The Influence of Element Lead (Pb) Content in Tin Plating on Tin Whisker Initiation/Growth

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ABSTRACT

The implementation of the Restriction of Hazardous Substances (RoHS) European Union (EU) Directive in 2005 resulted in greater use of pure tin as a surface finish for printed circuit boards and component terminations. The use of pure tin by electronics component fabricators is understandable as they are inexpensive, require simple plating systems to operate and have reasonable solderability characteristics. A drawback of pure tin surface finishes is the potential to form tin whiskers, which are a metallurgical phenomenon associated with tin rich/pure tin materials. Electronics used in high performance/harsh environment, such as avionics, typically have product life cycles that are measured in decades and therefore are much more susceptible to the potential long-term threat of tin whiskers. Including lead (Pb) is a well-accepted method for minimizing the risk of tin whiskers. The GEIA-STD-0005-2 "Standard for Mitigating the Effects of Tin Whiskers in Aerospace and High Performance Electronic Systems" established the definition of the term "Pb-free tin" as: pure tin or a tin alloy with <3% lead (Pb) content by weight. This investigation was conducted to assess the influence of 1% - 5% elemental Pb content in tin plating on tin whisker initiation and growth to determine if the acceptable minimum amount of Pb could be revised. Results indicate that the current definition of 3% Pb content should be maintained.

INTRODUCTION

The implementation of the Restriction of Hazardous Substances (RoHS) European Union (EU) Directive in 2005 resulted in the introduction of pure tin as an acceptable surface finish for printed circuit boards and component terminations. A drawback of pure tin surface finishes is their potential to form tin whiskers. The tin whisker metallurgical phenomenon is associated with tin rich/pure tin materials and has been a topic of intense industry interest [1 - 6]. Figure 1 illustrates tin whiskers observed on a component lead and in an immersion tin surface finished plated through hole that was incorrectly plated due to a formulation error in the plating bath that prevented the deposition of a sufficient amount of bismuth.

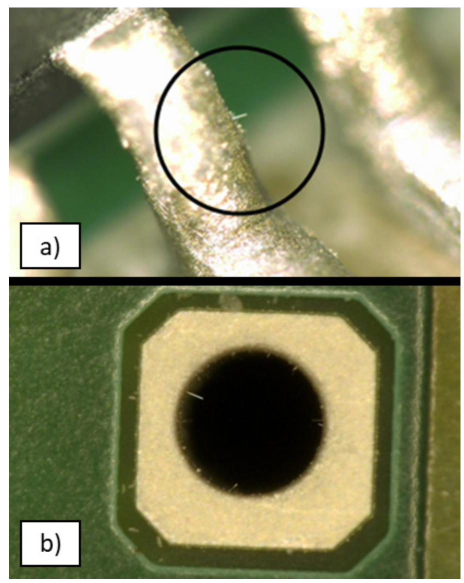

Figure 1: Tin Whiskers a) on a Component Lead and b) in a Plated Through Hole

The acceptance and usage of pure tin by the electronics industry component fabricators is understandable. Pure tin surface finishes are inexpensive, they have reasonable solderability characteristics, and their required plating systems are simple to operate. The commercial electronics segment, which uses the majority of electronic components, often has product life cycles that are measured in years. In contrast, high performance/harsh environment electronics, such as those used in military/aerospace applications, typically have product life cycles that are measured in decades. This longer product life increases the potential threat of tin whiskers. The GEIA-STD-0005-2 "Standard for Mitigating the Effects of Tin Whiskers in Aerospace and High Performance Electronic Systems" [7] was created to assist the harsh environment user segment with tin whisker mitigation. A definition for the term "Pb-free tin or pure tin" was established so that the industry was working from a standard baseline:

"**Pb-free Tin** is defined to be pure tin or any tin alloy with <3% lead (Pb) content by weight. This means that some Pb-free finishes other than pure tin, such as tin-bismuth and tin-copper, are considered to be "Pb-free tin" for the purposes of this standard". [7]

Defining "pure tin" was necessary so that the electronics industry could establish tin whisker risk protocols against a known target value in terms of soldering materials and processes. As discussed in Ref. [7] the genesis of the 3% Pb criteria for pure tin began with testing done at Bell Labs in the 1950s with continuing work to refine the approach.

Investigations [8, 9] have shown that pure tin surfaces can be "poisoned" with tin/lead solder, provided that the tin plating is replaced during the soldering process. With many components with physically short leads, such as chip resistors or capacitors, the soldering process consistently and repeatedly reduces tin whisker risk. However, the component lead geometry, solder paste deposit and component pad dimensions all factor into whether a component can be successfully poisoned by the soldering process. The criterion for solder poisoning is a minimum of 3% lead (Pb) (all alloy composition values shown in this paper are by weight) in the resulting finish on the entire component lead, per the GEIA-STD-0005-2 definition. Figure 2 illustrates two components, one of which was successfully poisoned and one inadequately poisoned based on solder flow changing the original tin plating surface finish.

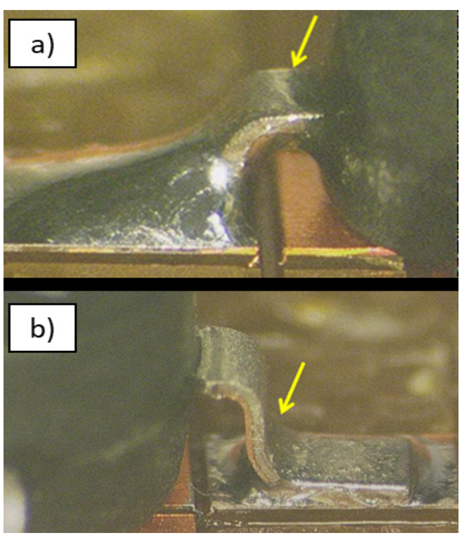

Figure 2: Solder Process "Poisoning", (a) - Acceptable, (b) - Inadequate (Note: The yellow arrow indicates the highest point of solder flow)

Pinsky reported, in an IPC PERM consortium round robin test program [10], that there is some variation in the solder wetting and coverage even on components that are routinely "poisoned" in automated soldering processes. An example of these occurrences is the 0603 surface mount component that was soldered in a tin/lead solder paste as part of the round robin testing program (Figure 3). The 0603 component achieved a 99.9% poisoning success rate, but there was the 0.1% chance that poisoning success was not achieved. Figure 3 shows metallurgical cross-sectional and scanning electron microscopy (SEM) analyses of a 0603 component with poor wetting that did not meet the "3% Pb" rule, since resulting finish, after reflow, only achieved a 1.5% Pb content.

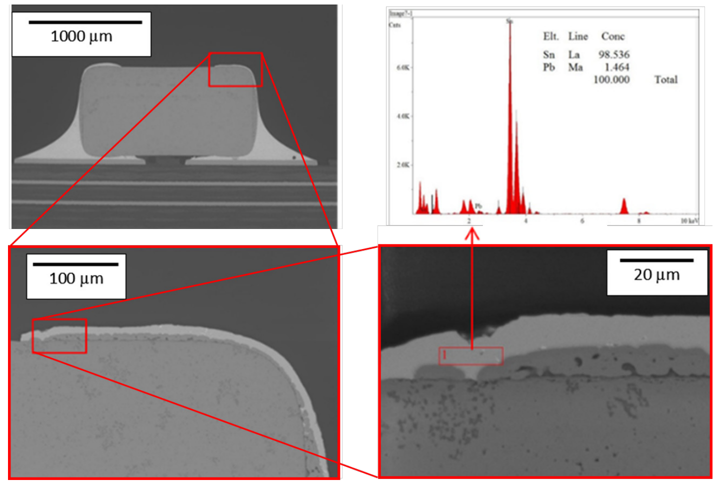

Figure 3: SEM-EDS Assessment of 0603 Component with Inadequate Solder Poisoning, increasing SEM magnification showing location of EDS measurement; adapted from [10] (Copyright IPC, reprinted with permission)

The IPC PERM consortium round robin test program results highlighted the fact that, since successfully achieving the 3% Pb minimum value is not guaranteed, a combination of tin whisker risk mitigation methodologies should be considered. However, the IPC PERM consortium round robin test program results also raised the following questions:

- Is a lower % Pb content minimum value acceptable?
- Should an investigation be conducted to better characterize the validity of the 3% Pb minimum value?

INDUSTRY PUBLISHED LITERATURE REVIEW

A review of the industry published literature was conducted to understand the potential origin and evolution of the 3% Pb minimum value used in the GEIA-STD-0005-2 specification. The initial investigations of tin and zinc whisker phenomenon were published in 1951 by Bell Laboratory technical staff [11]. Compton et al. [12] published early results of an investigation on the influence of base metals, plating bath composition, plating thickness, contamination and conditioning environment on whisker initiation/growth. Arnold and others [13-20] continued the whisker investigation by expanding into crystallographic orientation characterization, plating bath parameter influences, post plating treatments and other surface finish application technologies (i.e. vapor deposition, dipping, etc.) over the next 10 years.

Arnold published data on "repressing the growth of tin whiskers" in 1966 [21]. He reported that the elements that appeared to influence tin whisker initiation/growth were antimony, cobalt, copper, germanium, gold, lead and nickel. Of those elements, Pb had the best results. A 12-year study of a Sn99Pb1 plated surface finish revealed that, under 95% relative humidity (RH) conditions, only an occasional whisker was found and those whiskers had a maximum length of 20 mils. Arnold concluded that "…tin alloys containing as little as 1% Pb are satisfactory substitutes for tin coatings…". Britton published a comprehensive review paper covering 20 years of International Tin Research Institute (ITRI) tin whisker research in 1974 [22]. Britton stated that the use of Pb as an alloy element was effective in retarding and/or eliminating tin whisker initiation/growth. Britton found general agreement between his investigation results and Arnold's published results [21], despite some differences in test parameters/conditions.

In 2011, two groups of researchers published results on the influence of % Pb on tin whisker initiation and growth. Baated et al [22] investigated 100% Sn, Sn2Cu, Sn10Pb, Sn3.5Ag, and Sn2Bi surface finishes plated on component lead frames and stored at room temperature conditions. In several instances, the 100% Sn and the Sn2Cu surface finishes grew long whiskers within 24 hours. The Sn10Pb and Sn2Bi surface finishes grew tin whiskers less than 0.2 mils in length after 420 days. The test results showed that Pb, Ag and Bi had a suppressing effect on tin whiskers. Sobiech et al [24] investigated the influence of Sn10Pb and Sn20Pb surface finishes on tin whiskers initiation/growth on copper and iron lead frame materials under room temperature conditions for a 12-month period. The Sn10Pb and Sn20Pb surface finishes, for both substrate types, remained tin whisker free for the 12-month period. Zhang and Schwager [28] investigated the influence of Sn60Pb40 films on tin whisker growth on copper surfaces/ambient conditions as a function of storage time. They concluded that Pb prevented tin whisker growth due to the formation of a uniform copper/tin intermetallic compound (IMC) layer. Jadhav et al [26] investigated the influence of Sn90Pb10 plating on tin whisker initiation/growth using thermally induced stress methodologies. Their test results demonstrated that the Sn90Pb10 plating had a significant stress relaxation effect in comparison to 100% Sn plating and should reduce whiskers.

In 2013, two investigation reports, which focused on small Pb percentages, were published. Nielsen and Woodrow [27] produced copper coupons with tin plating containing 1-3% of the following elements: Cu, Ni, Co, Sb, Ge and Au. Table 1 lists the plating alloys and the weight percentages achieved on the copper coupons using inductively coupled plasma (ICP) analysis. Tin whisker inspection intervals were 4000, 8000, and 12000 hours while subjected to a conditioning environment of 50°C/50%RH.

Table 2 illustrates results for the SnPb plated samples after 8000 hours of conditioning, with the majority of observed tin whiskers in the 10-20 µm range for average number of whiskers/cm2. Nielsen and Woodrow noted that the whiskers appeared to be more like multi-faceted, cubic shaped filaments than typical tin whisker structures [27]. Figure 4 illustrates one of the whiskers observed on the SnPb plating. The investigation concluded that plating that contained Au, Sb or Ge had the greatest tin whisker suppression effects.

Table 1: ICP Analysis Results for Weight Percent of Elements in Plating [27]

Plated Film	ICP Analysis		
	Dopant Weight % (1st Coupon)	Dopant Weight % (Last Coupon)	Average Dopant Weight %
SnPb	3.10%	3.10%	3.10%
SnCu	2.10%	2.10%	2.10%
SnNi	3.10%	3.00%	3.10%
SnCo	0.84%	0.95%	0.90%
SnSb	2.40%	2.20%	2.30%
SnGe	1.00%	1.10%	1.10%
SnAu	1.00%	1.30%	1.20%

Table 2: Average Number of Whiskers/cm² on SnPb Plating [27]

Film	Coupon Number	Inspection Area (cm^2)	Whisker Count at 8,000 hours					Longest Whisker
			10-20µm	21-30µm	31-40µm	41-50µm	>50µm	
SnPb	71	1	37	6	0	4	0	< 20µm
	72	1	30	5	2	0	2	116
	73	1	19	0	1	0	2	157
	Average Whiskers/cm^2		28.7	3.7	0.0	1.3	1.3	
	Total Average Number of Whiskers/cm^2 = 36							

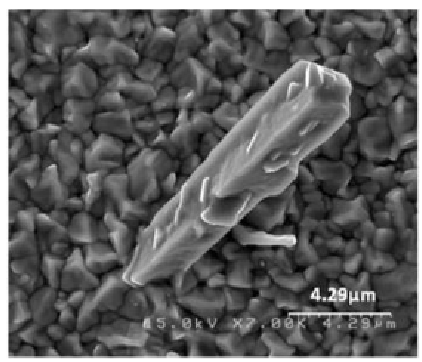

Figure 4: Multi-faceted, Cubic Shaped Filament Observed on SnPb plating After 8000 Conditioning Hours [27]

Jo et al [28] investigated the influence of Pb additions to tin plating using electroplated copper on quad flat pack (QFP) lead frames for a range of 0 to 10% Pb with room temperature conditions over a 12-month period. The investigation results revealed tin whisker initiation/growth on the 100% Sn samples and only hillock structures on the Pb addition samples (Figure 5, Figure 6).

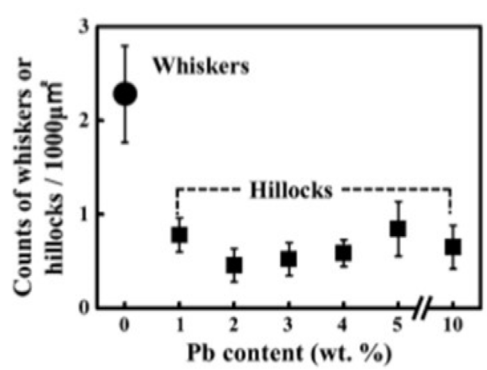

Figure 5: Whisker/Hillock Counts versus Lead (Pb) Content [28]

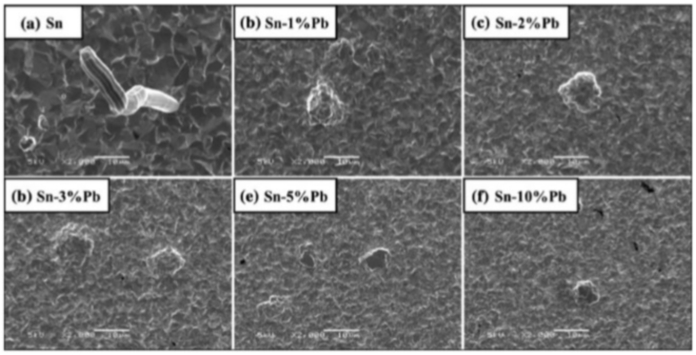

Figure 6: Plating Sample Growth Morphologies after One Year [28]

The published literature indicates that Pb clearly has an impact on the initiation/growth of tin whiskers for % Pb alloy percentages exceeding 10%. Additional data on whisker formation in aggressive temperature/humidity conditioning environments for surface finishes with Pb percentages below 10% would provide a better understanding of tin whisker initiation/growth for electronic component configurations.

OBJECTIVE

The objectives of the investigation were to:

- fabricate test samples with consistent internal stresses in low %Pb electroplated tin compositions,
- subject test samples to representative harsh environments of elevated temperature and humidity that tend to promote the formation of tin whiskers,
- accurately quantify the amount of tin whisker grown on the test samples as a function of the time exposed to harsh environments,
- determine the impact of the test sample material and tin composition on tin whisker initiation/growth
- recommend whether any changes should be made existing criteria for Pb content to prevent tin whisker growth.

PROCEDURES

The test specimens selected for the investigation were 0.020-inch diameter by 6-inch-long wire comprised of copper and Kovar. The wires were plated with a commercial tin plating solution by Forsite Inc. Plating for both wire materials were selected using solder ranging from 100% tin to 95% tin, in 1% Pb composition increments, with no prestrike plating metallization. A total quantity of 30 wires for each base metal and Pb content were produced. The final tin plating thickness on the copper wires was 120-200 microinches and on the Kovar wires was 350-420 microinches. Figure 7 shows the plating system, which used a modified Hull Cell with 100% tin electrode and a plating distance of 4-5 inches. A 3-4A of current was used on the 0.02 inch diameter x 6 inch long wires, leading to an overall average current density of ~1 – 1.5 A/cm^2.

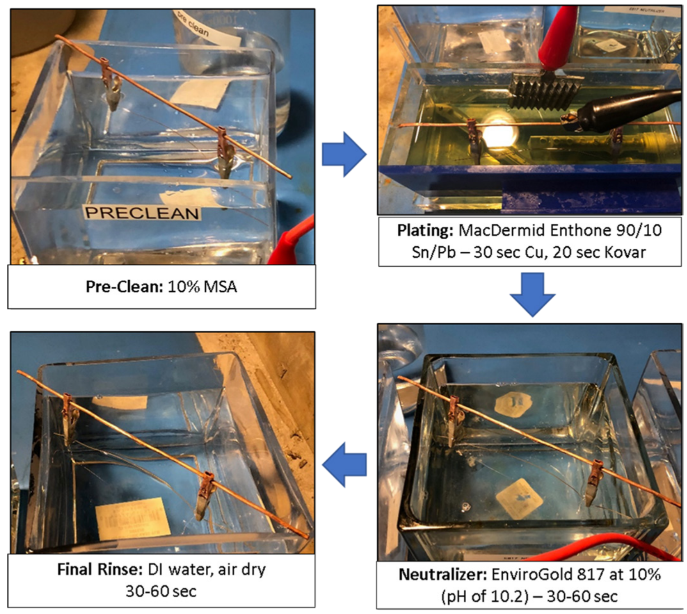

Figure 7: Plating System and Steps

The plating of very small diameter wires, in 1% Pb increments, is not an exact science so X-ray Fluorescence (XRF), using a Fischer XDAL XRF system, and Scanning Electron Microscopy Energy Dispersive Spectroscopy (SEM EDS), using a Hitachi SU3500 SEM system, assessment were both conducted to measure the actual % Pb values. Table 3 lists the measured % Pb values for the test specimens. Overall, there is good agreement in the % Pb values measured with the two methods, with a wider % Pb plating content variation being observed in the higher Pb content (4% Pb and 5% Pb) test specimens. Since the overall goal of the plating process was to produce a % Pb range from 0% Pb to 5% Pb, these results demonstrate that the plating approach achieved the investigation parameter purpose. Additionally, the plating finish was relatively smooth with no major visible defects (Figure 8a).

Table 3: Copper and Kovar Test Specimen Plating Characterization

	Measured %Pb			
	XRF		SEM-EDS	
Target %Pb	Copper	Kovar	Copper	Kovar
0%	0	0	0	0
1%	0.8-0.9	1.4-1.7	1.3-1.5	1.4-1.7
2%	1.7-2.2	2.4-2.6	2.5-3.3	2.0-2.7
3%	3.0-3.3	3.1-3.5	3.4-3.8	3.3-3.5
4%	3.9-5.6	3.6-4.2	4.5-5.0	4.2-4.6
5%	5.5-5.6	4.7-5.1	7.6-8.8	8.5-9.5

TEST SPECIMENS

Careful consideration was taken in the design of the tin whisker test specimen. A wire bending fixture (Figure 8b) was built using additive manufacturing to allow wire to be consistently bent into a center "pigtail" that had both compressive and tensile stress (Figure 8c). The bending fixture also produced test specimen mounting feet that could be soldered to a copper/laminate disc (Figure 8d). The disc shape/dimensions were selected to facilitate SEM assessment with minimum handling and to provide a uniform electrical conduction path to avoid SEM specimen charging.

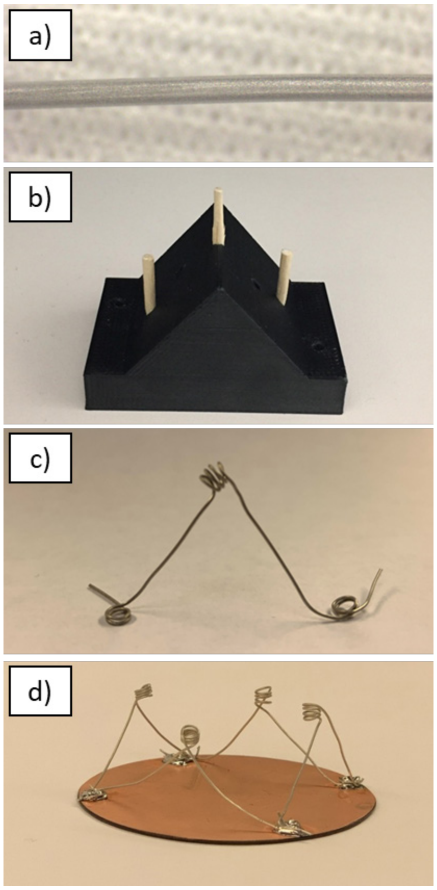

Figure 8: Tin Whisker Test Specimen: a) Wire Plated with Tin, b) Fixture for Bending Wire, c) Test Specimen after Bending, d) 4 Test Articles Soldered to SEM Assessment Disc

In total, 360 wire test specimens were fabricated for the study that included the two base metal types (copper and Kovar) and three conditioning intervals. Figure 9 shows the tin whisker test specimen groups when placed in the temperature/humidity chamber.

Figure 9: Tin Whisker Test Specimens

TEST SPECIMEN CONDITIONING PARAMETERS

A modified JESD201 test parameter matrix was followed for the wire specimens. The following test parameters were used:

- Chamber environmental parameters: 85°C / 85% RH, non-condensing environment
- All test specimens introduced to the conditioning chamber at time zero
- Whisker inspection intervals: 3000, 6000 and 9000 hours
- Only designated test specimens were removed at a given inspection interval with chamber interruption duration of 20 seconds
- Scanning Electron Microscope conducted for each inspection interval

INSPECTION METHODOLOGY

A sample set, including the full range of % Pb content copper and Kovar wires, was removed from the chamber at each of the three inspection intervals and documented with SEM imagery. Following this, SEM images were assessed to characterize the whisker population on each sample. A MATLAB code was created to define five non-overlapping squares of 40,000 pixels, which represented 7.3 square mil (4730 square micrometers) on a SEM image. These five square were randomly placed on a 300X magnification SEM image (see Figure 10).

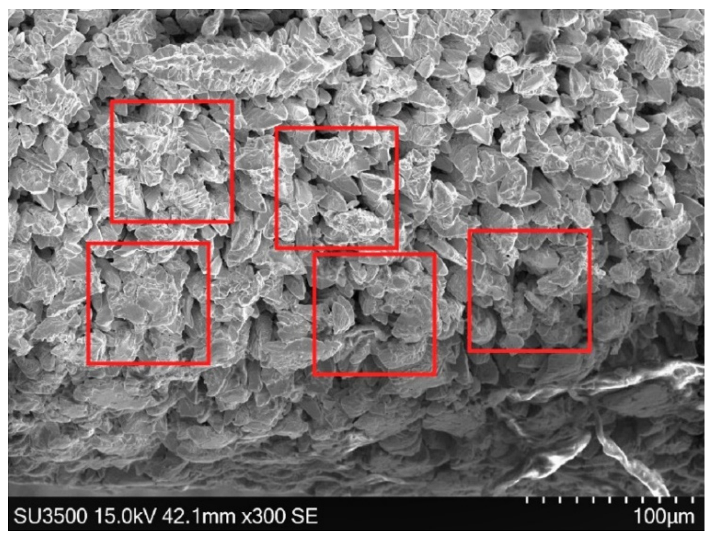

Figure 10: MATLAB Determined Tin Whisker Analysis Regions (5 squares)

Using the randomly placed analysis regions, tin whisker density data were collected by counting and recording the number of whiskers visible within in each analysis square (defined by the outer edge of the red lines). If any portion of a whisker was present in an inspection area, it was included in the count. Up to ten tin whiskers were individually counted in each area. If more than ten whiskers were observed in a given area, that area was recorded as having more than ten whiskers. The use of randomly placed analysis regions and using the same individual to count the tin whiskers helped to reduce the overall variation/bias in the investigation. Figure 11 and Figure 12 illustrate two examples of tin whisker data collection, with oval shapes denoting counted tin whiskers.

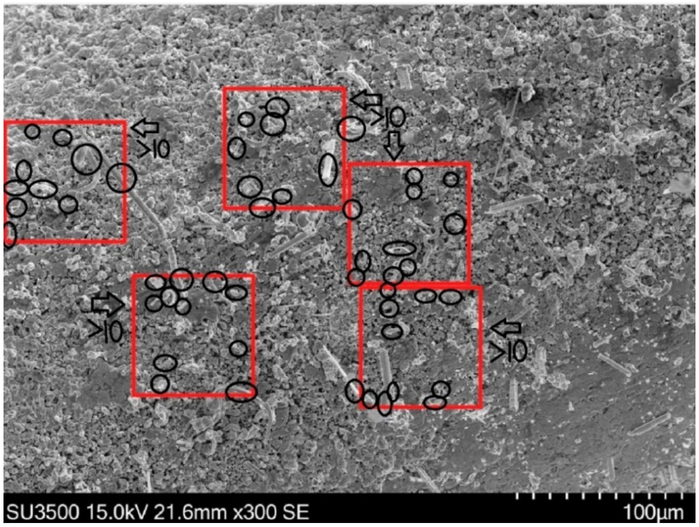

Figure 11: 98%Sn/2%Pb Kovar Wire Specimen with High Tin Whisker Density

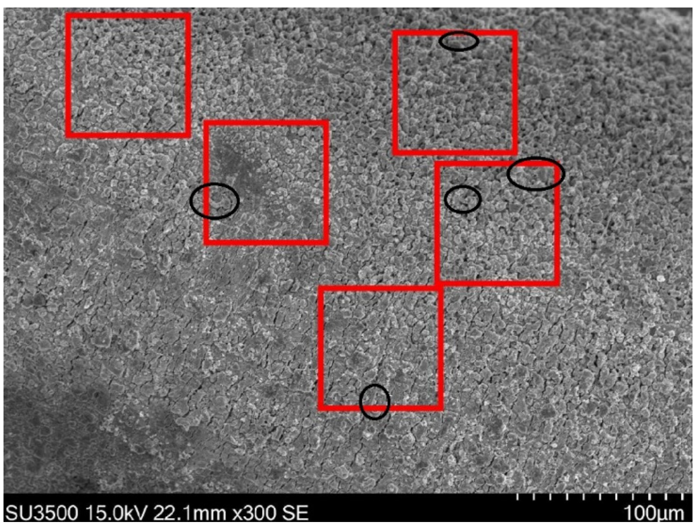

Figure 12: 96%Sn/4%Pb Copper Wire Specimen with Low Tin Whisker Density

TEST RESULTS

The average number of whiskers per sample group for the copper wires are shown in Table 4 and the average number of whiskers per sample group for the Kovar wires are shown in Table 5.

Table 4: Copper Wire Tin Whisker Averages

% Tin	*100%*	*99%*	*98%*	*97%*	*96%*	*95%*
3000 Hrs	1.02	2.7	1.04	1.42	1.98	1.73
6000 Hrs	1.2	2.53	1.15	1.48	1.05	0.98
9000 Hrs	4.93	4	3.51	2.8	3.18	2.33

Table 5: Kovar Wire Tin Whisker Averages

% Tin	*100%*	*99%*	*98%*	*97%*	*96%*	*95%*
3000 Hrs	2.98	5.46	3.9	1.28	0.68	1.58
6000 Hrs	4.33	4.85	3.9	0.9	0.93	2.33
9000 Hrs	5.28	6.62	5.36	2.27	2.44	3.24

DISCUSSION/CONCLUSION

The samples taken after 3000 hours in the conditioning chamber were the first to be examined. These results are shown in Figure 13, in which the y-axis expresses the average number of whiskers in the inspection area and the x-axis corresponds to the target tin percentages present on the wires. For the copper wires, the data do not indicate a correlation between Pb content and tin whiskers initiation after 3000 hours. However, the Kovar samples do appear to show a trend with the lower percentages of tin (95%-97%) exhibiting fewer whiskers than htose with higher tin percentages.

Statistical t-tests were conducted on the data with those measurements determined to have more than 10 whiskers given a value of 11. These showed no statistically significant effect of Pb content on the number of observed whiskers for the copper wires. However, with the Kovar wires, there was a statistically significant difference (>95% confidence level), in that more whiskers occurred on samples with 98-100% tin than on those samples with 95-97% tin.

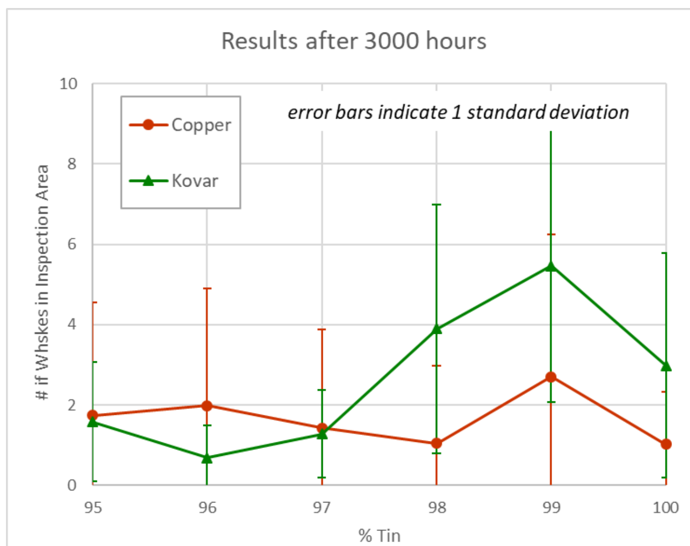

Figure 13: Results for Inspection after 3000 Hours Exposure

As the time in the conditioning chamber increased to 6000 hours, the average number of whiskers for the copper wires remained low and consistent throughout the differing tin purities. As with the samples at 3000 hours, the copper wires did not show a statistically significant impact of surface finish lead content. However, a t-test of the Kovar data again showed a statistically significant difference between the data for 95-97% tin than the 98-100% tin samples. The corresponding graph of the average data with one standard deviation error bars is shown in Figure 14.

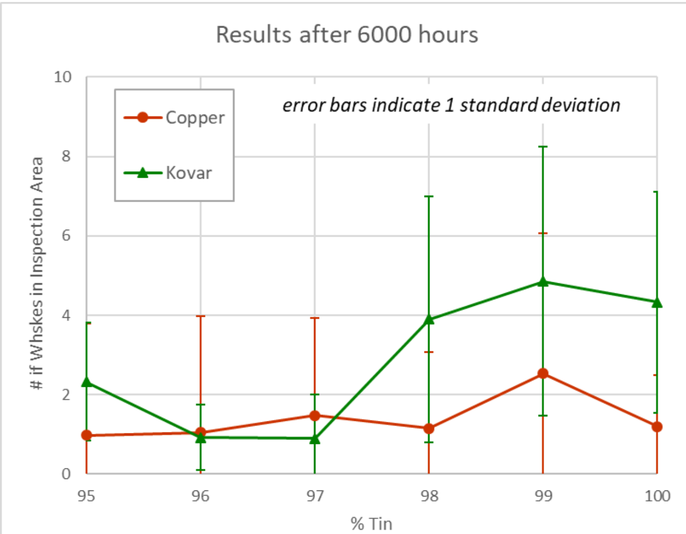

Figure 14: Results for Inspection after 6000 Hours Exposure

The trends changed slightly in the results after 9000 hours in the conditioning chamber. The average number of whiskers in the inspection areas increased for all tin purity levels and, unlike in the earlier results, the copper wires with lower Pb content appeared to have more whiskers. In the 9000-hour data, both the copper and Kovar wires with 98-100% Sn had more tin whiskers than samples with 95-97% Sn, to a statistically significant effect (confidence level >99%). Figure 15 shows the upward trends in the average number of tin whiskers with increasing levels of tin for both base wire material types.

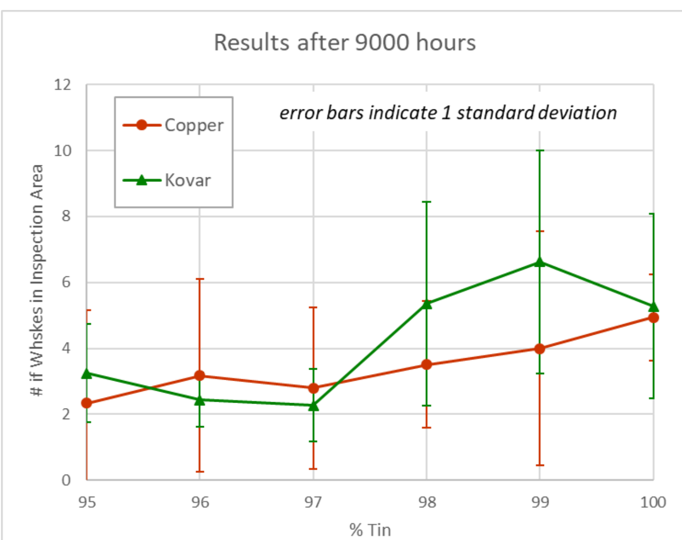

Figure 15: Results for Inspection after 9000 Hours Exposure

Figure 16 shows the same data as the previous figures, but with conditioning time instead of tin content used as the independent variable. This figure repeats the same data but places them into different sized bins. The top figure shows results for each of the nominal tin% content that were tested at levels of 95, 96, 97, 98, 99 and 100% (i.e., 1% range). The middle figure groups data together as 95-96%, 97-98%, and 99-100% tin (2% range). The final figure compares data in the 95-97% tin content to those in the 98-100% level. This last plot (Figure 16c) clearly illustrates the difference in the average number of whiskers with higher tin content (98-100%) than in the lower tin content (95-97%), i.e., 3% range. For Kovar this difference was seen after each level of conditions but with copper, this difference was only evident after 9000 hours of conditioning.

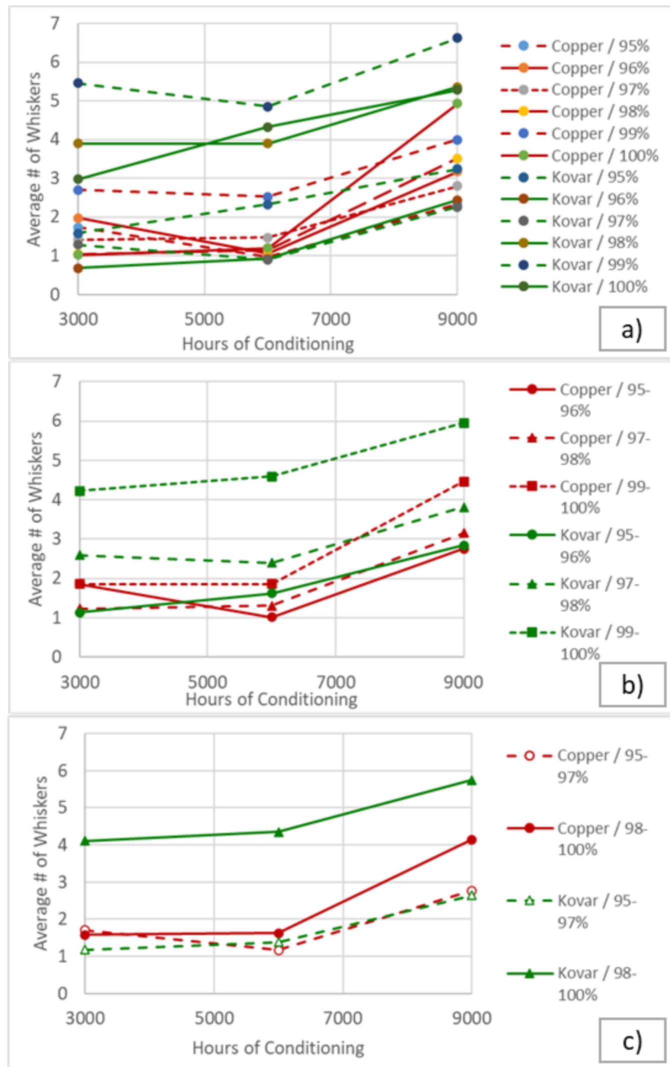

Figure 16: Average Whisker Data vs. Conditioning Time, Grouped by Different Tin Content Ranges: a) 1%, b) 2%, c) 3%

The specific mechanism that led to the Kovar samples being more prone to tin whiskers was not established in this study. One possible explanation is that the higher coefficient of thermal expansion (CTE) mismatch between the plating and the Kovar, as compared to copper, likely increased stresses within the tin plating. Also, most of the test results showed a small, but noticeable, reduction in the number of tin whiskers occurring in 100% tin as compared to 99%

tin. This is somewhat counterintuitive; one would expect that the most pure tin finishes would be most prone to tin whiskers. It is possible that the presence of trace amounts of Pb induced some additional stresses in the plating that promoted whisker initiation. Also, the analysis approach that limited measurements to no more than 10 whiskers in a given reading could have slightly biased the average values if the 100% tin data actually included some samples that had measurement squares with substantially more than 10 tin whiskers.

These investigation results differ from those of Arnold, which found that as little as 1% Pb was sufficient to prevent tin whiskers [21]. A number of investigation variables could account for the results differences, including the tin plating bath composition, plating process parameters, substrate conditions, etc.

Two obvious differences in the studies are the test vehicle geometry and the plating thickness. Arnold's work primarily used flat coupons, in contrast to the 0.020-inch diameter wires used in the current investigation. This difference in the substrate geometry likely influenced the magnitude of local plating stresses; residual stresses within solder are widely recognized as having a tendency to initiate tin whiskers. In addition, Arnold utilized a tin plating thickness of 200 microinches in much of his work in contrast to the tin plating thickness of 120-200 microinches that was used in test samples in this investigation. Many prior researchers have observed that thinner tin plating thicknesses are more prone to tin whisker initiation.

Since Arnold did not provide detailed information on the statistical basis of his conclusion, it is not possible to conclusively determine the reasons for, or the statistical significant of, the differing conclusions between this study and his recommendation of a 1% Pb minimum tin plating content. Future researchers could use similar procedures as those used in this test but with flat test vehicles more similar to those used by Arnold to determine the degree to results were affected by plating stresses. Those results would primarily be relevant for a fundamental understanding of tin whisker initiation. They would, however, have limited practical application since the high plating stress regions at lead bends are the primary areas of concern for tin whisker avoidance.

The investigation results using the copper and Kovar wires with a 0%-5% Pb content range validates the 3% Pb minimum tin plating content, which the industry currently recognizes as an acceptable tin whisker risk mitigation approach, is acceptable.

In conclusion, the investigation does not support a revision to the 3% Pb minimum tin plating content is currently used by the electronics industry as a tin whisker risk mitigation metric.

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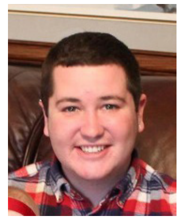
BIOGRAPHIES

David D. Hillman is a Metallurgical Engineer in the Advanced Operations Engineering Department of Rockwell Collins Inc. in Cedar Rapids, Iowa. Mr. Hillman graduated from Iowa State University with a B.S. (1984) and M.S. (2001) in Material Science & Engineering. In his present assignment he serves as a consultant to manufacturing on material and processing problems. He served as a Subject Matter Expert (SME) for the Lead-free Manhattan Project in 2009. He has published 200+ technical papers. Mr. Hillman was named a Rockwell Collins Fellow in 2016. He was named an IPC Raymond E. Prichard Hall of Fame award recipient in 2018. He serves as the Chairman of the IPC JSTD-002 Solderability committee. Mr. Hillman served as a Metallurgical Engineer at the Convair Division of General Dynamics with responsibility in material testing and failure analysis prior to joining Rockwell. He is a member of the American Society for Metals (ASM), the Minerals, Metals & Materials Society (TMS), and Surface Mount Technology Association (SMTA) and the Institute for Interconnecting and Packaging of Electronic Circuits (IPC).



Tim Pearson is a Materials and Process Engineer in the Advanced Operations Engineering department of Collins Aerospace in Cedar Rapids, Iowa. Mr. Pearson graduated from Iowa State University with a BS in Materials Science and Engineering. Tim began his career as a Thin Films Engineer at Texas Instruments in a 300mm wafer fab. Tim has been working for Collins Aerospace (formerly Rockwell Collins) since 2015. In his current role, he helps develop new manufacturing processes, troubleshoots production issues, and does root cause analysis of failures related to soldering. He is a member of SMTA and IPC.

Dr. Ross Wilcoxon is a Senior Technical Fellow in the Collins Aerospace Advanced Technology group in Cedar Rapids, IA. He conducts research and supports product development in the areas of component reliability, electronics packaging and thermal management for airborne communication, processing, displays and radars. He has more than 50 journal and conference publications, is an inventor on over 30 US Patents, and is an editor of Electronics Cooling Magazine. Prior to joining Rockwell Collins (Now Collins Aerospace) in 1998, he was an assistant professor at South Dakota State University.

Grace Cooke is a Mechanical Engineer in the Microelectronics Packaging department of Collins Aerospace in Cedar Rapids, Iowa. Ms. Cooke graduated from Iowa State University with a BS in Mechanical Engineering and a M.Eng. in Systems Engineering. Grace has been working for Collins Aerospace (formerly Rockwell Collins) since 2019. In her current role, she helps develop new System-in-Package technology for the Mission Systems division of Collins Aerospace.

Sue Margheim is a Senior Principle Metallurgical Engineer at Collins Aerospace in Cedar Rapids, Iowa. During her 26 years with Collins, she has led many company-wide technical initiatives including Pb-free finish qualification and tin whisker mitigation, as well as failure analysis and material selection for various military and commercial avionics electronic applications. Sue is active in industry organizations including two terms as the Chairperson for ASTM Committee B08 for Metallic & Inorganic Coatings, Nadcap Task Group memberships (for welding, non-conventional machining, heat treating aerospace supply base accreditation), and Aerospace Industries Association (AIA) participation in the Additive Manufacturing Working Group. She was awarded "Engineer of the Year" for Collins Operations in 2012, and the ASTM "Award of Appreciation" for outstanding service as an ASTM Committee Chairperson. Before coming to Collins, Sue was a Senior Metallurgical Engineer at Olin Brass in East Alton, Illinois for 8 years. Sue earned her Bachelor of Science degree from Iowa State University in Metallurgical Engineering.

Terry Munson, owner and founder of Foresite Inc. a forensics laboratory for electronic assemblies and systems. Terry has 30 years of experience developing new techniques to better understand fabrication and assembly cleanliness issues and their impact on field performance. Prior to founding Foresite, Terry was employed with Delco Electronics where he applied ion chromatography analysis techniques to wafers, plating samples, and PCB / PCBAs, an industry first. He presented the new analysis techniques to the industry at IPC Expo 1990 in San Diego. As Senior Consultant, Terry directs a team of 20 staff members with four lead investigators supporting client investigations. Terry, utilizing ion chromatography, localized C3 extractions and Foresite's knowledge database, has established cleanliness limits which are used by many of Foresite's clients to improve field performance.

Dennis Fritz is currently a consultant to the US Partnership for Assured Electronics (USPAE) concerning lead-free electronics for Defense applications. He has retired previously from both SAIC, Inc at Crane, IN and MacDermid/Enthone in Waterbury, CT. For 12 years at SAIC, Dennis supported the Executive Agent assignment for printed circuits and electronic interconnects within Defense. For MacDermid/Enthone – Dennis worked directly for 19 years, and consulted for 10. He specializes in lead-free electronics, advanced circuit board technology, environmentally restricted materials, and supply chain issues. Dennis is particularly active with IPC, being named to the IPC Hall of Fame in 2012, given an IPC President's award in 1997, and one of the initial Dieter Bergman IPC Fellows in 2014. Fritz holds a BS degree in Chemical Engineering from Rose Hulman Institute of Technology and an MBA degree in Marketing from the University of Delaware.