

Case Study: Bright Tin Whisker Risk in Pb-free Connector Applications

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Abstract

Bright tin plating finishes have been widely used in the electronics industry on various hardware applications, including connectors. In recent years, suppliers have gradually transitioned from the use of bright tin-lead plating to bright tin plating in order to comply with EU RoHS regulations. However, electroplated bright tin is known to grow long whiskers (greater than 2mm) in real life applications [1]. This spontaneous growth of whiskers poses a significant reliability risk to today's electronics. As such, it is imperative to evaluate tin whisker risks and determine Pb-free (Lead-free) readiness in the connector component space.

This study is intended to provide a realistic snapshot of tin whisker growth propensity on commercially available connectors under JEDS-201 [2] testing conditions. The parts were chosen to include a sampling of connector attributes, suppliers, and whisker mitigation methodologies.

A summary of test results will evaluate the probability and impact of tin whiskers based upon key connector attributes. Based on the observed trends, the authors will attempt to provide an assessment on tin whisker risk.

Key words: bright tin, tin whiskers, connectors, risk mitigation, lead-free

Introduction:

The onset of EU RoHS regulations has triggered a wide range of studies into potential reliability concerns. One of these potential concerns is the growth of tin whiskers from tin plated layers utilized as a replacement for tin lead plated components.

A fair number of connector applications have migrated to electroplated bright tin plated finishes for various reasons. This move has generated some concern due the long whisker growth that has occurred in some real life applications [1]. In some cases these whisker growths have resulted in product level field failures due to shorting between leads of a particular component or between multiple components [3].

Much work has been performed to try to understand the tin whisker growth mechanism. The prevailing theory regarding tin whiskering is that stress within tin layer causes the whisker to initiate [4]. There are

a number of ways this plated layer stress can be induced, including but not limited to stress inherent in the plating, intermetallic layer formation, mechanical stress, or corrosion of the tin layer.

While the mechanism has been widely studied very little work has been published looking into the tin whisker risk across a broad base of actual "in production" connectors utilizing an electroplated bright tin plating. This study aims to provide a snapshot of whisker growth risk for commercially available connectors. Additionally a number of key connector attributes were investigated to better stratify the results. These attributes included underlayer (plating layer between the base material and the tin plating), base material/underlayer combination, plating/forming sequence, and whether the supplier classifies the part as "mitigated".

Statistical evaluations were performed to determine the effects of these critical attributes. The goal of this

evaluation was to compare risk levels observed. Quite simply, risk level can be expressed as:

$$\text{Risk} = \text{Probability (occurrence)} * \text{impact (severity)}$$

For the purposes of this study probability was determined based on the fraction of failed manufacturing part number sets. A larger percentage of failure is thought to imply a greater occurrence in the field.

Impact or severity was evaluated utilizing a combination of two results. First, the maximum length of whiskers observed. As whisker length increases the risk of a whisker bridging multiple pins or bridging to an adjacent component is increased. Second, the time for a whisker to generate during acceleration testing (incubation time) was evaluated. An earlier onset of whisker growth can contribute to heightened field life impact.

Assessing risk in this method we can comment on relative risk levels of the attributes being studied.

Test Method:

Sample Selection:

A cross-section of manufacturing part numbers were chosen to illustrate the range of the attributes of interest. Table 1 breaks down the number of manufacturer part numbers included in this test by the various attributes studied.

For each of the selected manufacturer part numbers, 18 standard production pieces (connectors) were obtained for testing. Since the goal was to evaluate a snapshot of industry risk, no special consideration was made as to production lot or lot codes for the individual pieces in any manufacturer's part number set (the pieces could be from a single production lot or could represent multiple lots).

Acceleration Conditions:

To simulate the effects of time (field life), each manufacturer part number set which passed the time zero inspection was subjected to JEDS-201 acceleration test conditions. A subset of 6 pieces was subjected to each of the 3 testing conditions outlined in Table 2.

Table 2: Details of acceleration conditions utilized

Condition	Duration	Frequency of interim insp.
Temp cycle -55 to 85°C, 10min soak	1500 cycles	500 cycles
30°C/60% RH storage	4000 hours	1000 hours
55°C/85% RH storage	4000 hours	1000 hours

Inspection Method:

Prior to acceleration testing each set of parts was visually inspected for the presence of tin whiskers (see inspection method for details). Additionally, interim whisker inspections were performed at the stated intervals during the testing, as well as, at the end of the acceleration condition duration. Any part number having pieces exhibiting tin whiskers >40µm in length during these inspections was considered to be failing.

Visual inspection was performed utilizing a stereo microscope with 67x magnification and a ring light source. The inspection area was 50% of visually accessible bright tin plated casing and/or hardware area and all visually accessible bright tin plated pins. Any part which exhibited whisker or nodule formation was SEM inspected for confirmation. The number of parts exhibiting confirmed tin whiskers greater than 40µm in length was documented as well as the length of the longest whisker.

Supplier	Base Material	Plating sequence and barrier layer						
		Preplated		Postplated			Unknown	
		Ni	None	Ni	Cu	None	Ni	None
A	BeCu							1
	Brass			4		3	2	1
	Cu			1				
	Phos Bronze			2				
B	Brass		1					
	Phos Bronze		1					
C	Cu-alloy		1					
D	Brass	2	1	1			1	
	Phos Bronze			3			1	
	Steel			4	6			
All suppliers and base materials tested		2	4	15	6	3	4	2

Table 1: Breakdown of parts by key attributes.

Discussion:

Underlayer Type:

Plating an underlayer (layer of plating between the base material and the final finish) is a common practice for connectors utilizing a tin finish. There are a few reasons for the use of an underlayer, the two most common being: adhesion promotion (e.g. copper striking of steel casings for d-sub) and barrier for metallic migration (a nickel underlayer is commonly used for this reason) [5]. For the latter reason, the underlayer is typically utilized for tin whisker mitigation purposes.

The results from the manufacturing part sets are presented in a mosaic plot (Figure 1). From this plot we can see that for the parts tested a nickel underlayer reduces the probability of whisker growth. This supports the barrier layer mitigation theory, but it is important to note that the mitigation was not found to be 100% effective.

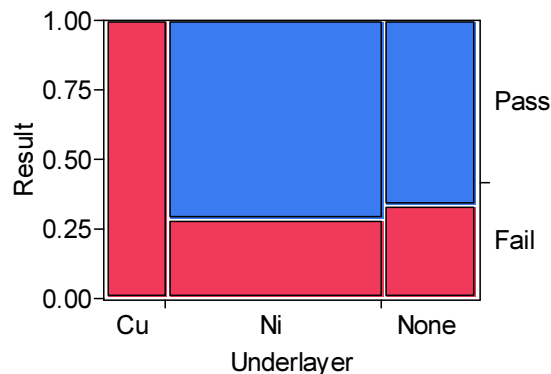


Figure 1: Failure rate evaluated by underlayer

Conversely all part sets utilizing a Cu underlayer failed (2 of 6 had whiskers in the as received state). This result is not surprising as copper is known to migrate into tin fairly readily.

It is unexpected that the failure percentage for parts not utilizing an underlayer is quite close to that of parts utilizing nickel. These parts predominantly utilized a copper alloy base material. Thus it would be expected that the failure percentage would be much higher. Initial cross-sectional analysis has demonstrated that other factors (including nickel layer quality) may be contributing to the failure rate of the nickel underlayer parts (Figure 2). Future work will investigate this in more depth.

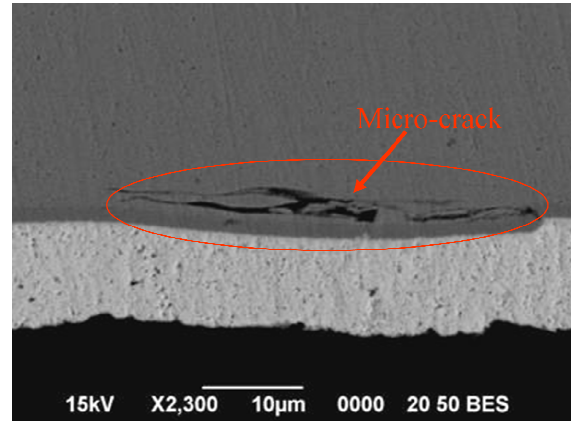


Figure 2: Cross-section picture demonstrating nickel layer and base material abnormalities .

In assessing the severity of the resultant failures the maximum whisker lengths were compared (Figure 3). Two interesting items were noted. First, while the average maximum whisker length of the Cu underlayer parts was greater than that of the nickel underlayer parts it was not statistically significant. Second, the parts with no underlayer grew very long whiskers (up to ~1.5mm). Since these lengths are statistically longer than those of both the nickel and copper underlayer parts, we can say the impact is greater.

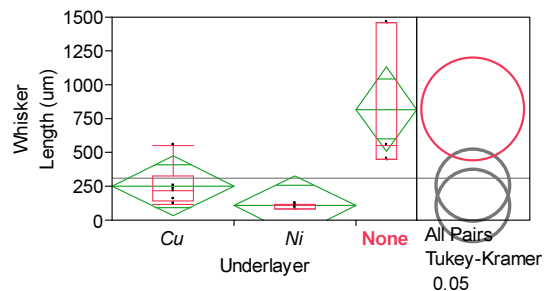


Figure 3: Whisker length evaluated by underlayer

Additionally a Weibull plot (Figure 4) was made to assess the time to failure for each underlayer condition (utilizing the elevated temperature and humidity testing data). The nickel condition shows the greatest characteristic life followed by the copper condition.

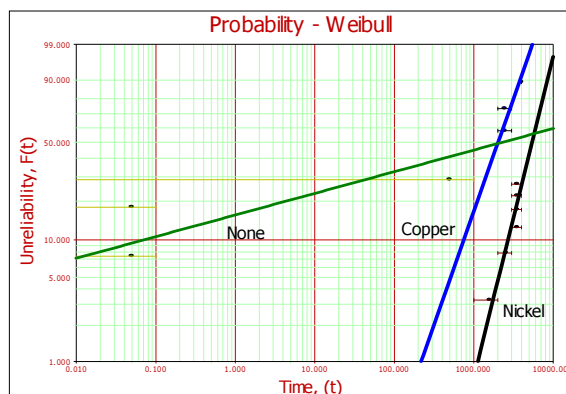


Figure 4: Weibull plot for incubation time by underlayer

Mitigated vs non-mitigated:

Some of the manufacturing part numbers were classified by the supplier as being “whisker mitigated”. The mitigation strategies employed on these parts were not uniform, but instead had different attributes or combinations of attributes. These included, but were not limited to use of an underlayer layer and whisker mitigated bright tin plating baths.

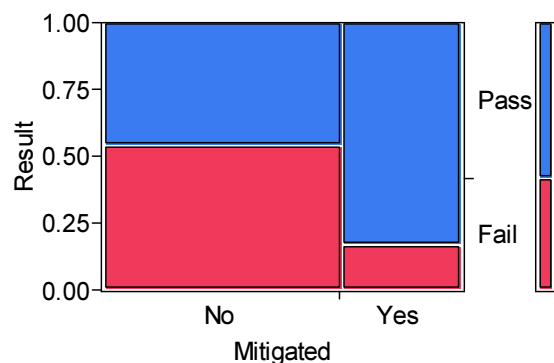


Figure 5: Failure rate evaluated by mitigated

In assessing the probability of whisker failure these parts did prove to have a mitigating effect (Figure 5). While this mitigation is significant, it did not fully eliminate whisker growth in our testing.

For the failed parts the “whisker mitigated” showed no statistical improvement in maximum whisker lengths observed (Figure 6). Thus impact is considered comparable.

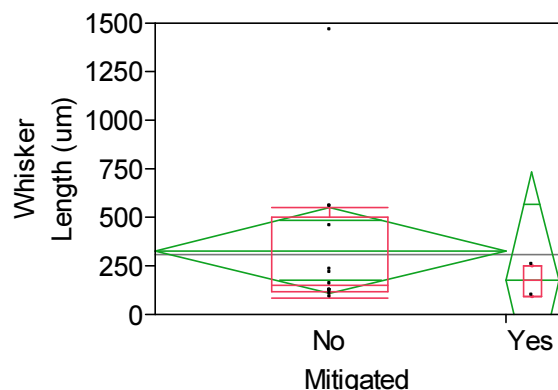


Figure 6: Whisker length evaluated by mitigated

Forming/Plating Sequence:

The results between parts which were plated prior to forming were compared to those formed after plating. For these cases the differences were negligible for both failure percentage and resulting max whisker length of failures (Figures 7 and 8). This result is a bit surprising as it was expected that the forming after plating samples would have a greater failure rate due to the mechanical stress to the tin layer from the forming process [6].

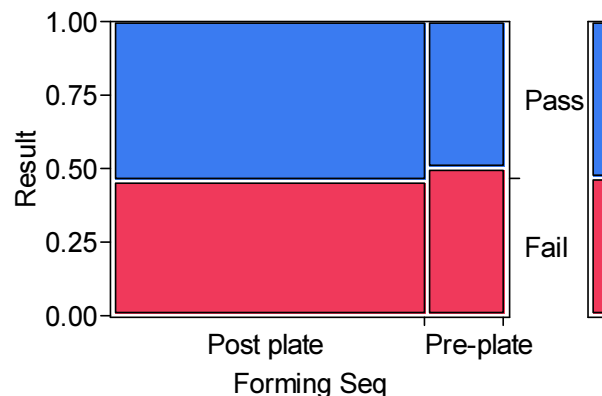


Figure 7: Failure rate evaluated by forming sequence

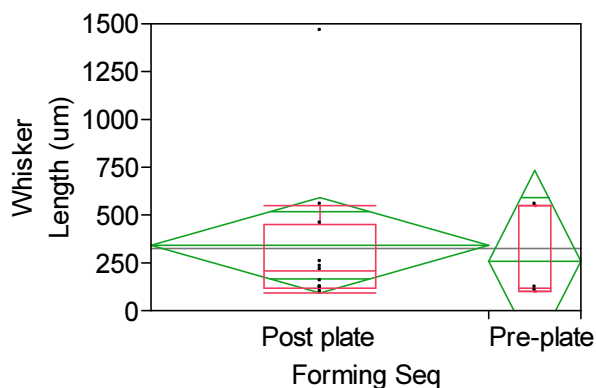


Figure 8: Whisker length evaluated by plating sequence

Base Material/Underlayer Combination:

The base material/underlayer combinations were analyzed to evaluate risk. Figures 9-11 show the failure percentage data. The two items that show prominently are that steel with a copper underlayer and brass (with or without a nickel underlayer) account for all of the failures found in this study. Additionally it is worth noting that the presence of a nickel barrier on a brass base material did not significantly reduce the probability of whisker growth. Further cross-sectional analysis (SEM and EDX mapping) has been initiated on these samples to better understand this mechanism. These results will be presented at a future time.

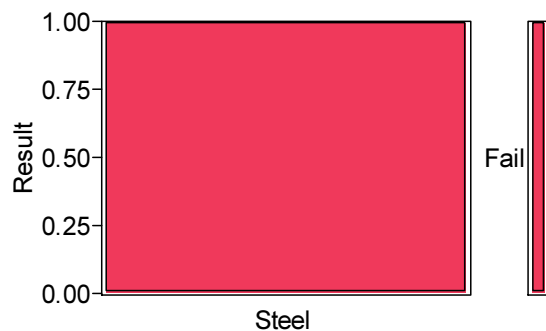


Figure 9: Failure rate evaluated by base material for copper underlayer parts

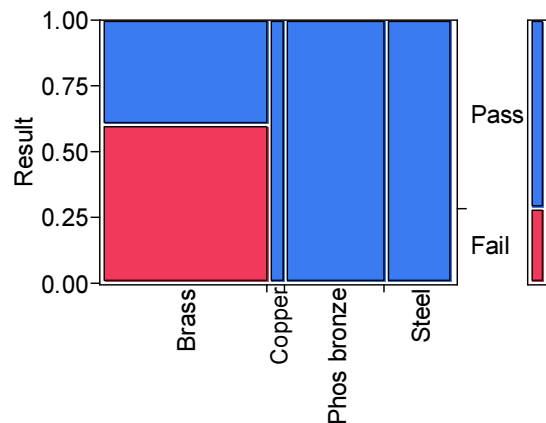


Figure 10: Failure rate evaluated by base material for parts with a nickel underlayer

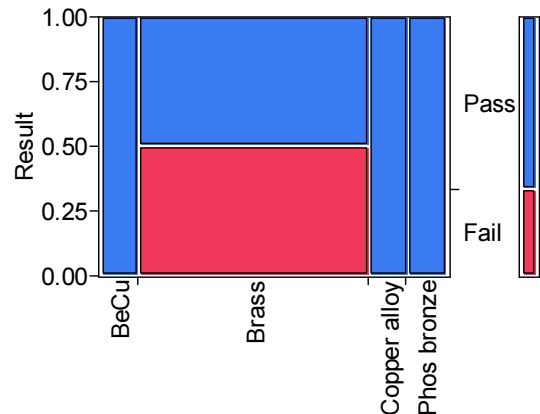


Figure 11: Failure rate evaluated by base material for parts without an underlayer

The impact of brass base material failures were compared utilizing whisker lengths (Figure 12). The nickel barrier did significantly reduce the whisker lengths observed on failed parts. Thus the presence of a nickel barrier is an effective mitigation to tin whisker impact.

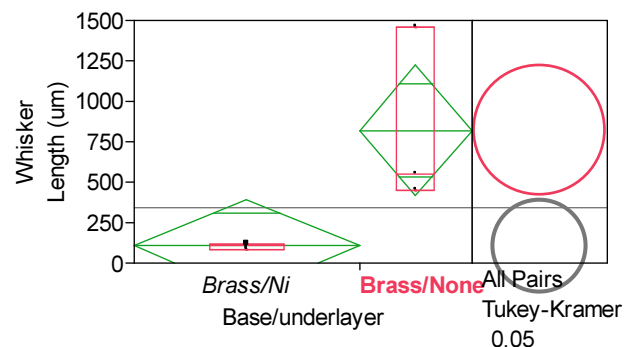


Figure 12: Whisker length evaluated by base material and barrier layer combination

Conclusion:

Tin whisker testing was performed on a broad base of bright tin plated, commercially available connector part numbers. The results were analyzed based upon several key attributes to determine risk levels. Key findings from this study were:

- Supplier designation of parts as “whisker mitigated” demonstrates only a partial mitigate. “Whisker mitigated” parts have a reduced occurrence and severity of tin whisker growth.
- Inclusion of a nickel underlayer effectively mitigates impact when whisker growth occurs. The results did not show that a Ni underlayer significantly mitigated the probability of whisker growth. Initial cross-sectional analysis indicates that the quality of the nickel underlayer may be contributing to the higher than expected failure rate. Future work will investigate this in more detail.
- Forming sequence (pre or post plating) has insignificant effect on whisker risk.
- Base material has a significant effect on tin whisker risk. Brass and steel base materials accounted for all failures in this study. Further work needs to be performed (specifically for brass) to better understand the significance of this result.

References:

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