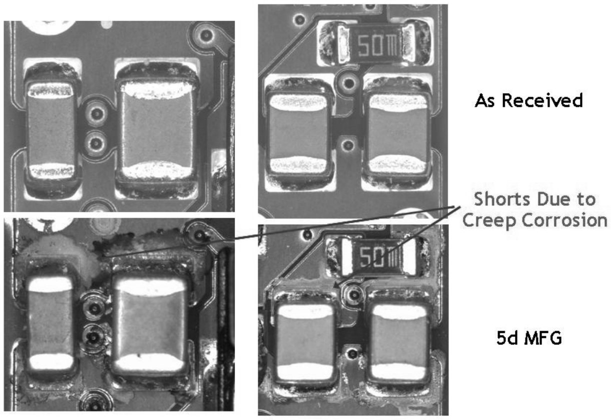


Figure 5 – Optical images of samples before and after 5 days MFG test

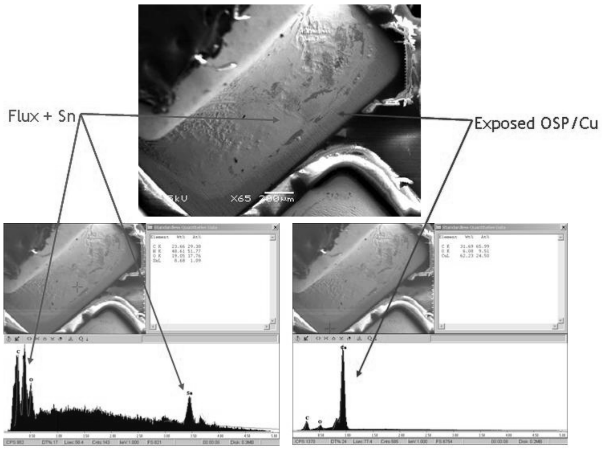


Figure 6 – ESD Analysis of OSP coated Cu pads after reflow soldering

To further understand how the flux residues and post-reflow cleaning affect creep corrosion, samples were collected at different stages of the cleaning process.

1) Directly after reflow: samples were removed immediately after reflow and have not seen any cleaning action.
2) After first wash section: samples were reflowed and went through the first wash station but without going through the two rinsing stations.
3) After final rinse section: samples were collected after going through the standard cleaning process (first wash, rinse and final rinse).

All the samples were then subjected to 5 days MFG test. Fig. 7 shows images taken at two identical locations for the three circuit boards after 5 days MFG testing.

Severe corrosion was seen for all three samples. The two images on the left were from the sample removed immediately after reflow. In addition to corrosion, creep of corrosion products was also observed. However, creep of corrosion products is rather localized and extends only just beyond the perimeters of the Cu pads. The two images in the middle were from the sample removed after going through the first wash section but without rinsing. Interestingly, the creep of corrosion products in this case is significantly more extensive than the sample removed immediately after reflow. The wash seems to help flux residues spread further onto the solder mask surface, which creates a larger creepable surface around the Cu pads, hence more extensive creep corrosion on this sample. The two images on the right were from the sample removed after going through the entire cleaning process (reflow, wash, rinse and final rinse). Only minor creep corrosion was observed at one location (bottom right corner in the top image). Most of the creep promoting flux residues seem to be removed in this case during the standard cleaning. However, the presence of creep corrosion indicates that there is still some flux residue left on the surface, even though the surface cleanliness measurement using the Alpha Metals Ionograph 500M showed a typical reading of ~1ug/sqin, well below the 10 ug/sqin IPC limit. Clearly, a PWB surface, which is clean enough for preventing electrochemical migration, may not be adequate for preventing creep corrosion. This could be due to the fact that creep corrosion is more sensitive to the flux residues than ECM. The alternative explanation is that creep corrosion is promoted by species other than ionic residues, which are responsible for ECM and analyzed using the standard ionograph.

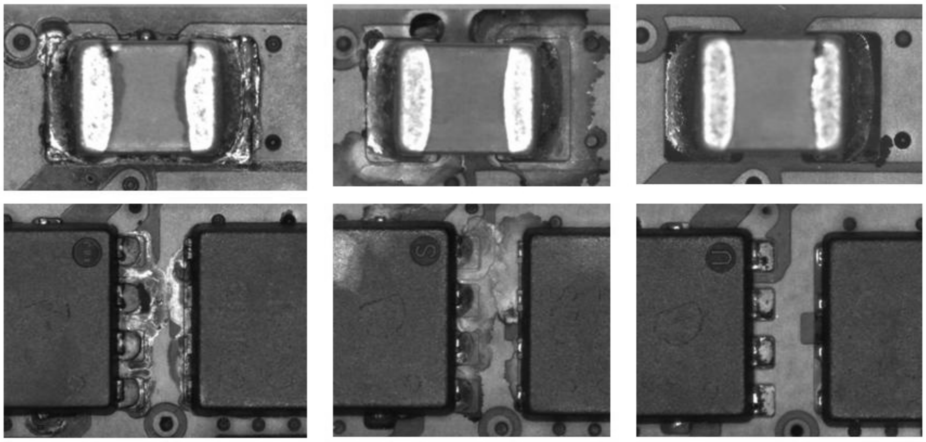
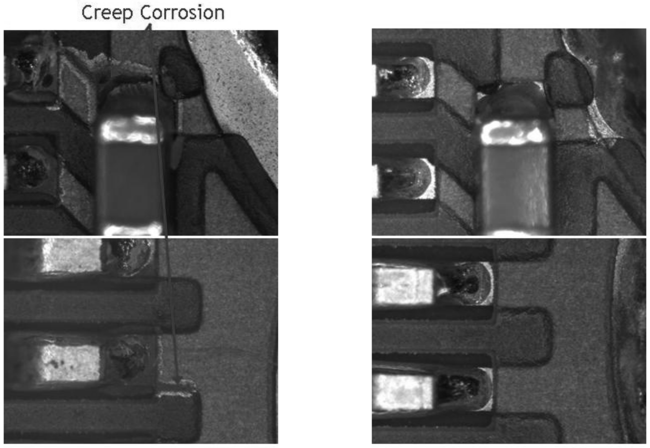

After Reflow After Wash After Final Rinse

Figure 7 – Effect of post-reflow cleaning on creep corrosion

In order to further minimize creep corrosion, the standard cleaning process needs to be improved. As the first wash tank is highly contaminated with flux residues, the drag-in of solution from wash tank to the first rinse tank would contaminate the first rinse tank with flux residues and compromise the cleaning operation. To minimize the drag-in, an air knife was installed

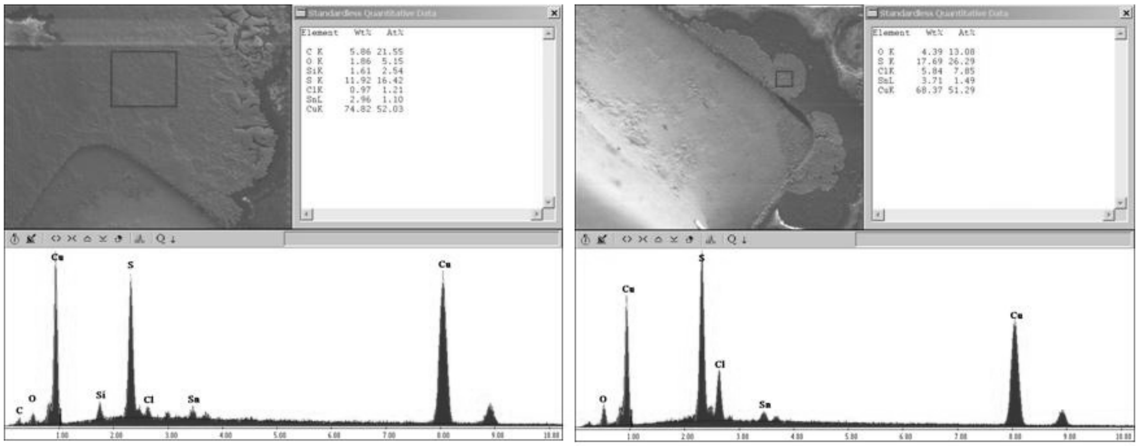


Without Air-Knife With Air-Knife

Figure 8 – Comparison between standard and improved cleaning processes

between the wash section and the first rinse section to blow off trapped solution on the circuit boards after the wash. Samples for MFG testing were then collected from both the standard operation and the improved operation. In Fig.8, results after 7 days MFG test are summarized. The two images on the left are from the sample cleaned using the standard process and show some creep corrosion. The two images on the right are from the sample cleaned using the improved cleaning process and show no creep corrosion.

The chemical composition of the creeping species was also determined using EDS analysis and results are summarized in Fig.9. The image on the left side of Fig.9 shows that the creeping species is mostly copper sulfide, with a small peak due to chlorine. This is very typical for most areas analyzed. However, in some of the areas a rather large Cl peak is also observed in addition to copper sulfide, as the image on the right side of Fig.9 shows. A small oxygen peak is also observed in both cases and is most likely due to the substrate (solder mask coated FR-4). This is consistent with the fact that copper sulfide is highly mobile and creeps readily on many surfaces, while copper oxide typically does not creep.



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Element   Wt%    At%

 C K      5.86  21.55
 O K      1.86   5.15
 SiK      1.61   2.54
 S K     11.92  16.42
 ClK      0.97   1.21
 SnL      2.96   1.10
 CuK     74.82  52.03
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Element   Wt%    At%

 O K      4.39  13.08
 S K     17.69  26.29
 ClK      5.84   7.85
 SnL      3.71   1.49
 CuK     68.37  51.29
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Figure 9 – Composition of creeping corrosion products

4. Discussion

There are three key findings in this work: 1) creep corrosion can occur on PWBs with OSP as final finish and is promoted by the flux residues left on the surface after assembly. 2) The current IPC cleanliness standard, developed for preventing electrochemical migration on the assembled circuit, is not adequate for preventing creep corrosion, as creep corrosion is sensitive to different types of flux residues than electrochemical migration. A new set of cleanliness standards has to be established for circuit boards prone to creep corrosion. 3) The corrosion test using mixed flowing gases provides a realistic accelerated test for equipment to be deployed in various environments encountered in the current global market place. No condensing condition is required for simulating product failure due to creep corrosion in the laboratory.

In the following, these three key findings will be discussed in detail. The mitigation strategies for minimizing and preventing creep corrosion will also be addressed.

4.1 Creep corrosion on OSP covered Cu pad

Creep corrosion has been often associated with circuit boards having ImAg as final finish. The creeping species are determined to be predominately copper sulfide [1, 5 and 7]. The effect of ImAg plating chemistry, solder mask and assembly flux on creep corrosion has been studied previously [1]. It was found that the key parameter in causing creep corrosion is the type of flux used for assembly. Type of ImAg and solder mask has only minor effect on creep corrosion. Neither clean circuit boards nor circuit boards assembled using rosin based flux are susceptible to creep corrosion. However, residues left on the solder mask surface by organic acid flux form a "creepable" surface and are highly active for supporting creep of copper sulfide corrosion product. As demonstrated above, OSP finished circuit boards, which are assembled using solder paste containing organic acid flux, are also prone to the creep corrosion, if the flux residues are left on the surface. This result is not unexpected, as copper sulfide, the active creeping species, is the primary corrosion product formed on both ImAg- and OSP-coated Cu pads in MFG testing and environments containing reduced sulfur. As Ag will also corrode in corrosive environments containing reduced sulfur compounds, the corrosion typically occurs faster on an ImAg surface than on an OSP surface and there is a delay of corrosion onset on the OSP surface compared to the ImAg surface. However, OSP only provides limited protection to the Cu substrate, which will eventually be attacked by corrosive gases such as H_2S, forming copper sulfide. If a creepable surface is present around OSP-coated Cu pads, copper sulfide will creep onto that surface and eventually cause short circuits between adjacent pads. It is worthwhile to reiterate here that this is true with any surface; the formation of copper sulfide coupled with a creepable surface will lead to the creep corrosion.

4.2 PWB cleanness required for preventing creep corrosion

Incomplete post-reflow washing/cleaning seems to initially increase the propensity for creep corrosion due to the spreading of the residues aided by the washing solution. However, with further cleaning, the flux residues are removed from the PWB surface and the creeping of corrosion products is also reduced. In order to prevent creep corrosion, the creep-promoting flux residues have to be completely removed from the surface after assembly. For quality control purposes in production, a set of test methods and pass/fail criteria are needed for ensuring the cleanliness of the assembled board to resist creep corrosion. The current IPC cleanliness standard, developed for preventing electrochemical migration on the assembled circuit, is not adequate for preventing creep corrosion, as creep corrosion is sensitive to different types of flux residues than electrochemical migration. A new set of cleanliness standard has to be established for circuit boards prone to the creep corrosion.

4.3 Lab test for simulating creep corrosion

The simulation of creep corrosion in the laboratory has to take the highly surface sensitive nature of creep corrosion into consideration. Mixed flowing gas testing can simulate the environmental conditions in the global market place and has been successfully used to generate creep corrosion on electrical contacts (metallic surface) and IC components (dielectric surface) previously. In this work, creep corrosion was successfully reproduced on printed circuit boards using MFG testing. The previous inconsistency in generating creep corrosion on ImAg and OSP coated samples using MFG lies in the failure to recognize the highly surface sensitive nature of creep corrosion. Test vehicles containing only surface finishes and solder mask without going through the assembly process are not appropriate samples for generating and understanding creep corrosion, as clean FR4 and solder mask surfaces do not support creep corrosion. Searching for creep corrosion resistant PWB final finishes should be done on an assembled board with solder mask and flux. The MFG test provides a viable and realistic accelerated aging test for the creep corrosion.

4.4 Mitigation strategies for minimizing and preventing creep corrosion

For creep corrosion to occur, two prerequisites have to be met: a site for generating corrosion product and a surface for supporting the creep of corrosion product generated. By eliminating either the corroding site or the “creepable” surface (surface capable for supporting the creep of corrosion product) surrounding the corroding site, creep corrosion can be minimized or eliminated.

In sulfur-containing environments, both Cu and Ag will corrode readily to form highly mobile species of sulfide. Consequently, PWBs with ImAg surface finish are known to be prone to tarnishing in a sulfur containing environment. OSP can provide some limited protection to the Cu substrate but sulfide will also form quickly on OSP-coated Cu pads, while ENIG will exhibit slower Cu corrosion in those environments. Unlike ImAg/OSP/ENIG, ImSn and HASL with adequate thickness (more than 1 micron) do not show significant sulfur-related corrosion. This is due to the inertness of Sn in those environments as well as the reverse galvanic potential between Sn and Cu [21]. The onset of sulfide formation for various PWB finishes can be ranked in the following order:

ImAg > OSP > ENIG >> ImSn~HASL

By choosing the appropriate surface finish, copper sulfide formation will be eliminated (for ImSn and HASL finishes) or reduced (ENIG finish). However, creep corrosion is only one of several reliability risks associated with PWB finishes. The final choice of PWB surface finish has to take assembly performance and long-term reliability into consideration, which is beyond the scope of this paper and will not be discussed here. If ImAg or OSP are used as PWB finish and the circuit boards are exposed to a sulfur containing environment, copper sulfide will most likely form with the time of the deployment. In this case, creep corrosion can only be minimized or prevented if the surrounding surface does not support creep of the corrosion products. This is for instance true for clean FR-4 and solder mask surfaces. In general, circuit boards assembled with rosin wave soldering fluxes and solder paste containing rosin flux are also resistant to the creep corrosion. The right choice of assembly flux can keep the corrosion product at the location where it was generated and minimize/eliminate product failure due to creep corrosion. If organic acid flux is used for the assembly of the circuit board, its residues are generally highly active in supporting the creep of copper sulfide and have to be removed by an effective cleaning process.

Summary

Creep corrosion on printed circuit boards is not limited to ImAg surface finish and can also occur on OSP. In both cases, the active creeping species is copper sulfide. The creep corrosion can be minimized or prevented either by eliminating the corroding site or the creepable surface adjacent to the corroding site. While residues from rosin flux do not promote creep corrosion, the residues of certain type of organic acid fluxes are highly active in promoting the creep of copper sulfide. If the circuit boards are assembled using these types of fluxes, they have to be cleaned thoroughly to avoid creep corrosion when they are deployed in corrosive environments. The current IPC cleanliness standard, developed for preventing electrochemical migration on the assembled circuit, is not adequate for preventing creep corrosion, as creep corrosion is sensitive to different type of flux residues than electrochemical migration. A new set of cleanliness standards has to be established for circuit boards prone to creep corrosion. Corrosion testing using mixed flowing gases provides a realistic accelerated test for the equipment to be deployed in various environments encountered in the current global market place. No condensing condition is required for simulating the product failure due to the creep corrosion in the laboratory.

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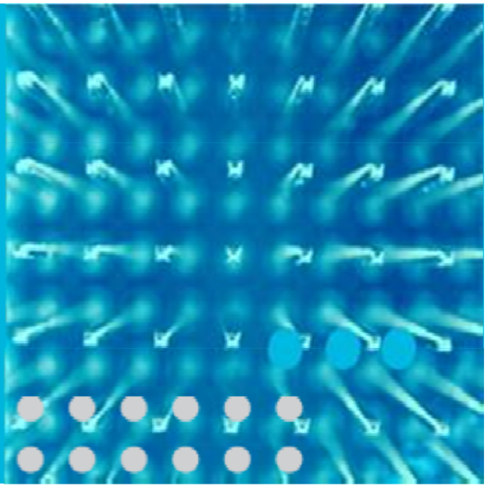

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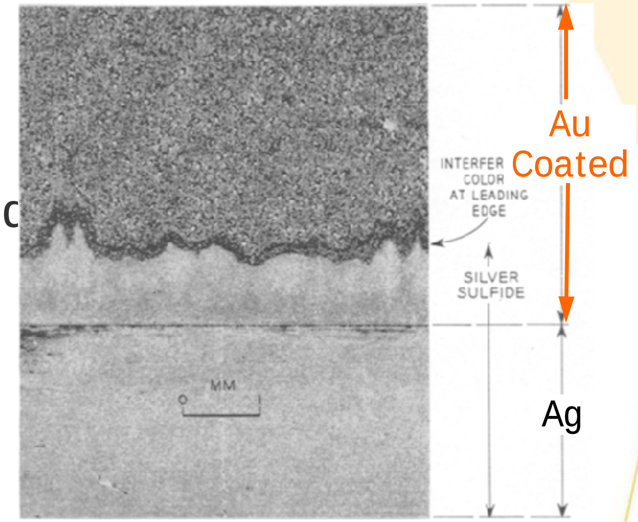
Outline

- Background/Motivation
- Experiment and Results
- Conclusion

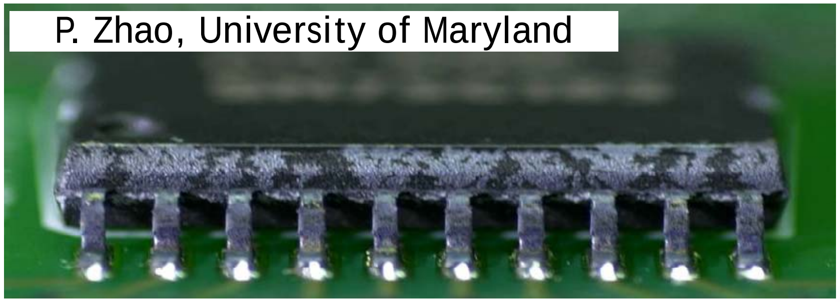
Creep Corrosion

- Creep corrosion is the mass transport process in which solid corrosion products (typically sulfide and chloride) migrate over a surface ***without*** the influence of an electric field.



- Creep corrosion was first reported by Egan and
    - ✓ Silver sulfide creeping over Au surface
    - ✓ AgSx creeps over Au but not Rh and Pd

- Creep corrosion can also occur over plastic surfaces.
    - ✓ First field failure was observed on DIP component

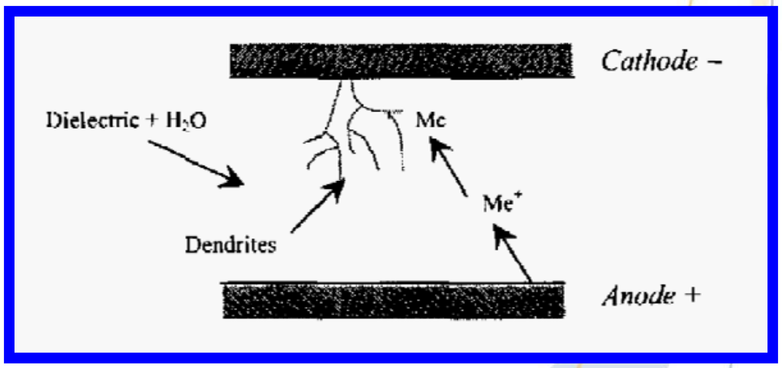


P. Zhao, University of Maryland

Creep Corrosion vs. Electrochemical Migration

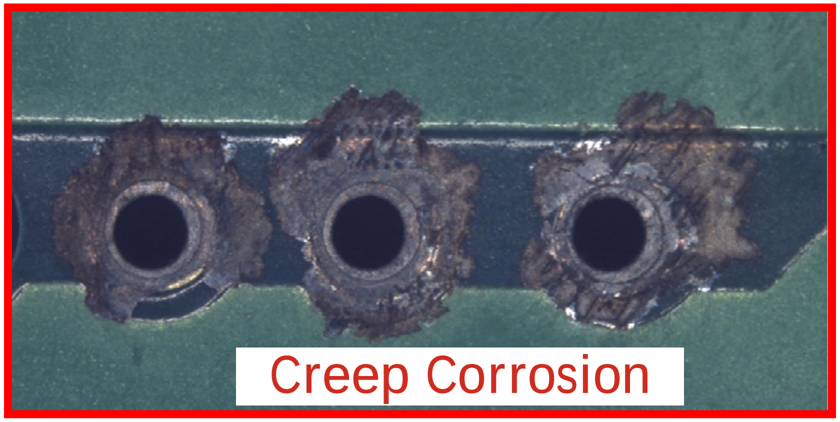
	Creep Corrosion	Electrochemical Migration
Electrical Bias	No	Yes
Low-resistance electrolytic path between anode and cathode	No	Yes, supplied by condensed water layers
Sensitive to surface chemical characteristics	**Strong**	**Weak**

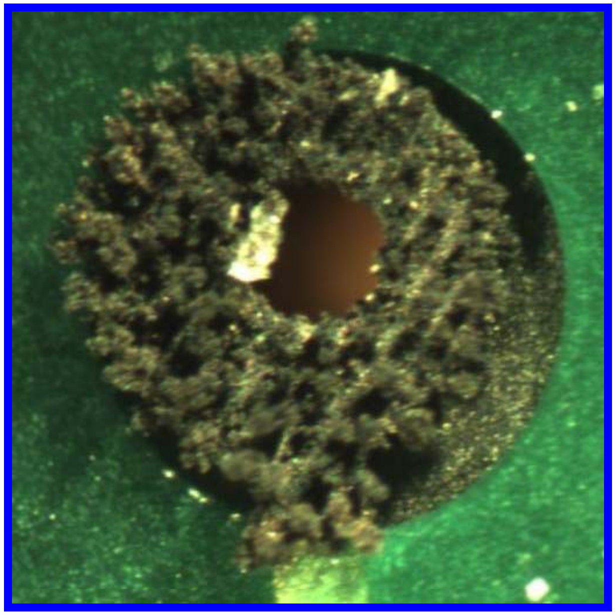
Creep Corrosion



Electrochemical Migration

Creep Corrosion vs. Growth

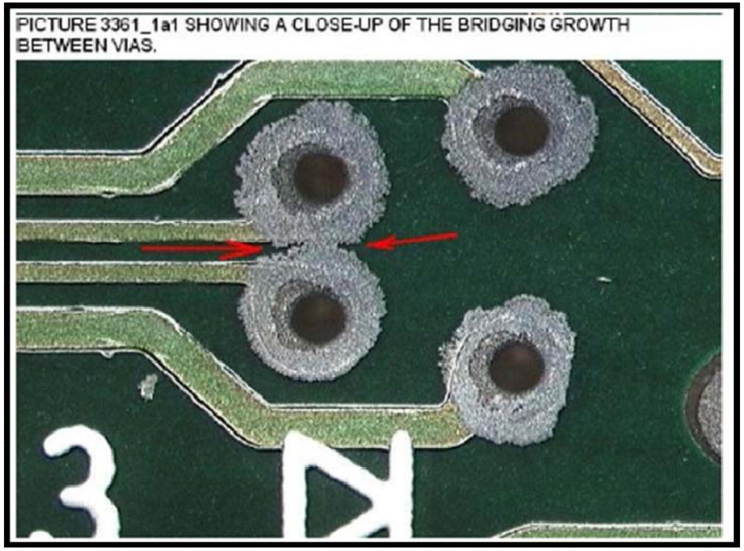

Creep Corrosion

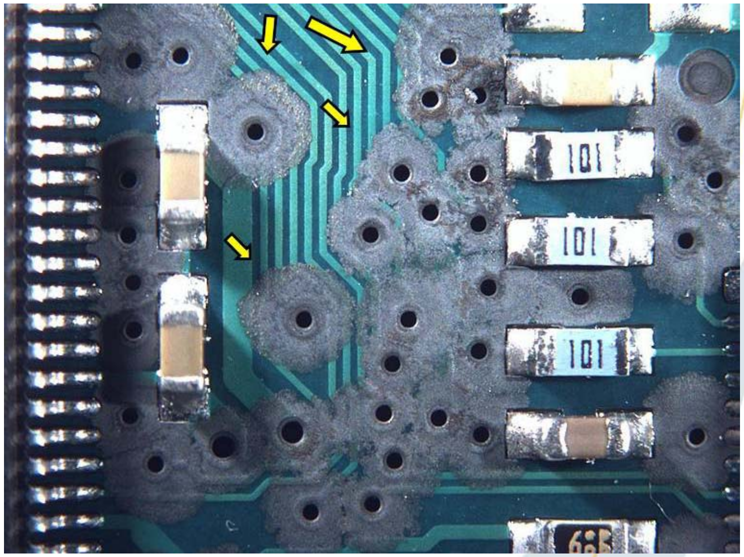

Dendrite Growth


Silver Sulfide Whisker Growth

Creep Corrosion Failure Due to PWB Finish

- R. Veale, “Reliability of PCB Alternate Surface Finishes In A Harsh Industrial Environment”, SMTA 2005
- P. Mazurkiewicz, “Accelerated Corrosion of Printed Circuit Boards due to High Levels of Reduced Sulfur Gasses in Industrial Environments”, Proceedings of the 32nd International Symposium for Testing and Failure Analysis, November 12-16, 2006, Renaissance Austin Hotel, Austin, Texas, USA
- C. Xu, D. Flemming, K. Demerkin, G. Derkits, J. Franey, W.Reents, “Corrosion Resistance of PWB Surface Finishes”, Alcatel-Lucent, APEX, 2007.
- R.Schueller, “Creep Corrosion On Lead-Free Printed Circuit Boards In High Sulfur Environments” SMTA 2007





Outline

- Background/Motivation
- Experiment and Results
- Conclusion

Mixed Flowing Gas Test Condition

Chamber	T (°C)	RH	Experiments
MFG 1	40	70%	Int'l

Gas	Concentration (ppb)
H_2S	**1700***
NO_2	**200**
Cl_2	**20**
SO_2	**200**

The Cu corrosion rate was determined to be ~550 nm/day, which represents Battelle class IV and ISA class G2.

*Highly accelerated conditions

Recap on Previous Work on ImAg

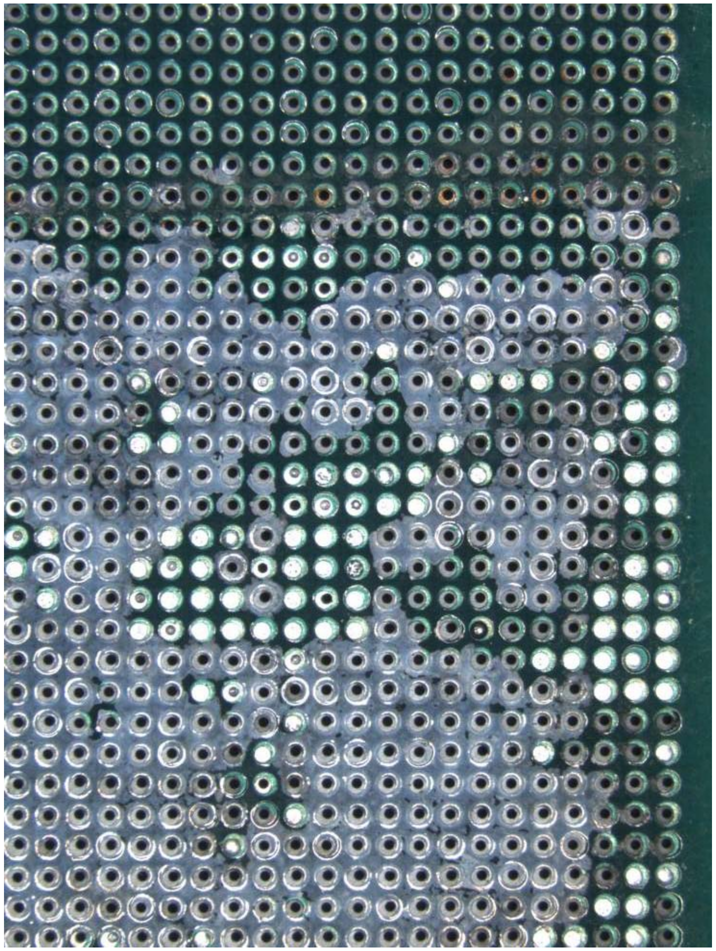
APEX 2009

- Eight different wave soldering fluxes (four ORL0, three ROL0 and one ROM1 fluxes) and six different solder pastes (four containing ROL0 fluxes and two containing ROL1 fluxes).
- Test vehicles were fabricated by six different board houses using various type of ImAg and solder mask combination.
- The boards were then assembled at four different EMS locations.

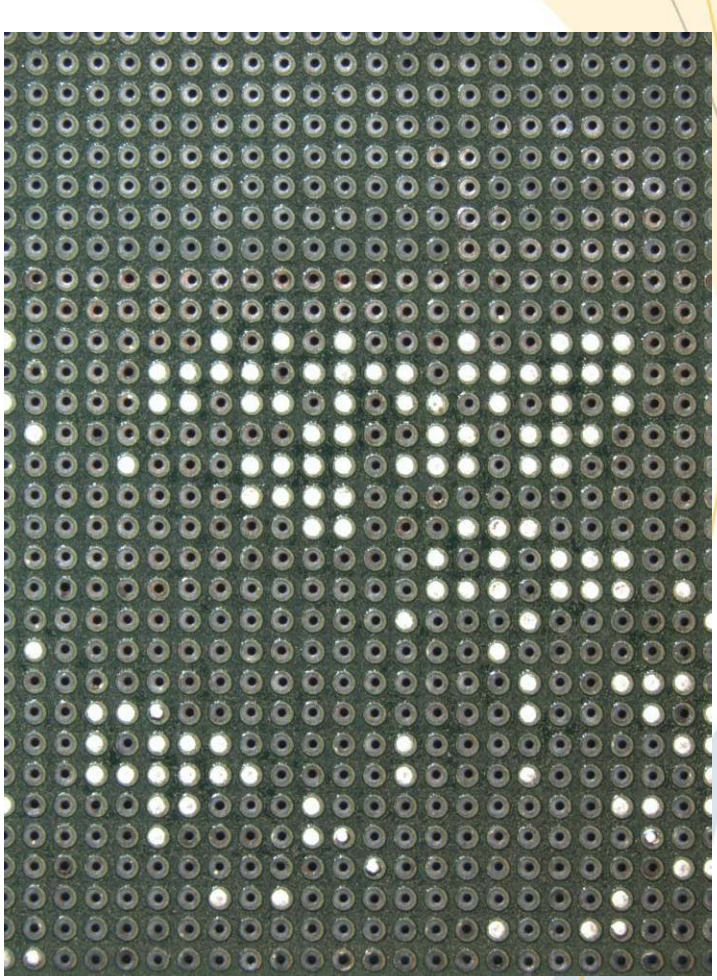
Flux is the key parameter in determining whether creep corrosion occurs

Creep Corrosion on ImAg

APEX 2009



Assembled with ORL0 Flux



Assembled with ROL0 Flux

Summary of Creep Corrosion After 5 Days MFG Testing

APEX 2009

	bare board	assembled with rosin flux	assembled with organic acid flux
bad	0	0	29
marginal	0	2	10
good	12	28	9

bad	moderate creep corrosion to severe creep corrosion
marginal	creep corrosion in small isolated areas
good	no/minor creep corrosion

Summary of Previous Work on ImAg

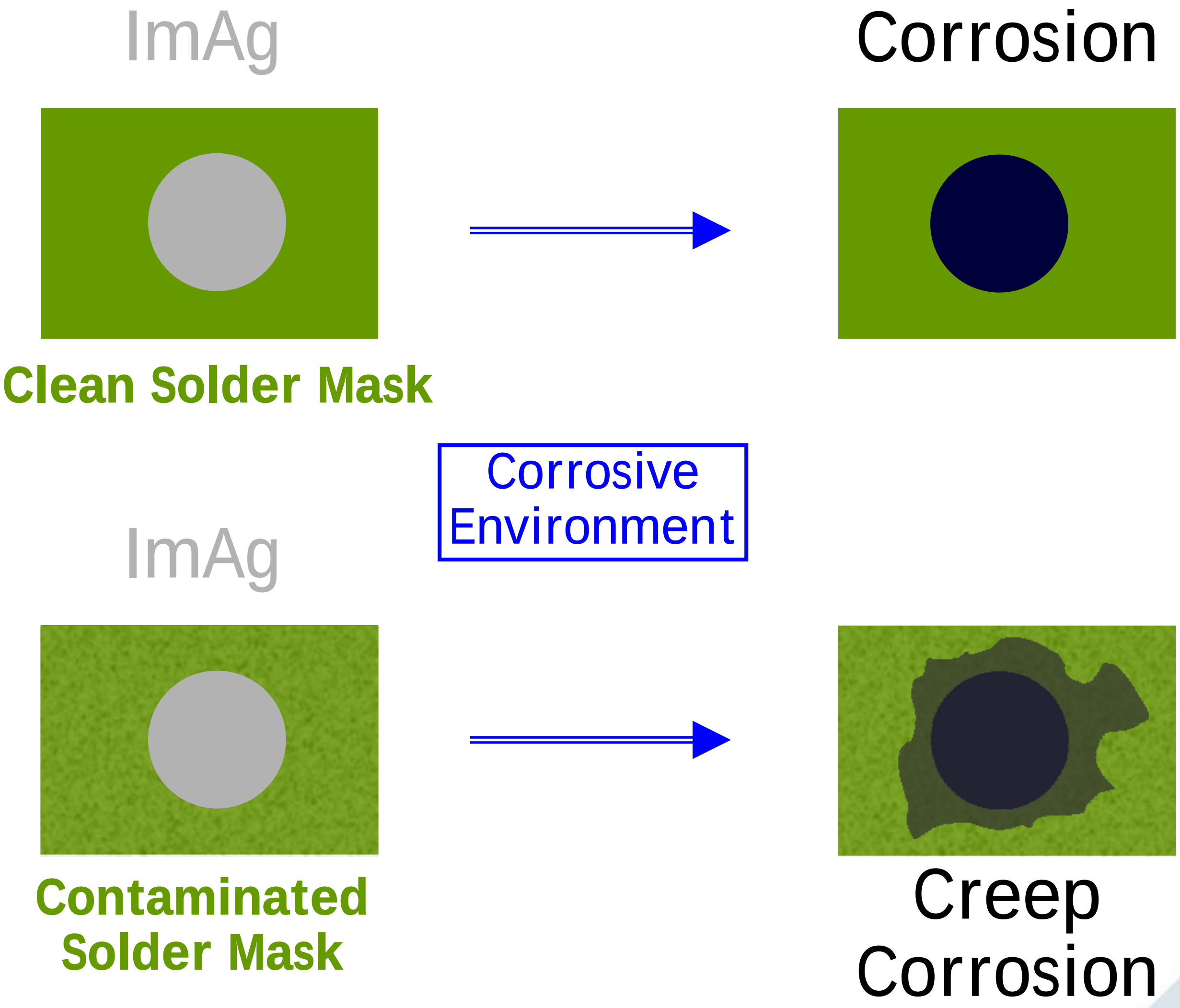
APEX 2009

- Creep corrosion on printed circuit boards is highly sensitive to the surface condition. Neither clean FR4 nor clean solder mask surfaces support the creep corrosion.

- In general, the board assembled with rosin fluxes is also resistant to the creep corrosion.

- The residues left on the solder mask surface by certain types of organic acid flux form a “creepable” surface and are highly active for supporting the creep corrosion of copper sulfides.

Creep Corrosion and Surface Contamination



ImAg

Corrosion

Clean Solder Mask

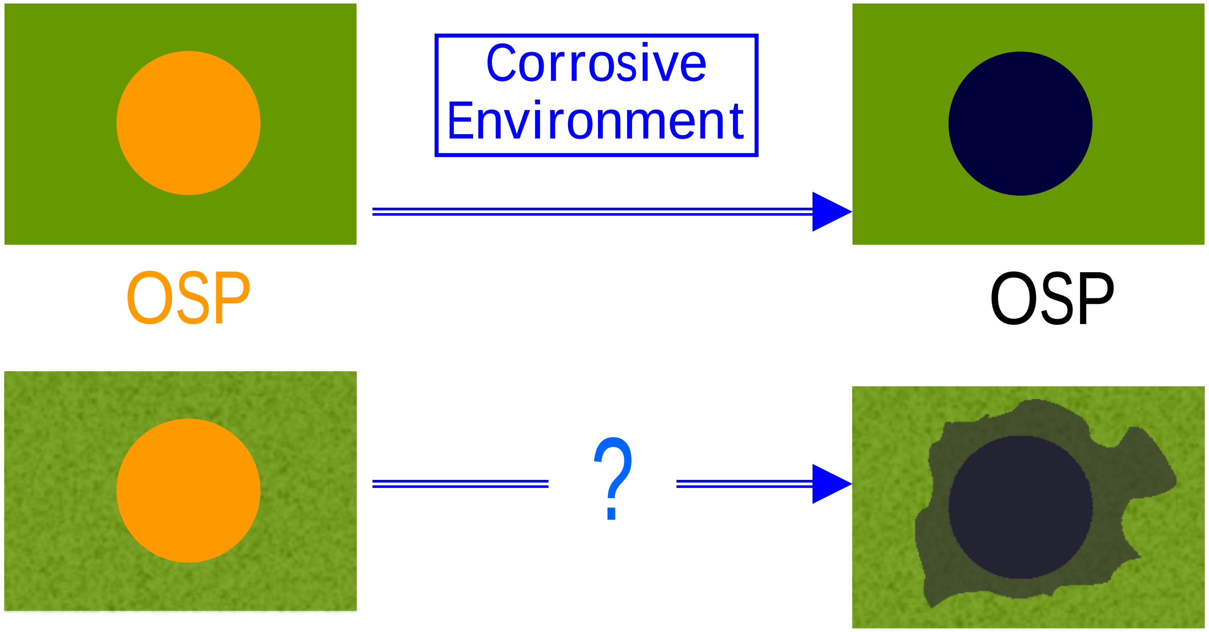
Corrosive Environment

ImAg

Contaminated Solder Mask

Creep Corrosion

Objective of This Work



Corrosive Environment

OSP

OSP

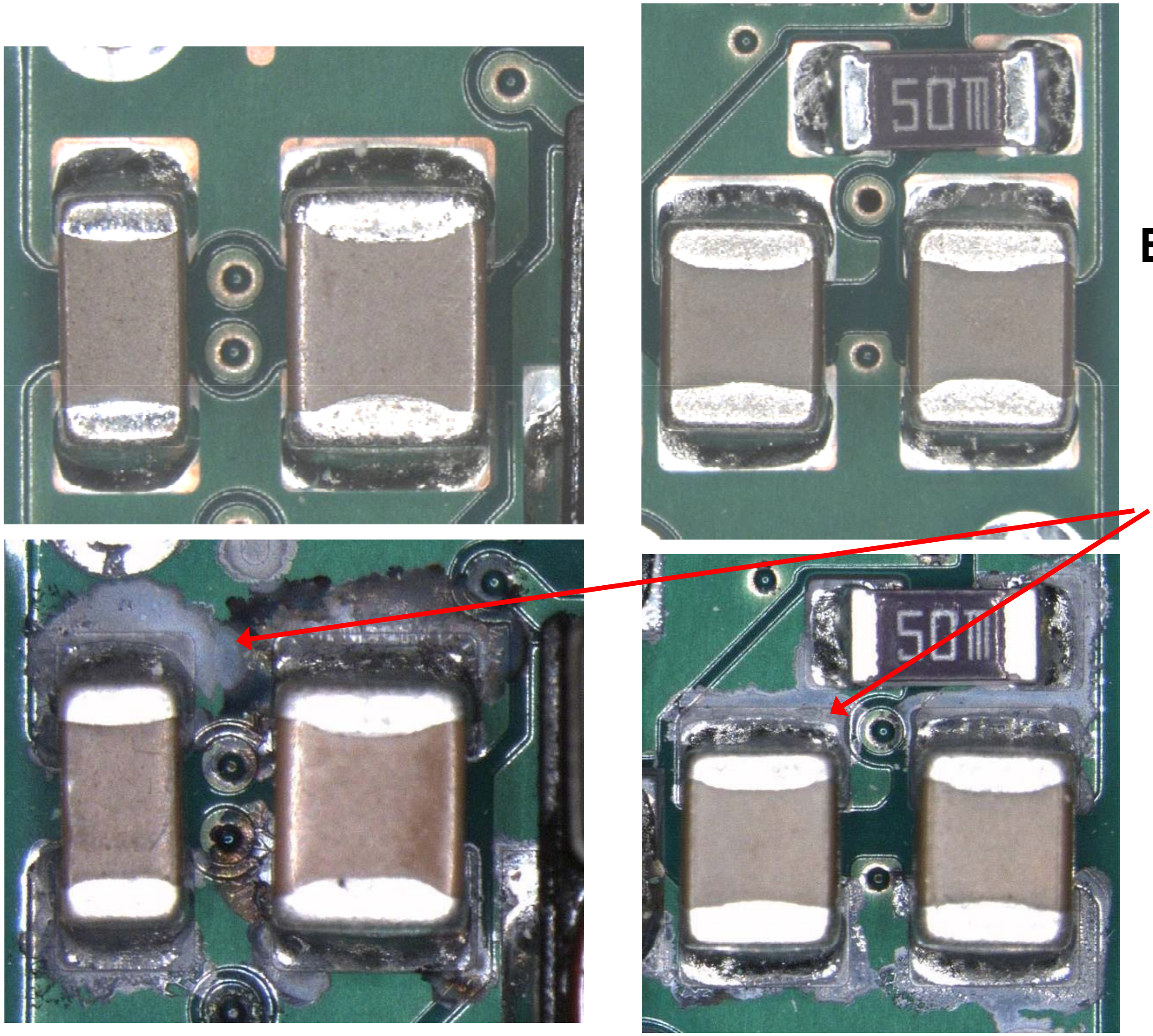
?

- ➢ Do flux residues on solder mask promote creep corrosion on OSP?
- ➢ Can the surface be cleaned enough for avoiding creep corrosion and how clean is clean enough?

Sample Description

- Boards Finish: OSP
- Solder Paste: a halide free, water cleanable solder paste. organic acid flux and IPC classification of the flux is ORM0
- According to paste supplier’s specification, post reflow residue can be easily removed in warm DI water cleaning systems. A Trieber Aqua SMD Junior was used for the post-reflow cleaning and has one wash section, a rinse section and final rinse section. There is no rinse or air knife between the wash section and the rinse sections. Wash water is heated in the machine to 130ºF. No saponifiers or de-foaming agents are added to the water.
- The surface cleanliness is monitored with an Alpha Metals Ionograph 500M. Typical readings are around 1ug/sqin, well below the 10 ug/sqin IPC limit.

Creep Corrosion After 5 Days MFG Test

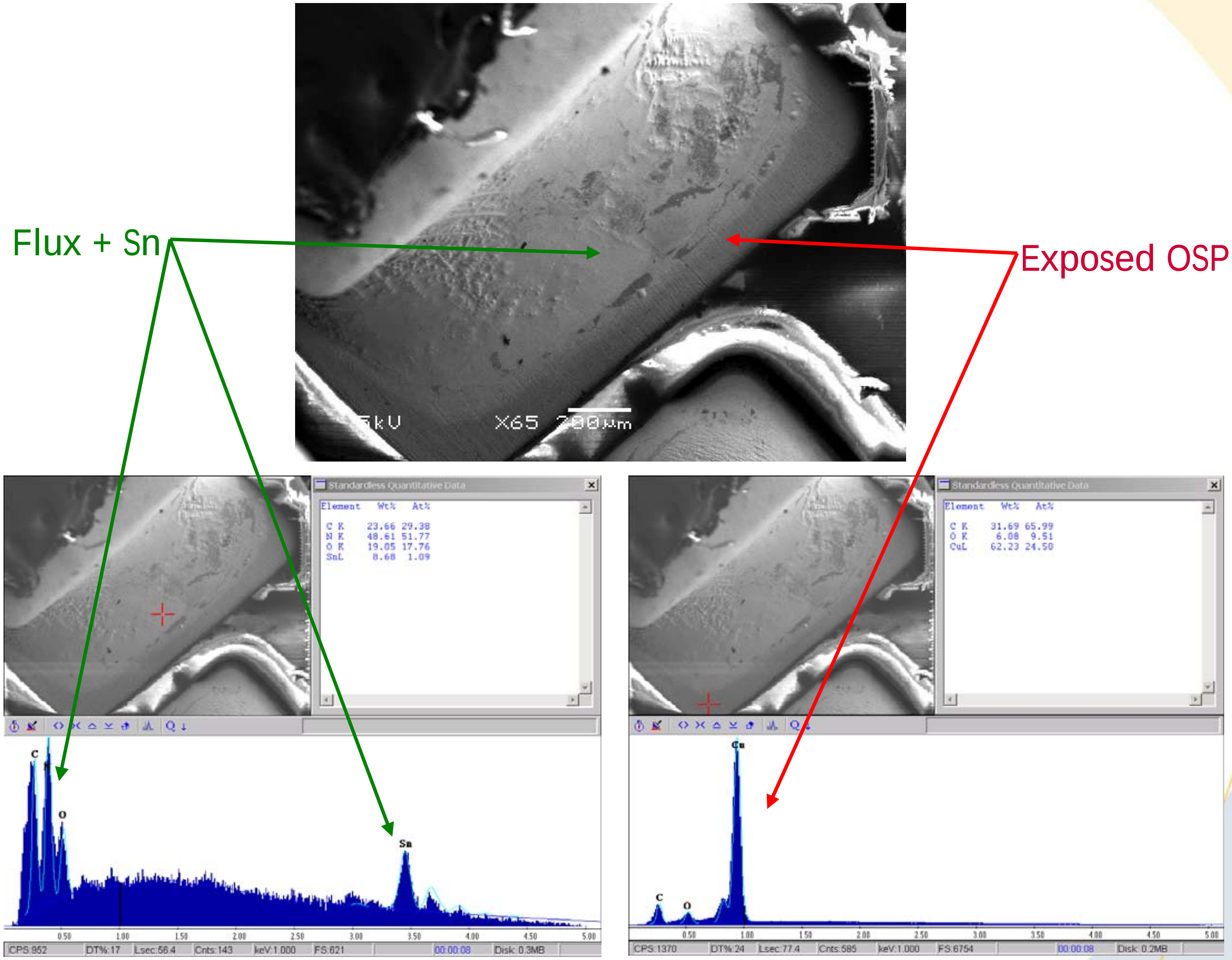


Before MFG Test

Shorts Due to Creep Corrosion

5d MFG

SEM and EDS at 5eV
Samples Before MFG Test



Flux + Sn

Exposed OSP/Cu

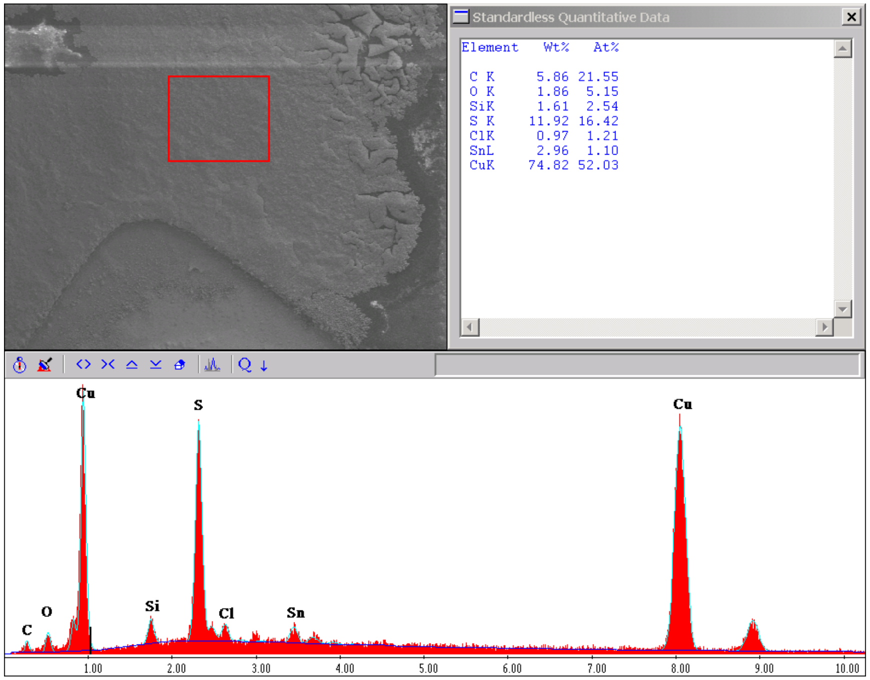
```
Element   Wt%   At%

 C K    23.66 29.38
 N K    48.61 51.77
 O K    19.05 17.76
 SnL     8.68  1.09
```

```
CPS:952  DT%:17  Lsec:56.4  Cnts:143  keV:1.000  FS:621  00:00:08  Disk: 0.3MB
```

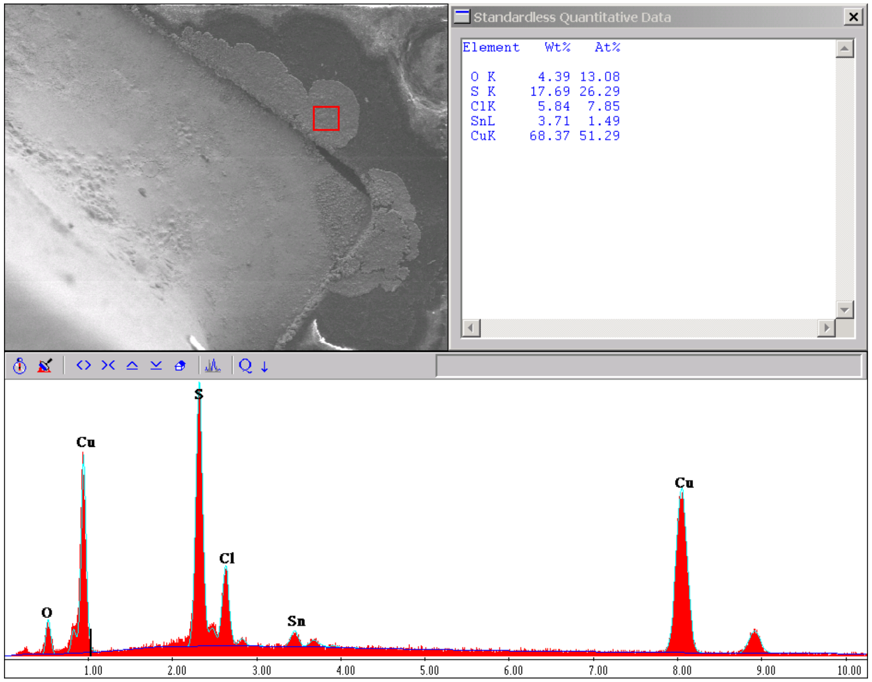
```
Element   Wt%   At%

 C K    31.69 65.99
 O K     6.08  9.51
 CuL    62.23 24.50
```

```
CPS:1370  DT%:24  Lsec:77.4  Cnts:585  keV:1.000  FS:6754  00:00:08  Disk: 0.2MB
```

Composition of Creeping Corrosion Products

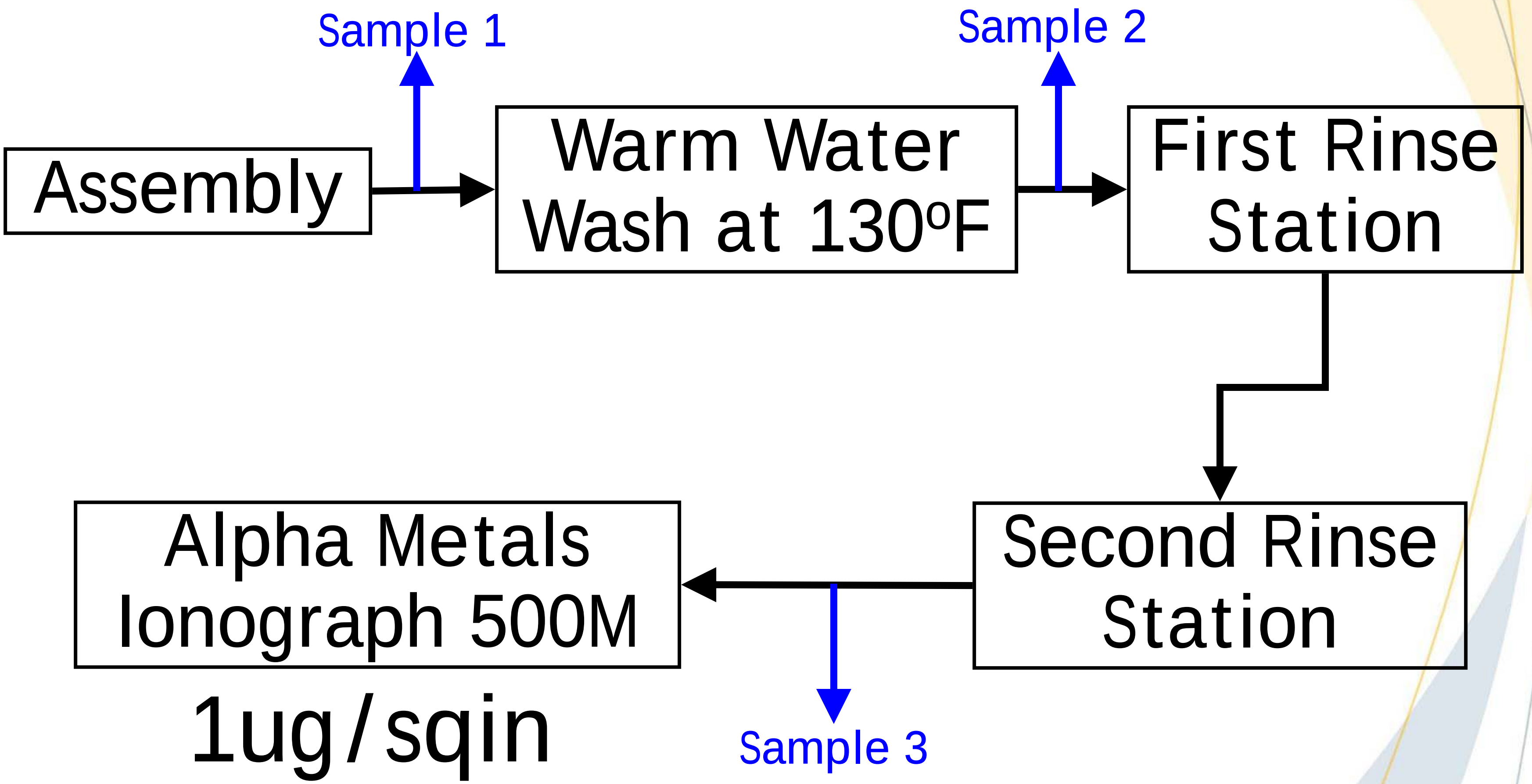


```
Element   Wt%   At%

 C K      5.86 21.55
 O K      1.86  5.15
 SiK      1.61  2.54
 S K     11.92 16.42
 ClK      0.97  1.21
 SnL      2.96  1.10
 CuK     74.82 52.03
```



```
Element   Wt%   At%

 O K      4.39 13.08
 S K     17.69 26.29
 ClK      5.84  7.85
 SnL      3.71  1.49
 CuK     68.37 51.29
```

Cleaning Process



Sample 1

Sample 2

Assembly

Warm Water Wash at 130ºF

First Rinse Station

Second Rinse Station

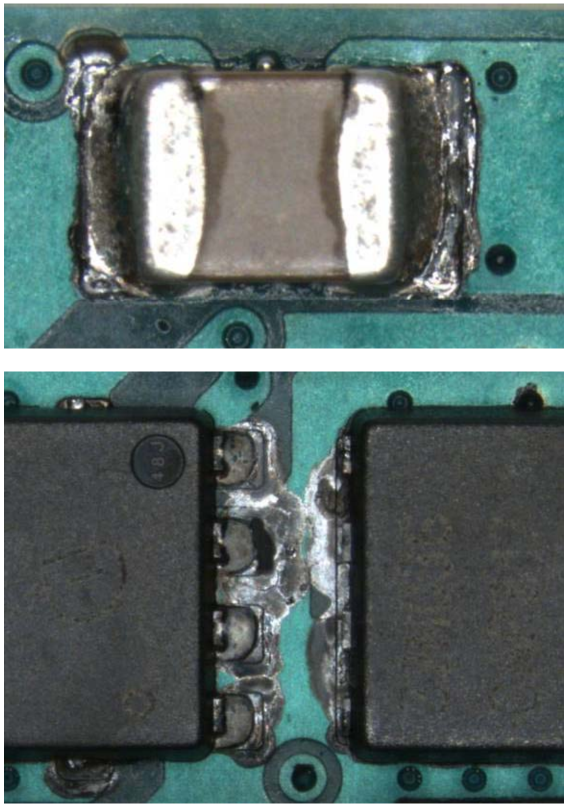
Alpha Metals Ionograph 500M

1ug/sqin

Sample 3

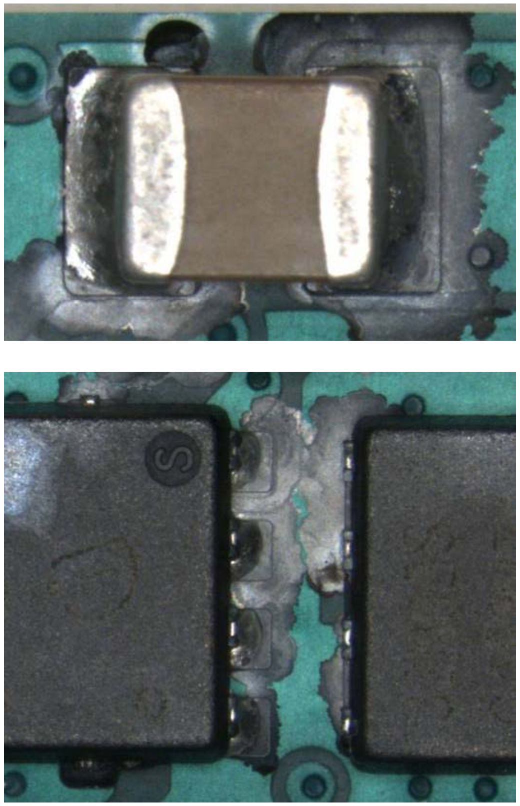
Effect of Post-Reflow Cleaning on Creep Corrosion

Sample 1



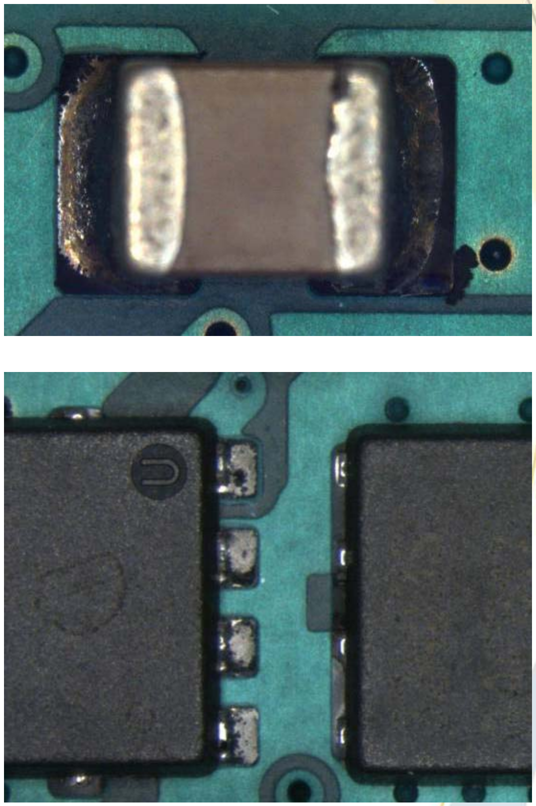
After Reflow

Sample 2



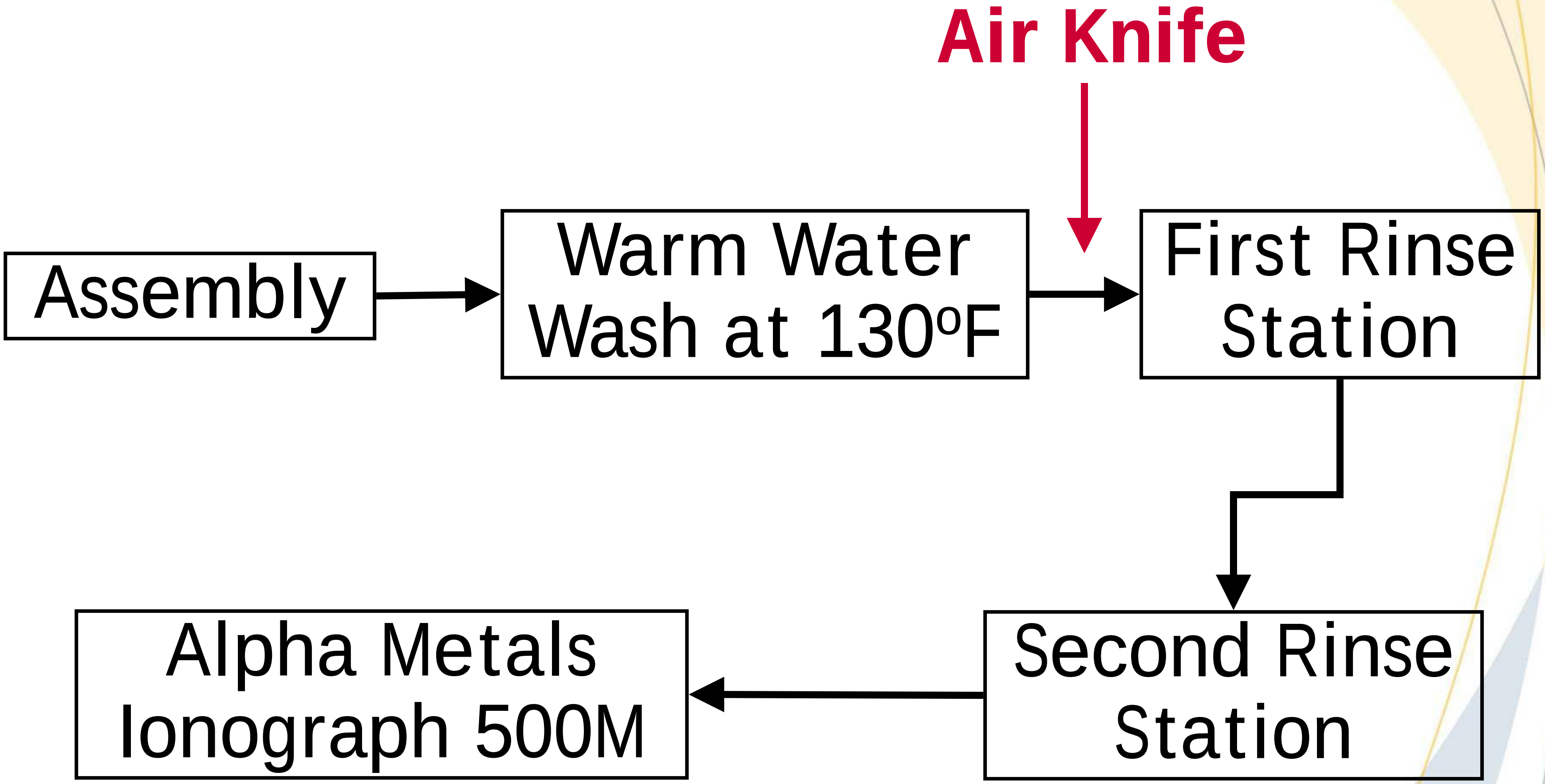
After Wash

Sample 3



After Final Rinse

Modified Cleaning Process



Air Knife

Assembly

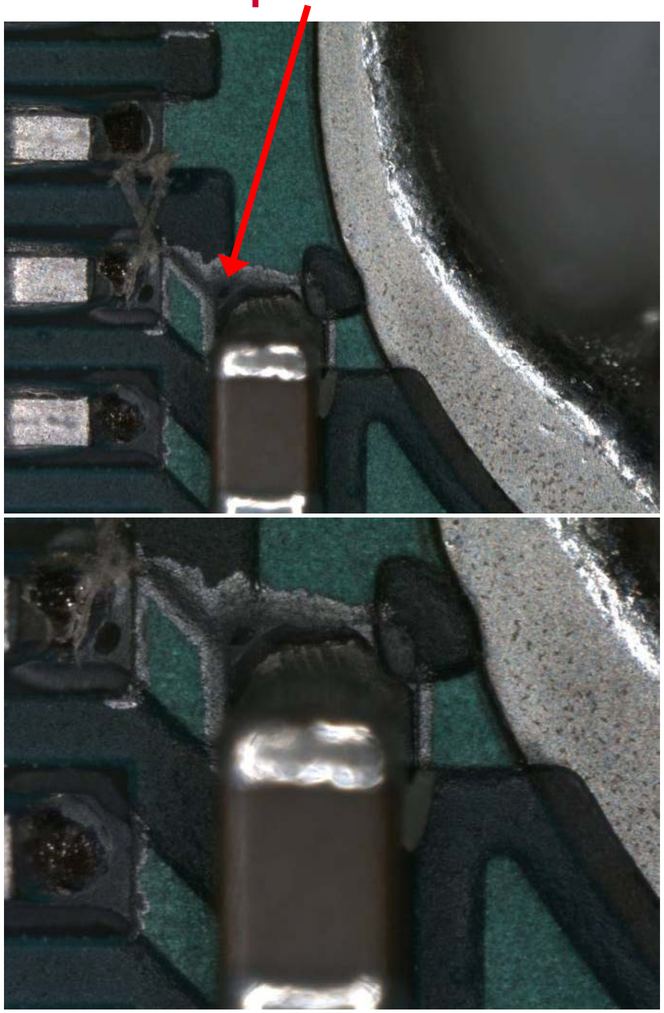
Warm Water Wash at 130°F

First Rinse Station

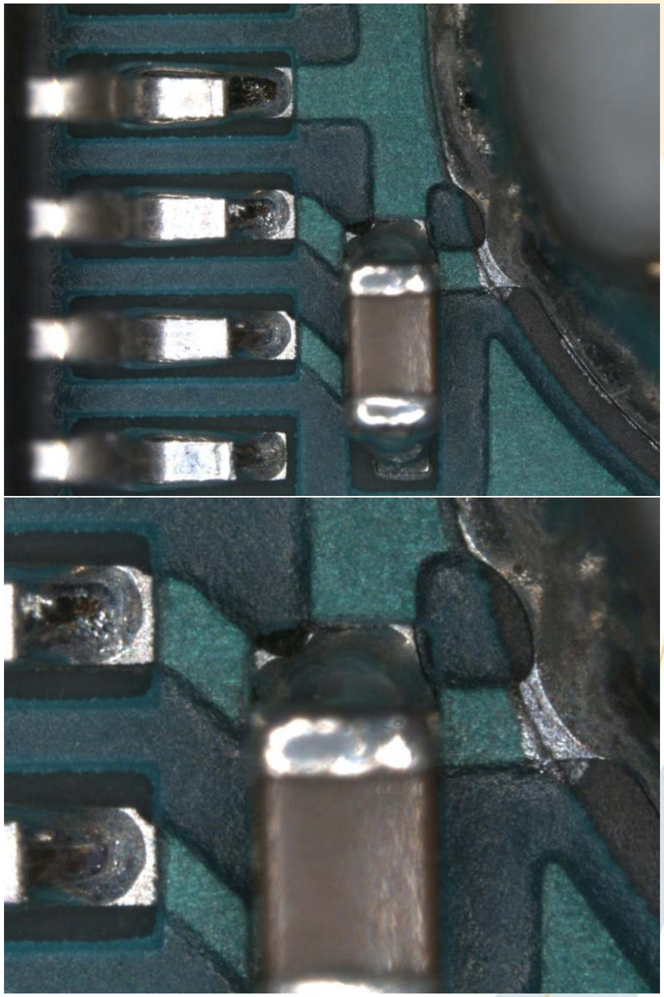
Second Rinse Station

Alpha Metals Ionograph 500M

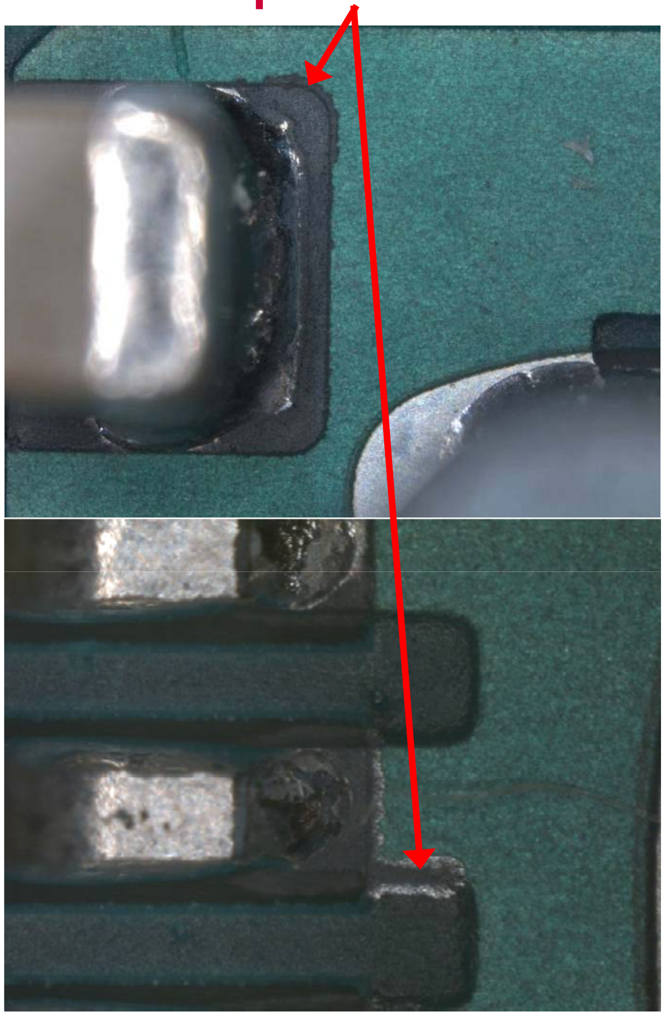
After 7d MFG Test


Creep Corrosion

Without Air-Knife

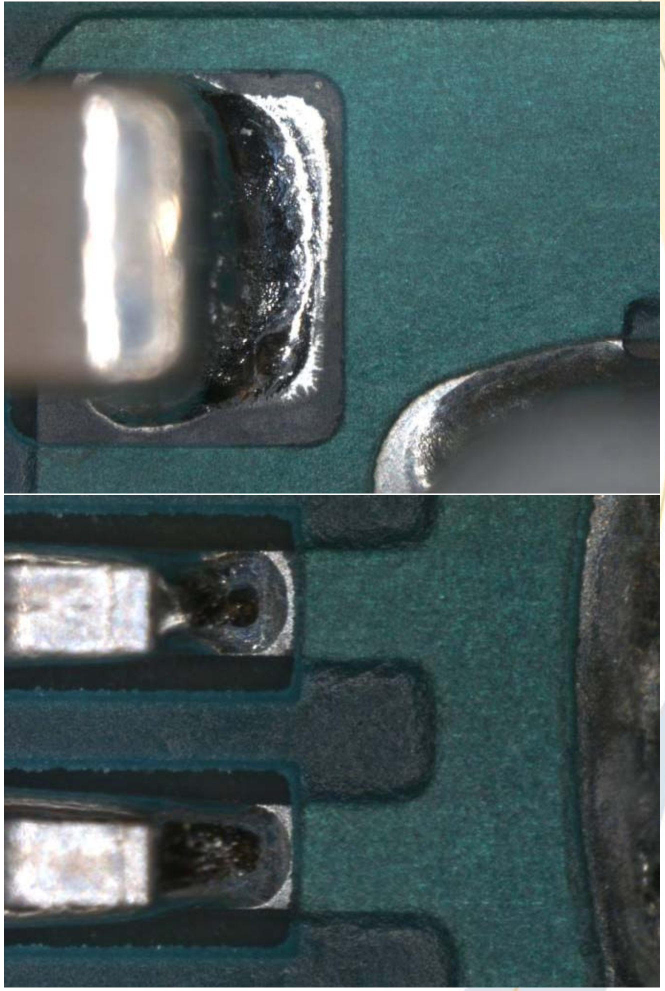

With Air-Knife

After 7d MFG Test



Creep Corrosion

Without Air-Knife



With Air-Knife

Summary

- Creep corrosion on printed circuit boards is not limited to ImAg surface finish and can also occur on OSP. In both cases, the active creeping species is copper sulfide.
- The creep corrosion can be minimized or prevented either by eliminating the corroding site or the creepable surface adjacent to the corroding site. While residues from rosin flux do not promote creep corrosion, the residues of certain type of organic acid fluxes are highly active in promoting the creep of copper sulfide.
- If the circuit boards are assembled using creep promoting fluxes, they have to be cleaned thoroughly to avoid creep corrosion.
- The current IPC cleanliness standard, developed for preventing electrochemical migration on the assembled circuit, is not adequate for preventing creep corrosion, as creep corrosion is sensitive to different type of flux residues than electrochemical migration. A new set of cleanliness standards has to be established for circuit boards prone to creep corrosion.