Originally distributed at the SMTA International Conference on Soldering and Reliability
Toronto, Ontario, Canada; May 14-17, 2013

SERDP Tin Whisker Testing and Modeling: High Temperature/High Humidity Conditions

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ABSTRACT

Driven by European Union directives, most commercial electronics manufacturers began delivering lead-free electronic components, assemblies, and equipment in 2006. As a result of a global movement away from using lead (Pb), component manufacturers are increasingly applying tin-rich finishes to the leads of their devices and soldering with lead(Pb)-free solders. Unfortunately, this can create a risk of tin whisker formation that can result in electrical failures. Motivated by its unique requirements such as long service lifetimes, rugged operating environments, and high consequences of failure, the aerospace and defense industries must mitigate the detrimental effects of tin whisker formation when lead-free materials are used. The present paper provides a status on the effort associated with a multi-year testing and modeling program that aims to assess and quantify tin whisker growth on lead-free manufactured assemblies. The tin whisker growth of tin finished parts soldered with SAC305 (Sn-3.0Ag-0.5Cu) solder alloy under high temperature/high humidity (85 °C/ 85 percent relative humidity) conditions were evaluated. Significant whisker growth was observed from the SAC305 solder alloy, particularly in the fillet regions where it was less than 25 microns thick. Details of the sample inspection and whisker growth results are provided.

Key words: Tin Whiskers, Lead Free, Assembly, Testing, High Humidity, Statistics

BACKGROUND

The elimination of lead (Pb) from consumer electronics has resulted in an increase in tin whisker risk mitigations [1] in aerospace and defense systems using dual-use commercial/aerospace components. Environmental prohibitions of lead in commercial electronics have made these electronic parts and assemblies become more susceptible to tin whiskering. Tin whisker shorting issues were known to be an issue decades ago and at that time whisker issues were solved by the addition of lead into tin. Unlike consumer electronics, aerospace systems can have high consequences of failure and are exposed to many kinds of environmental conditions that promote whisker growth. Some conditions of concern are thermal cycling, vibration, shock, humidity, salt fog, sulfur rich environments, rework, and long term storage.

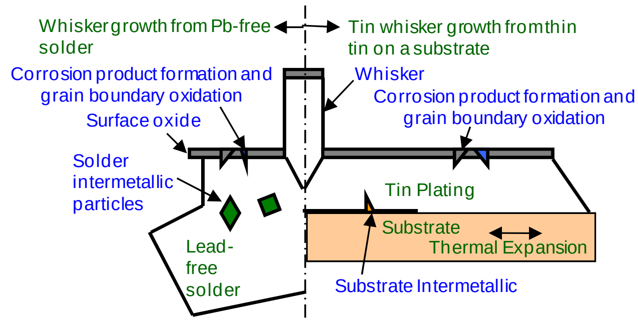

Figure 1: Sources of compressive stress contributing to whisker growth.

There is a need to further understand the combinations of factors that promote whisker growth on assemblies in an effort to improve whisker mitigation practices. The present work is the 85 °C / 85 percent relative humidity environment subset of a systematic tin whisker growth test previously described [2][3][4]. The testing herein is performed on circuit cards with pure tin plated copper and alloy 42 parts soldered with SAC305 (Sn-3.0Ag-0.5Cu).

The dynamic recrystallization model provides a useful means to describe whisker growth [5]. An interesting aspect of the dynamic recrystallization model is that for a given temperature and grain size if the compressive stress in the tin is either too low or too high, whisker growth does not occur. Figure 1 shows several sources of compressive stress in a typical tin plated lead and solder joint. Corrosion product formation and grain boundary oxidation can increase the tendency of tin to whisker [6][7][8]. Further, intermetallic compound oxidation in the presence of rare earth elements [9] and intermetallic formation at the substrate interface [10][11] can also contribute to whisker formation. In addition, thermal cycling coupled with a expansion differences between the substrate and the tin can also cause whisker growth [12][13].

TEST VEHICLE AND ENVIRONMENT

The test variables are given in Figure 2. The custom designed test board used for the lead-free soldered assembly whisker growth testing is shown in Figure 3 and the parts are summarized in Table 1. The printed circuit board is a 6 cm x 6 cm x 2.36 mm thick double sided glass epoxy board with 1 ounce copper external base layers. The board surface finish is immersion tin. The test vehicles fit easily into the scanning electron microscope (SEM) sample chamber. The part placement area was limited to 5 cm x 5 cm to ensure all leads of interest were contained in a region that could be viewed by the SEM. Each board is designed with enough parts to have 50 to 100 leads for each part type.

The present work assemblies used the same lot of parts and were soldered at the same time as the assemblies used in the low stress simulated power cycling (+50 to +85 C thermal cycling) [4]. The part and assembly contamination combinations are shown in Figure 5. In preparation for assembly, an initial parts inspection was performed and then samples were examined using SEM and cross-sectioning. Following this, the parts were divided into clean and contaminated groups. The parts needing cleaning were placed in a KPak® bag with a solution of 10% IPA / 90% v/v deionized water and sealed. The parts were then exposed to two cycles of heating and agitation using the following procedure: 40 minutes in steam bath at 80°C (to provide controlled elevated temperature), followed by 40 minutes on a vibration shaker table to agitate the solution. Then the parts were removed from the bags, placed lead-side-up in clean aluminum dishes and baked at 60°C for 10 minutes. The parts requiring contamination were immersed in a beaker containing a solution of 166 ppm NaCl in deionized water. The solution and parts were then poured through a stainless steel mesh (previous cleaned with isopropyl alcohol). The parts on the mesh were then placed in an oven to dry at 60°C for 10 minutes. (Note during the development of the contamination procedure, it was found that pre-cleaning the parts was not necessary to ensure proper contamination). A target of 3 $\mu g/in^2$ contamination level was selected because it was within the level observed on typical production parts; not the cleanest, but also not the most contaminated. The boards were not specially cleaned prior to soldering.

Then the parts were soldered with SAC305 solder. After assembly, all the boards were cleaned. Then selected boards were re-contaminated by immersion in a solution of 160 ppm NaCl in deionized water, placed with the components facing up on aluminum pans that angled the boards ~10 degrees. The pans were then put in an 85 °C oven for one hour. The assemblies were contaminated to a contamination level low enough to allow electrical operation without dendrite formation.

Three board replicates were tested at 85 °C/85 percent relative humidity in the chamber shown in Figure 6. The temperature control was performed using thermocouples and humidity was controlled using both dry bulb temperature and wet bulb temperatures. A sheet metal shield was placed above the samples to ensure no condensation would collect on the samples. As shown in Figure 7, the samples were hung in a vertical position Inspections were performed at 1,000 hours and 4,000 hours.

The electrical schematic for the test vehicle is shown in Figure 4. The SOT3 and SOT5 parts on the left half of the board are connected to 5V and on the right half are connected to ground. The SOT6 parts are not connected. The board current draw was 31 mA resulting in only 155 mW power dissipation with negligible self heating. There are two bias parameters used to define the voltage state on the parts (bias1) and leads (bias2). All SOT6 parts and pins are no-connects so bias1 is zero and bias2 is zero. For the SOT3 and SOT5 parts that are grounded (V=0), bias1 is zero. Since the grounded SOT3 and SOT5 parts have all leads connected to ground (0V), all leads are assigned a bias2 of zero. For the parts with power applied in accordance with the schematic, bias1 is five. For the powered parts, the leads SOT3-1, SOT3-3, SOT5-2 and SOT5-5, bias2 is five and for the remaining leads bias2 is zero.

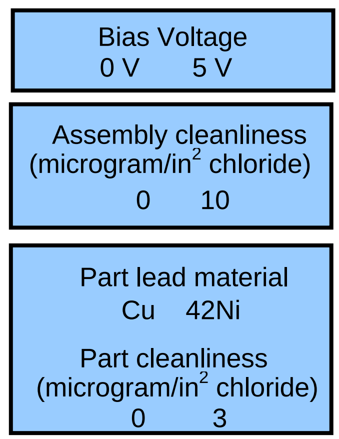

Figure 2: Experimental matrix

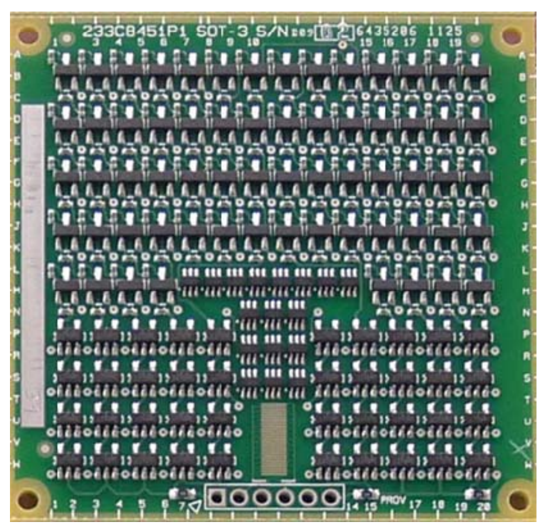

Figure 3: Test vehicle.

Table 1: Parts

Designation Part No. Package	Lead Frame Matl	Plating Matl	No. of Leads/ No. of parts
SOT3 2N7002 SOT23-3	Alloy 42(1)	Matte Sn	3/64
SOT5 NC7S08M5X SOT23-5	Cu194	Matte Sn	5/40
SOT6 2N7002DW-7-F SOT363	Alloy 42(1)	Matte Sn	6/17
Note (1): From the manufacturer’s data sheet the alloy is Fe39-41Ni-0.6Mn-0.05Cr-0.02Si-0.05C			

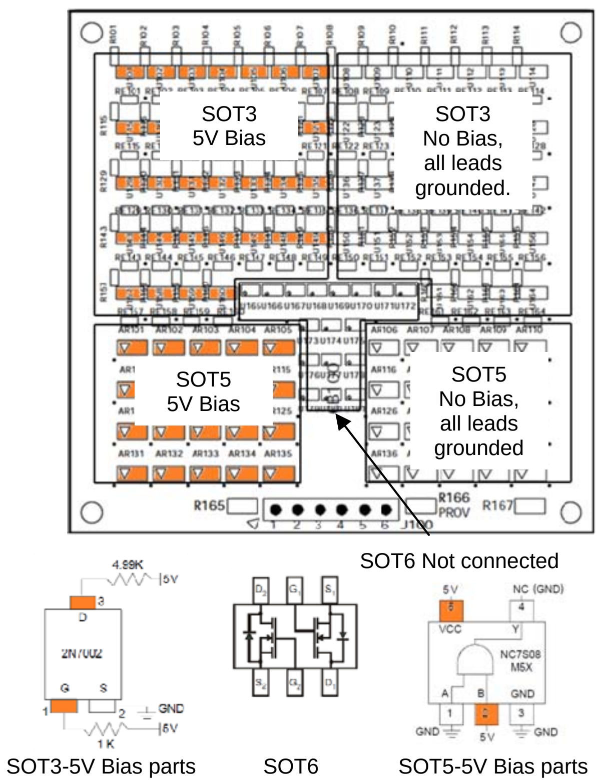

Figure 4: Electrical schematic

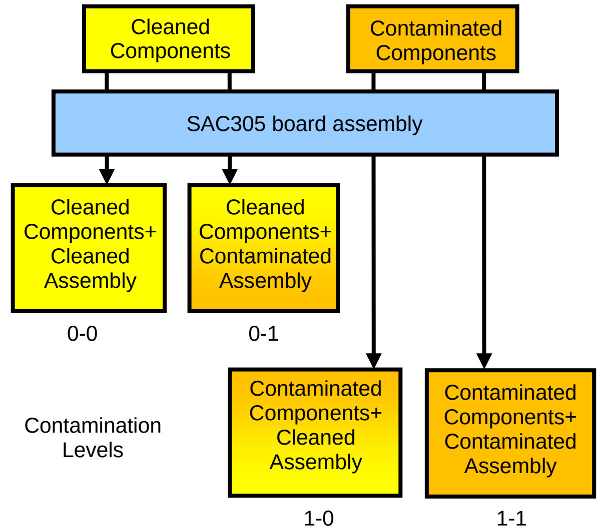

Figure 5: Experiment contamination levels

Figure 6: Temperature/humidity chamber

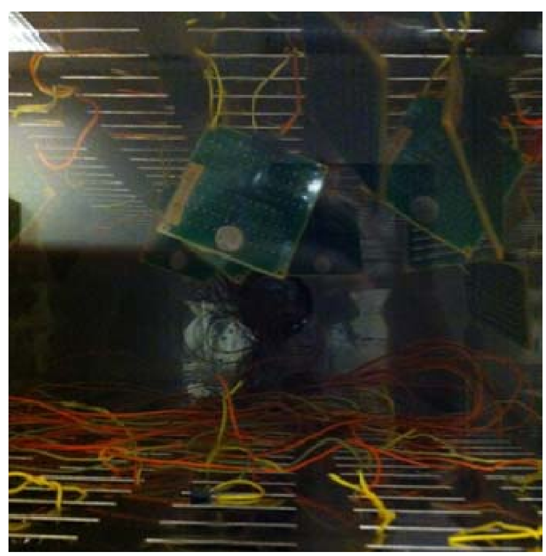

Figure 7: Sample orientation in the test chamber

INITIAL INSPECTION

Summarizing the details previously reported [4], there were no significant anomalies in the plating that would influence assembly solder joint quality. However as shown in Figure 8, some lead conditions exist that would increase whisker risk such as exposed base metal that increases galvanic corrosion potential and plating features that could trap contamination and increase corrosion induced whiskering.

CLEANING AND CONTAMINATION

The part and assembly cleaning and contamination were done at the same time as was previously reported [4]. The cleaned part contamination levels are given in Table 2. The contamination levels of the purposely contaminated parts are shown in Table 3. The goal was to have the part level contamination equal to 3.0 µg/in^2 Cl$^-$, but more contamination was trapped by SOT5 and SOT6 because they had rougher lead surfaces and greater numbers of gaps than the SOT3s. The contamination segregated on the tin surface to the rough regions, grain boundaries and plating gaps (see typical view in Figure 9).

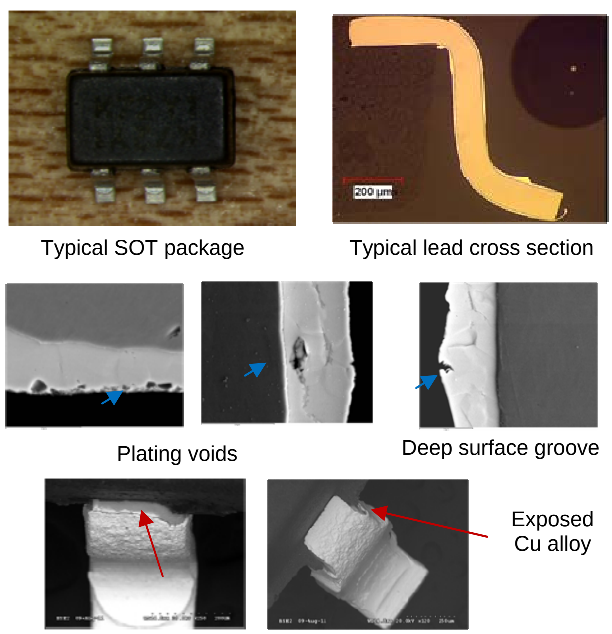

Figure 8: SEM and optical images of as-received part lead conditions contributing to whisker growth.

Table 2: Part contamination levels after cleaning

Part	Total Inorganic anions (µg/in²)	Total Organic anions (µg/in²)
SOT3	0.4	3.3
SOT5	0.2	0
SOT6	0.2	3.5

Table 3: Part Recontamination Levels

Part	Total Inorganic anions (µg/in²)	Total Organic anions (µg/in²)
SOT3	2.3	0
SOT5	8.7	0
SOT6	7.4	0

Following the contamination process, the SAC305 assembly soldering was performed. The boards were populated entirely either with clean parts or contaminated parts. After soldering and flux residue cleaning, selected boards were contaminated at the assembly level to 10 µg/in^2 Cl$^-$ to simulate the maximum level of contamination allowed by the J-STD-001 ionic residues test [14]. The assemblies were immersed in a solution of 160 +/- 10 ppm NaCl and then baked dry in an oven.

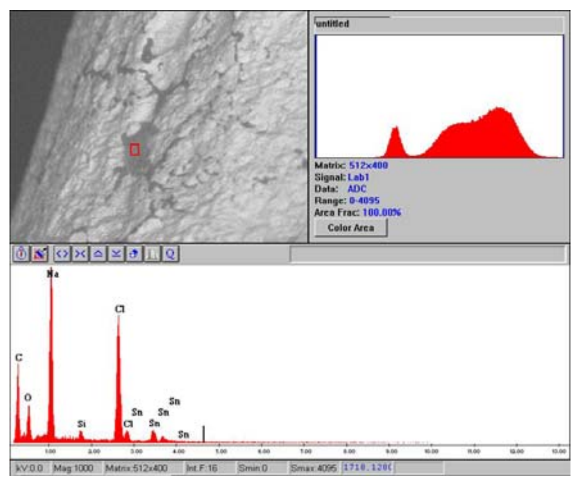

Figure 9: Contamination regions on recontaminated SOT5.

The resulting assembly contamination level of the purposely contaminated assemblies was 5.2 ppm Cl$^-$ by ion chromatography with a total concentration of 12.5 µg/in^2 equivalent Cl$^-$ as measured by resistivity of solvent extraction.

INITIAL ASSEMBLY CROSS-SECTIONS

After soldering, the solder coverage and intermetallic compounds were characterized using cross-sectioning [4]. As shown in Figure 10, Figure 11 and Figure 12, the SOT3 and SOT6 leads were fully covered in solder, but the SOT5 leads were not. The thinnest intermetallic was observed on the alloy 42 leads. The SOT3 part was found to have Cl trapped at the thinnest part of the joint between the lead and Cu pad.

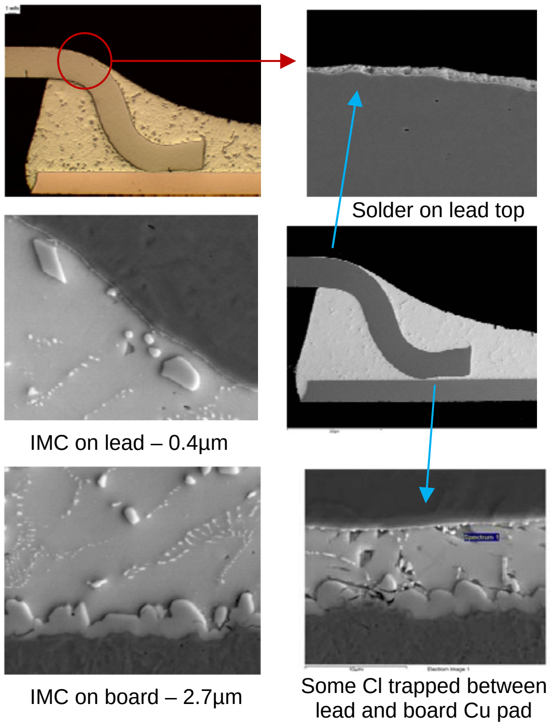

Figure 10: SEM and optical images of the SOT3 soldered assembly cross-section.

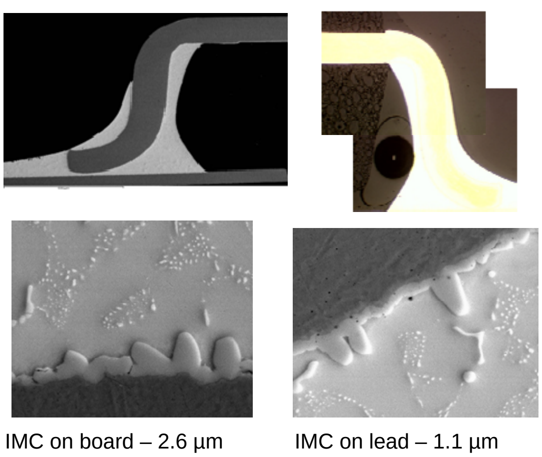

Figure 11: SEM and optical images of the SOT5 soldered assembly cross-section.

WHISKER GROWTH RESULTS

The parts were randomly selected for inspection such that 50 to 100 leads of each part were examined. SEM photographs of all the leads were taken and post processed to obtain whisker density. The whisker length criterion in JESD22A121A was used to perform the whisker length measurements [15] in the SEM. Whisker diameter was also measured in the SEM. A unique aspect of measuring whiskers on part solder joints is that nothing is planar and the sample must be continually rotated and tilted during the inspection. As the stage is tilted, the whisker length appears to increase until the SEM inspection azimuth angle is perpendicular to the whisker. Further tilting results in whisker beginning appear shorter.

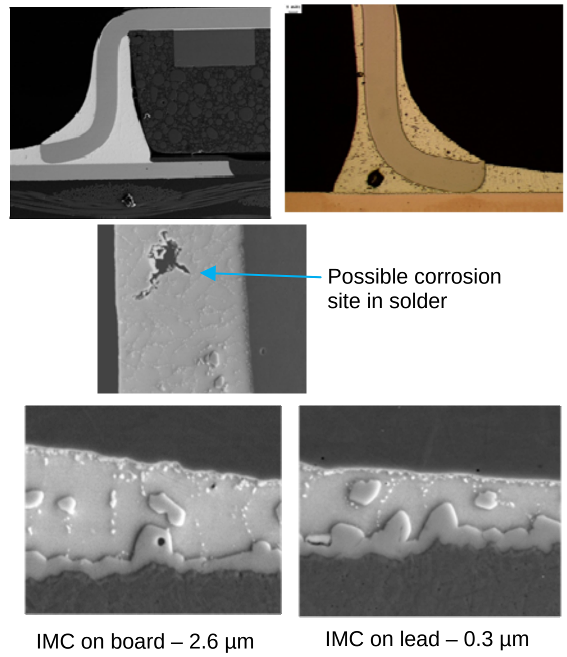

Figure 12: SEM and optical images of the SOT6 soldered assembly cross-section.

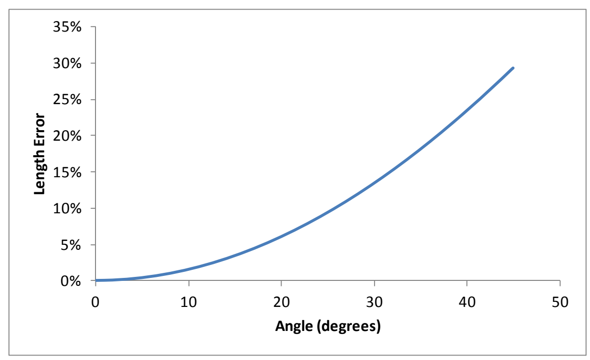

Figure 13: Whisker measurement error estimate.

In the present work, the reported whisker length measurements are conservative. During the length measurement procedure, the SEM inspection azimuth axis was adjusted to be aligned to within ~30 degrees from perpendicular to the whisker. The SEM axis mis-alignment from the whisker normal results in a potential whisker length under-reporting of up to 15 percent as shown in Figure 13.

1,000 HOUR INSPECTION:

A total of 15,564 whiskers were counted and 4,741 whiskers were measured (see Table 4 - Table 7). The whisker lengths were longer for copper than alloy 42 lead materials (see Figure 14). The longest whiskers were: SOT3 – 74 microns, SOT5 – 186 microns and SOT6 – 54 microns. As shown in Figure 15 and Figure 16, the majority of the whiskers grew from the thin solder fillet regions that were 3 to 25 microns thick near the printed circuit board copper pad and many were kinked.

Table 4: Whisker measurement summary after 1,000 hours at 85 °C/85 percent relative humidity

Component	Counted	Measured	Percent measured
SOT3	2438	867	35.6
SOT6	1106	486	43.9
SOT5	12020	3388	28.2
Total	15564	4741	30.5

Table 5: SOT5 (copper leads) whisker distribution

Cleanliness	Counted	Number of components	Whiskers per component
0-0	1566	11	142.4
1-0	4094	12	341.2
0-1	3531	12	294.3
1-1	2829	20	141.5

Table 6: SOT3 (alloy 42 leads) whisker distribution (Note that more SOT3 parts were examined because it has fewer leads than the SOT5 and SOT6 parts)

Cleanliness	Counted	Number of components	Whiskers per component
0-0	407	16	25.4
1-0	998	16	62.4
0-1	684	16	42.8
1-1	349	24	14.5

Table 7: SOT6 (alloy 42 leads) whisker distribution

Cleanliness	Counted	Number of components	Whiskers per component
0-0	195	8	24.4
1-0	278	8	34.8
0-1	269	8	33.6
1-1	364	12	30.3

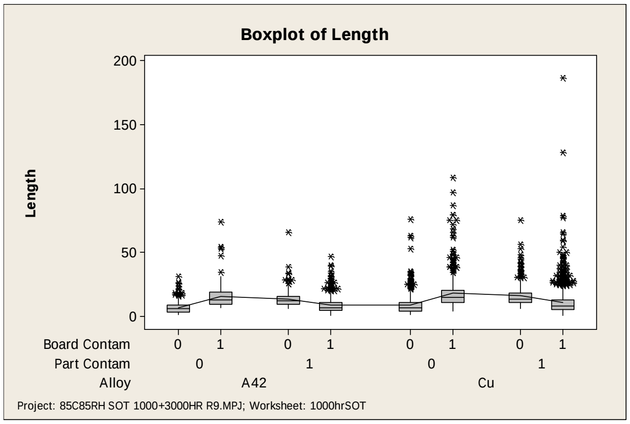

Figure 14: Box plot of whisker lengths after 1,000 hours at 85 °C/85 percent relative humidity broken down by lead alloy, part contamination, and board contamination levels (Note: Bias2=0).

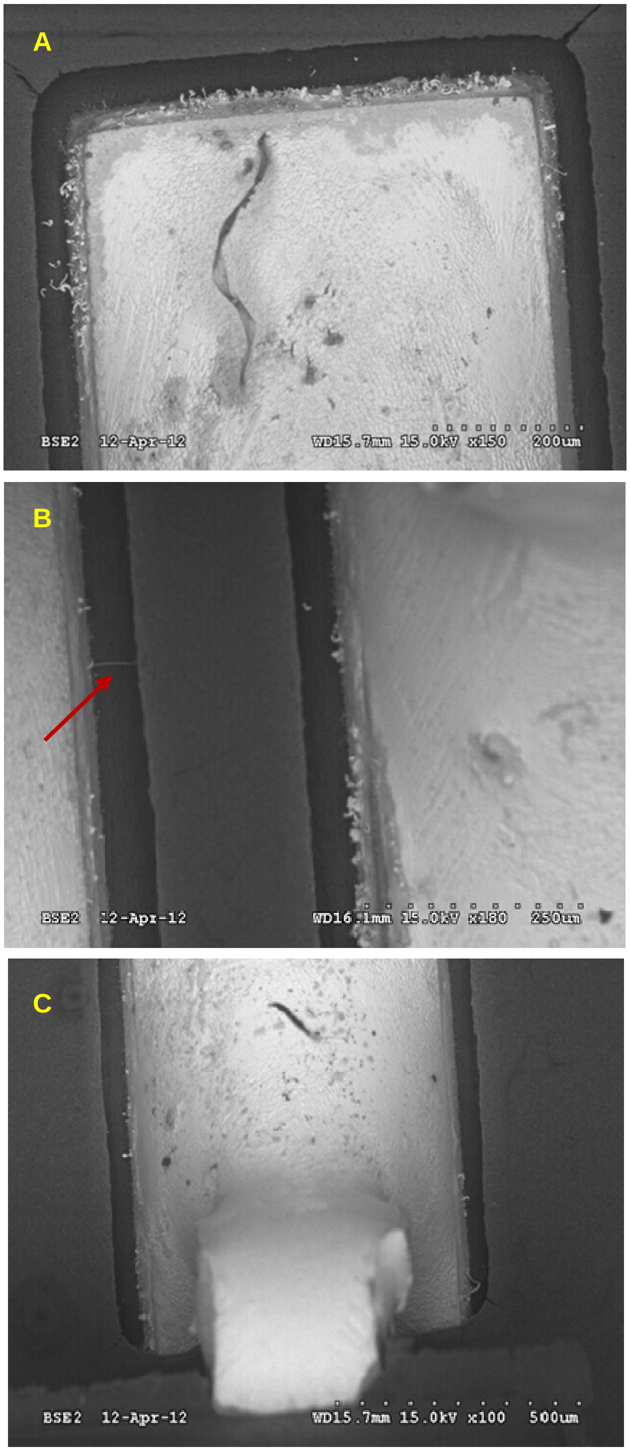

Figure 15: SEM images of copper lead frame SOT5 part with a 1-0 contamination level after 1,000 hours at 85 °C/85 percent relative humidity; (A) toe, (B) side, and (C) heel region of a typical solder joint. In (B), an arrow indicates the location of a lone straight whisker along the edge.

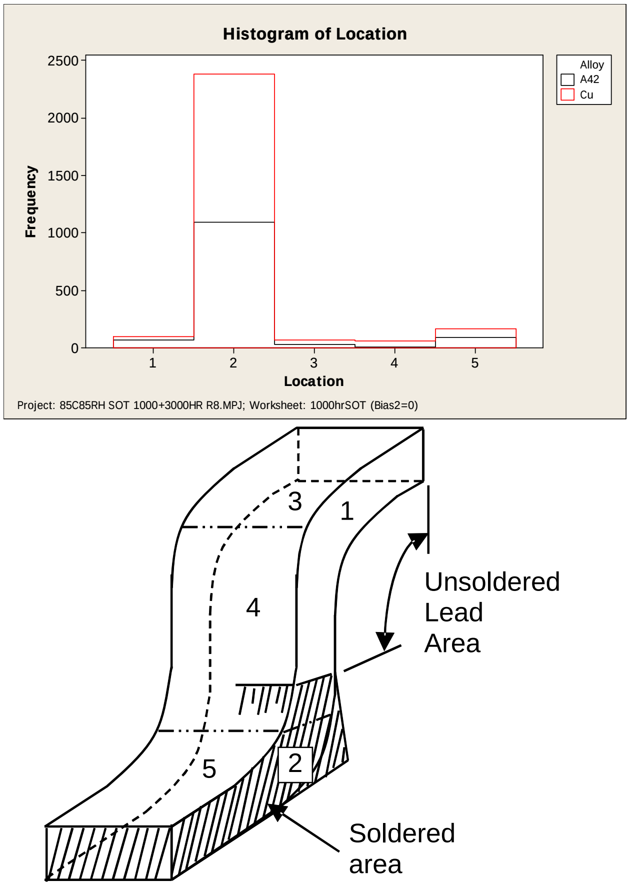

Figure 16: Whisker locations after 1,000 hours at 85 °C/85 percent relative humidity; histogram (top) and location definition (bottom)

Lead material and contamination had the most significant influence on whiskering. The number of whiskers per lead was greater for the copper leads than the alloy 42 leads for all contamination levels (see Figure 17). The whisker density and whisker length depended upon contamination level. The intermediate 0-1 and 1-0 (part-board) contamination levels exhibited the greatest whisker density and longest 50th percentile whisker length (see Figure 17, Figure 18 and Figure 19). However, for the copper leads, the longest whiskers were observed with the 1-1 contamination level.

The lognormal curve fit [16][17][18] seem to represent many of the whiskers length distributions reasonably well. Unfortunately some of the longest whiskers did not seem match the lognormal characteristic of the shorter whiskers [19].

Regarding bias voltage, there was no appreciable change in whisker length with applied bias (see Figure 20 through Figure 23). Since the contamination levels were low enough to ensure that there would be no dendrite formation risk, the electrochemical bias effect may not significantly influence whiskering.

As far as whisker diameter is concerned, as shown in Figure 24 and Figure 25, the majority of whiskers were between 1 and 5 microns regardless of alloy or contamination level. In addition, the longer whiskers tended to be smaller in diameter while the largest diameter whiskers tended to be short.

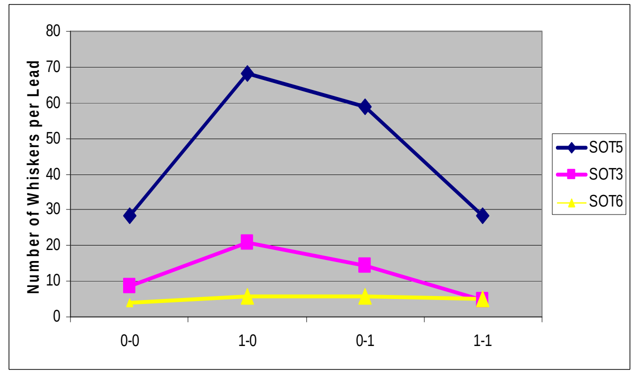

Figure 17: Whiskers per lead after 1,000 hours at 85 °C/85 percent relative humidity for various contamination levels. The SOT5 device has copper leads and the SOT3 and SOT6 devices have alloy 42 leads.

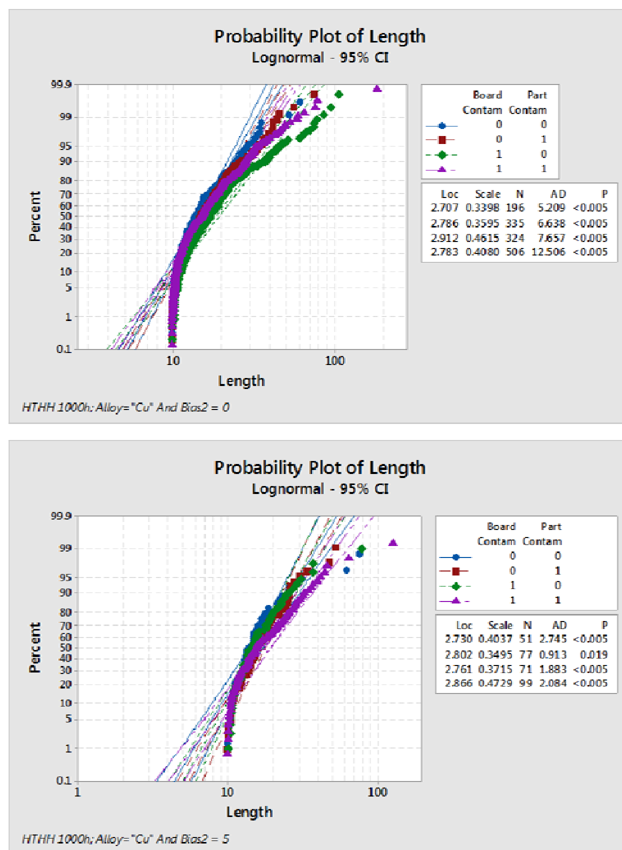

Figure 18: Probability plot of tin whisker lengths longer than 10 microns from copper part lead terminations after 1,000 hours at 85 °C/85 percent relative humidity; bias2= 0 (top) and bias2 =5 (bottom) levels broken down by part contamination, and board contamination.

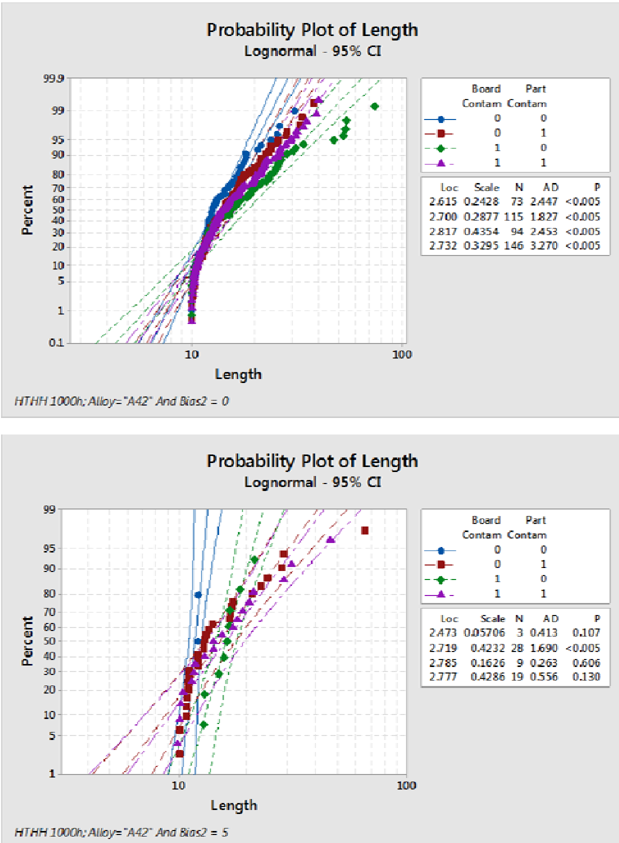

Figure 19: Probability plot of tin whisker lengths longer than 10 microns from alloy 42 part lead terminations after 1,000 hours at 85 °C/85 percent relative humidity; bias2=0 (top) and bias2=5 (bottom) levels broken down by part contamination, and board contamination.

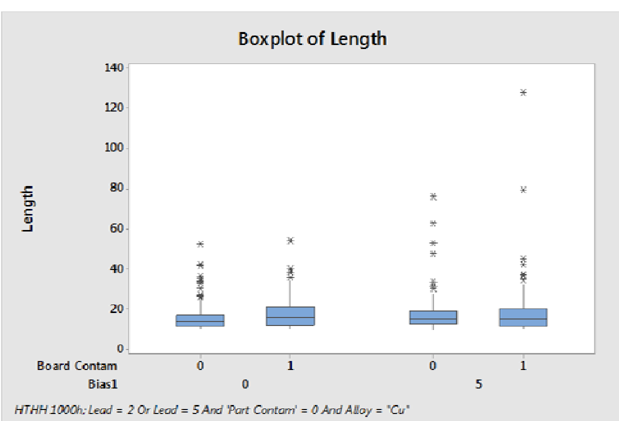

Figure 20: Box plot of tin whisker lengths longer than 10 microns from copper part lead terminations after 1000 hours showing the effect of board contamination and bais1 with no part contamination.

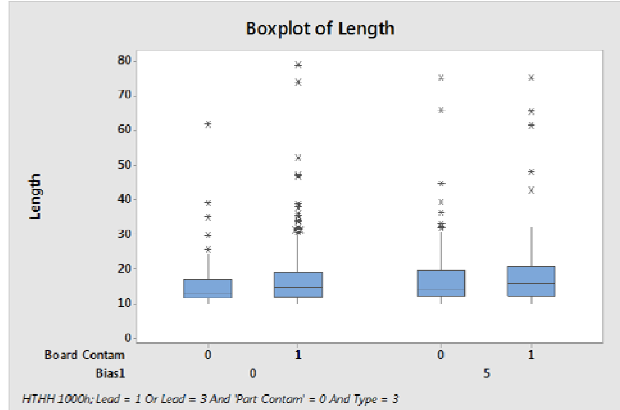

Figure 21: Box plot of tin whisker lengths longer than 10 microns from alloy 42 part lead terminations (SOT3 device) after 1000 hours showing the effect of board contamination and bais1 with no part contamination

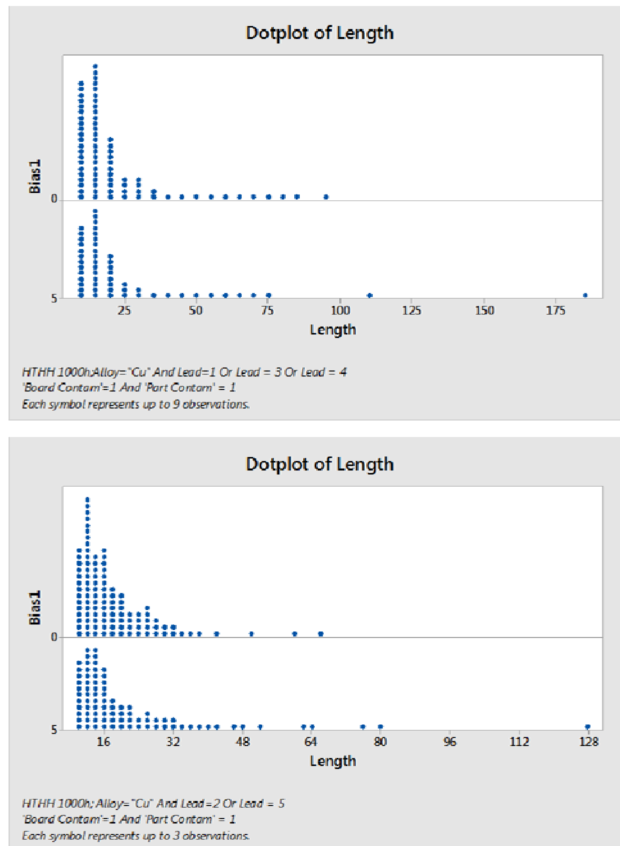

Figure 22: Dot plot of whisker lengths longer than 10 microns from copper part lead terminations (SOT5) at a 1-1 contamination level after 1,000 at 85 °C/85 percent relative humidity; ground leads (top) and 5V leads (bottom) with and without 5V part bias applied (e.g. bias1=0 and 5).

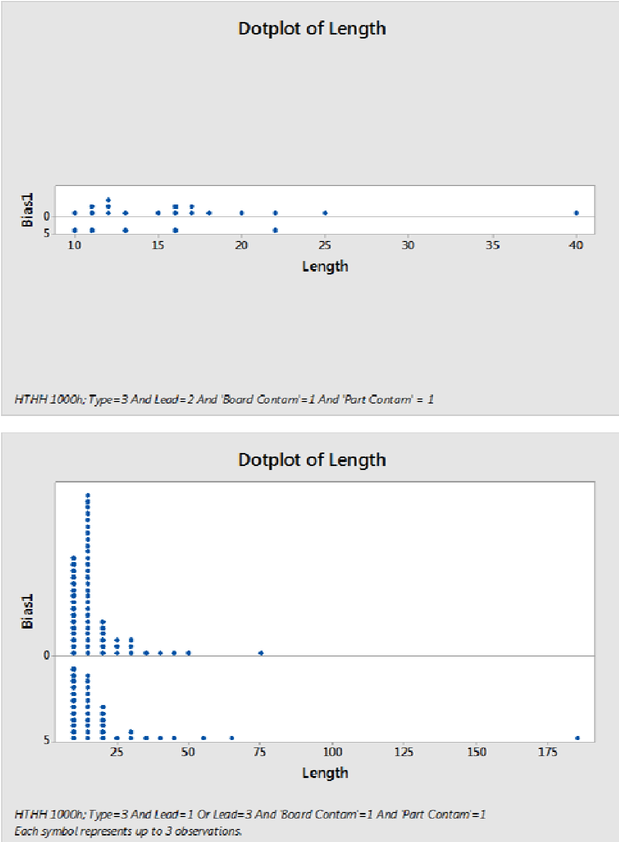

Figure 23: Dot plot of whisker length for alloy 42 leads (SOT3) at a 1-1 contamination level after 1,000 at 85 °C/85 percent relative humidity; ground leads (top) and 5V leads (bottom) with and without 5V part bias applied (e.g. bias1=0 and 5).

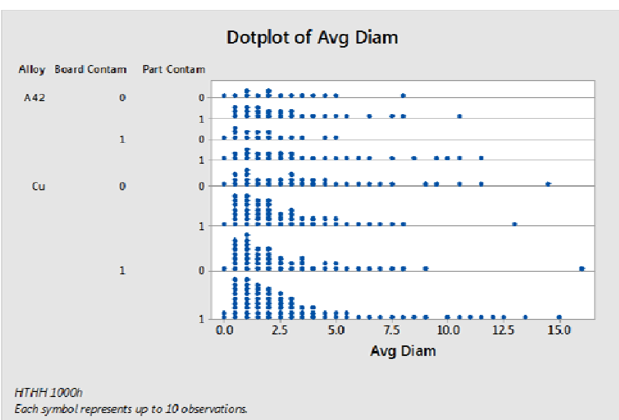

Figure 24: Dot plot of whisker diameter of whiskers longer than 10 microns after 1,000 hours at 85 °C/85 percent relative humidity broken down by lead material, part contamination and board contamination.

4,000 HOUR INSPECTION:

After the 1,000 hour inspection was completed, the boards were placed back in the humidity chamber for an additional 3,000 hours and then removed. Then the exact same parts and leads previously examined at 1000 hours were reassessed. The numbers of whiskers counted and measured are summarized in Table 8.

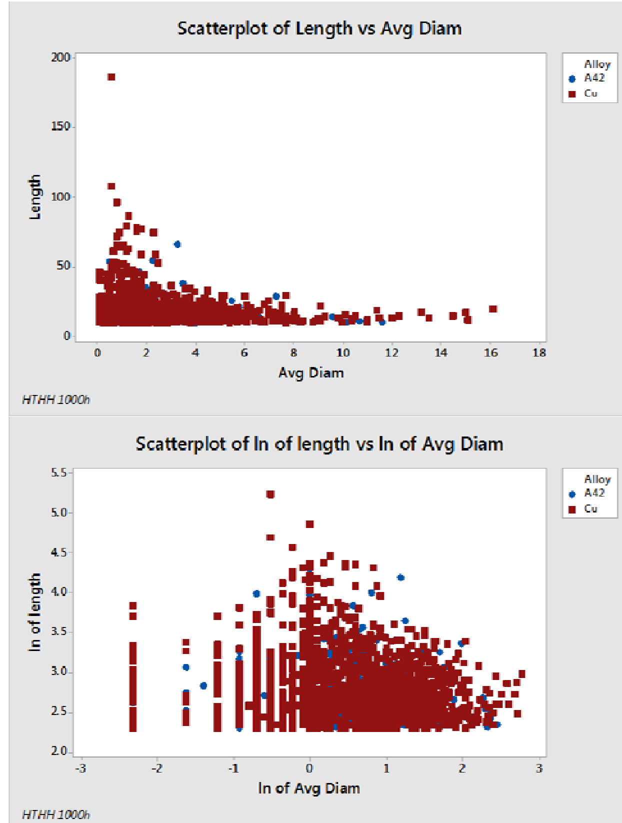

Figure 25: Scatterplot of whisker length versus diameter of whiskers longer than 10 microns for copper and alloy 42 leads after 1,000 at 85 °C/85 percent relative humidity. Bottom image shows the ln(length) versus ln(diameter) plotted.

After 4,000 hours 75,386 whiskers were counted, 4.84 times more than were counted after 1,000 hours. In an effort to manage the inspection time, only whiskers longer than about 40 microns were measured. Data on 489 whiskers has been recorded. Lognormal length distributions are not being reported because it was unclear how to best to treat the whiskers population below 40 microns that were not measured.

The longest whiskers were: SOT3 – 142 microns, SOT6 – 153 microns, and SOT5 - 214.6 microns. Note that for the 4,000 hour inspection interval, no whiskers shorter than 30 microns were measured in an effort to focus inspection resources on the longest whiskers. The individual value plot in Figure 26 shows that more "whiskers longer than 40 microns" and longer whiskers were observed after 4,000 hours as compared to 1,000 hours. As with the 1,000 hour observation, copper leads grew longer whiskers than alloy 42 leads. The probability plot shown in Figure 27 compares the whiskers observed at 1,000 and 4,000 hours. The lognormal location and scale parameter vary considerably. The box plot of whiskers per lead shown in Figure 28 indicates that the mean number of whiskers per lead was greater with the copper leads.

Another consideration in the whisker growth process is whisker nucleation time. If a long time is required to nucleate the whiskers, then the fraction of time that they are growing is reduced. Figure 29 reveals that more than 1,000 hours was needed for whisker nucleation with the alloy 42 lead in the 85 °C/85 percent relative humidity environment with SAC305 solder.

Table 8: Whisker measurement summary after 4,000 hours at 85 °C/85 percent relative humidity

Component	Counted	Measured whiskers(1)	Percent Measured
SOT3	24639	197	0.8
SOT6	37641	185	0.5
SOT5	13106	107	0.8
Total	75386	489	0.6

Note 1: Measurements limited to whiskers longer than 40 microns

Another important consideration is that other copper leaded parts included in the humidity test also have exhibited significant whisker growth at the 4,000 hour inspection interval. While not part of the main design of experiments, the QFP64 in Figure 30 exhibited a significant increase in whisker growth. While small whiskers were observed at 1,000 hours, at 4,000 hours it had whiskers long enough to nearly bridge between the printed circuit board pads.

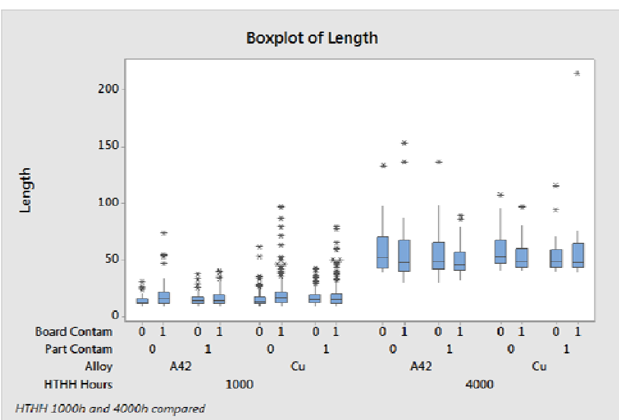

Figure 26: Box plot of whisker length showing the difference between 1,000 and 4,000 hours at 85 °C/85 percent relative humidity. Only whiskers longer than 40 microns were measured in the 4,000 hour data set.

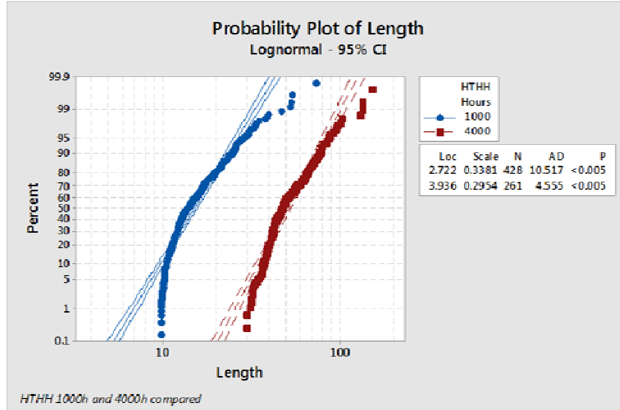

Figure 27: Probability plot of comparing whisker lengths after 1000 hours and 4000 hours at 85 °C/85 percent relative humidity. The 1000 hour data includes whiskers longer than 10 microns and the 1000 hour data includes whiskers longer than approximately 40 microns.

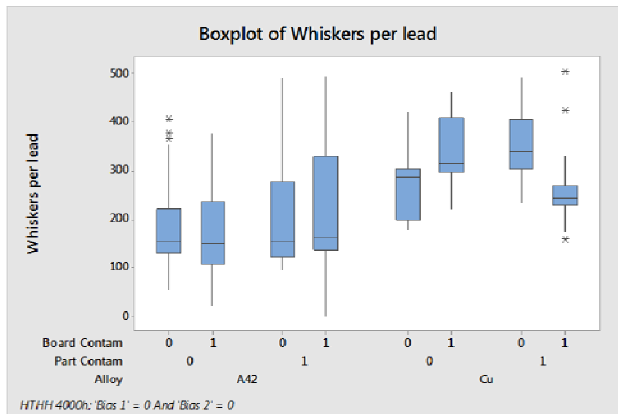

Figure 28: Box plot of whiskers per lead after 4,000 hours at 85 °C/85 percent relative humidity broken down by lead alloy, part contamination and board contamination.

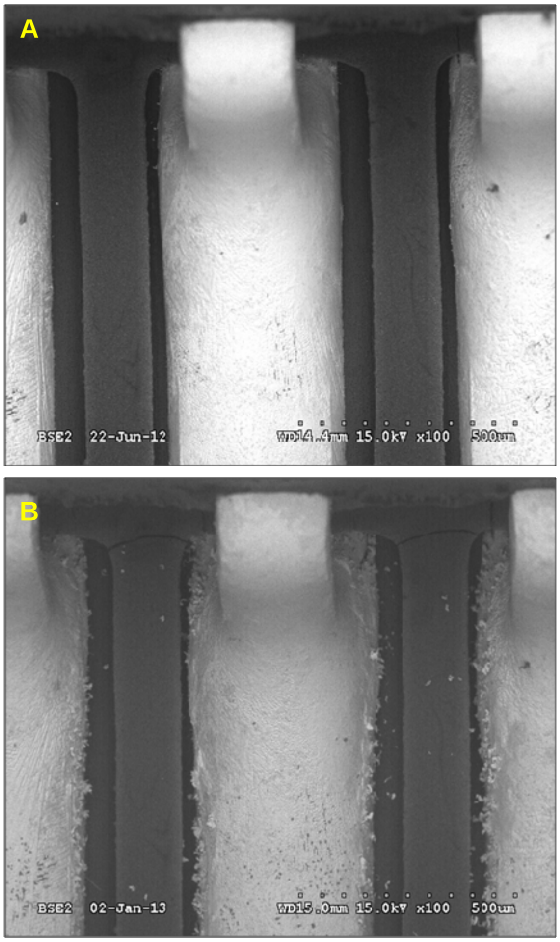

Figure 29: SEM images of an alloy 42 SOT6 at a 0-0 contamination level, U65, lead 4 (A) 1,000 hours and (B) 4,000 hours at 85 °C/85 percent relative humidity.

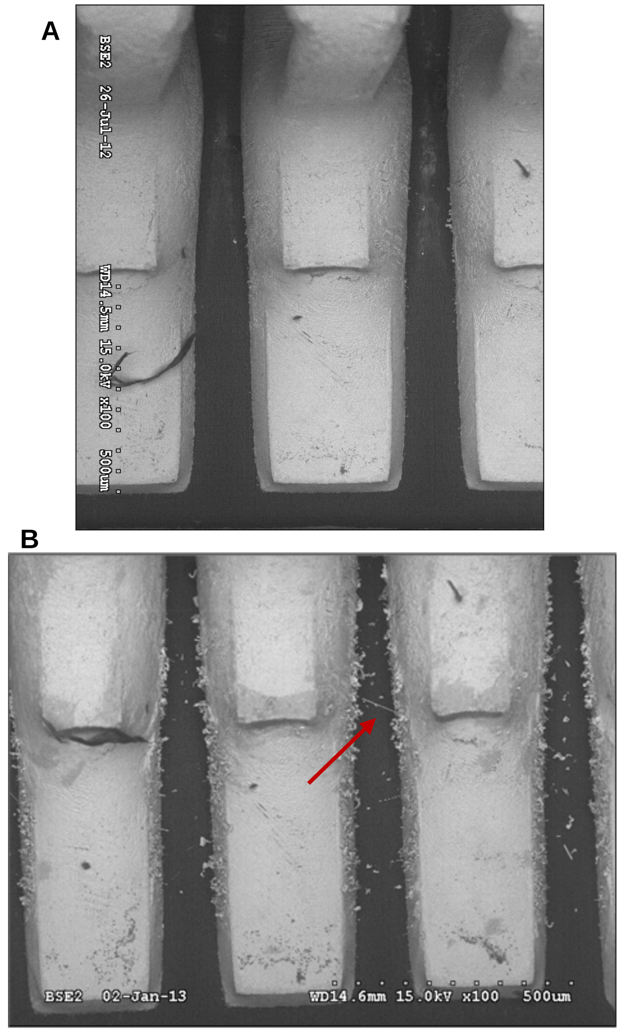

Figure 30: SEM images of a copper alloy lead 64 pin quad flat pack (QFP64 U08, lead 28) with a 0-0 contamination level after (A) 1,000 hours and (B) 4,000 hours at 85 °C/85 percent relative humidity. Arrow indicates a broken whisker that has nearly bridged between the printed wiring board pads. (Practical Components part number LQFP64 A-LQFP64-.7mm-.4mm-2.0-DC-Sn (0.4 mm pitch) C7025 Lead composition: Cu2.2-4.2Ni0.25-1.2Si0.05-0.3Mg).

METALLUGICAL OBSERVATIONS

The majority of the whisker growth was observed on the sides of the board pads. The majority of the whiskers grow from SAC solder that has flowed around the board pad. The solder thickness in this region is 3 to 25 microns thick. Figure 15 and Figure 31 shows representative whisker growth from the board pad edge when a copper lead is present with a 1-0 and a 1-1 contamination level. These whiskers are similar to those formed when an alloy 42 lead is present (see Figure 32).

The solder was observed to be partially oxidized (see Figure 33). The compressive stress caused by the 29~34 percent volume increase of the Sn oxides as compared with the βSn promotes whisker growth. These findings are consistent with other investigators assessing the role of humidity on tin whisker growth on electronic component leads [20][21][22] and on lead-free assemblies [23].

Two possible explanations for the large amount of broken whiskers were found during the cross section examination. In Figure 33, the thin regions of solder were completely oxidized and had no whiskers on the surface. This suggests that oxidation/corrosion propagating under a whisker can make the whisker attachment to the base more brittle. In another section of a whisker through its base, voids and a crack were observed (see Figure 34).

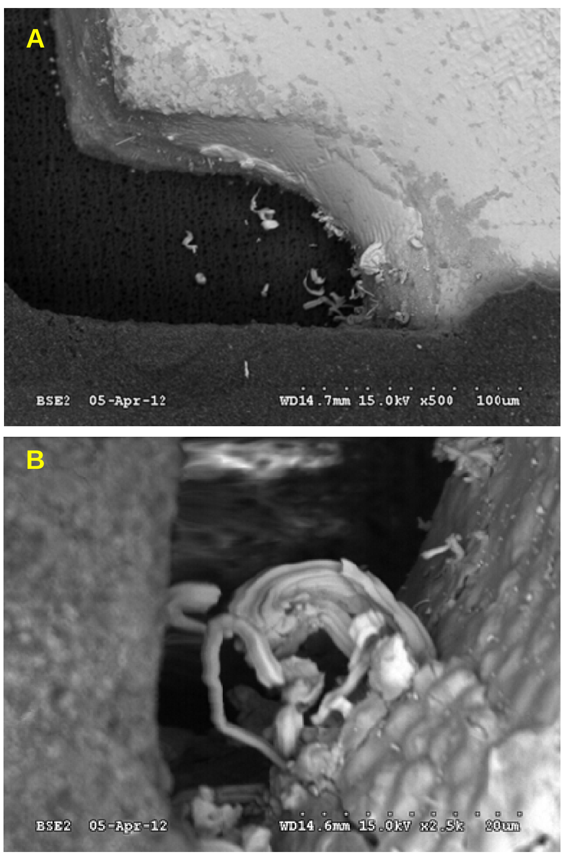

Figure 31: SEM images of a copper (SOT5) leaded part with a 1-1 contamination level after 1,000 hours at 85 °C/85 percent relative humidity. Increasing magnification views shown from top to bottom.

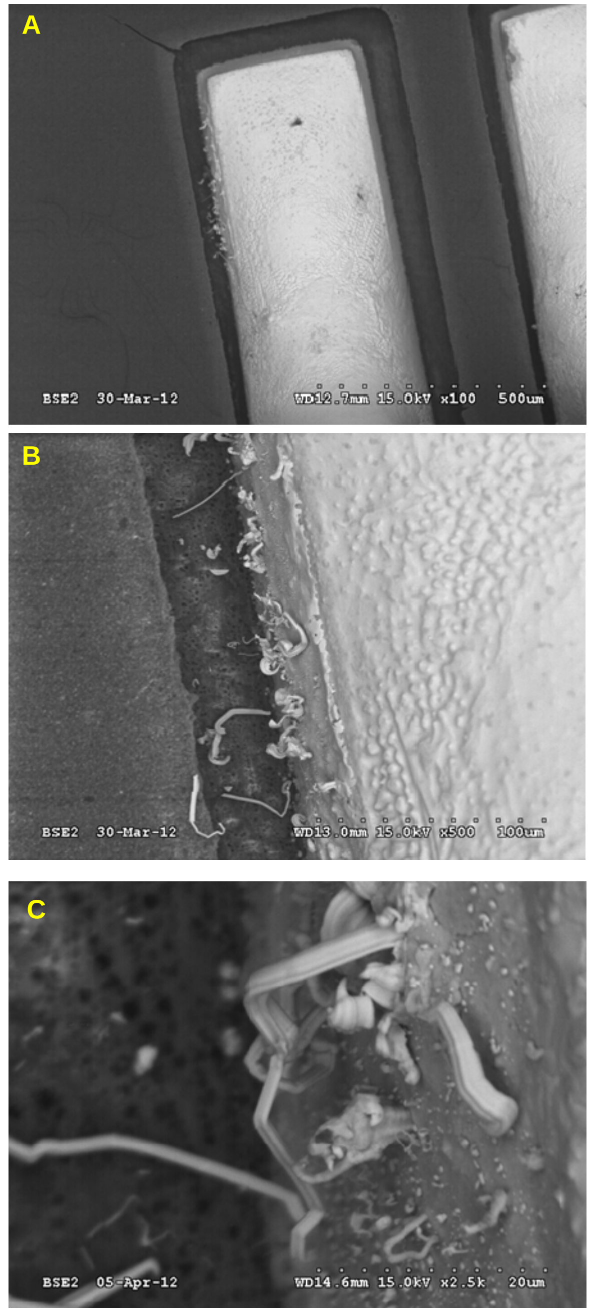

Figure 32: SEM images of an alloy 42 (SOT6) leaded part with a 1-1 contamination level after 1,000 hours at 85 °C/85 percent relative humidity. Increasing magnification views shown from top to bottom.

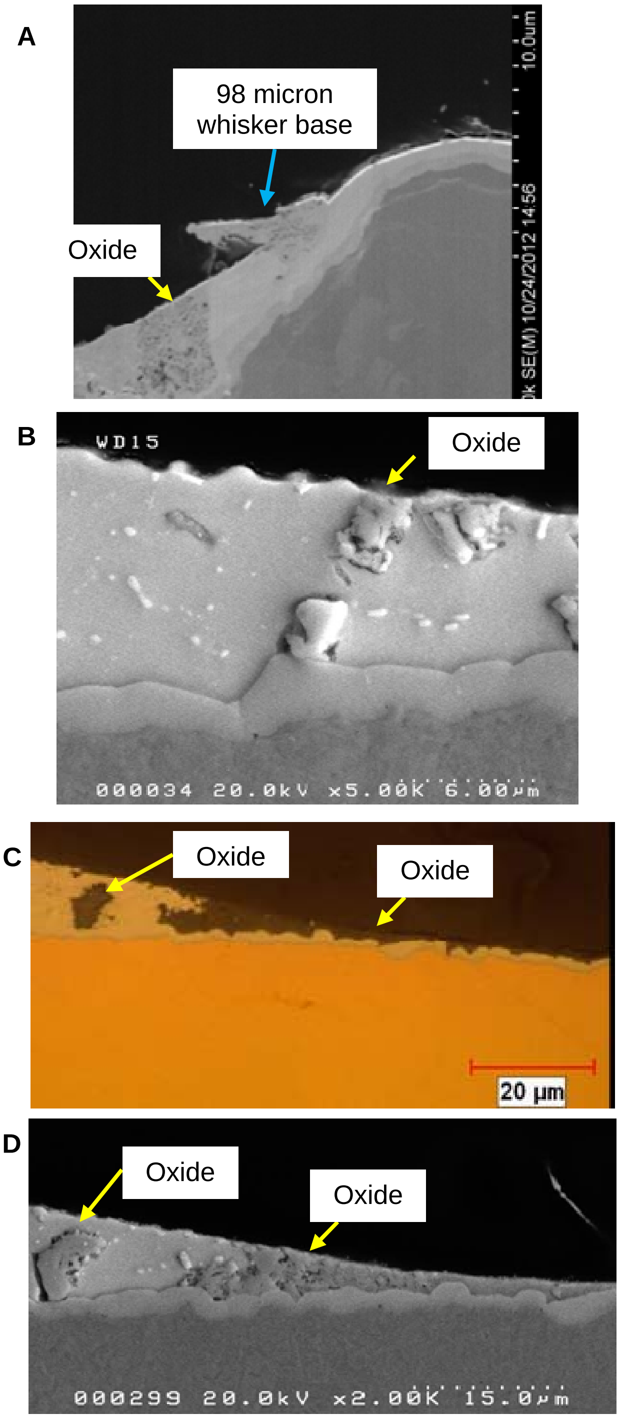

Figure 33: Partial oxidation of SAC solder with copper leaded part (SOT5) and 1-1 contamination. (A) SEM image of oxide near whisker, (B) SEM image of oxide in a thicker region of the SAC solder, (C) optical image of oxidation near solder to base metal wetting line, and (D) SEM image of region shown in (C).

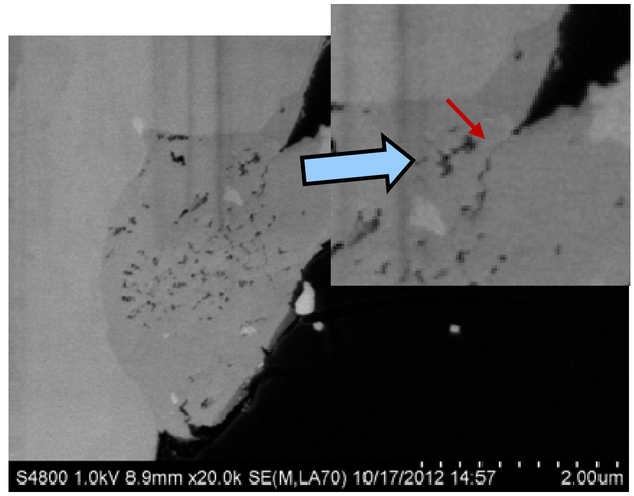

Figure 34: SEM image of voids and cracks observed in whisker base. Crack is highlighted by the arrow. A large number of voids are observed in the root of the whisker.

Whisker striations were also observed similar to those found by other researchers [24]. Vertical striations were on smaller diameter whiskers (see Figure 35) while both vertical and horizontal striations were observed on thicker whiskers (see Figure 36).

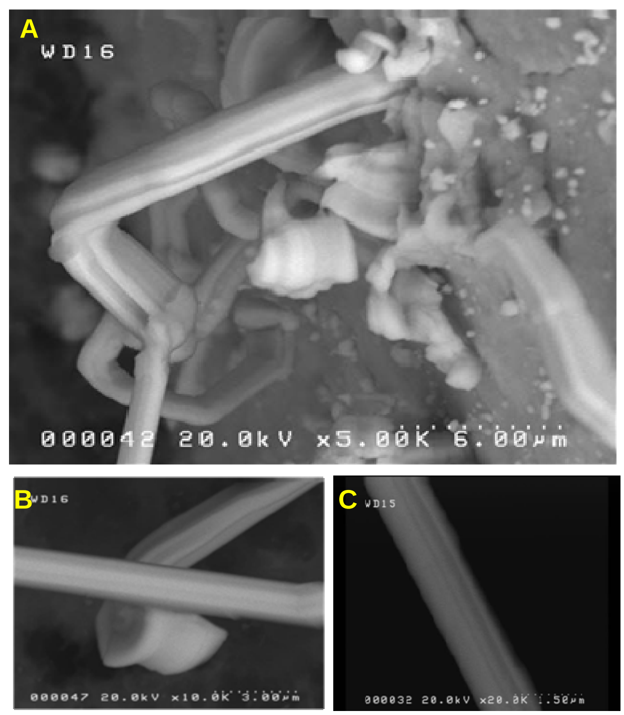

Figure 35: SEM images of vertical striations observed on smaller diameter whiskers. SEM images (A), (B) and (C) show increasing magnification views of typical striations.

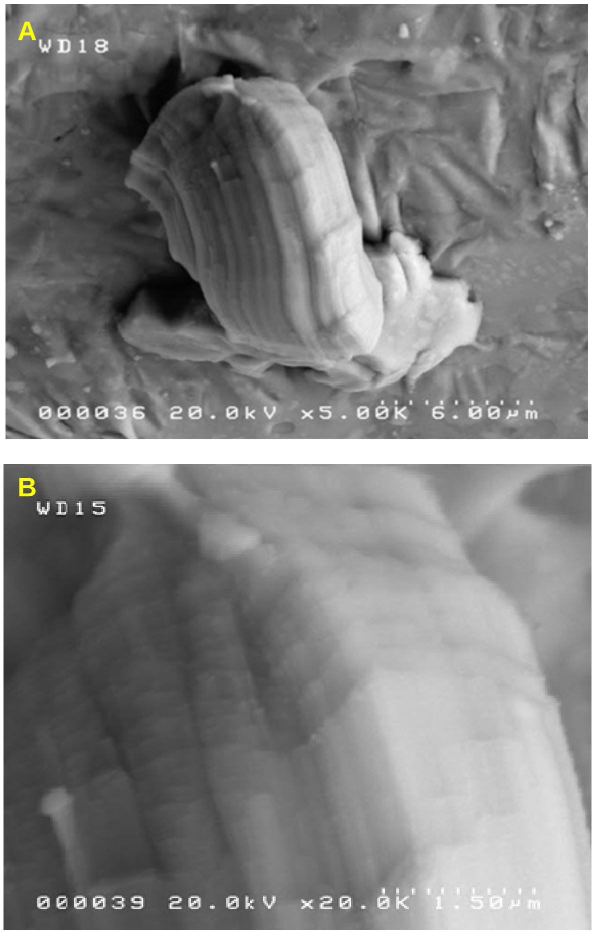

Figure 36: SEM images of vertical and horizontal striations observed on thicker whiskers. SEM images (A) and (B) show increasing magnification views of typical striations.

SUMMARY

AS-RECEIVED PART FACTORS

The lead-free Sn plated parts that meet the typical quality levels in order to form a good solder joint can have microstructural characteristics that may increase whisker formation such as:

- Uneven Sn plating with very thin or skipped Sn plating in some locations
- Void and cracks
- Excessive contamination

WHISKER LENGTH

Large whisker growth was observed after exposure to isothermal 85 °C/85 percent relative humidity conditions after 1,000 and 4,000 hours. Lead material and contamination level were the most significant factors contributing to whisker growth, while electrical bias had less influence.

The following key points can be made:

- There is a high risk of whisker growth in electronic assemblies if Pb-free SAC305 solder is used.
- Long whisker growth was observed from the SAC305 solder, particularly in the fillet regions where the solder became thin.
- Lead-free soldered assemblies exposed to 1,000 hours of 85 °C/85 percent relative humidity conditions grew whiskers with sufficient length to fail the JESD201 [25] piece part acceptance requirements for class 2.
- Whisker growth occurred on SAC305 solder joints containing either the copper or the alloy 42 leaded components, but the alloy 42 leads exhibited a delay in long whisker growth.
- Testing durations longer than 1,000 hours are needed to ensure whisker nucleation and growth in 85 °C/85 percent relative humidity conditions.
- Contaminated components in clean assemblies grow more long whiskers than clean components because of contamination entrapped in solder.

METALLUGICAL OBSERVATIONS

Optical microscopy, scanning electron microscopy in conjunction with cross-section examinations revealed that:

- The source of whisker growth stress was SAC305 solder oxidation and corrosion.
- Many whiskers were broken from the joints forming debris between the leads. Oxidation of whiskers is believed to cause embrittlement making the whiskers susceptible to fracture under mechanical loading conditions. Once a whisker has fractured, the growth has terminated.

FUTURE OPPORTUNITIES

It is expected that the work started here will provide the basis for an assembly level whisker test and inspection methodology that can be used to baseline manufacturing processes and designs for whisker growth tendencies.

ACKNOWLEDGEMENTS

The authors wish to thank the Strategic Environmental Research and Development Program (SERDP) office for providing funding for this research and Jie Qian for sample preparation and contamination.

REFERENCES

[1] GEIA-STD-0005-2, Standard for Mitigating the Effects of Tin Whiskers in Aerospace and High Performance Electronic Systems, Tech America, Washington DC, www.techamerica.org/standards

[2] Meschter, S.J., et.al., Tin Whisker Testing and Risk Modeling, ICSR Toronto, Ontario 2011.

[3] McCormack, H., et.al., Development of a Test Vehicle for the Study of Tin Whiskers, International Conference on Solder Reliability, Toronto, Ontario, Canada , 2011.

[4] Meschter, S.J., Snugovsky, P., Kennedy, J., Bagheri, Z., and Kosiba, E., Tin Whisker Testing: Low Stress Conditions, International Conference on Solder Reliability, Toronto, Ontario, Canada, 2012

[5] Vianco, P.T., and Rejent, J.A., "Dynamic Recrystallization (DRX) as the Mechanism for Sn Whisker Development Part I: A Model", Journal of Electronic Materials, Volume 38, Number 9, pp. 1815-1825, 2009.

[6] Snugovsky, P., et. al., Whisker Growth on SAC Solderjoints: Microstructure Analysis, SMTA Toronto May 2008, available at http://nepp.nasa.gov/whisker

[7] Snugovsky, P. et al., Influence of Board and Component Cleanliness on Whisker Formation, Proceedings of the IPC High Performance Cleaning and Coating Conference, 2010.

[8] Snugovsky, P., et al., Whisker Formation Induced by Component and Assembly Ionic Contamination, Proceedings of TMS Annual Meeting San Diego, CA, Feb. 28 – March 3, 2011.

[9] Snugovsky, P. et al., Microstructure Formation and Whisker Growth in SAC105 Solder Joints with Rare Earth Elements, Proceedings of TMS Annual Meeting San Diego, CA, Feb. 28 – March 3, 2011.

[10] Jadhav, N., Buchovecky, E., Chason, E., and Bower, A., Real-time SEM/FIB Studies of Whisker Growth and Surface Modification, Journal of Metals, July 2010, pp. 30-37.

[11] Jadhav, N., Buchovecky, E., Reinbold, L., Kumar, S., Bower, A., and Chason, E., Understanding the Correlation Between Intermetallic Growth, Stress Evolution, and Sn Whisker Nucleation, IEEE Trans on Electronics Packaging Manufacturing, Volume: 33, Issue: 3, 2010, pp 183 - 192

[12] Brusse, J., Tin Whisker Observations on Pure Tin-Plated Ceramic Chip Capacitors, AESF SUR/FIN 2002, June 24 - 27, Electronics Finishing II Session sponsored by the American Electroplaters and Surface Finishers Society, Orlando, FL. 2002.

[13] Suganama, K., Whisker Growth Behavior in High Vacuum with Thermal Cycling, Proceedings of TMS Annual Meeting San Diego, CA, Feb. 28 – March 3, 2011.

[14] J-STD-001 Requirements for Soldered Electrical and Electronic Assemblies, JEDEC Solid State Technology Association, Arlington, VA

[15] JESD22A121A Test method for measuring whisker growth on tin and tin alloy surface finishes, JEDEC Solid State Technology Association, Arlington, VA 2000

[16] L. Panashchenko, Evaluation of Environmental Tests for Tin Whisker Assessment, Masters Thesis, University of Maryland (College Park, Md.), 2009 http://drum.lib.umd.edu/handle/1903/10021

[17] Fang, T., Osterman, M., and Pecht, M., Statistical analysis of tin whisker growth, Microelectronics Reliability Vol. 46, 2006, pp 846–849

[18] Fukuda, Y., Osterman, M., and Pecht, M., Length Distribution Analysis for Tin Whisker Growth, IEEE Transactions on Electronics Packaging Manufacturing, Vol.30, No.1, January 2007, pp. 36-40

[19] Hilty, R. and Corman, N., Tin Whisker Reliability Assessment by Monte Carlo Simulation, IPC/JEDEC Lead-free Symposium, San Jose, CA, April 2005

[20] Oberndorff, P., Dittes, M., Crema, P., Su, P., and Yu E., Humidity Effects on Sn Whisker Formation, IEEE Transactions on Electronics Packaging Manufacturing, Vol. 29, No. 4, October 2006, pp. 239-245.

[21] Su, P., Howell, J., and Chopin, S., A Statistical Study of Sn Whisker Population and Growth during Elevated Temperature and Humidity Tests, IEEE Transactions on Electronics Packaging Manufacturing, Vol. 29, No. 4, October 2006, pp. 246-251

[22] Osenbach, J.W., DeLucca, J.M., Potteiger, B.D., Amin, A., Shook, R.L., and Baiocchi, F.A., Sn Corrosion and Its Influence on Whisker Growth, IEEE Transactions on Electronics Packaging Manufacturing, Vol. 30, No. 1, JANUARY 2007, pp. 23-35

[23] Osenbach, J.W., Shook, R.L, Vaccaro, B.T., Potteiger, B.D., Amin, A.N., Hooghan, K.N., Suraatkar, P. and Ruengsinsub, P., Sn Whiskers: Material Design, Processing, and Post-Plate Reflow Effects and Development of an Overall Phenomenological Theory, IEEE Transactions on Electronics Packaging Manufacturing, Vol.28, No.1, January 2005, pp. 36-62

[24] Fukuda, Y., Osterman, M., and Pecht, M., The Effect of Annealing on Tin Whisker Growth, IEEE Transactions on Electronics Packaging Manufacturing, Vol.29, No.4, October 2006, pp. 252-258.

[25] JESD201 Environmental Acceptance Requirements for Tin Whisker Susceptibility of Tin and Tin Alloy Surface Finishes, JEDEC Solid State Technology Association, Arlington, VA 2006