

Tin Whisker Risk Management by Conformal Coating

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Abstract

The objective of this study is to evaluate conformal coatings for mitigation of tin whisker growth. The conformal coatings chosen for the experiment are acrylic, polyurethane and parylene. The coatings were applied in thicknesses ranging from 0.5 to 3.0 mils on 198 bright tin plated coupons with a base metal of either Copper C110 or Alloy 42. Prior to coating, light scratches were applied to a portion of the coupons, and a second fraction of the coupons were bent at 45° angles to provide sources of stress thought to be a possible initiating factor in tin whisker growth. The coupons have been subjected to an environment of 50°C with 50% relative humidity for 9.5 years. Throughout the trial period, the samples were inspected by both optical and scanning electron microscopy for tin whisker formation and penetration out of the coatings by tin whiskers. Tin whiskers were observed on each coupon included in the test, with stressed regions of the bent samples demonstrating significantly higher tin whisker densities. In addition, the Alloy 42 base metal samples showed greater tin whisker densities than the Copper C110 base metal samples. There were no observable instances of tin whisker penetration out of the coatings or tenting of the conformal coat materials for any of the non-stressed test coupons. The stressed coupons demonstrated tin whisker protrusion of the 1.0 and 2.0mil thick acrylic coating and the 1.0mil polyurethane coating for the Alloy 42 base metal samples. The greater thickness coatings did not demonstrate tenting or tin whisker protrusion. Also included in this paper are tin whisker inspection results of tin-plated braiding and wire that was exposed to an environment of 50°C with 50% relative humidity for over five years.

Introduction

A tin whisker is a spontaneous growth of a tin crystal from tin-finished surfaces. The crystal often grows in a needle-like form, and due to the electrical conductivity of the anomaly, there is a resulting risk of current leakage and shorting due to bridging of adjacent conductors. There have been multiple studies into the mechanisms for whisker growth and both environmental and mechanical factors that may promote whisker growth¹⁻⁵.

Similarly there have been multiple studies on methods for mitigating tin whisker growth^{6,7}. Mathew et al. reviewed research into mitigation strategies such as conformal coating, electroplating techniques, surface treatments, alloying tin, use of various under-plates and annealing of tin⁶.

The conformal coating mitigation strategy has shown multiple results using various coating materials and environmental storage conditions. NASA studies⁸⁻¹⁰ indicated that bright tin plated brass coupons, conformal coated with a urethane-based material, was able to prevent tin whisker protrusion following nine years of ambient storage when the coating thickness was at least 2.0mils. If the coating was thinner, there were observations of tin whisker protrusions.

Woodrow and Ledbury released two papers^{11,12} examining tin whisker growth through multiple conformal coating materials. Both studies used bright tin plated brass test coupons. For the first study, when the test coupons were subjected to an environmental chamber set to 50°C with 50% relative humidity (RH), tin whisker penetration was noted after approximately one year for coatings of 1.5mils and less, but not for coatings of at least 3.9mils. For the second study, the conformal coatings examined were urethane-acrylic hybrid, silicone, acrylic and parylene. The test coupons were subjected to an environmental chamber set to 25°C with 97% RH. All of the test coupons exhibited tin whisker penetration of the conformal coatings, even on samples with up to 6.0mils of coating.

The University of Maryland's Center for Advanced Life Cycle Engineering (CALCE) has studied the interfacial strength of conformal coatings in comparison to the whisker buckling force¹³ initially presented by Kadesch and Leidecker⁸. Preliminary testing indicated that conformal coatings of 25 microns (approximately 1.0mil) or less with a modulus of 100MPa or less are at risk of tin whisker penetration. Nakagawa et al. similarly identified harder coatings with high adhesion strengths as the most likely materials to prevent tin whisker protrusion¹⁴.

Han et al. review the effectiveness of conformal coatings as a tin whisker mitigator on actual built circuit cards and determined that coating coverage is an essential factor¹⁵. As the coating thinned along the edges of component leads, the potential for tin whiskers to protrude through the coating, regardless of the coating type increased dramatically. This was confirmed by the NPL's Hunt and Wickham who designed a test vehicle to determine the propensity of whiskers to grow through coatings and contact a neighboring plate¹⁶.

Reviewing the multiple studies on the use of conformal coatings as a mitigation technique for tin whiskers indicates that tin whiskers can grow through a coating. One of the leading factors for the risk of a protrusion through a coating is the thickness. Coating thicknesses below 2.0mils appear to present a greater risk of tin whisker penetration, although extreme environmental conditions coupled with the type of tin plating could promote tin whisker growth through any type of coating at relatively large coating thicknesses.

This company conformal coats 99% of all circuit boards using one of three (3) different conformal coating materials: acrylic, polyurethane and parylene. This study examined the affects of tin whisker growth on the three coatings applied to test coupons at varying thicknesses.

Acrylic conformal coatings are perhaps the most popular of all conformal coating materials due to their ease of application, removal and forgiving nature¹⁷. Acrylics dry rapidly, reaching optimum physical properties in minutes, are fungus resistant and provide long pot life. Additionally, acrylics give off little or no heat during cure eliminating potential damage to heat-sensitive components. They do not shrink during cure and have good humidity resistance and exhibit low glass transition temperatures.

Polyurethane coatings are available as either single or two-component formulations¹⁴. Both formulations provide excellent humidity resistance and far greater chemical resistance than acrylic coatings. Single component polyurethanes, while easy to apply, enjoy long pot life but sometimes require very lengthy cure cycles to achieve full or optimum cure. Two component formulations can reach optimum cure properties in as little as one to three hours with the assistance of heat. However, when compared to single component formulations, two-component formulas can have a relatively short pot life sometimes making them difficult to work with. Since polyurethanes are polymerized and cross-linked in place, they have excellent resistance to chemicals, moisture and solvents. They are available in tough, abrasion-resistant varieties and also in low modulus varieties for extreme temperature ranges. Polyurethanes have good adhesion to most materials and provide for a robust coating process. The material is difficult to remove following cure except by thermal or mechanical means.

Parylene coating is chemically inert and moisture resistant¹⁴. Very thin, uniform layers can be applied to the surface with no pinholes or voids. Parylene coating has a high dielectric strength. Due to the nature of the deposition process used to apply the coating, there are no volatiles generated. Parylene coatings are extremely low weight and yet have the highest modulus of the three coatings being examined. The coating process must be performed in batch mode, using specialized coating equipment. Rework is difficult, and a microabrasion process is usually required to remove the coating.

The spray process used at the company for application of the acrylic and polyurethane coatings is automated with a rotating spray head. The motion of the head is designed to cover a given width from all angles. Masking is required to keep coating out of areas that should not be coated.

Parylene is applied at room temperature with deposition equipment that controls the coating rate and ultimate thickness. Polymer deposition takes place at the molecular level in three stages. The raw material dimer is vaporized under vacuum and heated to a dimeric gas. The gas is then pyrolyzed to cleave the dimer to its monomeric form. In the room temperature deposition chamber, the monomer gas deposits as a transparent polymer film.

In addition to tin whisker growth on component leads and coatings, the risk of tin whisker growth on braiding and wires is also of concern. Hillman et al. indicated a low risk for tin coated copper wire, braid and cable following exposure of samples to 85°C and 85% relative humidity¹⁸.

Scope and Objective

This study was designed to examine the effects of tin whisker growth on the three coatings, applied to test coupons at varying thicknesses. In addition, the tin whisker growth on braiding, stranded wire and solid single strand wire with pure tin coating was also monitored to determine the risk of use in high-reliability products.

Examination of conformal coating as a mitigating material for tin whisker growth

Test coupons consisting of two types of base material (Copper C110 alloy and Alloy 42) were electrodeposited with a layer of 'bright tin' plating. Copper C110 and Alloy 42 are common base metals utilized for component leads. After plating and prior to conformal coating a quantity of the plated coupons were scratched to simulate those found during handling and shipping conditions, and another quantity of plated coupons were bent (without scratches) to induce tensile and compressive stresses on the plating. All of the test coupons were then conformal coated on approximately half of the surface with the other half remaining uncoated. The coupons were masked, coated, and then demasked to ensure the coating thickness was uniform and there was no thinning at the edges. The test coupons were placed in an environmentally controlled temperature / humidity chamber to promote the growth of the tin whiskers.

At specific time intervals, a sampling of test coupons were removed from the temperature / humidity chamber and evaluated for tin whisker growth on the plated and uncoated surfaces versus the plated and conformal coated surfaces. Data samples were collected and examined under high magnification, photomicrographs, or scanning electron micrographs. Energy dispersive spectroscopy (EDS) analysis also provided metallurgy to confirm anomalies as tin whiskers. All data collected was documented, logged and charted to show whisker growth and other variations.

The test had three primary objectives:

1. Grow tin whiskers on the bright tin plated test coupons.
2. Provide positive evidence that conformal coating, over a bright tin plated coupon protects against tin whiskers through growth reduction, abatement or containment.
3. Evaluate the different conformal coating materials and thicknesses to evaluate which materials and coating thicknesses provide the best protection against tin whisker growth.

Examination of the tin whisker growth risk for tin coated braiding, stranded wire and solid single strand wire:

Three samples each of pure tin coated braiding, stranded wire and solid single strand wire were taken directly from stock reels manufactured in 2008. The samples were inspected for the presence of tin whiskers using optical microscopy and scanning electron microscopy prior to exposure to an environmentally controlled temperature / humidity chamber to promote the growth of the tin whiskers. Following five years of exposure, the samples were removed from the temperature / humidity chamber and evaluated again for the presence of tin whiskers.

The primary objective of the testing was to determine if the typical pure tin coating present on braiding and wire would grow tin whiskers of the size capable of causing electrical failure to an assembly.

Procedure and Materials

Examination of conformal coating as a mitigating material for tin whisker growth

A diagrammed outline of the test coupon preparation procedure is shown in Figure 1.

The test coupons measured 1in x 4in x 0.032in. The bright tin coating was applied to the test coupons by electrodeposition according to ASTM B545. The thickness of the tin coating was 215-225µin. The test coupons were supplied and tin plated by Alexandria Metal Finishers. There were a total of 99 coupons with the Copper C110 base metal and 99 coupons with the Alloy 42 base metal.

Following the plating process, 69 Copper C110 base metal coupons and 69 Alloy 42 base metal coupons were ‘scratched’ along the surface. Brown paper wrapping material was cut in sheet sizes approximately 8.5in x 11in, wrinkled by ‘balling and crushing’ and then unraveled and flattened. Each coupon was separately wrapped (one sheet/coupon), then individually laid on a hard surface (i.e. table top) and shuffled around several times on each of the flat sides thereby randomly creating ‘light’ scratches on the tin surface. These scratches were intended to simulate those found on the surface of component leads as a result of shipping and handling. The typical ‘light’ scratch created by this method was photo documented.

Also following the plating process, 30 Copper C110 base metal coupons and 30 Alloy 42 base metal coupons had a 45° bend placed in 2 places as shown in Figure 2 using a machine vise with appropriate protection applied to the jaws of the vise (i.e. Teflon tape or equivalent). This bend was intended to put the tin plating under stress. Necessary precautions were taken to protect the transfer of metal to the tin plating during the bending process. These coupons do not have scratches in the tin plated surfaces.

The conformal coatings used in the testing were acrylic per MIL-C-46058, Type AR, polyurethane per MIL-C-46058, Type UR, and parylene per MIL-C-46058, type XY. Table 1 includes mechanical properties of the coatings used in the testing. The application thickness of the coatings was 1.0, 2.0 or 3.0mils for the acrylic and polyurethane coating and 0.5mils for the parylene coating. Prior to the coating process, the samples were cleaned using the existing in-line cleaner and then baked at 85°C for two hours. The appropriate areas of the coupons were masked using tape. The acrylic and polyurethane coatings were applied using a spray coat process and the parylene coating was applied using a vapor deposition process. All test coupons were coated by the company. The samples were labeled according to Table 2.

Following the conformal coating of the test coupons, and a visual inspection to insure continuity of the coating as well as a measurement of the coating thickness on approximately ten samples to insure that the proper coating thicknesses were applied, the samples were placed in an environmental chamber. The environmental chamber was capable of maintaining a temperature of 50° ± 10°C and a relative humidity of 50% ± 15%. The oven was equipped with a fail-safe device to ensure against overheating. The internal working envelope of the environmental chamber was 16in x 16in X 12in. The temperature

and humidity was continually monitored by an electronic recording device. The date of the initial insertion of the coupons to the environmental chamber was June 15, 2004.

On one occasion during the last quarter of each year, a sample of test coupons was removed from the environmental chamber and inspected. The inspection consisted first of optical microscopy, using the indirect light procedures described on the 'NASA Tin Whisker Homepage' website¹⁹. Anomalies in the integrity of the conformal coating were noted, and any areas with suspect tin whisker growth were noted and inspected further using scanning electron microscopy. SEM was also used on the areas of the test coupons without conformal coating to determine the length and density of tin whiskers.

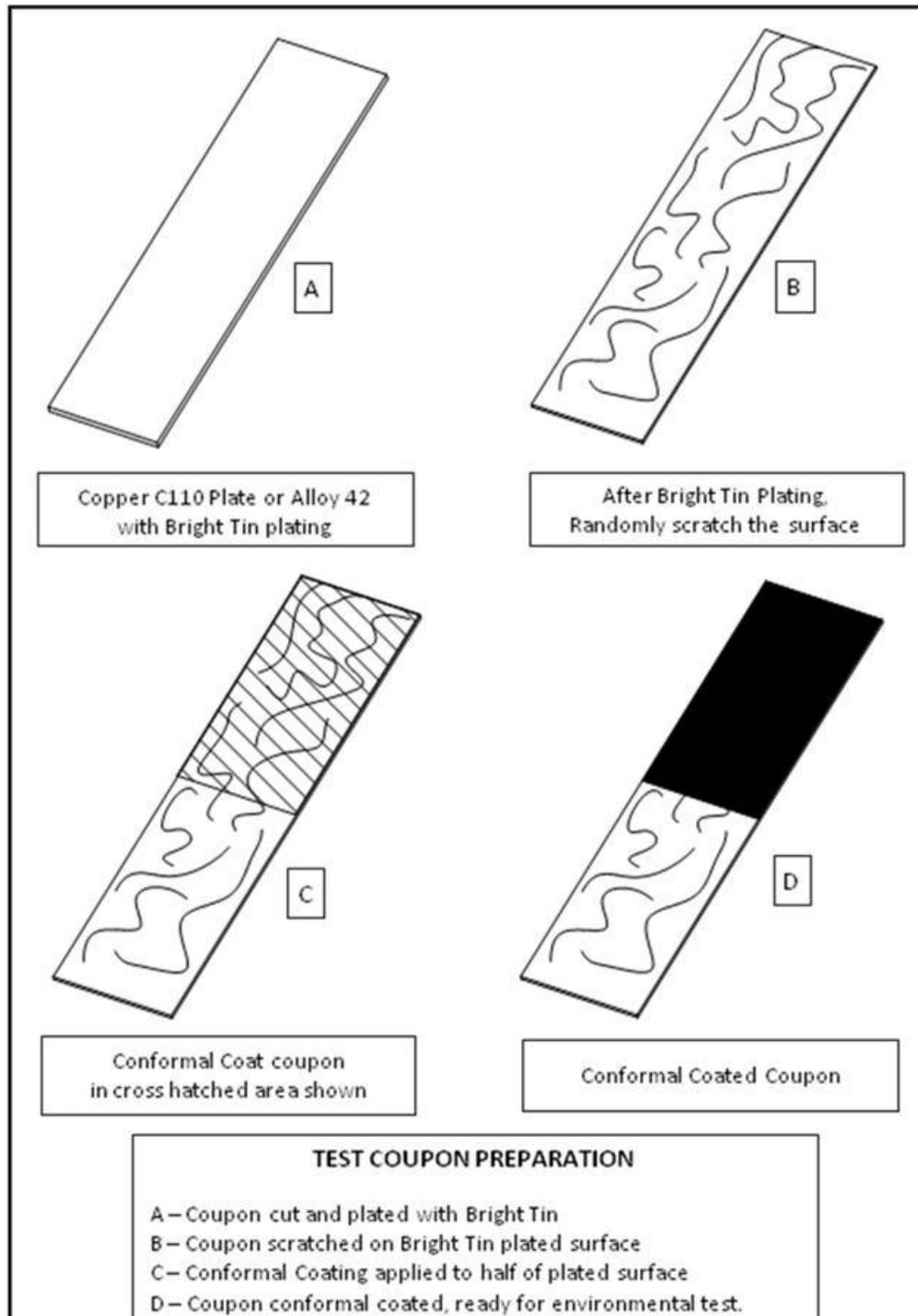


Figure 1 – Test coupon preparation procedure

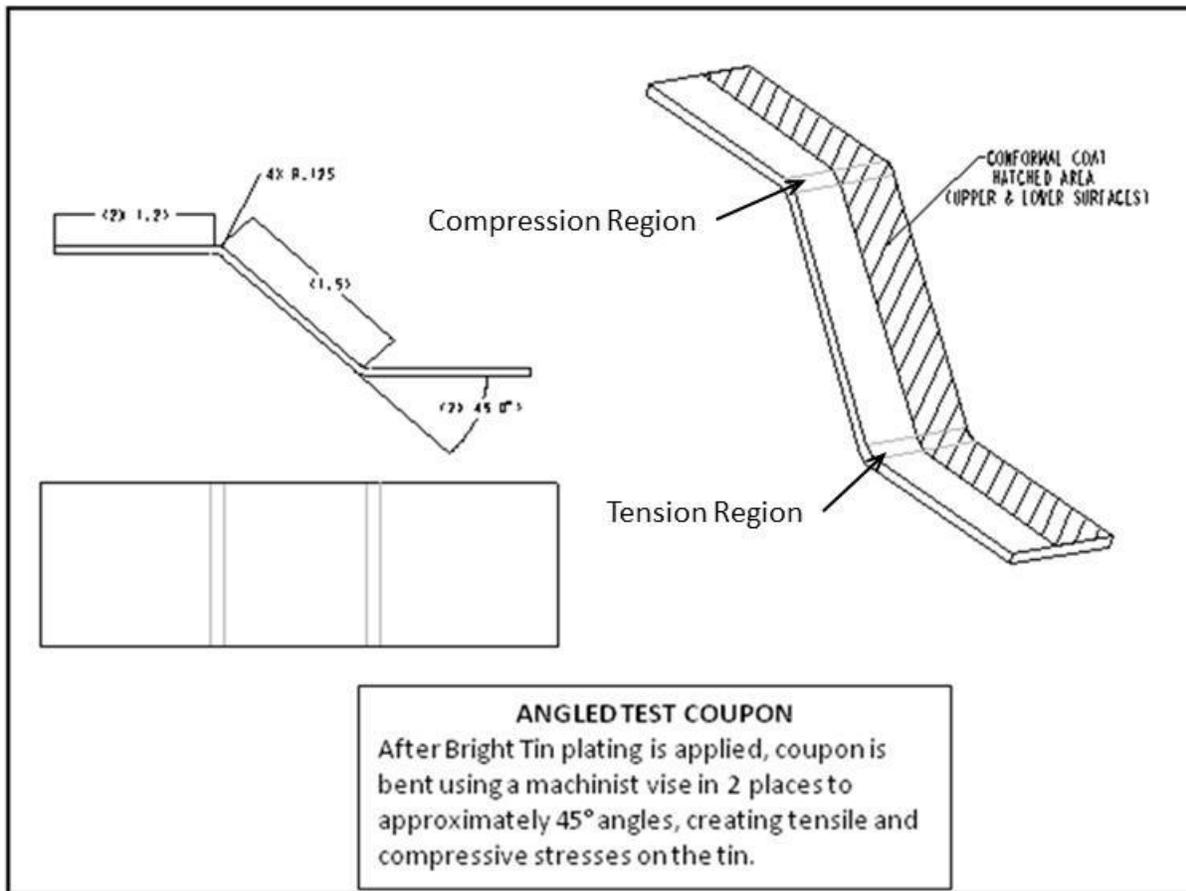


Figure 2 – Drawing of bent test coupons

NOTE: For the bent test coupons, the regions of compression and tension in the tin plating, caused through relaxation of the material following the bending process are identified in the schematic.

Table 1 – Properties of Conformal Coatings Used in Testing

Property	Test Method	Conformal Coating		
		Acrylic Type AR	Polyurethane Type UR	Parylene Type XY
Young's Modulus (psi)	ASTM D882	11,600	13,000	400,000
Elongation to Break (%)	ASTM D882	100	100-1000	200
Water Absorption (% after 24 hours)	ASTM D570	0.3	0.02-1.50	<0.1
Hardness	ASTM D785	M68-M105	10A-25D (Shore)	R80
Dielectric Strength (V/mil)	ASTM D149	3,500	3,500	5,600

NOTE: Properties from material technical data sheets

Table 2 – Test Coupon Matrix

Coupon Base Material	Conformal Coating	Coating Thickness (mils)	Number of Coupons
Samples below were scratched along the surface prior to coating			
Copper C110 (Scratched)	None – Bare	NA	5
	Acrylic	1.0	8
		2.0	8
		3.0	8
	Polyurethane	1.0	10
		2.0	10
		3.0	10
Parylene	0.5	10	
Total Coupons: 69			
Alloy 42 (Scratched)	None – Bare	NA	5
	Acrylic	1.0	8
		2.0	8
		3.0	8
	Polyurethane	1.0	10
		2.0	10
		3.0	10
Parylene	0.5	10	
Total Coupons: 69			
Samples below angled 45° to stress the bright tin plating			
Copper C110 (Bent)	Acrylic	1.0	5
		2.0	5
		3.0	5
	Polyurethane	1.0	5
		2.0	5
		3.0	5
Alloy 42 (Bent)	Acrylic	1.0	5
		2.0	5
		3.0	5
	Polyurethane	1.0	5
		2.0	5
		3.0	5
Total Coupons: 60			
Test coupon size prior to plating: 1in x 4in x 0.032 in Plating: Electrodeposited bright tin (per ASTM B545); thickness 215-222µin 1.0mil = 0.001in = 25.4µm			

Examination of the tin whisker growth risk for tin coated braiding, stranded wire and solid single strand wire:

Three samples each of braiding, stranded wire and solid single strand wire were removed directly from stock reels. The braiding selected had a braid length of 4in, an average braid width of 0.172in, an average braid height of 0.029in and a strand quantity of 30. The stranded wire selected conformed to the M22759/34-24-9 specification. The insulation was stripped on each sample to expose approximately 3in of wire. The solid single strand wire selected conformed to the A-A-59551, Type S, 20AWG tin coated specification. All of the samples examined were manufactured in 2008.

Prior to environmental exposure, the samples were inspected by optical microscopy and scanning electron microscopy for the presence of tin whiskers. The samples were placed in an environmental chamber set to 50° ± 10°C and a relative humidity of 50% ± 15% in September 2008. In September 2013, all of the samples were removed from the environmental chamber and again inspected by optical microscopy and scanning electron microscopy for the presence of tin whiskers.

Results and Discussion

Examination of conformal coating as a mitigating material for tin whisker growth

A detailed review of the annual inspection results for the initial 5.5 years of environmental exposure was reported previously²⁰.

Original inspection of the test coupons following application of the tin plating indicated no observable anomalies in plating integrity (Figure 3). Cross-sections of ten samples confirmed the plating thickness to be between 215 and 225 μ in. The thickness of the applied conformal coating was confirmed from several previous processing tests run to evaluate processing parameters for required coating thickness. Inspection of the conformal coating integrity indicated no significant anomalies. The coating thickness at the line of demarcation for the flat samples tended to be slightly less than that for the remainder of the sample but not significantly.

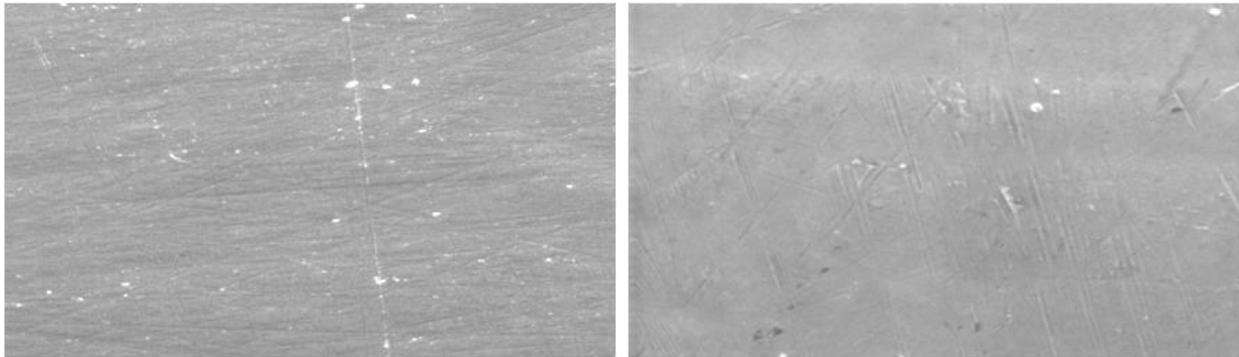


Figure 3 – Scanning electron micrographs (800X magnification) demonstrating the condition of the surface of the tin plating prior to conformal coating for both the Copper C110 base metal (left) and Alloy42 base metal (right)

Figure 4 includes scanning electron micrographs of the tin plating on a Copper C110 base metal coupon at the location of the bend prior to conformal coating. There are observable stress cracks in the tin plating caused by the bending process. The tin plating on the Alloy 42 base metal appeared similar.

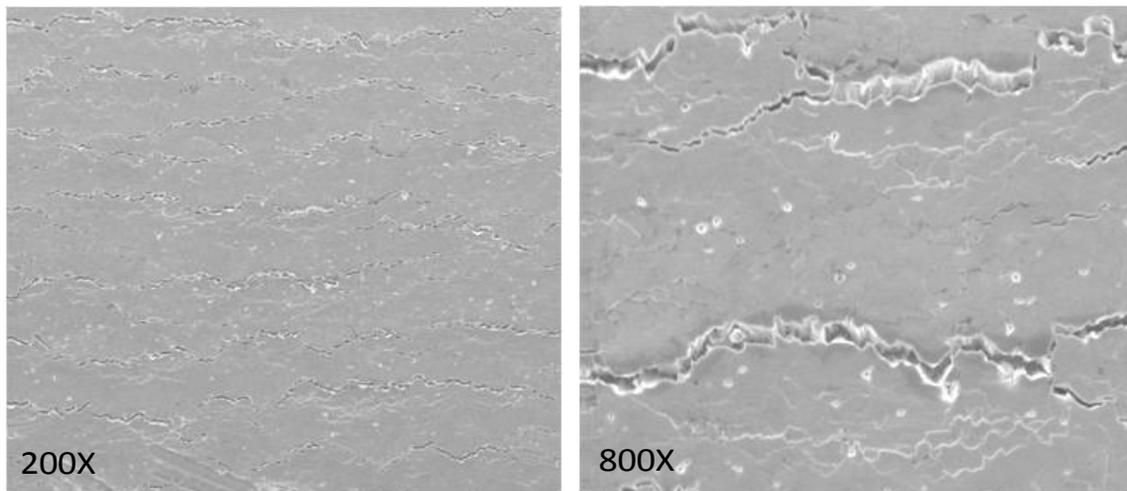


Figure 4 – Scanning electron micrographs of the tin plating following the bending process on the Copper C110 base metal.

Inspection Results for Coupons without Conformal Coating

Table 3 includes whisker density values for the uncoated samples for both the Copper C110 base metal and the Alloy42 base metal on the control samples and on the bent samples for both regions in tension and compression. As of the fourth quarter of 2013 sampling, the whisker density on the Alloy 42 base metal control sample (62 whiskers/mm²) was greater than that of the whisker density on the Copper C110 base metal control sample (39 whiskers/mm²). The largest tin whiskers and odd-shaped eruptions observable on the control samples approached 5.0mils, indicating that whiskers were present with minimum lengths dimensionally capable of extending through the conformal coating thicknesses applied to the test coupons. The effect

of the light scratches applied to the surface of the control samples was negligible with no observable pattern of whiskers accumulating along the scratches.

Table 3 – Average Tin Whisker Densities on *Uncoated* Regions throughout Environmental Exposure

Sample	Whisker Density (# / mm ²)									
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Copper C110	0	2	5	13	19	26	31	34	36	39
Alloy 42	0	4	11	21	33	47	53	57	60	62
Copper C110 (Compression)	0	3	9	20	29	53	72	101	121	128
Alloy 42 (Compression)	4	38	71	131	212	291	320	336	352	367
Copper C110 (Tension)	0	2	7	16	22	31	40	48	57	59
Alloy 42 (Tension)	3	18	41	74	94	130	161	182	201	213

As of the fourth quarter 2013 sampling, the whisker densities in the stressed regions were considerably higher than that for the control samples (Figure 5). The regions in compression exhibited greater whisker densities than the regions in tension for both the Copper C110 and Alloy 42 base metal coupons. The whiskers tended to grow along stress cracks in the tin plating caused by the bending process. The Alloy 42 coupons had significantly greater tin whisker density in both regions of compression (367 whiskers/mm²) and tension (213 whiskers/mm²) than that of the bent Copper C110 base metal coupons (128 whiskers/mm² in regions of compression and 59 whiskers/mm² in regions of tension). The length of tin whiskers growing along the surface of the samples from both base metals approached 8.0mils (Figure 6).

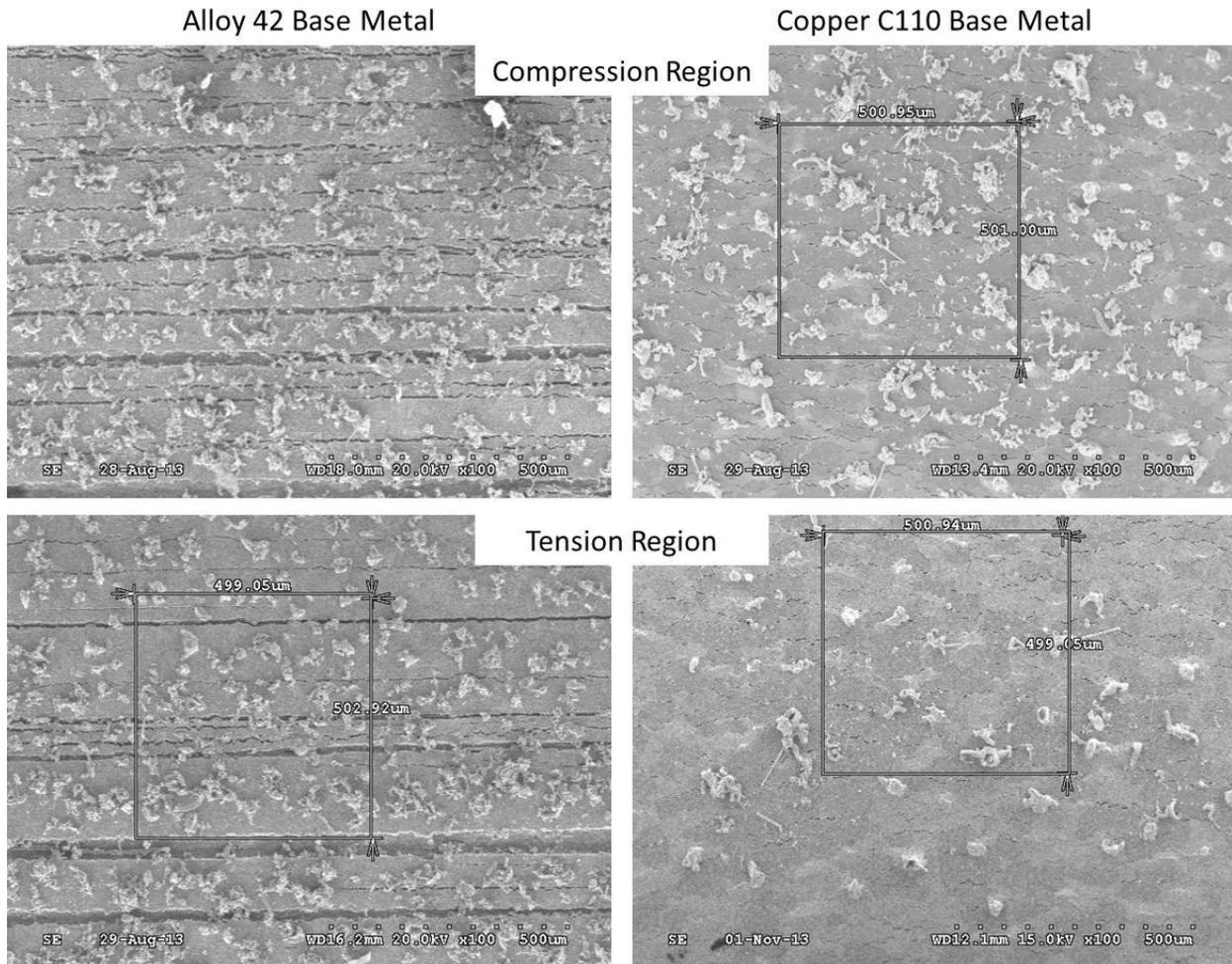


Figure 5 – Scanning electron micrographs (100X magnification) demonstrating the density of tin whiskers on the uncoated areas in the compression regions the bent coupons (top two micrographs) and the regions of tension for the bent coupons (bottom two micrographs).

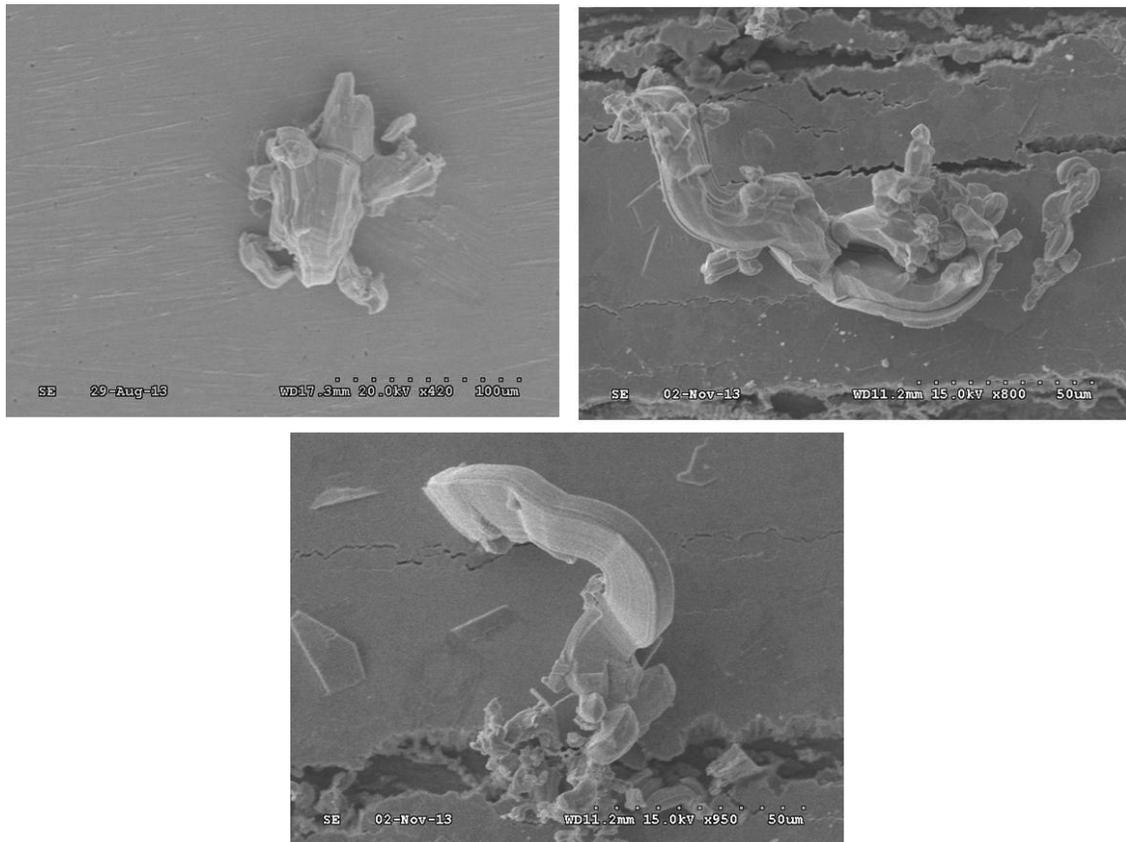


Figure 6 – Scanning electron micrographs detailing the appearance of tin whiskers growing on uncoated regions of the bright tin plated coupons.

The observations of the conformal coated test coupons as of the fourth quarter of 2013 are summarized in Table 4.

Inspection Results for Straight, Scratched Coupons with Conformal Coating

There were no observed tin whisker protrusions through any of the conformal coating materials used on the coupons that were not bent for both base metals (Table 4). In addition, there was no indication of tenting of the conformal coat where a tin whisker may push the coating away from the tin plating. There were tin whiskers or odd-shaped eruptions observed beneath the conformal coating for samples of both base metals and all coating types; however the observed tin whiskers did not cause any disturbance to the conformal coating. The presence of conformal coating over the tin whiskers was confirmed by EDS. Figure 7 includes a scanning electron micrograph detailing the interface of the parylene coating to the uncoated region of one coupon. Tin whiskers are observed growing on the uncoated region of the coupon; however the parylene coating appears undisturbed.

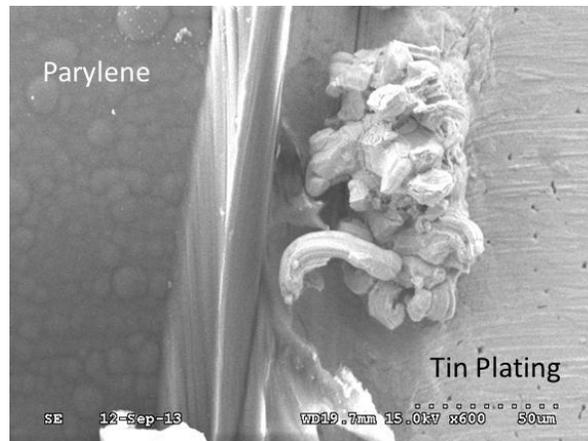


Figure 7 – Scanning electron micrograph (600X magnification) detailing the appearance tin whiskers growing on an uncoated region of a coupon adjacent to the parylene coating.

Table 4 – Tin Whisker Observations at end of Experiment

Coupon Base Material	Conformal Coating	Coating Thickness (mils)	Observations	
Samples below were scratched along the surface prior to coating				
Copper C110 (Scratched)	Acrylic	1.0	No tenting or tin whisker protrusions	
		2.0	No tenting or tin whisker protrusions	
		3.0	No tenting or tin whisker protrusions	
	Polyurethane	1.0	No tenting or tin whisker protrusions	
		2.0	No tenting or tin whisker protrusions	
		3.0	No tenting or tin whisker protrusions	
Parylene	0.5	No tenting or tin whisker protrusions		
	Acrylic	1.0	No tenting or tin whisker protrusions	
		2.0	No tenting or tin whisker protrusions	
3.0		No tenting or tin whisker protrusions		
Alloy 42 (Scratched)	Polyurethane	1.0	No tenting or tin whisker protrusions	
		2.0	No tenting or tin whisker protrusions	
		3.0	No tenting or tin whisker protrusions	
	Parylene	0.5	No tenting or tin whisker protrusions	
		Samples below angled 45° to stress the bright tin plating		
		Copper C110 (Bent)	Acrylic	1.0
2.0	Tenting in compression regions initially observed following 9.5 years of exposure; no protrusions			
3.0	No tenting or tin whisker protrusions			
Polyurethane	1.0		No tenting or tin whisker protrusions	
	2.0		No tenting or tin whisker protrusions	
	3.0		No tenting or tin whisker protrusions	
Alloy 42 (Bent)	Acrylic	1.0	Tin whisker protrusions in compression and tension regions initially observed following 5.5 years of exposure	
		2.0	Tin whisker protrusions in compression regions initially observed following 9.5 years of exposure. Tenting in tension regions initially observed following 9.5 years of exposure; no protrusions.	
		3.0	No tenting or tin whisker protrusions	
	Polyurethane	1.0	Tin whisker protrusions in compression and tension regions initially observed following 5.5 years of exposure	
		2.0	Tenting in compression regions only initially observed following 9.5 years of exposure; no protrusions.	
		3.0	No tenting or tin whisker protrusions	

Inspection Results for Bent Coupons with Conformal Coating

There was observable tenting but no tin whisker protrusion of the 1.0 and 2.0mil thick acrylic conformal coating on the regions in compression for the Copper C110 base metal samples during the sampling in the fourth quarter of 2013. There was no indication of tenting or tin whisker protrusion for the 3.0mil thick acrylic conformal coating or any of the thicknesses of polyurethane conformal coating. The regions in tension similarly showed no evidence of tenting or tin whisker penetration for any of the coated areas of the Copper C110 base metal samples.

For the bent Alloy 42 base metal samples, there was tin whisker protrusion of both the 1.0mil thick acrylic and polyurethane conformal coatings in both the regions of compression and tension as reported previously. The Alloy 42 base metal samples with acrylic conformal coating of 2.0mil thickness exhibited tin whisker protrusion in the compression region (Figure 8), and the Alloy 42 base metal samples with polyurethane coating of 2.0 mil thickness exhibited tenting of the coating in the compression region (Figure 9). The 3.0mil thick acrylic and polyurethane coatings showed no indication of tenting or tin whisker protrusion in either the tension or compression regions.

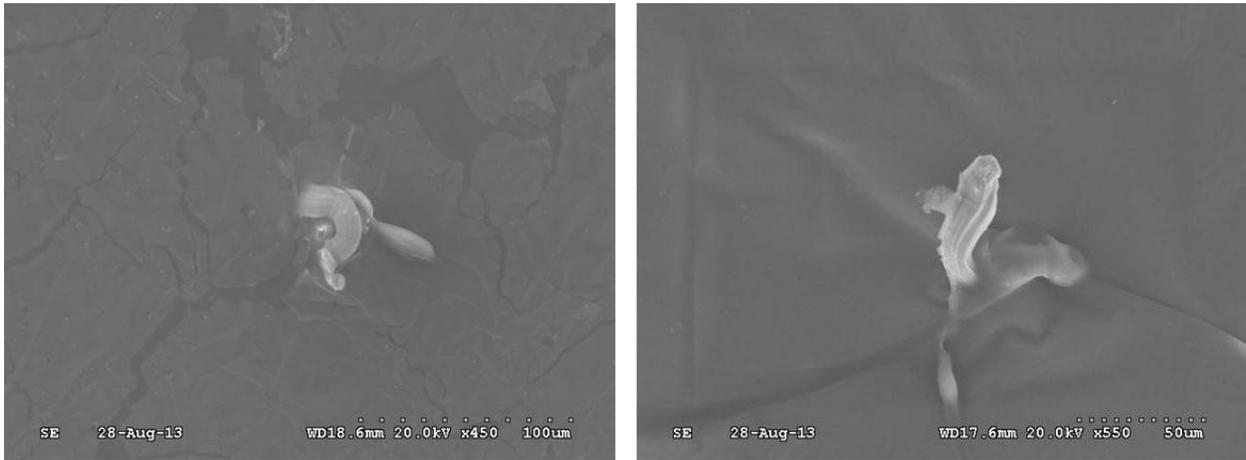


Figure 8 – Scanning electron micrographs detailing the appearance of tin whiskers protruding through 2.0mil thick acrylic coating in the compression region of a bent Alloy 42 base metal coupon.

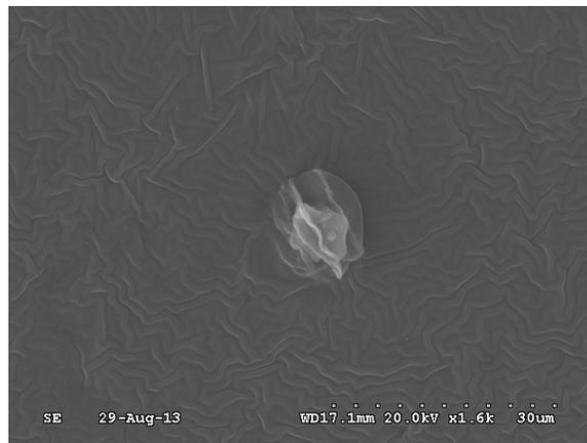


Figure 9 – Scanning electron micrograph characteristic of tenting of the 2.0mil thick polyurethane coating in a region of compression on a bent Alloy 42 base metal coupon.

Examination of the tin whisker growth risk for tin coated braiding, stranded wire and solid single strand wire:

Following exposure of the samples to a temperature of 50°C and a relative humidity of 50% for five years, the tin coated braiding and the stranded wire exhibited no observable tin whisker growth. For the solid single strand wire, there was a significant concentration of tin whiskers along the surface of all three samples (Figure 10). The longest whiskers present on the surface of the wire measured up to 40µm in length (Figure 11).

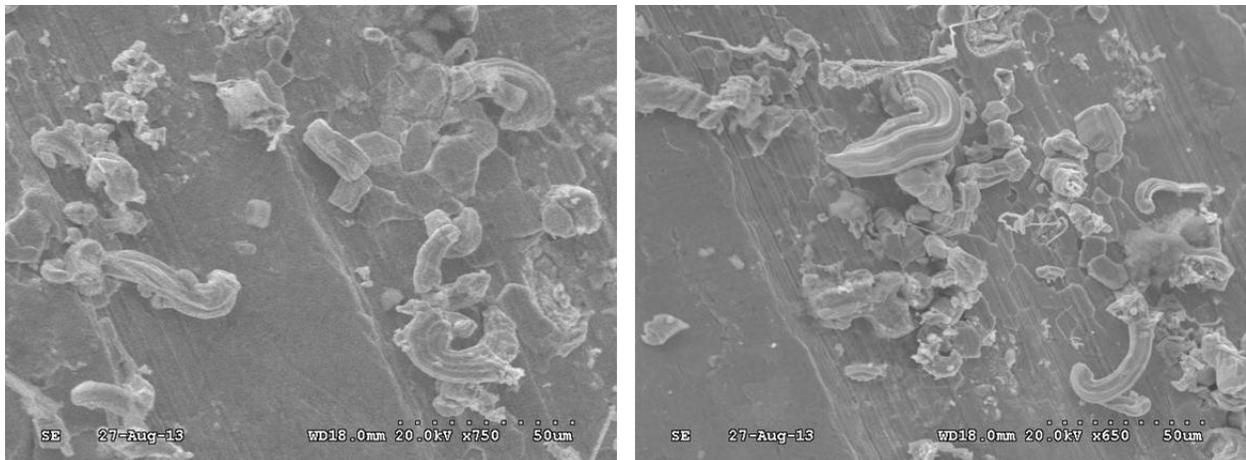


Figure 10 – Scanning electron micrographs detailing the concentration of tin whiskers on the surface of tin coated solid single strand wire following five years of exposure to 50°C / 50% relative humidity.

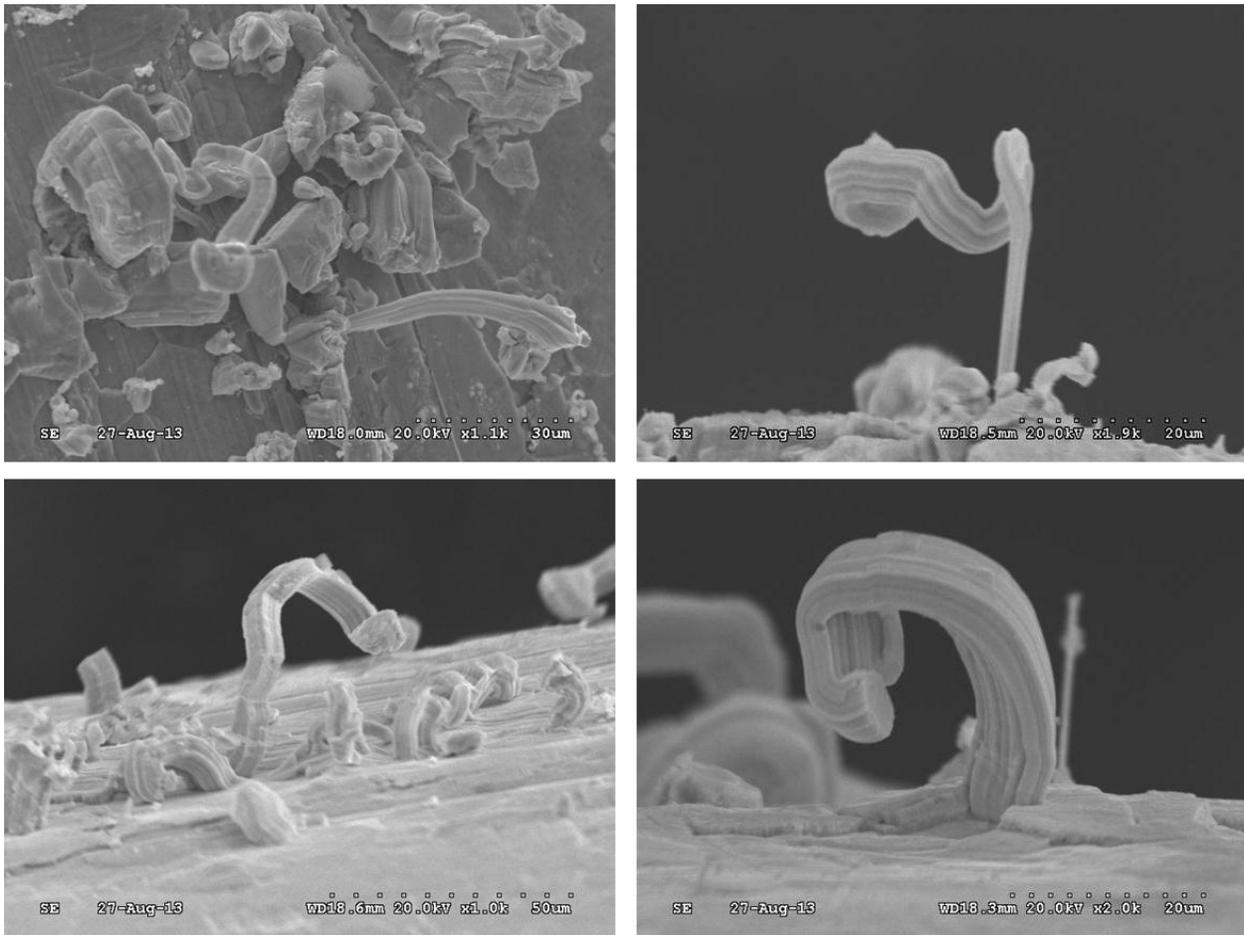


Figure 11 – Scanning electron micrographs detailing the characteristic appearance of tin whiskers on the surface of tin coated solid single strand wire following five years of exposure to 50°C / 50% relative humidity.

Conclusions

The Alloy 42 base metal test coupons exhibited higher tin whisker densities in uncoated regions than that of the Copper C110 base metal test coupons. The stressing of the test coupons by applying a 45° bend in two locations caused a significant increase in tin whisker density for both regions of tension and compression. The effect of the bending was noticeably more significant for the Alloy 42 base metal test coupons and the regions of compression had higher whisker density than the regions of tension. The negative effect of Alloy 42 base metal on the propensity of electrodeposited bright tin coatings to whisker has been shown in previous research. In addition, the effect of stressing tin plating resulting in increased tin whisker density has also been previously reported.

The conformal coatings used in this experiment mitigated tin whisker protrusions for the test coupons that were *not stressed*. Parylene coating at a thickness of 0.5mils and both acrylic and polyurethane coatings with a minimum thickness of 1.0mils did not exhibit any tenting following the 9.5 years of environmental exposure to 50°C and 50% RH.

Tenting was observable on the 1.0 and 2.0mil thick acrylic coating in regions of compression for the bent Copper C110 base metal samples; however there were no indications of tin whisker protrusions. There was no disruption of the polyurethane coating of any thickness for the bent Copper C110 base metal samples.

For the Alloy 42 base metal samples, in addition to the tin whisker protrusion in the tension and compression regions for the 1.0mil thick acrylic coating reported after 5.5 years, there was tin whisker protrusion of the 2.0mil thick acrylic coating in the compression regions observed initially after 9.5 years. The 2.0mil thick acrylic coating also exhibited tenting due to tin whisker growth in the tension regions. While there was observable tin whisker protrusions through the 1.0mil thick polyurethane coating in regions of tension and compression for the bent Alloy 42 base metal samples, there was no observable tin whisker protrusions through the 2.0mil thick polyurethane coating. The 2.0mil thick polyurethane coating did exhibit tenting only in the compression regions, initially observed after 9.5 years. The improved tin whisker mitigation with

thicker conformal coating is in agreement with the CALCE study stating that coatings of 1.0mils and thickness and low modulus are at risk for tin whisker penetration.

The conformal coating materials used in this testing mitigated the growth of tin whiskers through the coating for this specific electrodeposited tin plating and this specific environmental exposure when there were no additional stresses applied to the coupons. It should be noted that the tin plating selected and applied during this experiment were intentionally designed to promote the growth of tin whiskers and would not normally be considered as an acceptable plating for component leads of real hardware. Parylene, which has a significantly higher modulus demonstrated in this experiment the ability to mitigate tin whiskers at a thickness of 0.5mils; however there were no stressed (bent) samples for parylene. The bent samples indicate that stressed regions of tin plating will have a greater tendency to whisker. Additional testing on real world component leads mounted to circuit cards is warranted to determine minimum requirements for each coating type.

For the tin coated braiding and stranded wire subjected to temperature and humidity exposure, there was no observable tin whisker growth on the surface following five years of exposure. The lack of observed tin whiskers may be due to the minimal thickness of the tin coating and the lack of stressed regions within the strands. In addition, the thin tin coating may have been consumed by the tin-copper intermetallic layer relatively quickly following manufacturing, resulting in the reduced risk of tin whisker formation. The braiding and stranded wire products should be considered acceptable for use in high-reliability assemblies without having to add mitigation steps to reduce the risk of tin whisker growth.

The tin coated single strand wire did exhibit a high concentration of tin whisker growth with whiskers measured up to 40 μ in length. This does comply with the JESD201 maximum tin whisker length for Class 2 hardware; however the presence of tin whiskers is not allowable for JESD201 Class 3 hardware. While the JESD201 specification is not accepted industry-wide, the observed presence of tin whiskers on the tin coated single strand wire indicates that further analysis may be required to insure that the potential growth of tin whiskers on the product is accounted for in design and building of hardware.

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Tin Whisker Risk Management by Conformal Coating

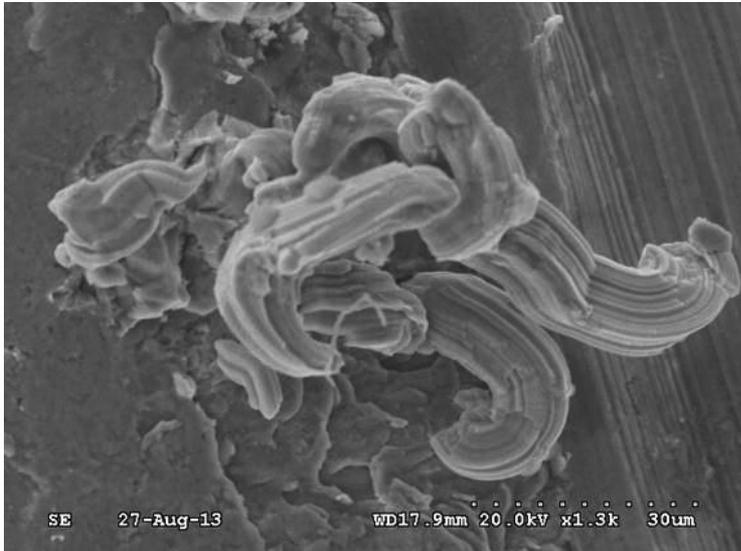
Linda Woody and William Fox
Lockheed Martin Missiles & Fire Control
Ocala, Florida

LOCKHEED MARTIN

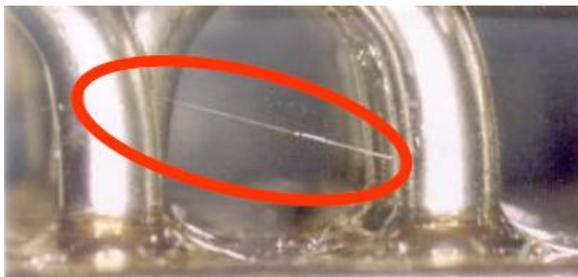
Presentation Outline

- Tin Whisker Risks and Mitigations
- Conformal Coating Studies Past and Present
- Environmental Testing and Inspection Results
- Conformal Coating Study
Conclusions/Recommendations
- Tin Coated Braiding and Wire Testing and
Results

Tin Whiskers and Their Risk to Electrical Assemblies



A spontaneous growth of a tin crystal from tin-finished surfaces



Risk of current leakage and shorting due to bridging of adjacent conductors

Photo from
<http://nepp.nasa.gov/whisker/>

Tin Whisker Mitigation Strategies

- Conformal coating
 - Suppress the growth of tin whiskers and to prevent whiskers growing from a tin plated surface from coming in contact with the adjacent conducting surface
- Electroplating techniques
 - Varying additive concentration, current densities, electrolyte composition and graded stress layer deposition
- Surface treatments
 - Surface treatments of the base metal prior to tin plating or surface treatments of the tin plating
- Tin alloys
 - Alloying tin with materials other than lead
- Under-layer materials
 - Under-layer materials which will form intermetallic compounds at the layer interface but induce relatively lower stress in the tin plating
- Tin annealing
 - Determine conditions such as temperature, hold time and heating and cooling rates required to sufficiently remove the residual stress in tin plated finishes

Notable Previous Conformal Coating Studies

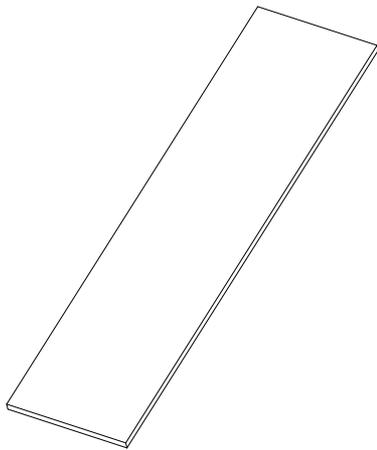
- NASA
 - Uralane coated coupons
 - 9 years of ambient storage
 - No tin whisker protrusion on coatings that were minimum 2.0mils
- Boeing
 - Multiple conformal coating materials
 - Storage at 50° C / 50%RH showed no tin whisker protrusion on coatings that were minimum 3.9mils
 - Storage at 25° C / 97%RH showed tin whisker protrusion on coatings up to 6.0mils
- CALCE
 - Multiple conformal coating materials
 - Conformal coating of entire circuit card assemblies
 - Tin whisker protrusion occurred in areas of the leads where the coating was thin (i.e. edges or bends in the leads) regardless of the coating material
- NPL
 - Created a parallel plate test vehicle to determine when tin whiskers protruded through a coating and contacted a neighboring surface
 - Multiple conformal coating materials
 - All coatings were found to suppress the formation of whiskers
 - Coating coverage and thickness were the major factors identified in reducing the risk of tin whisker protrusion

Current Study – Conformal Coating Materials Utilized

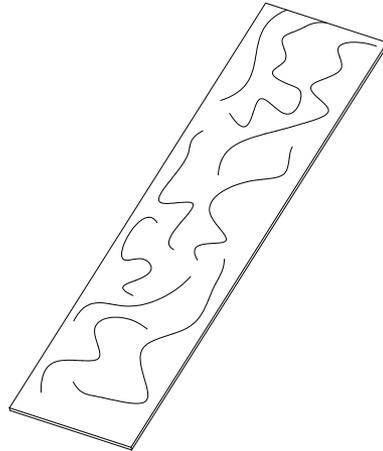
Property	Test Method	Conformal Coating		
		Acrylic Type AR	Polyurethane Type UR	Parylene Type XY
Young's Modulus (psi)	ASTM D882	11,600	13,000	400,000
Elongation to Break (%)	ASTM D882		100-1000	200
Water Absorption (% after 24 hours)	ASTM D570	0.3	0.02-1.50	<0.1
Hardness	ASTM D785	M68-M105	10A-25D (Shore)	R80
Dielectric Strength (V/mil)	ASTM D149	3,500	3,500	5,600

- The spray process used for application of the acrylic and polyurethane coatings is automated with a rotating spray head
- Acrylic and polyurethane coatings applied at 1.0, 2.0 and 3.0mils
- Parylene is applied at room temperature with vapor deposition equipment
- Parylene coating applied at 0.5mils

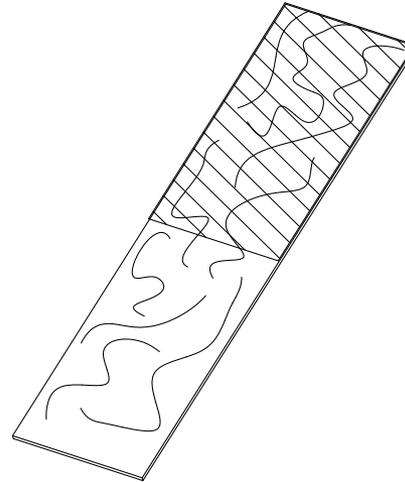
Current Study – Test Coupon Preparation



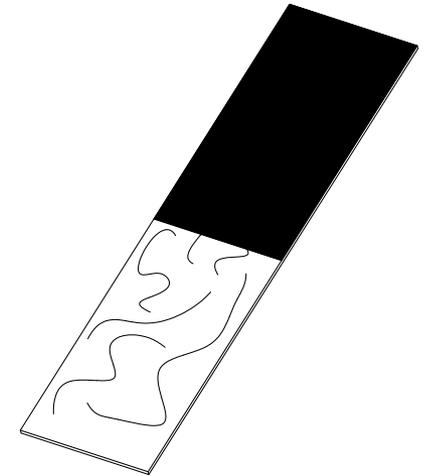
Copper C110 Plate or Alloy 42
with bright tin plating



After bright tin plating,
randomly scratch the surface



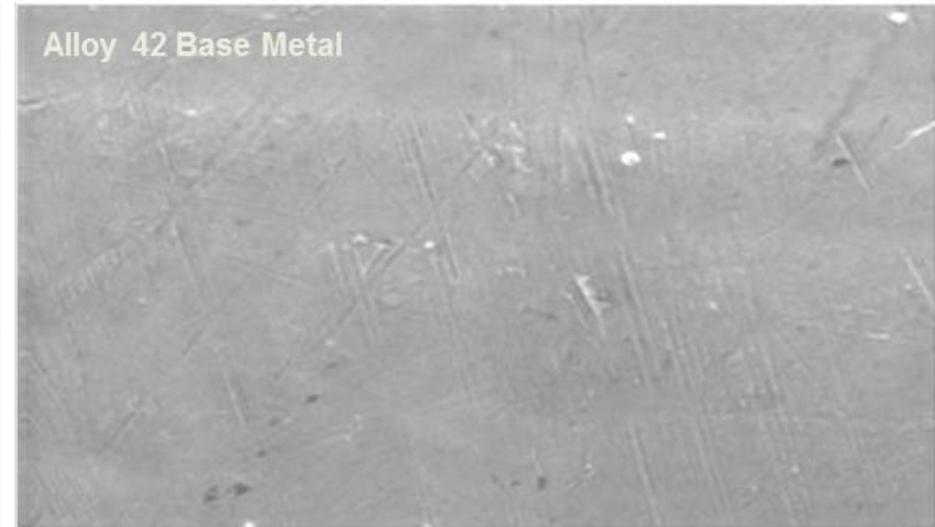
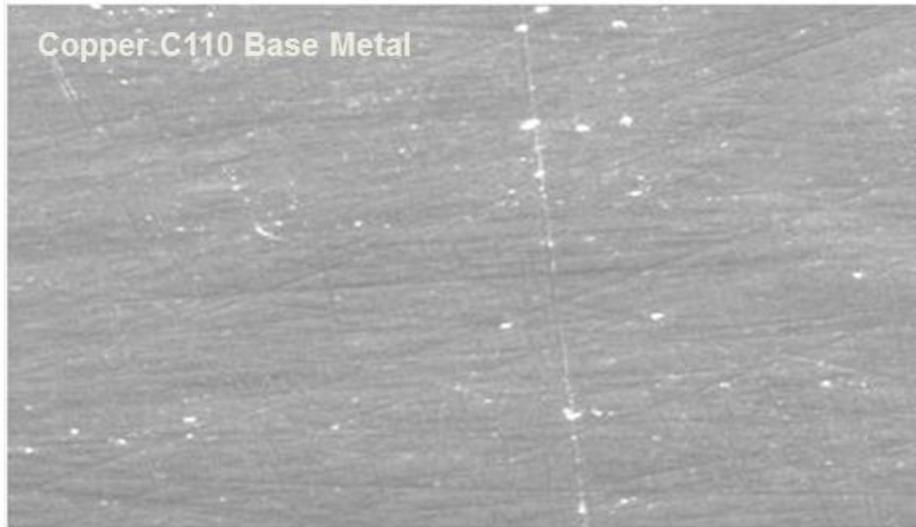
Conformal coat coupon
in cross hatched area shown



Conformal coated coupon

- Test coupons measured 1in x 4in x 0.032in
- Bright tin coatings were applied to the test coupons by electrodeposition according to ASTM B545; thickness of 215-225 μ m
- Tin platings were purposely designed to promote tin whisker growth

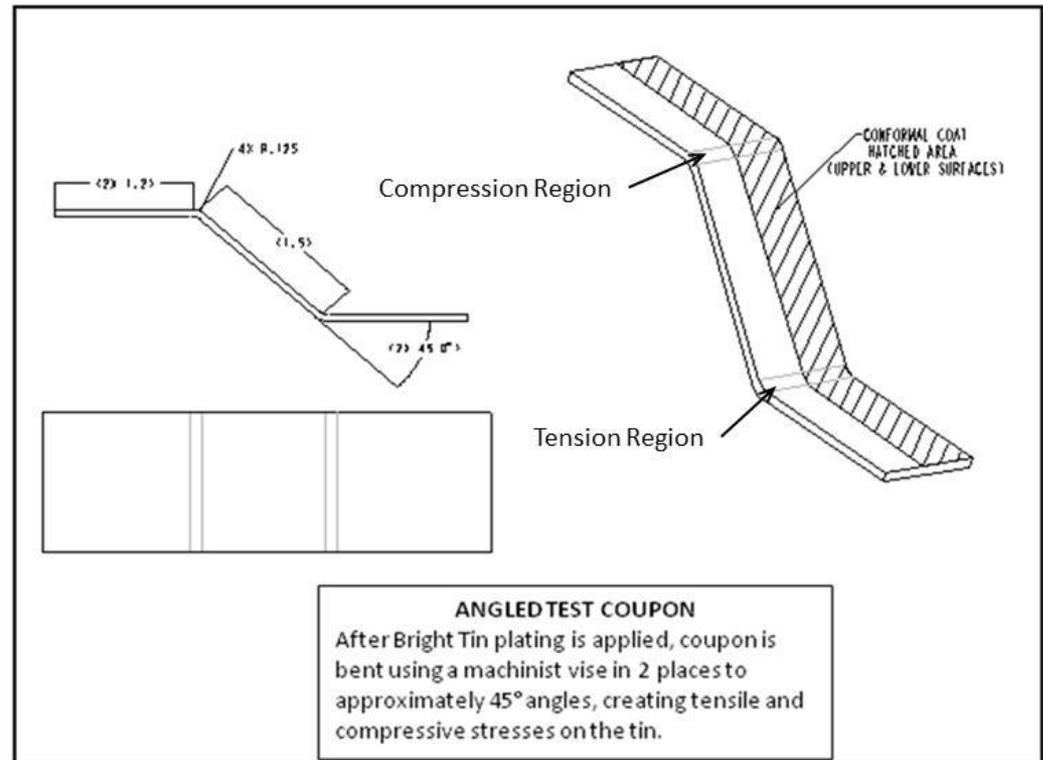
Surface of Test Coupons Prior to Conformal Coat



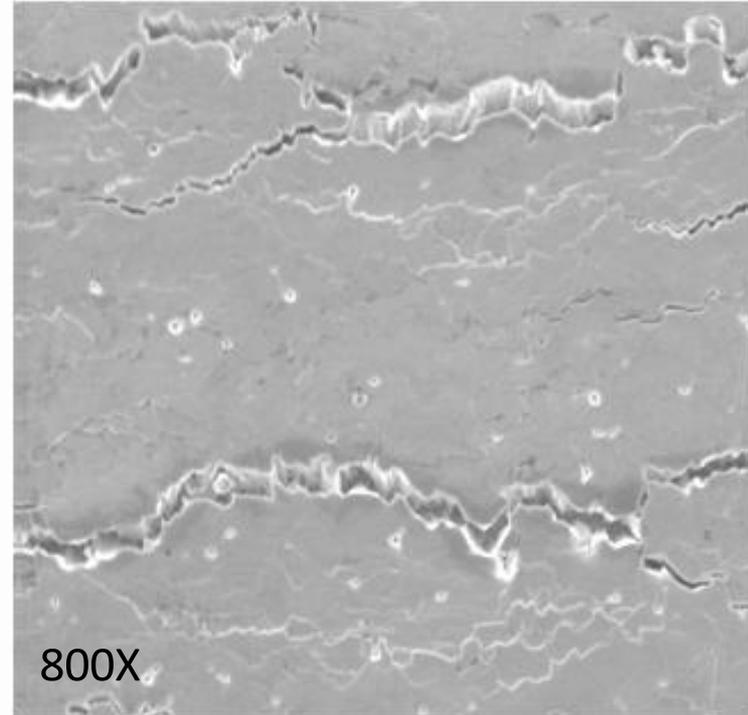
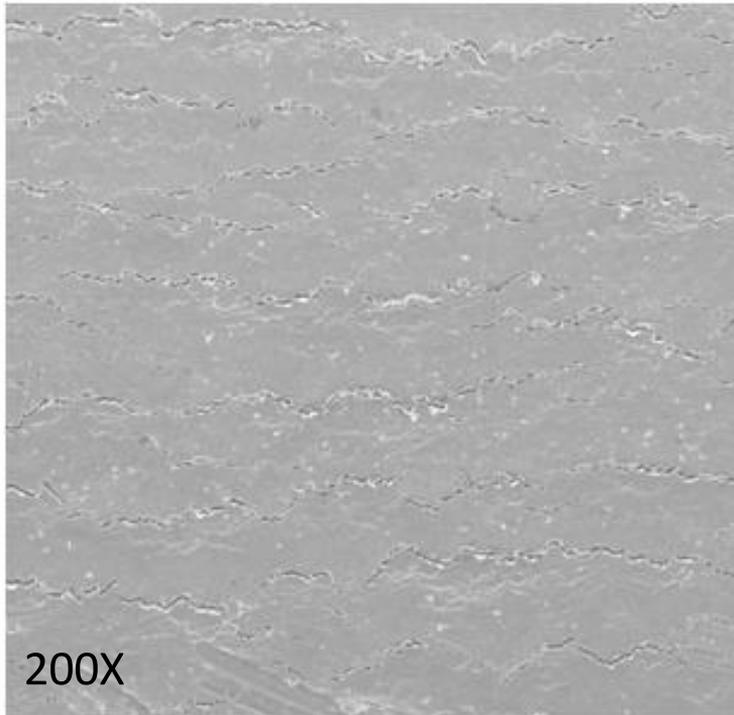
- Scanning electron micrographs (800X magnification)
- No observable anomalies in plating integrity

Current Study – Application of Bend to Coupons

- A portion of the test coupons were bent
- Coupon bent using a machinist vise in two places to 45° angles, creating tensile and compressive stresses on the tin
- The noted compression and tension regions are due to relaxation of the plating following the bending process
- Conformal coating applied following the bend process to one half of each coupon



Surface of Bent Test Coupons Prior to Conformal Coat



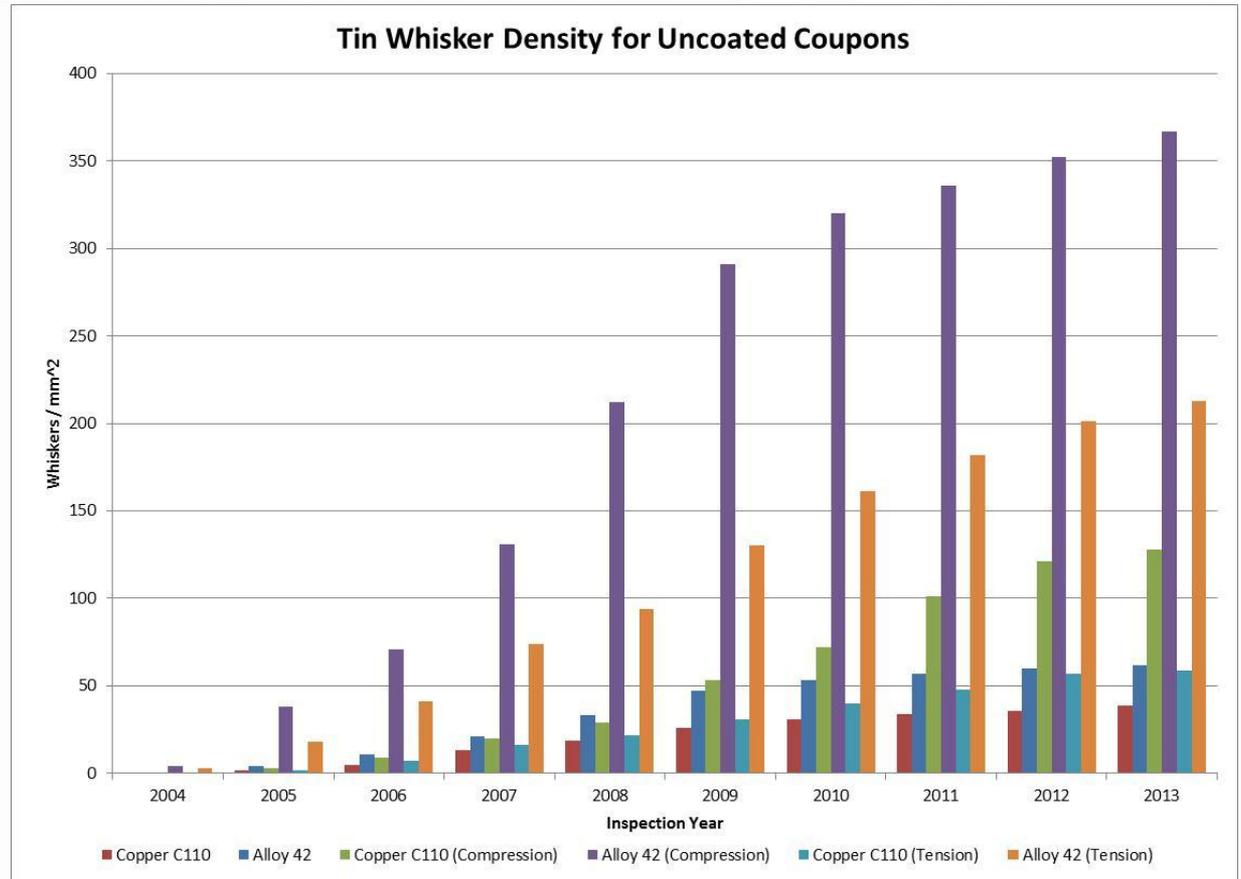
- Tin plating on a Copper C110 base metal coupon at the location of the bend
- Observable stress cracks in the tin plating caused by the bending process
- Similar results observed on the Alloy 42 coupons

Current Study – Environmental Testing

- Exposure to 50° C / 50%RH
- Coupons first introduced to chamber on June 15, 2004
- Sampling performed during fourth quarter of each year through 2013

Coupon Base Material	Conformal Coating	Coating Thickness (mils)	Number of Coupons	
Copper C110 (Scratched)	None – Bare	NA	5	
		Acrylic	1.0	8
			2.0	8
			3.0	8
	Polyurethane	1.0	10	
		2.0	10	
		3.0	10	
	Parylene	0.5	10	
		None – Bare	NA	5
	Alloy 42 (Scratched)	Acrylic	1.0	8
2.0			8	
3.0			8	
Polyurethane		1.0	10	
		2.0	10	
		3.0	10	
Parylene		0.5	10	
		Samples below angled 45° to stress the bright tin plating		
Copper C110		Acrylic	1.0	5
			2.0	5
	3.0		5	
	Polyurethane	1.0	5	
		2.0	5	
		3.0	5	
Alloy 42	Acrylic	1.0	5	
		2.0	5	
		3.0	5	
	Polyurethane	1.0	5	
		2.0	5	
		3.0	5	

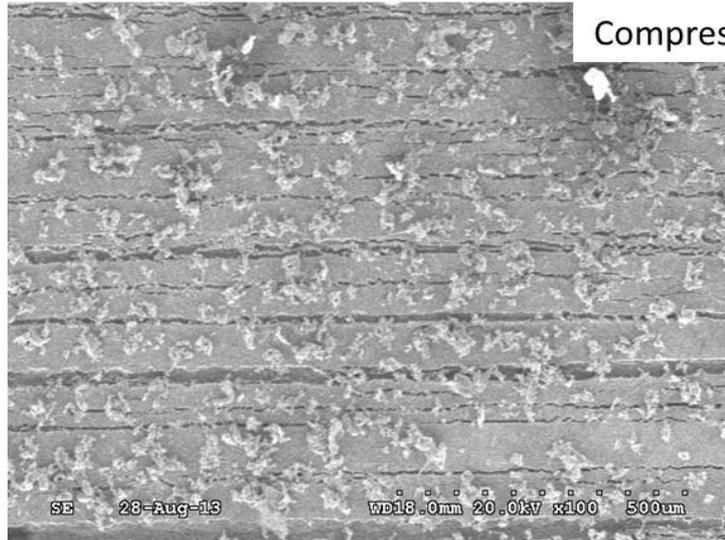
Tin Whisker
Densities
Throughout
Environmental Test



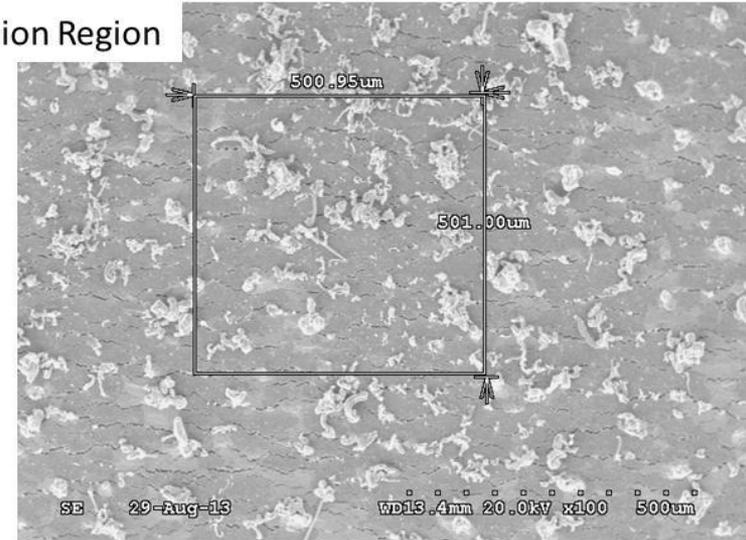
Sample	Whisker Density (# / mm ²)									
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Copper C110	0	2	5	13	19	26	31	34	36	39
Alloy 42	0	4	11	21	33	47	53	57	60	62
Copper C110 (Compression)	0	3	9	20	29	53	72	101	121	128
Alloy 42 (Compression)	4	38	71	131	212	291	320	336	352	367
Copper C110 (Tension)	0	2	7	16	22	31	40	48	57	59
Alloy 42 (Tension)	3	18	41	74	94	130	161	182	201	213

Tin Whisker
Density on
Uncoated,
Stressed Areas
of Coupons

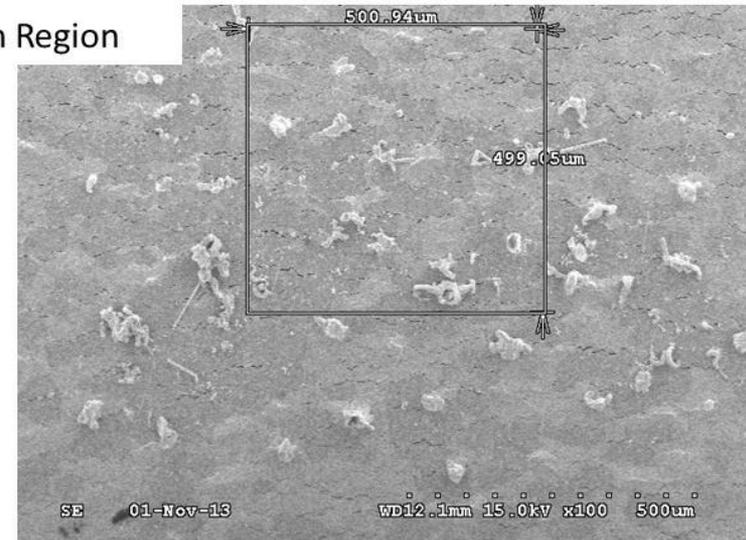
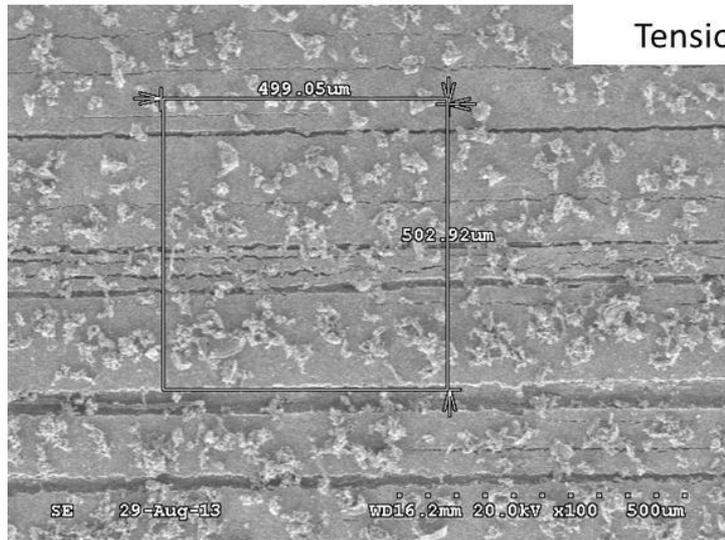
Alloy 42 Base Metal



Copper C110 Base Metal



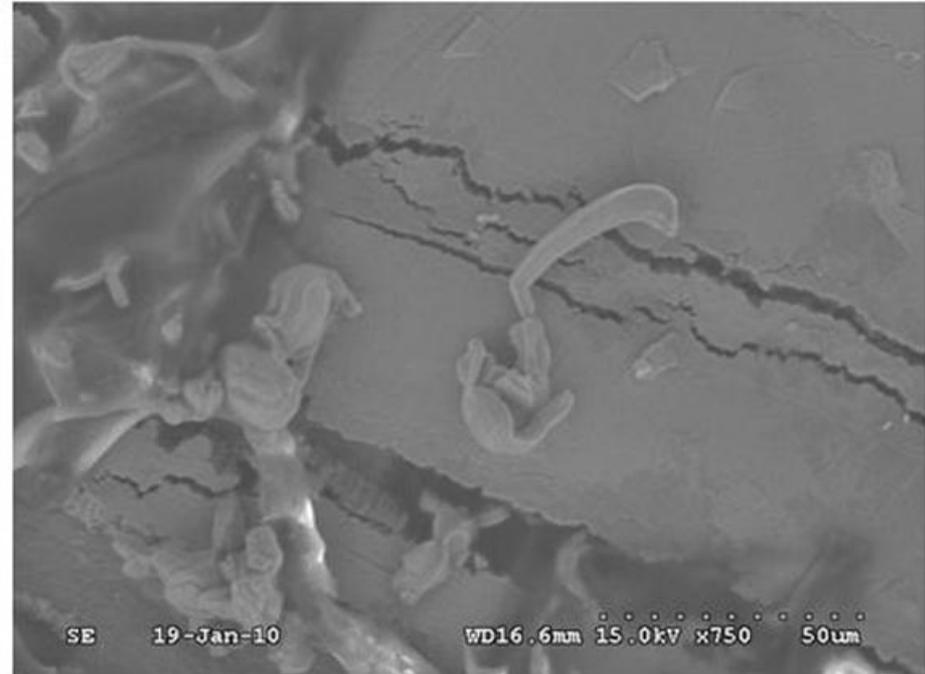
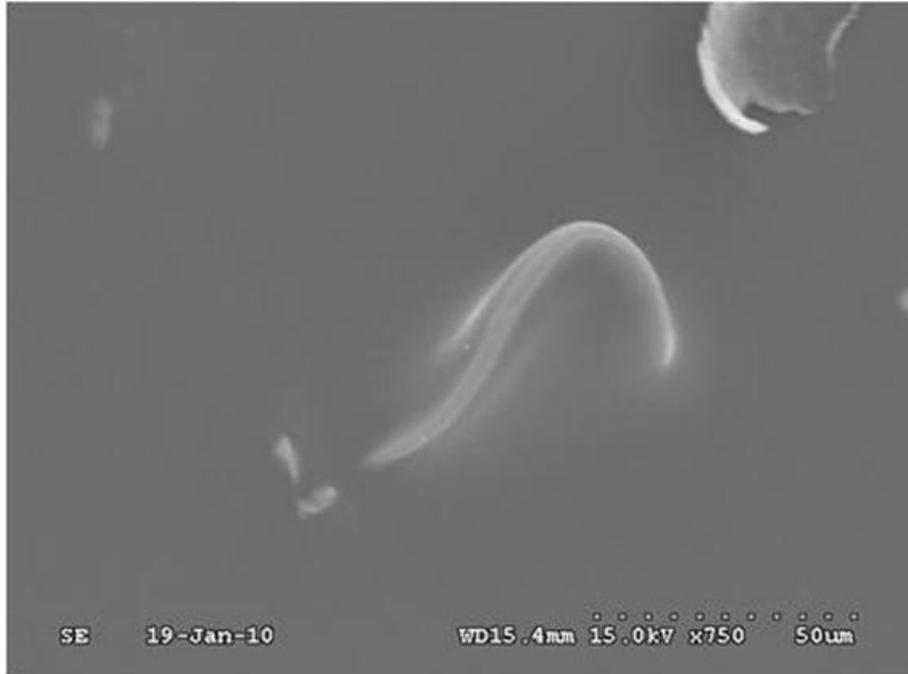
Tension Region



Observations on Flat Coated Coupons Following 9.5 years of 50/50 Exposure

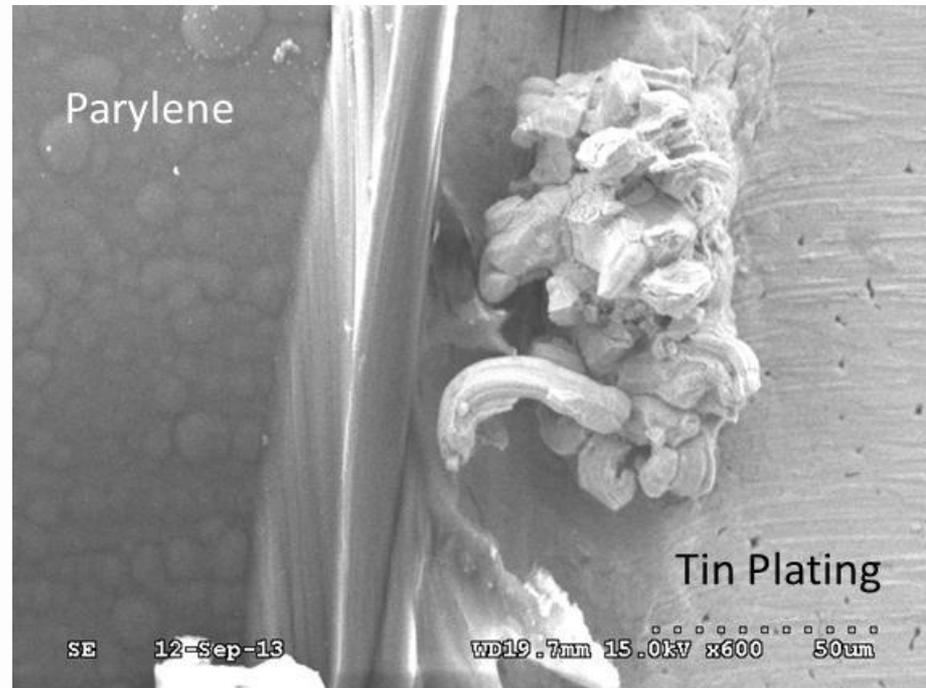
Coupon Base Material	Conformal Coating	Coating Thickness (mils)	Observations
Copper C110	Acrylic	1.0	No tenting or tin whisker protrusions
		2.0	No tenting or tin whisker protrusions
		3.0	No tenting or tin whisker protrusions
	Polyurethane	1.0	No tenting or tin whisker protrusions
		2.0	No tenting or tin whisker protrusions
		3.0	No tenting or tin whisker protrusions
Parylene	0.5	No tenting or tin whisker protrusions	
Alloy 42	Acrylic	1.0	No tenting or tin whisker protrusions
		2.0	No tenting or tin whisker protrusions
		3.0	No tenting or tin whisker protrusions
	Polyurethane	1.0	No tenting or tin whisker protrusions
		2.0	No tenting or tin whisker protrusions
		3.0	No tenting or tin whisker protrusions
	Parylene	0.5	No tenting or tin whisker protrusions

Observations on Flat, Scratched Coupons Following 9.5 years of 50/50 Exposure – Tin Whiskers Beneath Coating



- Tin whisker observed beneath 2.0mil thick acrylic coating (left), along with a second micrograph of the whisker following removal of the coating (right). Surface growth confirmed as tin by EDS.
- The tin whisker growth did not result in any observable disturbance of the coatings (i.e. no observed tenting)

Observations on Flat, Scratched Coupons Following 9.5 years of Exposure – Parylene Coating (0.5mil Thick)



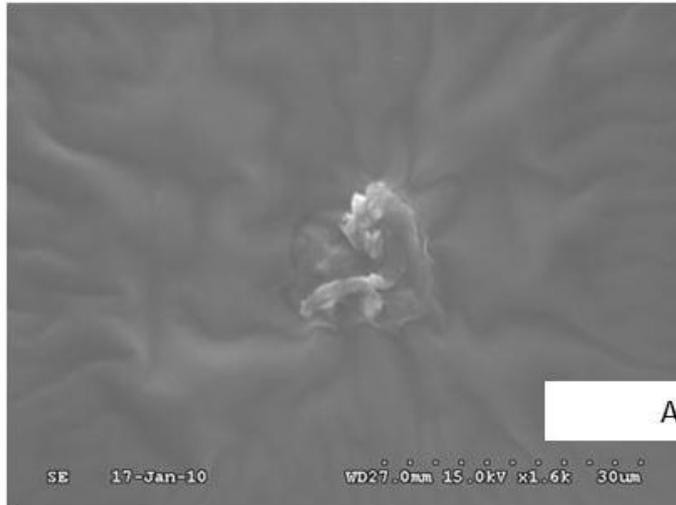
- Tin whisker observed growing at the interface to the parylene coating
- No observable disturbance to the parylene coating

Observations on Bent Coupons Following Testing

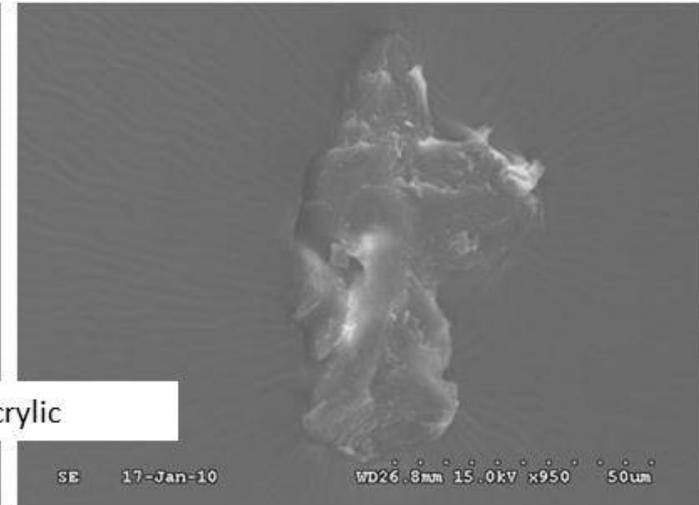
Coupon Base Material	Conformal Coating	Coating Thickness (mils)	Observations
Copper C110	Acrylic	1.0	Tenting in compression regions initially observed following 5.5 years of exposure; no protrusions
		2.0	Tenting in compression regions initially observed following 9.5 years of exposure; no protrusions
		3.0	No tenting or tin whisker protrusions
	Polyurethane	1.0	No tenting or tin whisker protrusions
		2.0	No tenting or tin whisker protrusions
		3.0	No tenting or tin whisker protrusions
Alloy 42	Acrylic	1.0	Tin whisker protrusions in compression and tension regions initially observed following 5.5 years of exposure
		2.0	Tin whisker protrusions in compression regions initially observed following 9.5 years of exposure. Tenting in tension regions initially observed following 9.5 years of exposure; no protrusions.
		3.0	No tenting or tin whisker protrusions
	Polyurethane	1.0	Tin whisker protrusions in compression and tension regions initially observed following 5.5 years of exposure
		2.0	Tenting in compression regions only initially observed following 9.5 years of exposure; no protrusions.
		3.0	No tenting or tin whisker protrusions

Tin Whisker Protrusions Through 1.0mil Conformal Coating

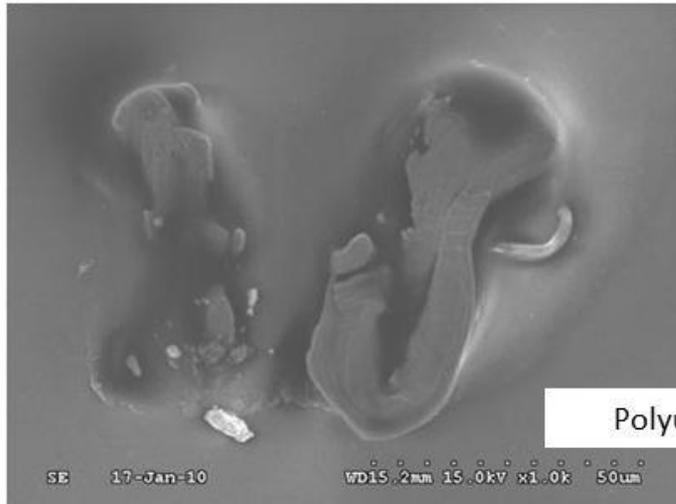
- Tin whisker protrusion observed for 1.0mil thick acrylic and polyurethane conformal coating following 5.5 years of exposure to 50° C / 50% RH



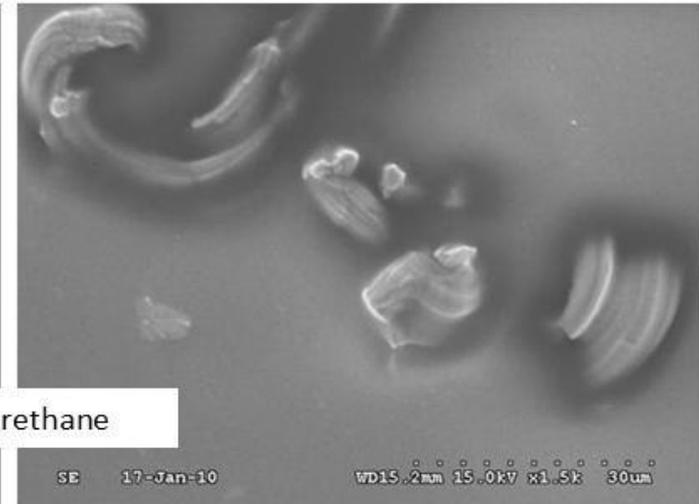
Acrylic



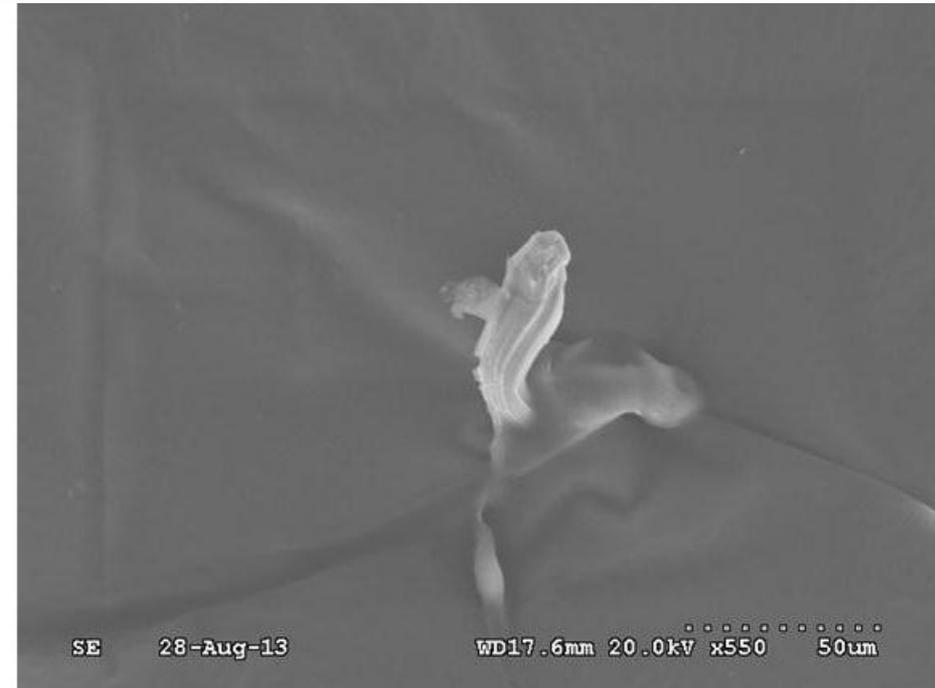
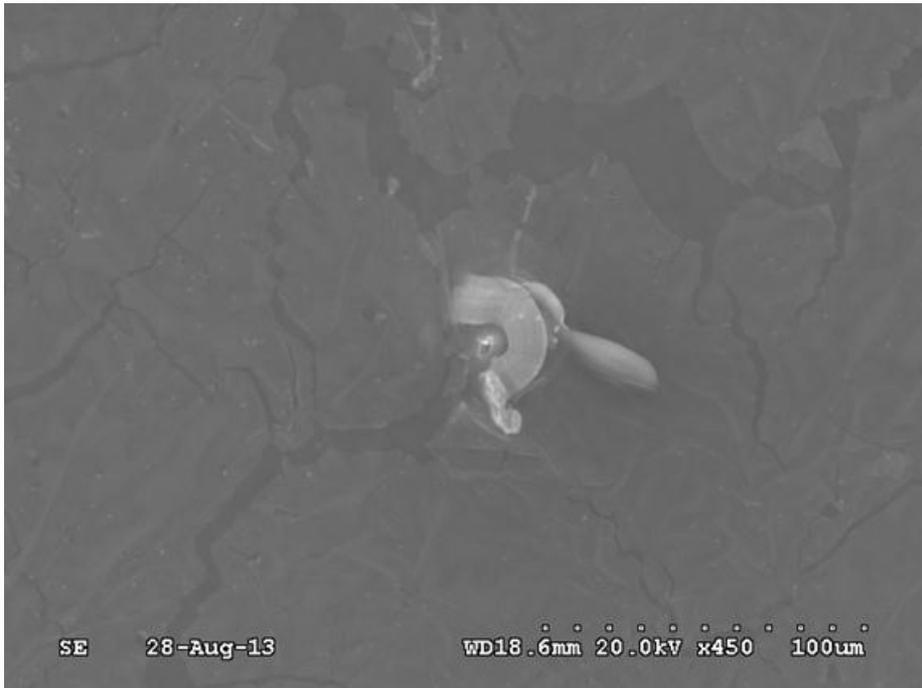
- Alloy 42 base metal bent test coupon
- Regions of tension and compression



Polyurethane

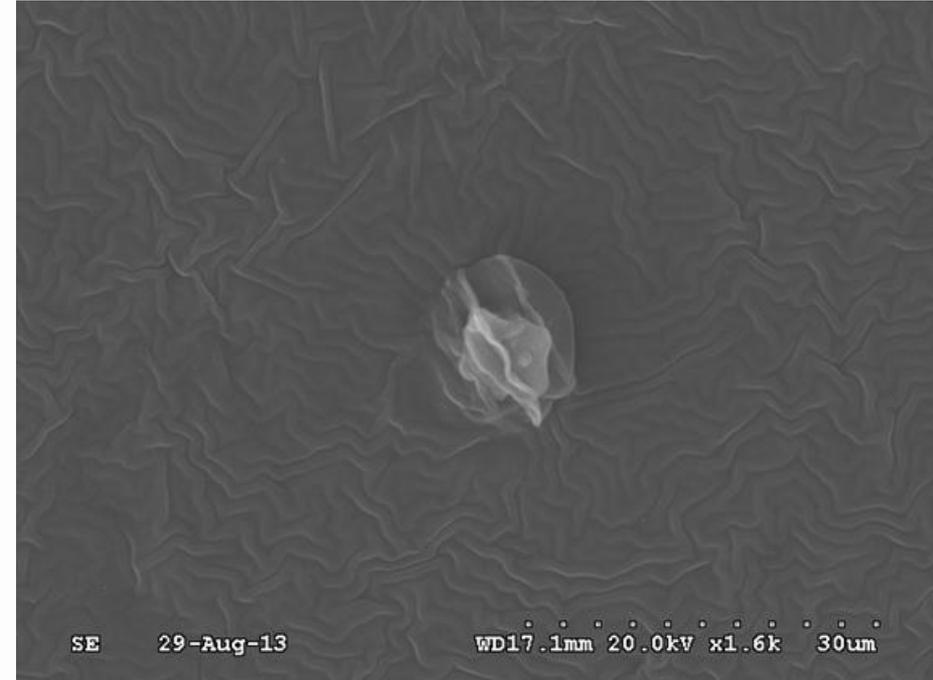
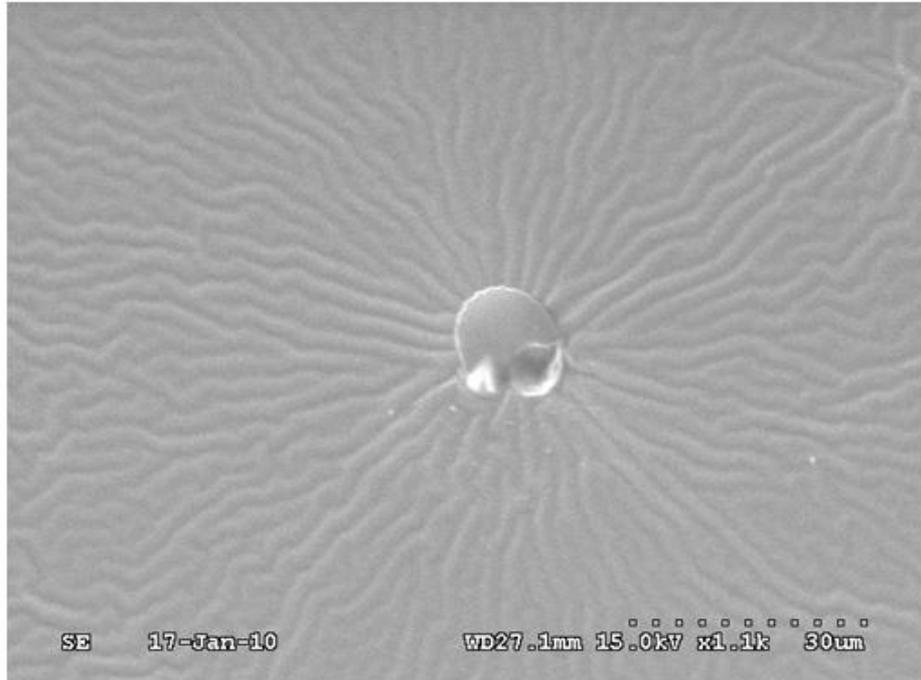


Tin Whisker Protrusions Through 2.0mil Conformal Coating



- Tin whisker protrusion observed for 2.0mil thick acrylic conformal coating following 9.5 years of exposure to 50° C / 50% RH
- Alloy 42 base metal bent test coupon
- Regions of compression

Tenting of Conformal Coating



- Tenting observed for both 1.0 and 2.0mil thick acrylic conformal coating
 - C110 base metal bent test coupons in the regions of compression
 - Tenting initiated in the 1.0mil thick coating following 5.5 years of exposure (left micrograph)
 - Tenting initiated in the 2.0mil thick coating following 9.5 years of exposure
- Tenting observed for the 2.0mil thick polyurethane conformal coating
 - Alloy 42 base metal bent test coupons in the regions of tension
 - Tenting initiated following 9.5 years of exposure (right micrograph)

Conclusions – Tin Whisker Risk Management by Conformal Coating

Inspection of Coupons with no Conformal Coating

- Alloy 42 and Copper C110 base metal coupons with electrodeposited bright tin plating were conformal coated and exposed to 50° C / 50% RH for 9.5 years
- Alloy 42 base metal coupons demonstrated higher tin whisker densities in uncoated regions than Copper C110 base metal coupons
- Stressing of the test coupons increased the tin whisker density, with a larger increase noted in regions of tension than regions of compression

Inspection of Straight, Scratched Coupons with Conformal Coating

- No conformal coat tenting or instances of tin whisker protrusion were noted on the flat, scratched test coupons for all coatings at all thicknesses

Conclusions (cont'd) – Tin Whisker Risk Management by Conformal Coating

Inspection of Bent Coupons with Conformal Coating

- Conformal coat tenting was observed on 1.0mil thick acrylic coating after 5.5 years for bent Copper C110 base metal coupons in regions of compression
- Conformal coat tenting was observed on 2.0mil thick acrylic coating after 9.5 years for bent Copper C110 base metal coupons in regions of compression
- Tin whisker protrusion was noted for 1.0mil thick acrylic coating after 5.5 years for bent Alloy 42 base metal coupons in regions of tension and compression
- Tin whisker protrusion was noted for 2.0mil thick acrylic coating after 9.5 years for bent Alloy 42 base metal coupons in regions of compression.
- Conformal coat tenting was observed on 2.0mil thick polyurethane coating after 9.5 years for bent Alloy 42 base metal coupons in regions of compression.
- Tin whisker protrusion was noted for 1.0 mil thick polyurethane coating after 5.5 years for bent Alloy 42 base metal coupons in regions of tension and compression.
- No disturbances of conformal coating applied at 3.0mil thickness were observed.

Recommendations

- Components with leads of Alloy 42 base metal and bright tin plating should be considered an especially high risk for growing tin whiskers
- Current test data indicates that conformal coatings should be applied at a minimum thickness of 2.0mils for tin whisker mitigation; however additional testing is required using “real” world components and assemblies. Note: the tin plating used in this study was formulated to grow whiskers and is not representative of today’s tin platings.
- Parylene coatings, due to their high modulus may be able to provide tin whisker mitigation at lower thicknesses; further testing should be completed on parylene coatings applied to stressed tin surfaces

Tin Whisker Growth Risk for Tin Coated Braiding and Wire

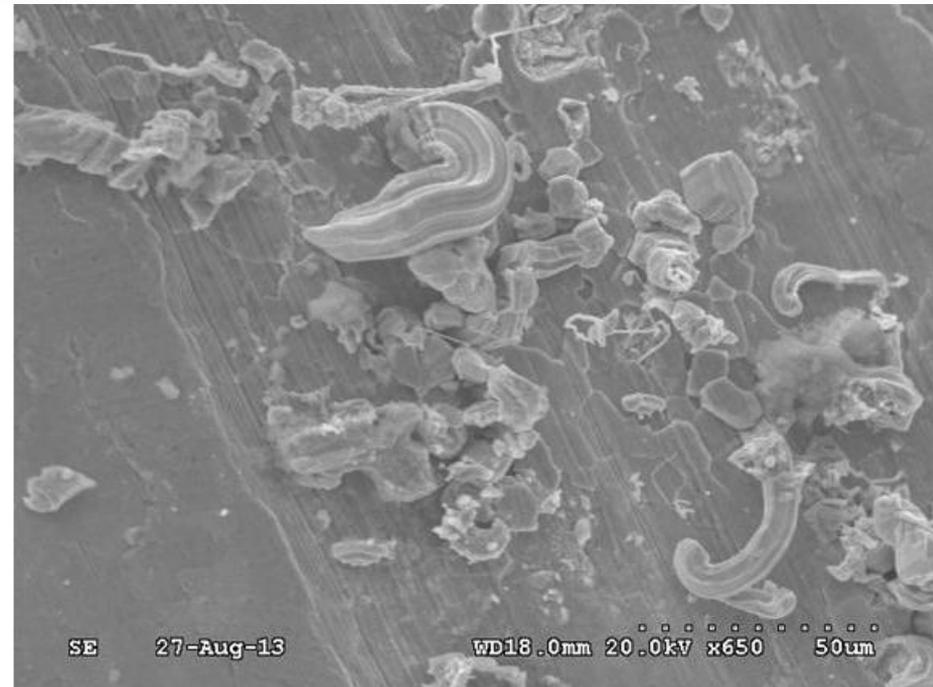
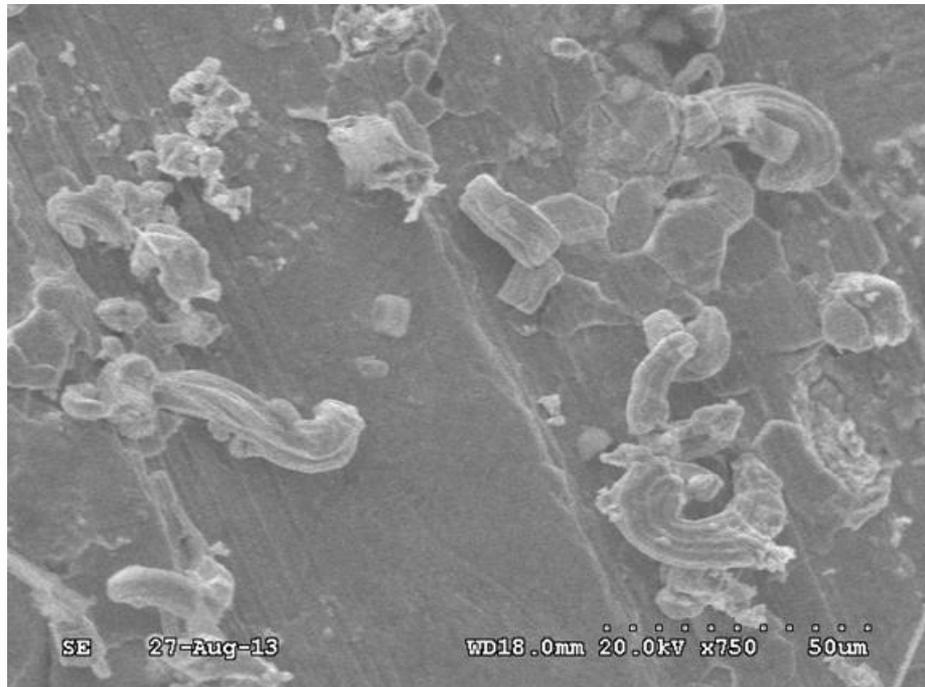
Experimental Design

- The following samples of braiding and wire were examined:
 - Braiding (length 4in, width 0.172in, height 0.029in, strand count 30)
 - Stranded wire M22758/34-24-9
 - Solid single strand wire A-A-59551, Type S, 20AWG
- Each sample was manufactured in 2008
- For the wire samples, the insulation was stripped to expose at least 2in
- Initial inspection of each sample indicated no observed tin whiskers
- Samples were subjected to 50°C / 50%RH for five years

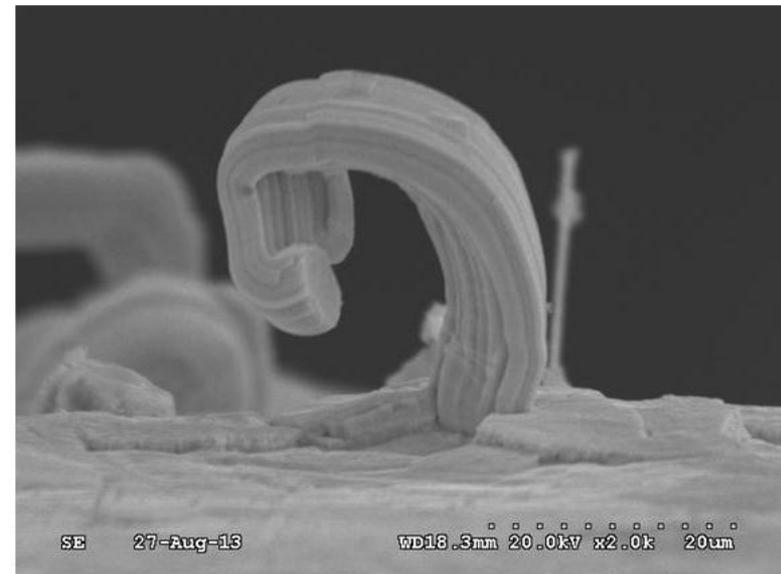
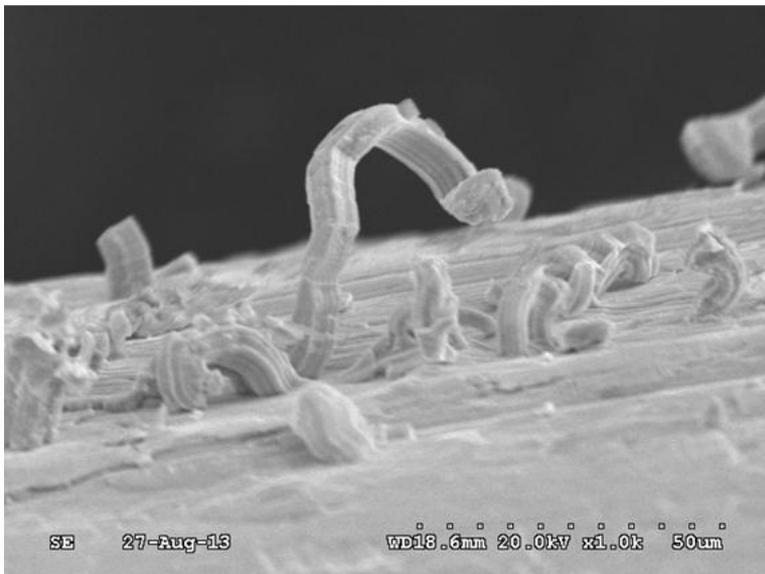
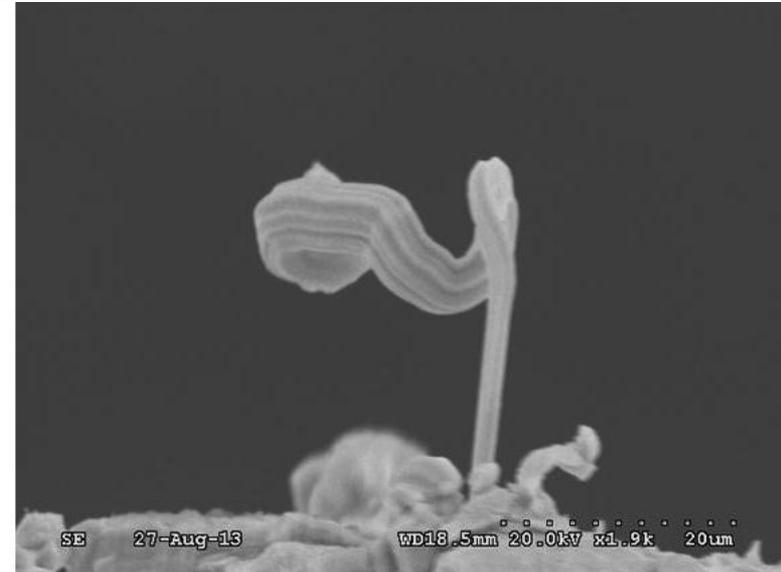
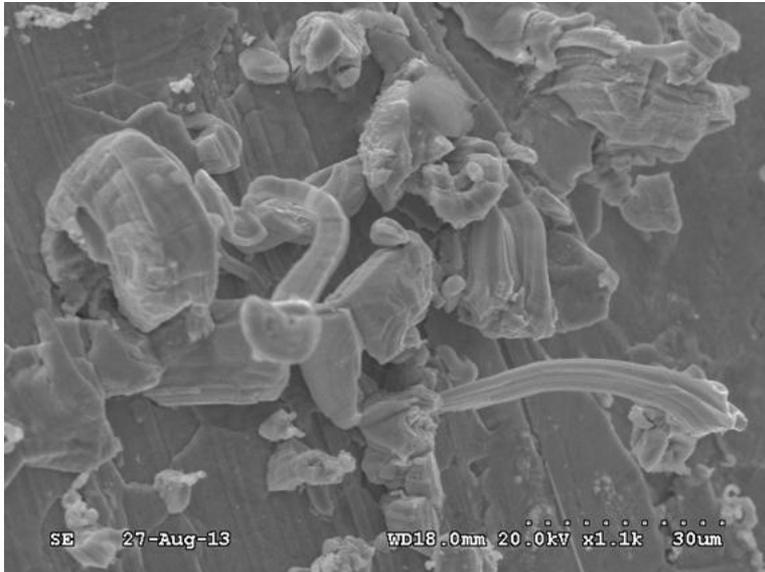
Results

- The braiding and stranded wire exhibited no observable tin whiskers
- The solid single strand wire exhibited a high concentration of tin whiskers with lengths measured to 40µm

Tin Whisker Density on Solid Single Strand Wire



Tin Whisker
Appearance
on Solid
Single
Strand Wire



Conclusions – Tin Whisker Growth Risk for Tin Coated Braiding and Wire

- The braiding and stranded wire should be considered low risk for use in high reliability electronics assemblies in terms of tin whisker growth.
- The lack of observed whiskers may be due to:
 - Minimal thickness of tin coating
 - Minimal stress within the conductor strands
 - Consumption of the tin coating by tin-copper intermetallic compounds
- The solid single strand wire exhibited a high concentration of tin whiskers following exposure to 50° C / 50%RH.
 - The wire should be considered a potential source of tin whiskers when considering assembly design and process development.
 - Exposed wire may require a solder dip process or insulation to mitigate the risk of tin whiskers

Thank you

Questions?