ROHS Reliability Impact

A Reality Check !!!!

Presented by
Larry Akre
May 17, 2007

ROHS Reliability Impact

- RoHS Directive 2002/95/EC
  - WEEE Directive 2002/96/EC
- Failure Mechanisms
  - Tin Whiskers
    - Mechanisms
  - Solder Joint Failures
  - Mitigation Strategies
- Tensile Strength
- Solderability
  - Testing
  - Shelf Life
  - Plating Considerations

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RoHS Directive

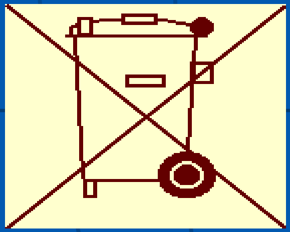
- This Directive takes effect on **July 1, 2006**, and with some exceptions (Annex) totally bans the use of (Article 4.1):
  - lead,
  - mercury,
  - cadmium,
  - hexavalent chromium,
  - polybrominated biphenyls (PBB's),
  - polybrominated diphenyl ethers (PBDE's),
  - in electronic and electrical products and equipment

RoHS Directive

- Council Decision COM(2004) 606, adopted Sept. 23, 2004), amends the Annex of the **RoHS Directive** to permit-- in any application that was not already exempted--a homogenous material to contain a maximum of:
  - 0.1% lead by weight.
  - 0.1% mercury by weight.
  - 0.01% cadmium by weight.
  - 0.1% hexavalent chromium by weight.
  - 0.1% polybrominated biphenyls by weight.
  - 0.1% polybrominated diphenyl ethers by weight.

RoHS Directive
WEEE Directive Influence

- Makes the producer (the company whose brand is on the equipment-- or the importer/exporter) pay for the collection, treatment, recovery, and disposal of their equipment (Article 5). For sales to businesses, this cost may be shared between the seller and buyer (Article 9, as amended by Directive 2003/108/EC). The actual processing may be done by the company itself, or by participating in a producers' compliance scheme (Article 6.1).
- The producer must provide financial guarantees that they will pay for the handling of their waste equipment, by participating in a collective group for this financing, recycling insurance, or a blocked bank account (Article 8.2).
- Requires the producer to mark their electrical/ electronic equipment (or the packaging, instructions, and warranty) with the WEEE Symbol below (Annex IV) after **August 13, 2005** (Article 10, paragraph 3).



RoHS Directive

- Most solder materials in lead free components are many times more toxic than the current SnPb compound
- Soldering and finishing process uses so little lead compared to the rest of the industry (< 0.5%)
  - Elimination of lead will have no significant environmental impact

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Tin Whiskers

- What is a Whisker?
  - Whiskers are elongated single crystals of pure tin. 1 to 5 microns in diameter, 0.5 to 5.0 mm (.0197 to .197 inches)
    - Grow spontaneously without an applied electric field or moisture
      - Independent of atmospheric pressure
        - Can grow in a vacuum
  - Whiskers Appearance
    - Straight, kinked, hooked, forked and hollow
      - Outer surfaces are striated

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Tin Whisker Mechanisms

- Residual Stresses with the tin plating
  - **Contaminates**
    - **Organic brighteners**
    - **copper**
  - **Grain Size**
    - **Small grain size (bright acid tin) 0.5 to .8 um (19.7 to 31.5) micro-inches diameter, 0.2 to 1.0 % carbon content**
      - **Shiny appearance will exhibit high probability to promote whisker growth**
    - **Large grain size (Matte tin) 1 to 5 um (39.3 to 197) micro-inches diameter, 0.005 to 0.050 % carbon content**
      - **Dull appearance will exhibit low probability to promote whisker growth**
  - **Current density**
    - **Electro-deposited finishes are considered at greater risk because higher current densities produced higher residual stresses and more whiskers**

Tin Whisker Mechanisms

- Damage to Tin Coating Surfaces
  - Bending, stretching, scratching or nicking of the plating creates localized stresses which serve as the nucleation point for whiskers
    - Handling damage

- Mechanical Loading to Tin Coating Surfaces
  - Turning of nuts or screws or spring loaded fixtures

Tin Whisker Mechanisms

- **Formation of Intermetallic compounds**
  - **(Cu_6Sn_5), (Ni_3Sn_4) Eta and (Cu_3Sn), ($NiSn_3$) Epsilon phases between the Tin grain boundaries**
  - **Lack of barrier coating between substrate (i.e. Brass) and Tin Coating**
    - **Copper Ion Migration**
  - **Using Copper barrier coating between substrate (i.e. Brass) and Tin Coating**
    - **Copper Ion Migration**
  - **Using Nickel barrier coating between substrate (i.e. Brass) and Tin Coating**
    - **Nickel Ion Migration**

Whisker Photos

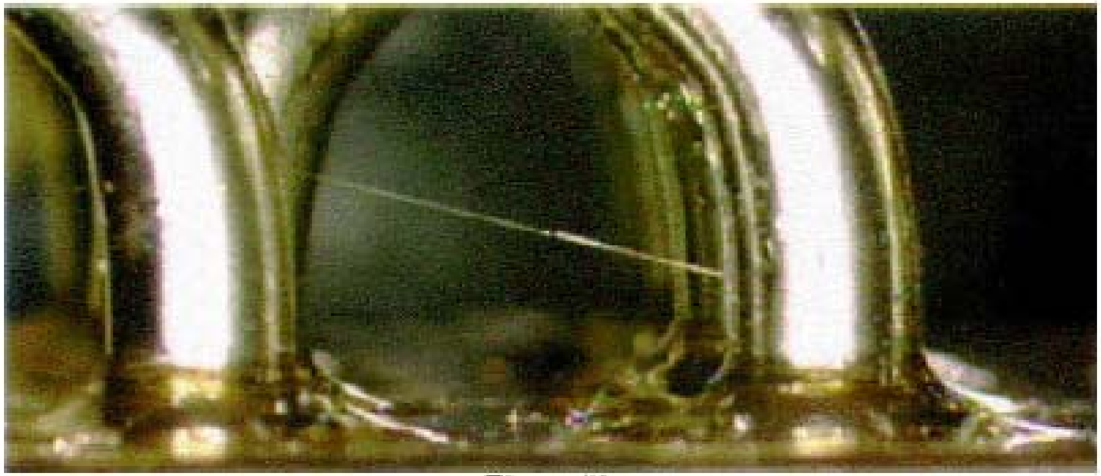
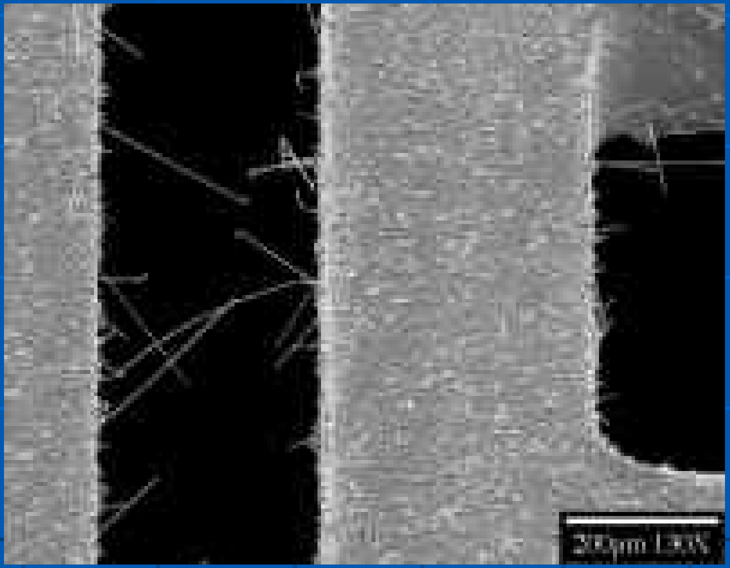
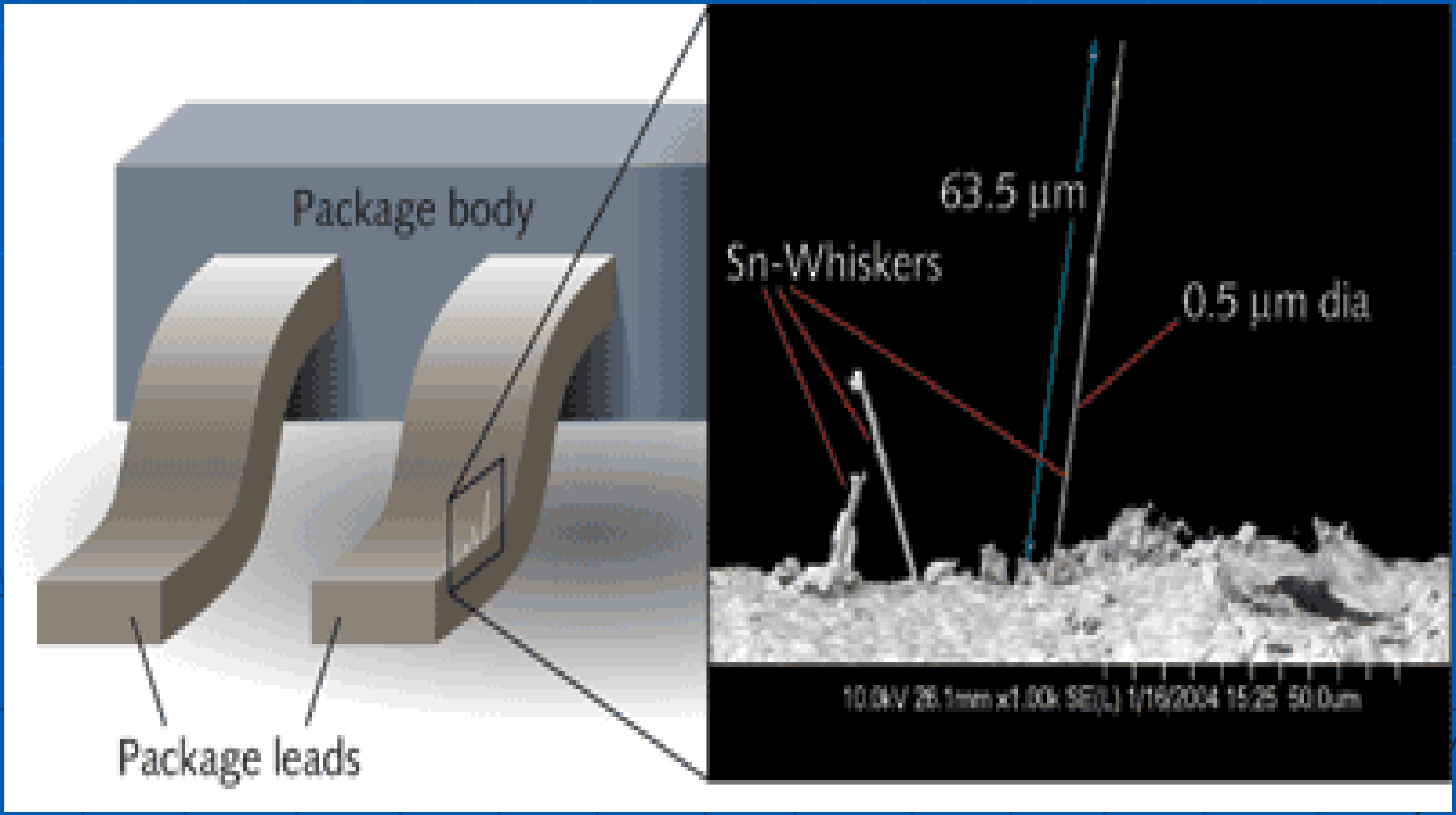


Figure #1.
Magnified photograph of a tin whisker growing from the electrical termination front right toward the termination front left. Taken from the NASA tin whisker web site:

Whisker Photos

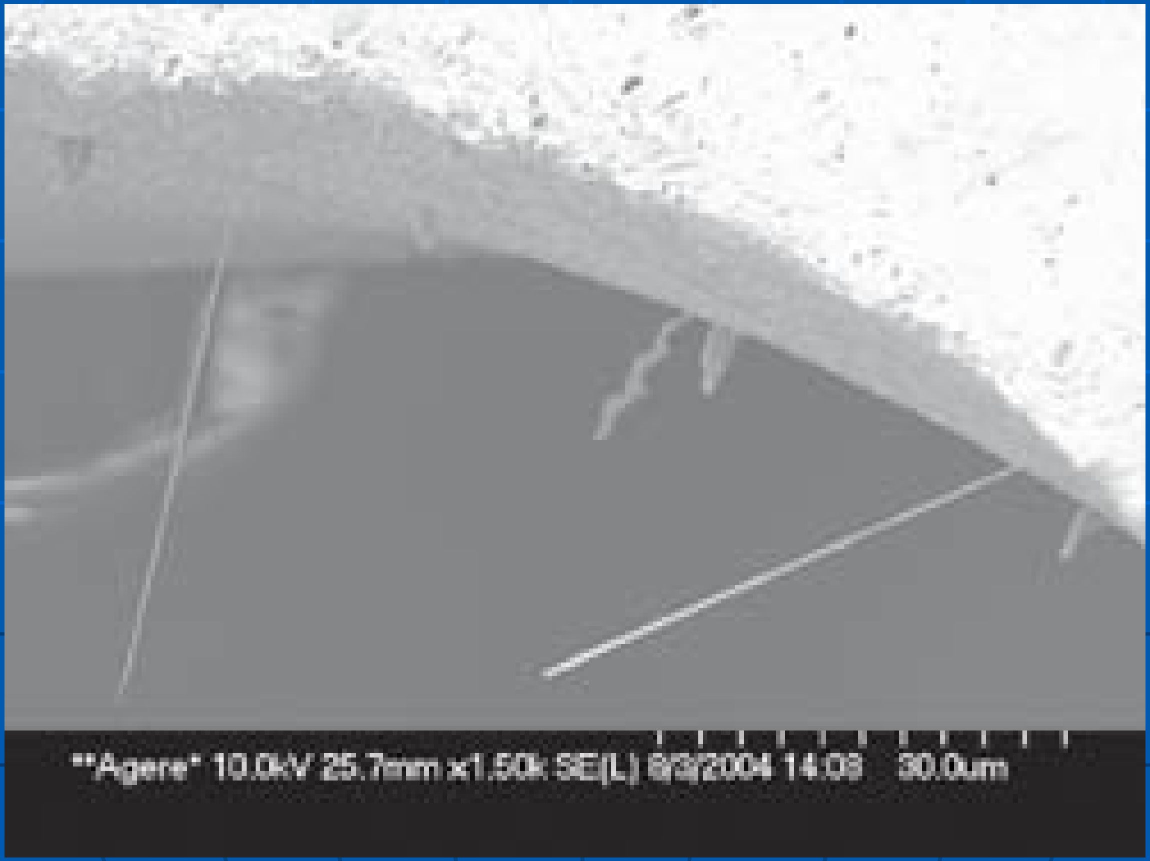


Whisker Photos



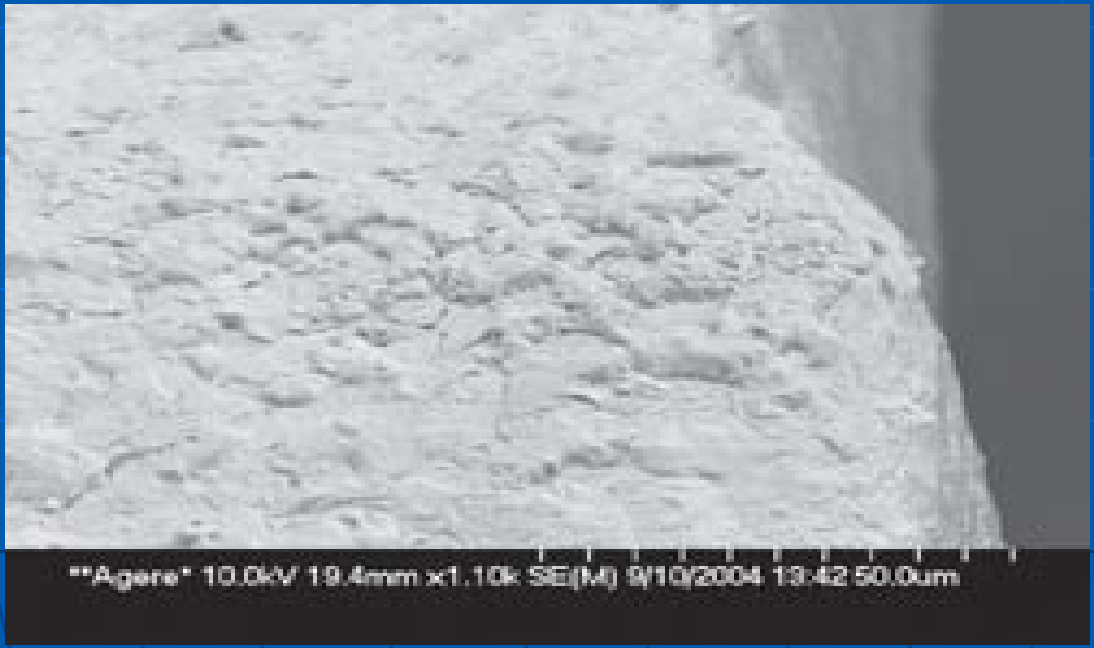
Whisker Photos

Matte Tin on Copper substrate subjected to 260°C(500°F) reflow grew tin whiskers in accelerated life tests.



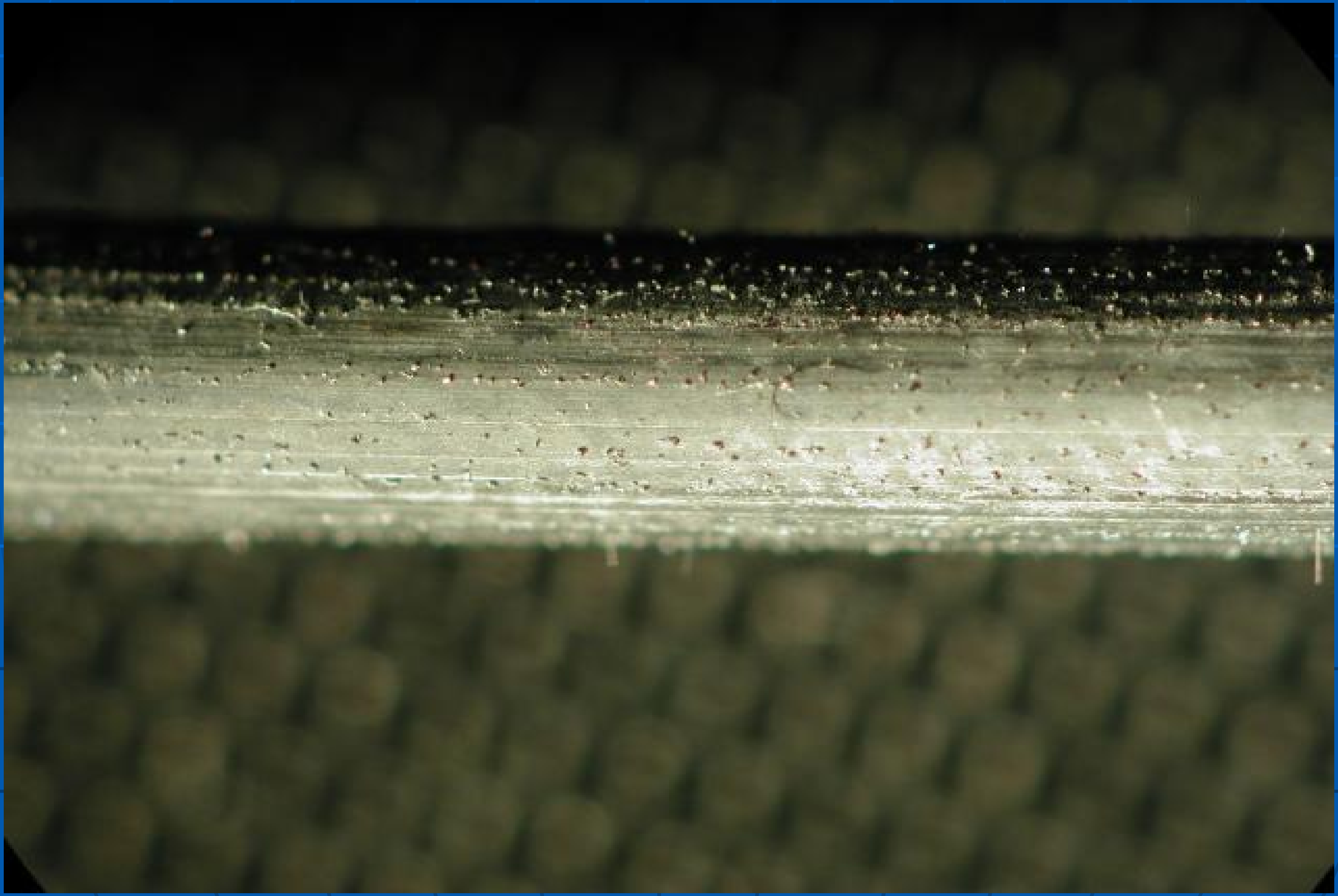
Whisker Photos

Matte tin with a nickel barrier between the copper substrate and tin, whiskers did not form in accelerated life tests @ 260°C(500°F)



Whisker Photos

Metal Whiskers/Nodules on Metal Binder Clip



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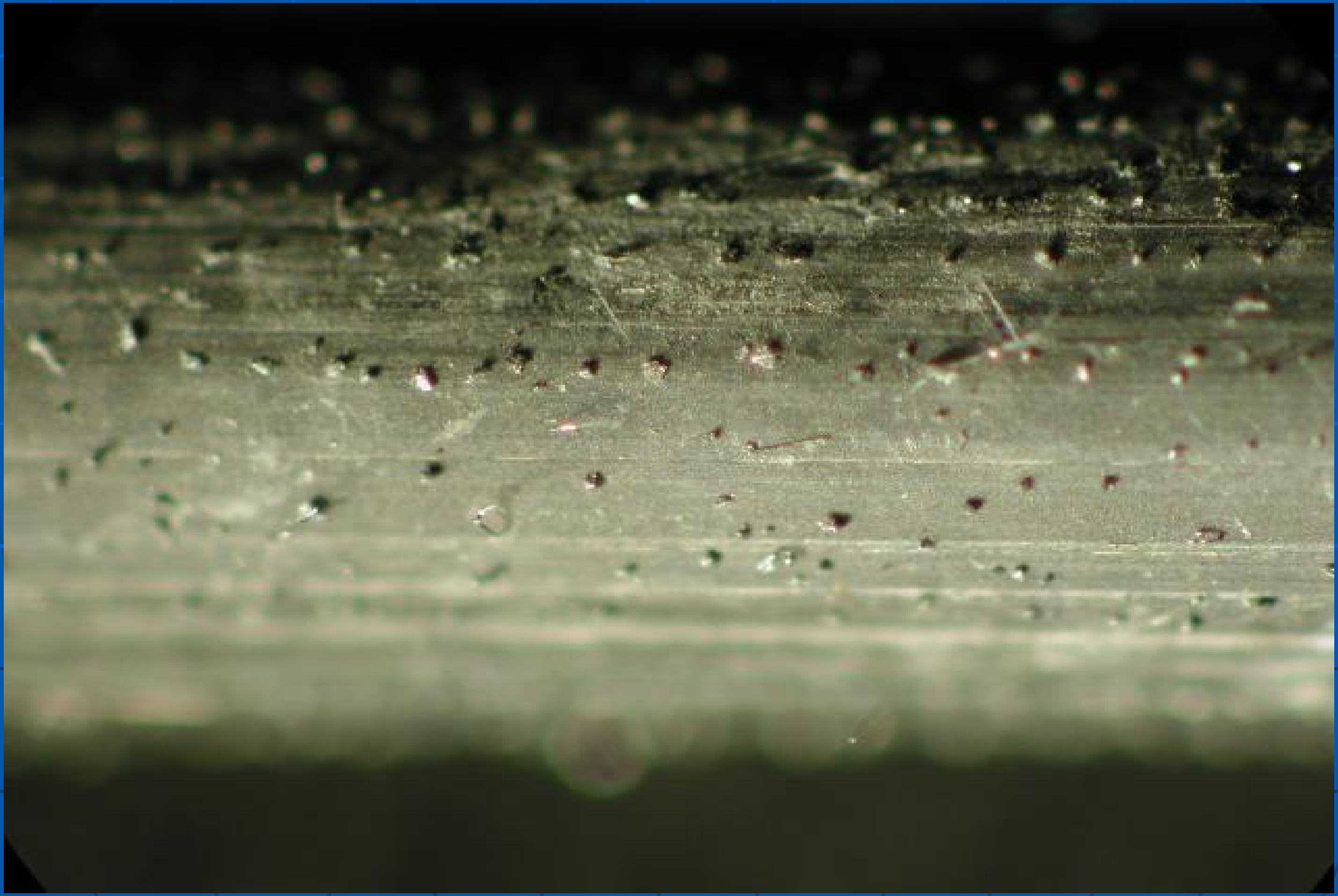

Military Failures from Whisker growth

- **Military Airplane:** G. Davy, "Relay Failure Caused by Tin Whiskers", Northrop Grumman Electronic Systems Technical Article, October 2002
- **Patriot Missile:** Anoplate WWW Site: Suspected tin whisker related problems (Fall 2000)
- **Phoenix Air to Air Missile:** L. Corbid, "Constraints on the Use of Tin Plate in Miniature Electronic Circuits", Proceedings 3rd International SAMPE Electronics Conference, pp. 773-779, June 20-22, 1989.
- **F-15 Radar:** B. Nordwall, "Air Force Links Radar Problems to Growth of Tin Whiskers", Aviation Week and Space Technology, June, 20, 1986, pp. 65-70
- **U.S. Missile Program:** J. Richardson, and B. Lasley, "Tin Whisker Initiated Vacuum Metal Arcing in Spacecraft Electronics," Proceedings 1992 Government Microcircuit Applications Conference, Vol. XVIII, pp. 119 - 122, November 10 - 12, 1992.
- **U.S. Missile Program:** K Heutel and R. Vetter, "Problem Notification: Tin Whisker growth in electronic assemblies", Feb. 19, 1988, memorandum

Medical Failures from Whisker growth

- Heart Pacemaker Recall Food and Drug Administration March 1986
- **Apnea Monitor Failures**: J. Downs, "The Phenomenon of Zinc Whisker Growth and the Rotary Switch (or, How the Switch Industry Captured the Abominable Snowman)", Metal Finishing, August 1994, pp. 23-25 **NOTE: This issue is a ZINC Whisker failure!**

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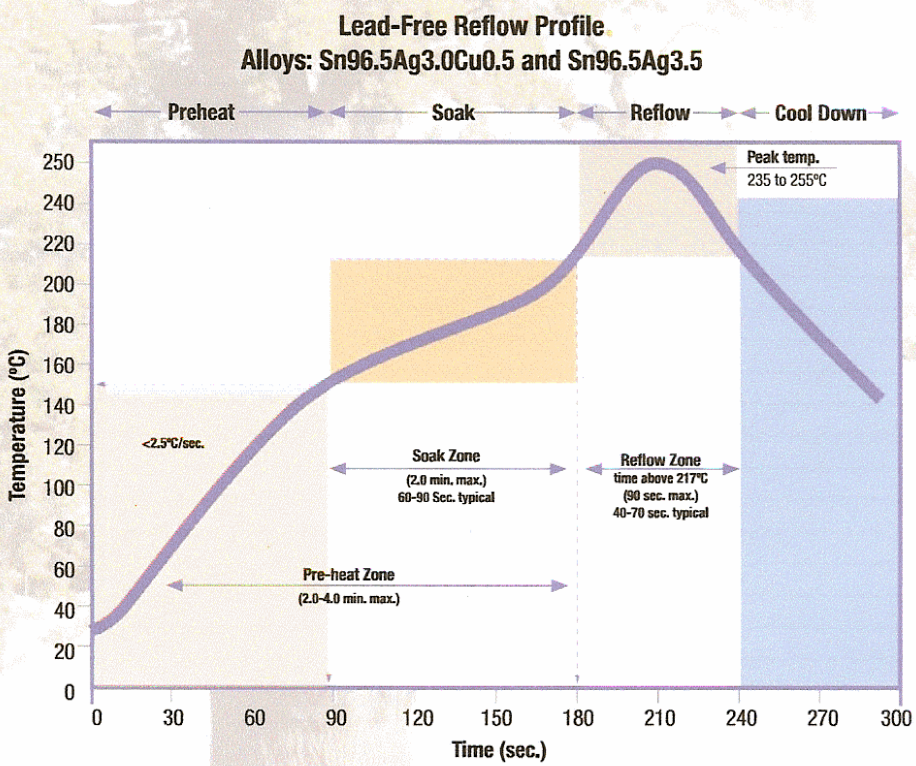
Solder Joint Failures

Stage 1 - Preheat Zone (Rapid Heating Stage)
The purpose of this zone is to quickly bring the assembly up to a temperature where solder paste can become chemically active.

Stage 2 - Soak Zone (Temperature Equalization Zone)
The purpose of this stage is for the thermal mass of the assembly to reach a uniform temperature plateau so that there is a very small differential between the hottest and coldest soldering locations on the assembly.

Stage 3 - Reflow Zone (Rapid Heating and Cooling)
The purpose of this stage is to rapidly heat the assembly above the melting (liquidus) temperature of the solder and subsequently cool the assembly down quickly to solidify the solder. Wetting of solder onto substrates occurs in the reflow zone.



Solder Joint Failures

- Elevated reflow temperatures threaten plated through hole reliability and increase the potential for delamination of a PWB
  - 230ºC (446ºF) versus 260ºC (500ºF)
- Glass Transition Temperature (Tg) – PWB
  - Tg of a resin system is the temperature as which the material transitions from a rigid to a softened state

Solder Joint Failures

  - -Tg is the material property typically used by Industry for comparing thermal robustness
- Coefficient of Thermal Expansion (CTE)
  - - CTE is the measure of a material’s expansion both below and above the Tg expressed in PPM

Solder Joint Failures

- - Below Tg, a PWB material will expand according to its CTE
- - At the Tg, a PWB material will exhibit a dramatic increase in its CTE
  - Low CTE values for a material at or above its Tg increases the reliability for PTHs
- Decomposition Temperature – Td
  - This value is determined by the measurement of the weight loss of a material versus temperature
    - IPC 5 % loss level

Solder Joint Failures

- Td is a very critical material property for assessment of a material's thermal survivability
  - TMA – Thermo-Gravimetric Analysis
  - DSC – Differential Scanning Calorimetry

FR4	Phenolic FR4
Td 270ºC	Td 345 - 365ºC

Solder Joint Failures

- 63 / 37 SnPb Melt Temperature
  - 361ºF (183ºC)
- 100 % Sn
  - 450ºF (232ºC)

89ºF(49ºC) Differential

- 96.3Sn(3.4 – 4.1)Ag(.45-.90)Cu (SAC)
  - 423ºF (217ºC)

62ºF(34ºC) Differential

Solder Joint Failures

- 96.3Sn(3.4 – 4.1)Ag(.45-.90)Cu (SAC) MP 423ºF (217ºC)
  - 30ºC higher surface mount reflow temp
  - Slower wetting time
  - Double the cost for the raw material
  - Environmental concerns with Ag
  - Stronger and stiffer than SnPb but lower ductility

Solder Joint Failures

- 96.3Sn(3.4 – 4.1)Ag(.45-.90)Cu (SAC) MP 423ºF (217ºC)
  - Large thermal mass of PWB
    - Large component- coldest spot
    - Small component – highest spot

30ºC (54ºF)

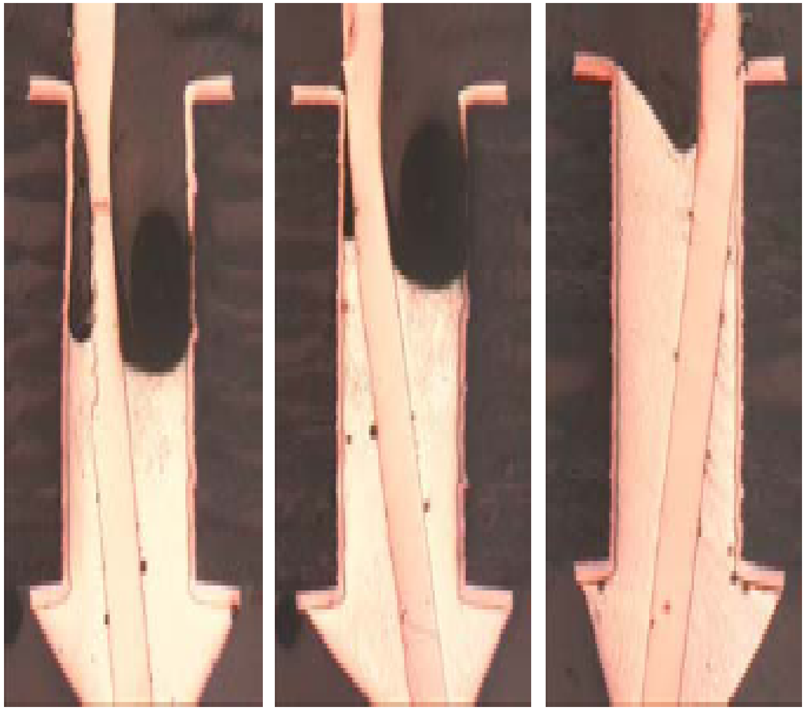
  - Reflow Soldering temperatures must reach ≥ 260ºC (500ºF)
    - Aluminum electrolytic capacitors suffer dielectric cracking at temp ≥ 245ºC (473ºF)
    - Large plastic grid arrays are prone to warping at ≥ 260ºC (500ºF)
    - Thermal expansion of PWB substrate resulting in weakened or cracked PTHs

Solder Joint Failures

- Lead Free Soldering will increase the following defects
  - Non-Wetting
  - Insufficient Solder
  - De-Wetting
  - Icicle Formation
  - Colder Solder Joints
  - Grainy Solder
  - Blow Holes
  - Solder Balls
  - Fillet Lifting
  - PTH Cracking

Solder Joint Failures

Solder pot temperature will play a role in hole-fill as temperature is increased. The photos to the right, indicate the degree of hole-fill as solder temperature increases from 240, 250 to 260°C using SAC solder.



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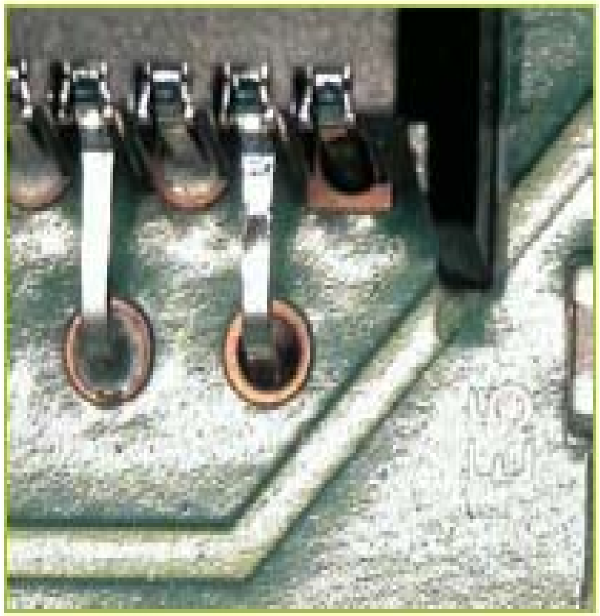


Insufficient hole-fill

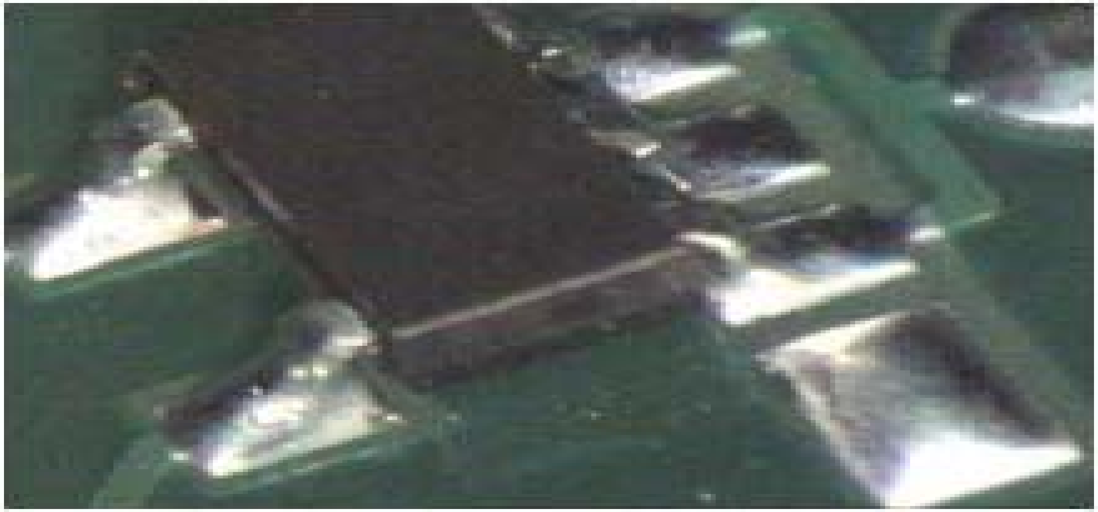
Exposed copper on bottom-side SMD

Solder Joint Failures

Well soldered SMD bottom-side

Icicling of SMD using No-clean ROLO Flux

Solder Joint Failures



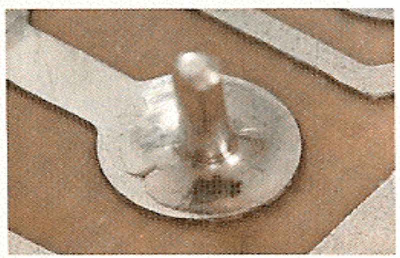
Nitrogen used at solder pot

Solder Joint Failures

Fillet lifting, photo from Bob Willis

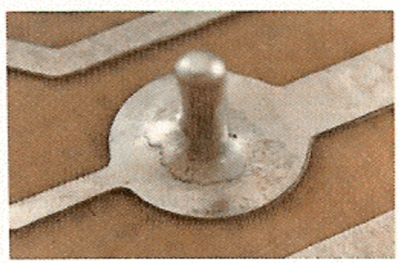
Fillet lifting with cracking, photo from Bob Willis

Solder Joint Failures



ACCEPTABLE MINIMUM

1. Solder shows graininess and surface flow lines with a dull metallic appearance.
2. Line of demarcation between solder fillet and land is abrupt; however solder flow is unbroken and entire solder connection is wetted.



REJECT

1. Solder has failed to flow and wet land.
2. Stress cracks in solder at edge of fillet.

4—56

Solder Joint Failures

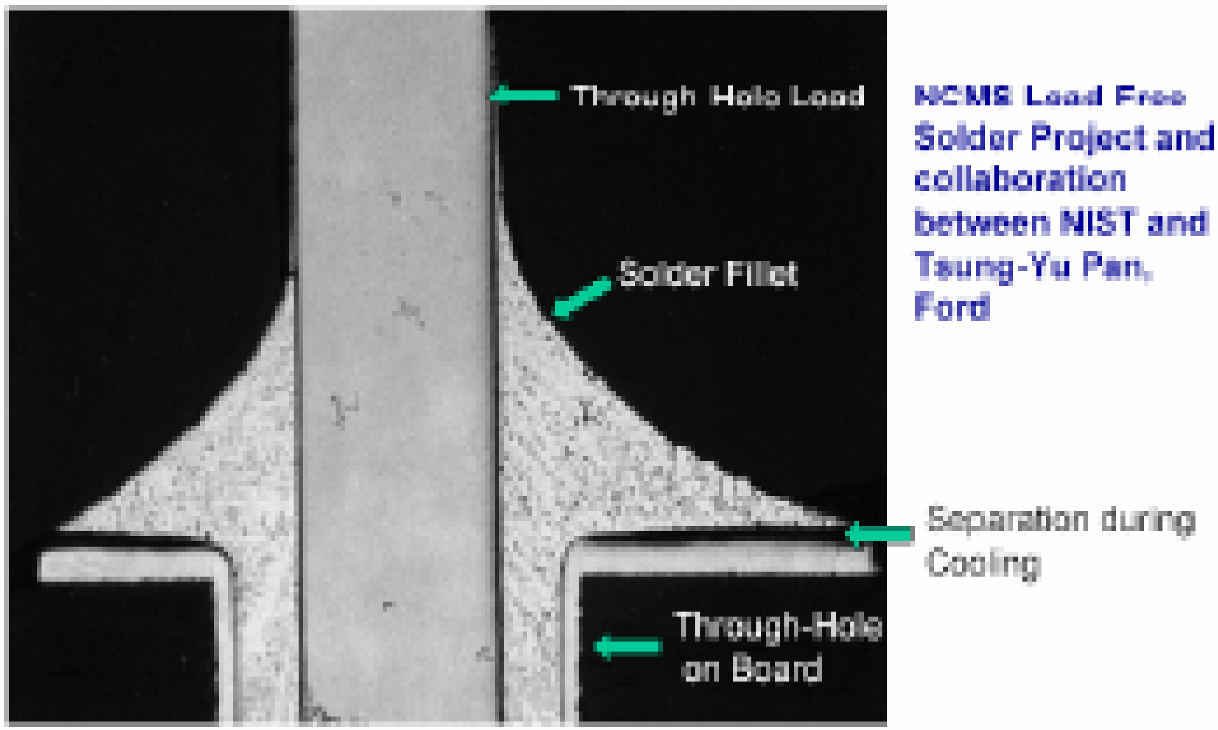


Figure 2. An example of fillet lifting after the Lead-free wave solder process.

Solder Joint Failures

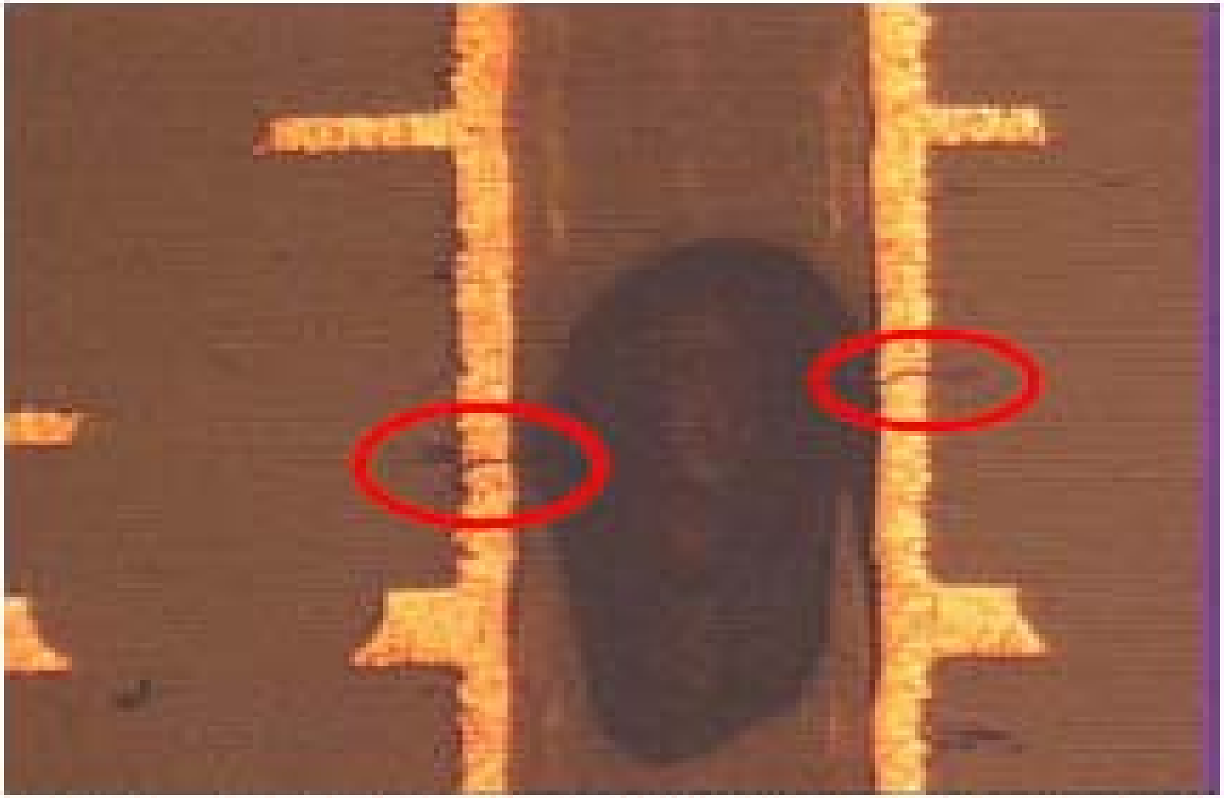
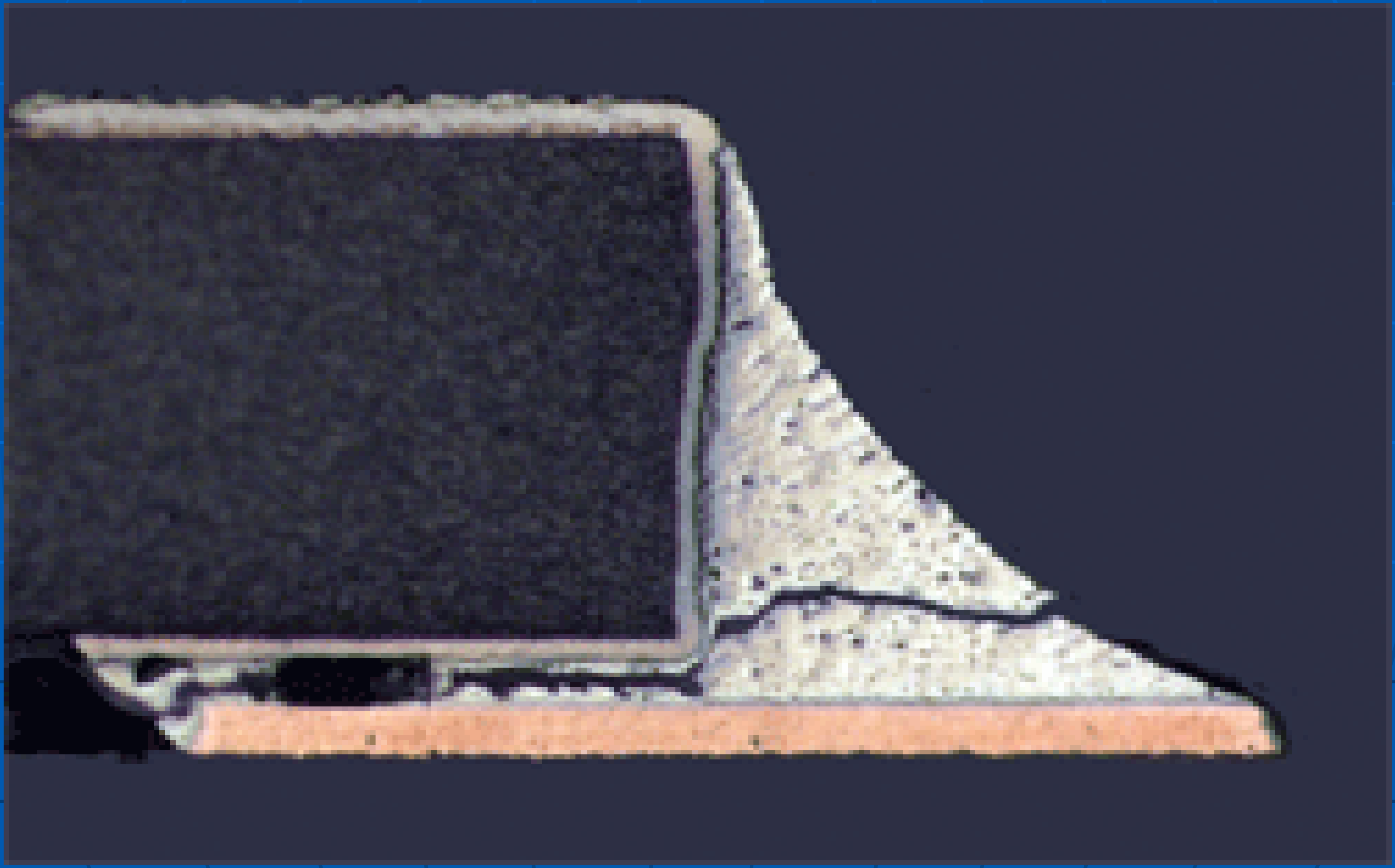


Figure 1. An example of PTH barrel cracking.

Solder Joint Failures



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Tin Whisker Mitigation Strategies

- **Conformal Coat applied over top of a whisker-prone surface will NOT prevent the formation of tin whiskers**
- **Whisker growths INITIATE faster on specimens that are covered with conformal coating**
  - **Conformal coating also reduces but does not eliminate) the rate of growth of tin whiskers compared to an uncoated specimen.**
- **Annealing Tin coating @ 302° F (150° C)**
  - **Initial testing appears to be promising**

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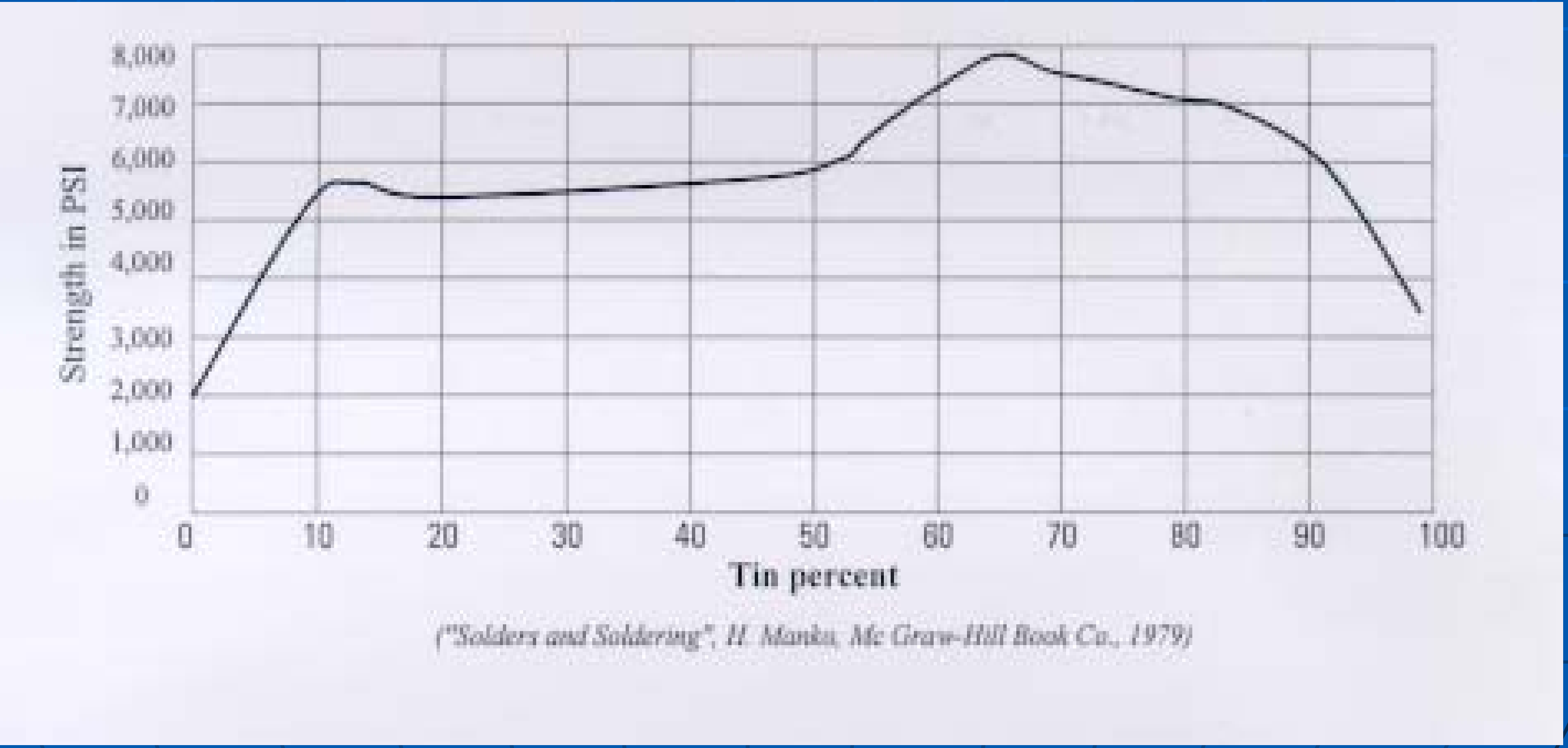
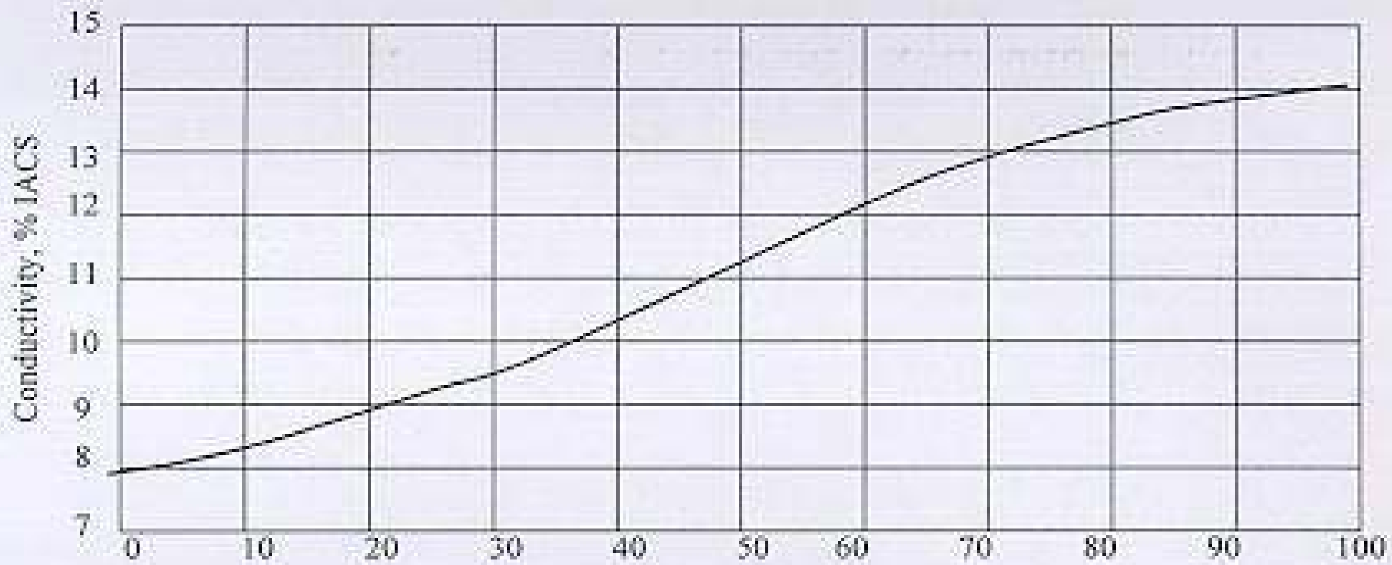
Tensile Strength

The tensile strength of solder increases depending on tin content. At room temperature the tensile strength reaches its peak at 65% (7,900 psi).



Electrical Conductivity

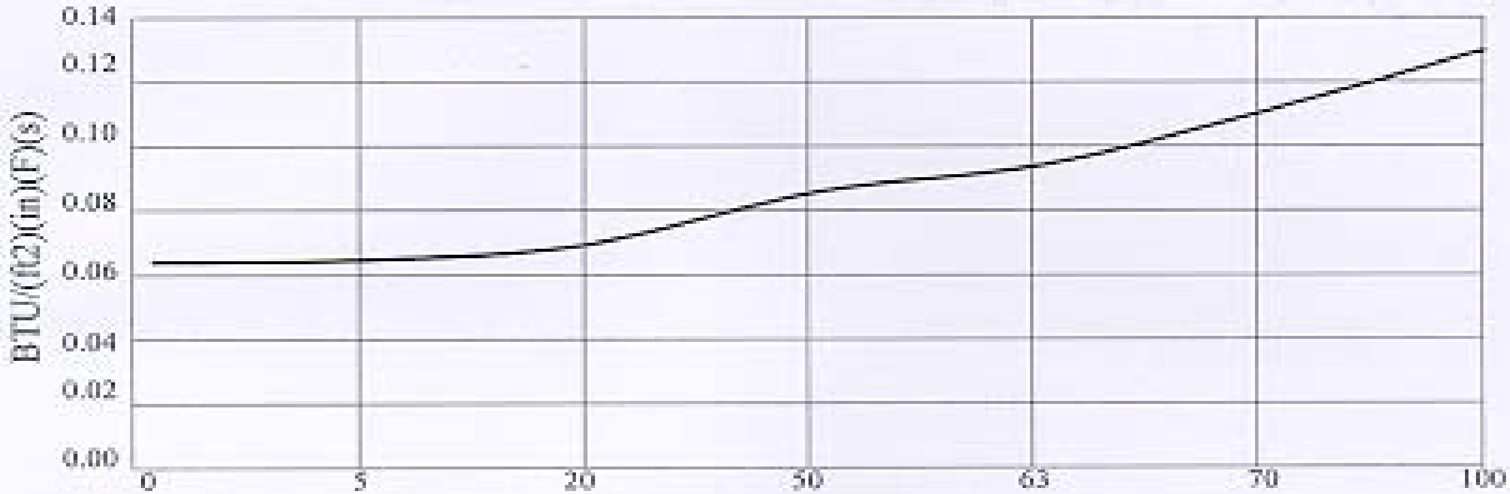
There is a straightforward linear correlation between the tin content and the electrical conductivity of the alloy. the higher the tin content in the alloy, the better the electrical conductivity.



Higher tin-content increases conductivity (%IACS: Percentage in reference to conductivity of Cu.)
("Solders and Soldering", H. Manko, Mc Graw-Hill Book Co., 1979)

Thermal Conductivity

The thermal conductivity diagram shows the linear relationship between the tin content and the thermal conduction capabilities of the solder alloy. the capability of the alloy to effectively conduct heat to the PC boards becomes an important parameter in residue-free soldering because of the improved capability of the solder to eliminate excess flux.



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Solderability Testing

- **Formation of Intermetallic compounds**
- **Copper**
  (Cu_6Sn_5) Eta and (Cu_3Sn)Epsilon phases between the Tin grain boundaries
- **Nickel**
  (Ni_3Sn_4) Eta and ($NiSn_3$) Epsilon phases between the Tin grain boundaries
  - **Eta Phase promotes solderability with a lower activation energy**
  - **Epsilon Phase does Not promote solderability because of a high activation energy**

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Solderability Testing

- IPC/EIA/JEDEC J-STD-002B
  - Coating Durability 3
    - Intended for Sn and SnPb coatings
    - Steam aging
      - 8 hours +/- 15 mins
    - Flux
      - 25% solids white water non activated Rosin
        - Kester 145
    - Solder Bath Temperature
      - 473 +/- 9º F (245 +/- 5º C)

Solderability Plating Considerations

- Solderability
  - Copper migration from base material requires a barrier plating
    - Copper 100 microinches
    - Nickel 50 microinches

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Solderability Shelf Life Considerations

- Shelf Life
  - Shelf life is dependent upon barrier and top coating thicknesses along with any thermal excursions that component experiences
- **Shelf life begins at the moment of plating!!!!**
  - 24ºC
    - 100 % Sn
      - 100 % acceptability – 6 months
      - 57 % acceptability – 12 months
      - 43 % acceptability – 18 months
    - 90/10 SnPb – 100 % acceptability for 6 months and 86 % acceptability out to 24 months
    - 60/40 SnPb – 100 % acceptability out to 24 months

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Plating Considerations

- Barrier Plating
  - Nickel per SAE AMS-QQ-N-290
    - 2.03um (80 microinches) minimum
      - Verify via Microsectioning per ASTM B487
- Top Coating
  - Tin Plating per ASTM B545
    - (5.08 –7.62 um)200 – 300 microinches
      - Verify via Microsectioning per ASTM B487

Plating Considerations

- Nickel barrier are not new to the electronics industry.
- They are used on surface-mount components to improve wetting, reduce solder leaching, and reduce tombstoning
- They have been used to prevent solder from leaching into parts like precision resistors so that their properties would not change over time
- They have also been used to keep copper from diffusing out into gold top coating

Plating Considerations

- Nickel Sulfamate
  - Low stress deposit
  - Hull Cell Analysis
    - Contaminates
      - Lead
      - Chromium
      - Zinc
    - Carbon Treatment

Plating Considerations

- Tin
  - Hull Cell Analysis
    - Contaminates
      - Lead
      - Chromium
      - Zinc
    - Carbon Treatment
      - Copper contamination critical to Tin Whiskering

Plating Considerations

- Barrier Plating
  - Nickel per SAE AMS-QQ-N-290
    - 2.03um (80 microinches) minimum
      - Verify via Microsectioning per ASTM B487
- Top Coating
  - Palladium Plating per ASTM B679
    - 1.27 um(50 microinches) minimum
      - Verify via Microsectioning per ASTM B487

Plating Considerations

- Barrier Plating
  - Nickel per SAE AMS-QQ-N-290
    - 2.03um (80 microinches) minimum
      - Verify via Microsectioning per ASTM B487
- Top Coating
  - Gold Plating per ASTM B488
    - 1.27-2.54um(50-100 microinches) minimum
      - Verify via Microsectioning per ASTM B487

Whisker Testing

- JEDEC Standard JESD22A121
  - Test Method for Measuring Whisker Growth on Tin and Tin Alloy Surface finishes
    - Ambient Storage (30ºC, 60% R/H) 3000 cycles
    - Temperature Cycling (-55 to +85ºC) 3000 cycles
    - Temperature Humidity Storage (60ºC, 93% R/H) 3000 cycles

Whisker Testing

- JEDEC Class Criteria

18.3.1. Class 1

Mission/Life Critical High-Reliability Applications — military, space and medical applications. Pure tin and high tin content alloys not acceptable.

18.3.2. Class 2

High-Reliability Business Applications — telecom infrastructure equipment, high-end servers, etc. which require long product lifetimes and minimal downtime. Products such as disc drives typically fall into this category. Breaking off of a tin whisker is a concern.

18.3.3. Class 3

Consumer Products — with relatively short product lifetimes (typically five years maximum). No major concerns by the user that the tin whiskers might break off and cause problems elsewhere in the product.

Whisker Testing

- JEDEC Acceptance Criteria

<table>
<tr><th colspan="4">Maximum Whisker Length</th></tr>
<tr><th>Device Considerations (Package type, lead pitch or operating frequency)</th><th>Class 1</th><th>Class 2</th><th>Class 3</th></tr>
<tr><td>Discrete Device (2 pins)</td><td rowspan="3">Pure tin and high tin content alloys not acceptable.</td><td rowspan="3">40 µm</td><td>67 µm (1)</td></tr>
<tr><td>Multi-lead packages</td><td>(Minimum gap between leads - .05mm)/3 or 67 µm, whichever is smaller(1)(2)(3)</td></tr>
<tr><td>Operating Frequency > 6GHz (RF)(4) or t_{rise} < 59 psec (digital)</td><td>50 µm</td></tr>
</table>