

ASSESSMENT OF WHISKER GROWTH FROM TIN COATED WIRE AND CABLE

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Objective

“What is the risk for whisker growth on tin-coated wire?”



Topics

- **Standards**
- **Historical data**
- **Analysis--variables**
 - Wire gauge
 - Age
 - Type of pure tin coating/grain size
- **Results**
 - SEM inspection
 - Cross section

Wire & Cable Standards

- Pure tin is a common finish for copper wire and cable
 - MIL-DTL-17 coaxial cable
 - AA-59551 (ss QQ-W-343) uninsulated “bus” wire
 - NEMA-WC27500 (ss MIL-DTL-27500) cable
 - SAE-AS22759 (ss MIL-W-22759) and MIL-DTL-16878 insulated wire
- Wire call-outs trace back to ASTM B33
- No restrictions or guidance on pure tin

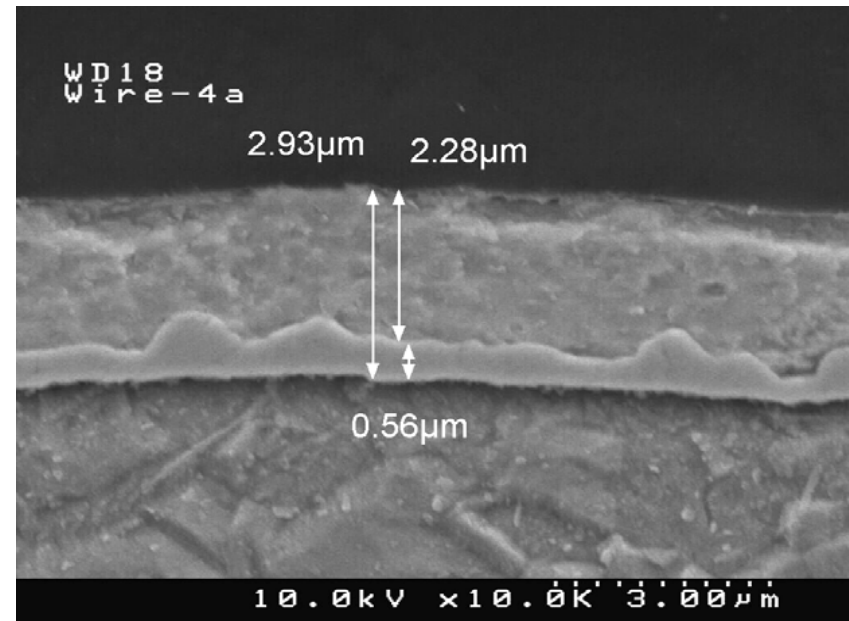
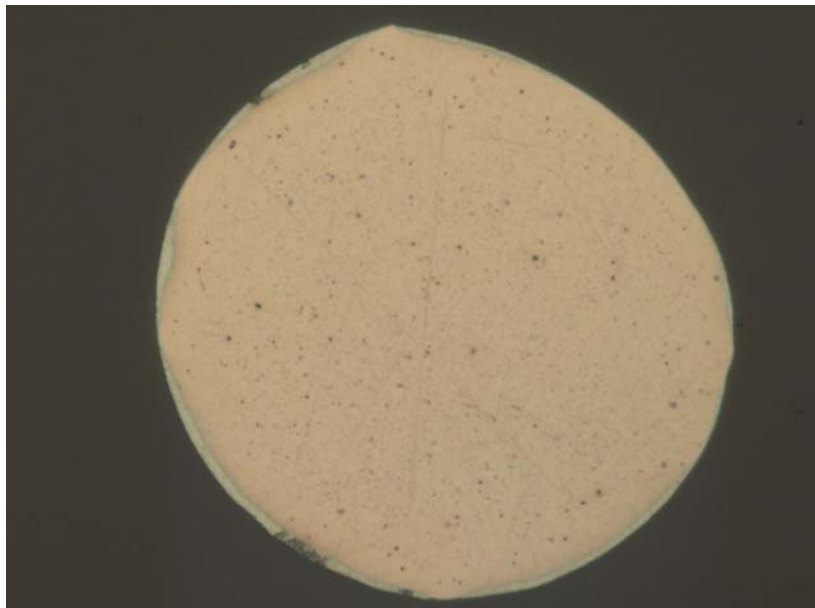


Wire & Cable Standards

- **ASTM B33 does not specify a tin coating thickness**

“It is necessary that the coating of tin on the wire be continuous.”

- **Tin coating consists of 2 parts**
 - Pure tin coating at surface
 - Intermetallic compounds between tin & copper



Wire & Cable Standards

- **Most common type of uninsulated wire: QQ-W-343 (superseded by AA-59551)**
- **Two types:**
- **Type S wire –single stranded, uninsulated**
 - Tin coating is 40 uin (1 um) thick minimum.
 - Thick enough to protect copper & prevent corrosion but limited shelf life
 - 1 um coating will not pass solderability test after steam aging due to oxidation of IMCs
- **Type H wire --“hookup wire”**
 - Additional solderability requirement (steam age)
 - Thicker tin coating, typically 300 uin (7.7 um) or more

Literature / Historical Data

- Sparse citations of whisker growth on tin plated wire
- Bell Labs studies in the 1950s and 60s
 - On tin coated wire, “*short whiskers, relatively few in number, were found*”
- NASA Goddard tin whisker website: whiskers on diode wire leads,
- Wire manufacturers: handful of customer reports of whiskers on tin coated wire over past 20 years, all on type H wire.
- Several references suggest that there is little to no risk for substantial whisker growth on tin coated wire and cable.
- No whiskers found on tin-coated wire on Titan missile harnesses
- MIL-STD-1547 (“Electronic Parts, Materials and Processes for Space and Launch Vehicles rev B”) includes an exemption for tin plated drawn wire products, such as cables, shielding and ground straps.

Analysis

- 20 samples of tin-coated wire, cable & braid
- Manufactured between 1965 and 2008
- 10 different suppliers
- Type S and H
- Two samples temperature cycled for 1000 cycles between -40 and 100°C
- Analysis
 - Microscope inspection
 - Energy Dispersive Xray (EDX)--material composition
 - Scanning Electron Microscopy (SEM)--size and density of whiskers, grain size
 - Cross section--intermetallic compound and tin layer thickness
- One electroplated mechanical part included for comparison

Samples Analyzed

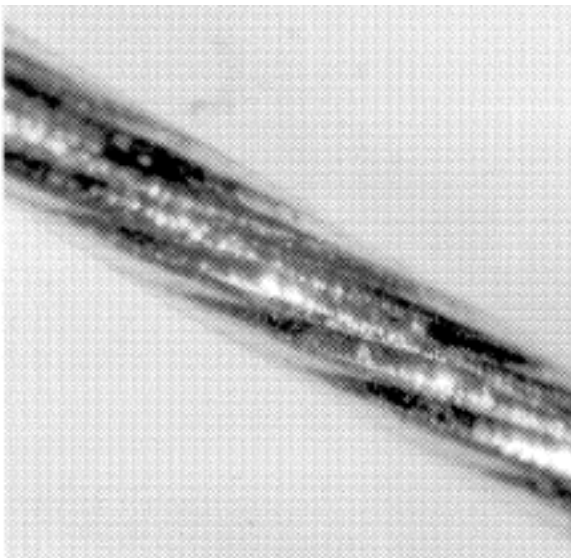
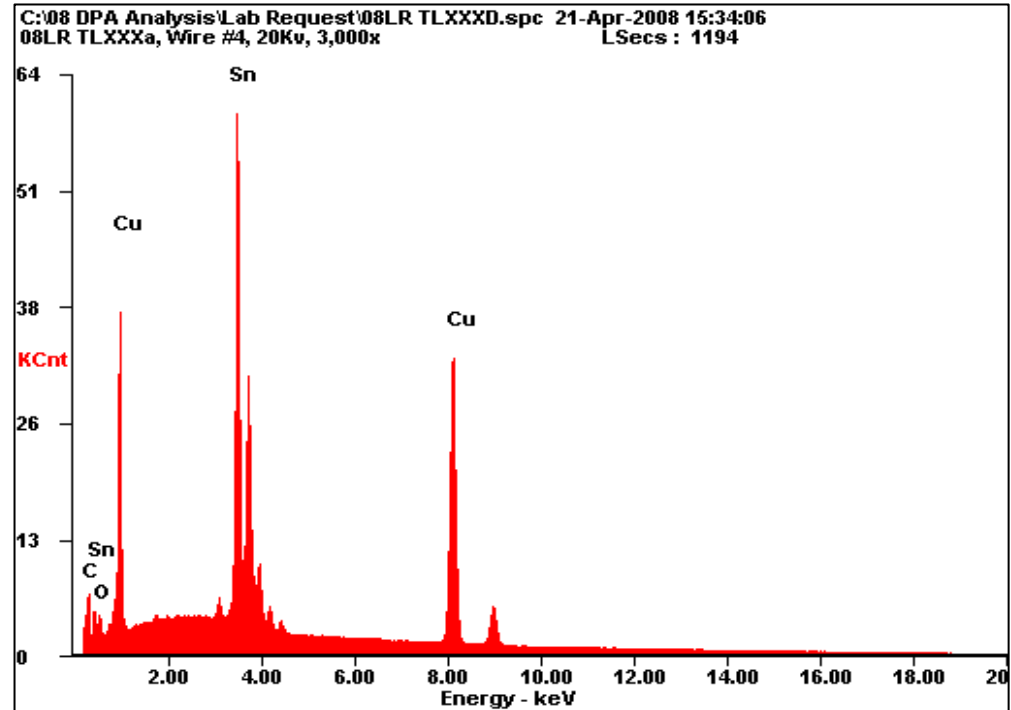
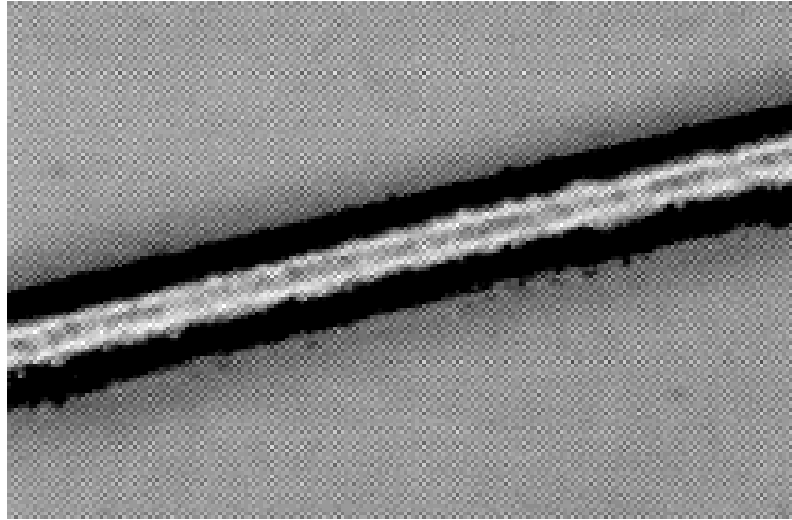
Sample i.d.	Description	Supplier	Year of Manuf	Storage Conditions
1	QQW343S24S1T bus wire	Blake	2007	Stored uncovered on spools, controlled temp & humidity
2	22-1-7C tin coated bus wire	Blake	2002	
3	C252583-222 tin coated bus wire	unk	unk	
4	QQB575R36T0500 ½" braid	Cont. Cordage	2007	
5	1188 tin coated 1/8" braid	Belden	1986	
6	100-C02A1000 5/8" braid	Glenair	2007	
7	EW88180 tin coated bus wire	Unk	1968	Stored in closed drawer on spools, controlled temp & humidity
8	ES600 tin coated 1/16" braid	Alpha	1968	
11	QQ-W-343 type H, 16 AWG tin coated bus wire	Belden	1966	
12	EO8237R QQW343 type H 20 AWG tin coated bus wire	Victor	1965	
13	Tin coated bus wire	MWS	1965	
14	QQW343 type S 24 AWG tin coated bus wire	Camden	1982	
15	EW-8815 tin coated bus wire	Victor	1965	

Samples Analyzed

Sample i.d.	Description	Supplier	Year of Manuf	Storage Conditions
16	MIL-DTL-17/133 tin coated copper semi-rigid cables	TIM-CO	1995	Stored uncovered, controlled temp & RH
17				1000 temp cycles -40 to 100°C
18	QQW343S22S1T 22 AWG tin coated copper bus wire	Blake	2002	1000 temp cycles -40 to 100°C
19	EW8812 14 AWG tin coated bus wire	National	1966	Stored in closed drawer on spools, controlled temp & RH
20	QQW343 Type S 26 AWG tin coated copper bus wire	Blake	1995	
21	C260796-001 QQB575 tin coated copper 1/8" braid	Blake	2003	
22	QQB575R30T1000 tin coated copper 1" braid	Cont. Cordage	2008	
23	MS35431-1 tin coated copper lug	Zierick	2002	
				Stored in controlled temp & RH 10

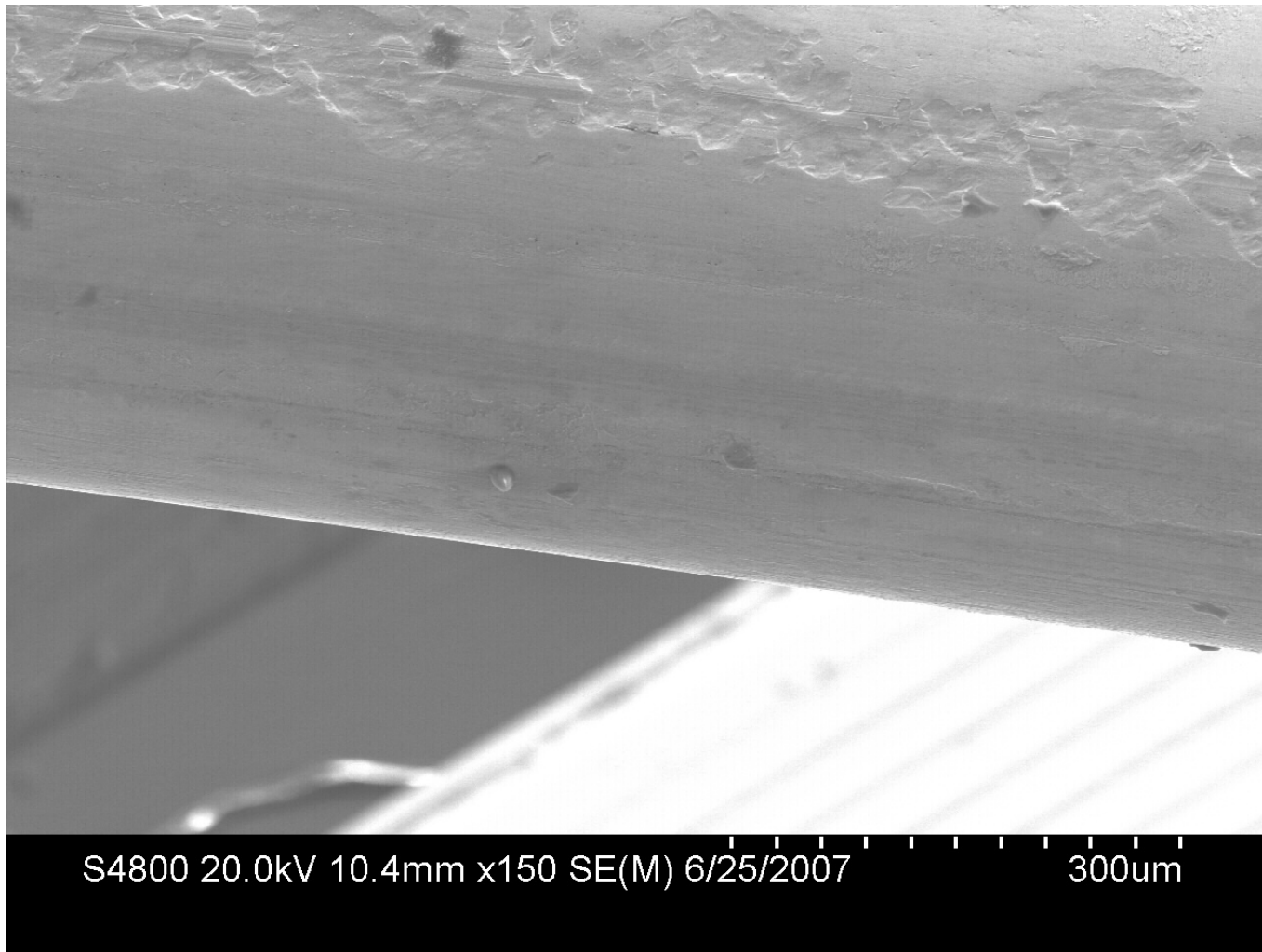
EDX/SEM Inspection

EDX confirmed pure tin coating over copper wire



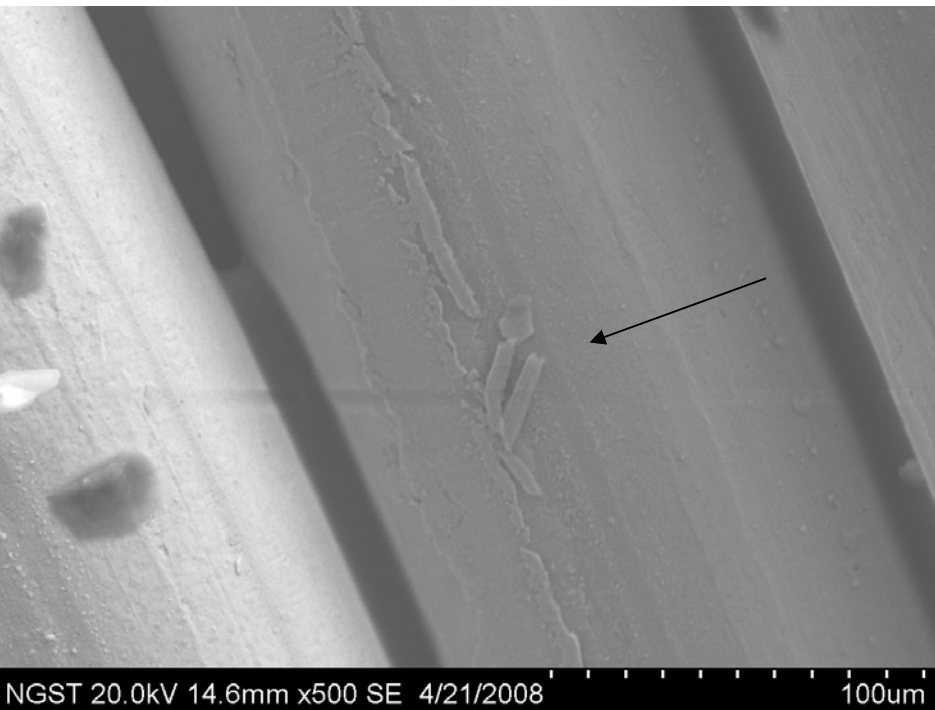
EDX/SEM Inspection

- None of the 20 wire and braid samples showed whiskers



EDX/SEM Inspection

- Braid samples showed some flat strands, believed to be “burrs” incurred from manufacturing process
- Electroplated terminal lug showed profuse whiskering

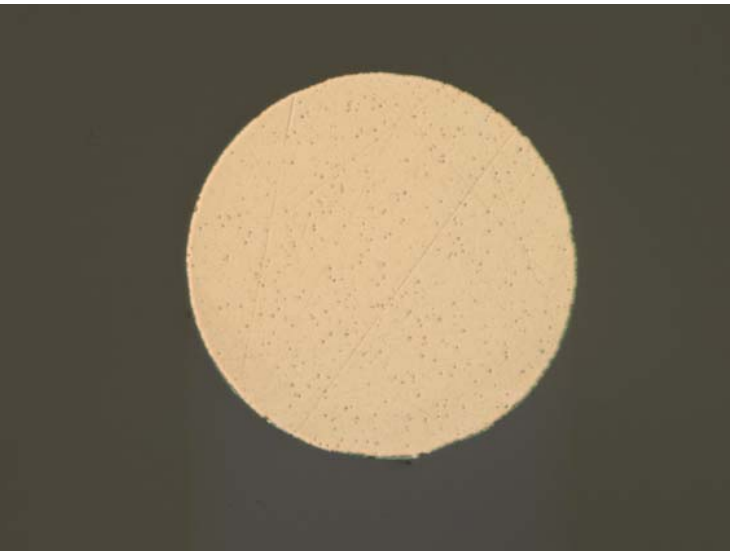


Tin plated copper braid

Tin plated copper terminal lug



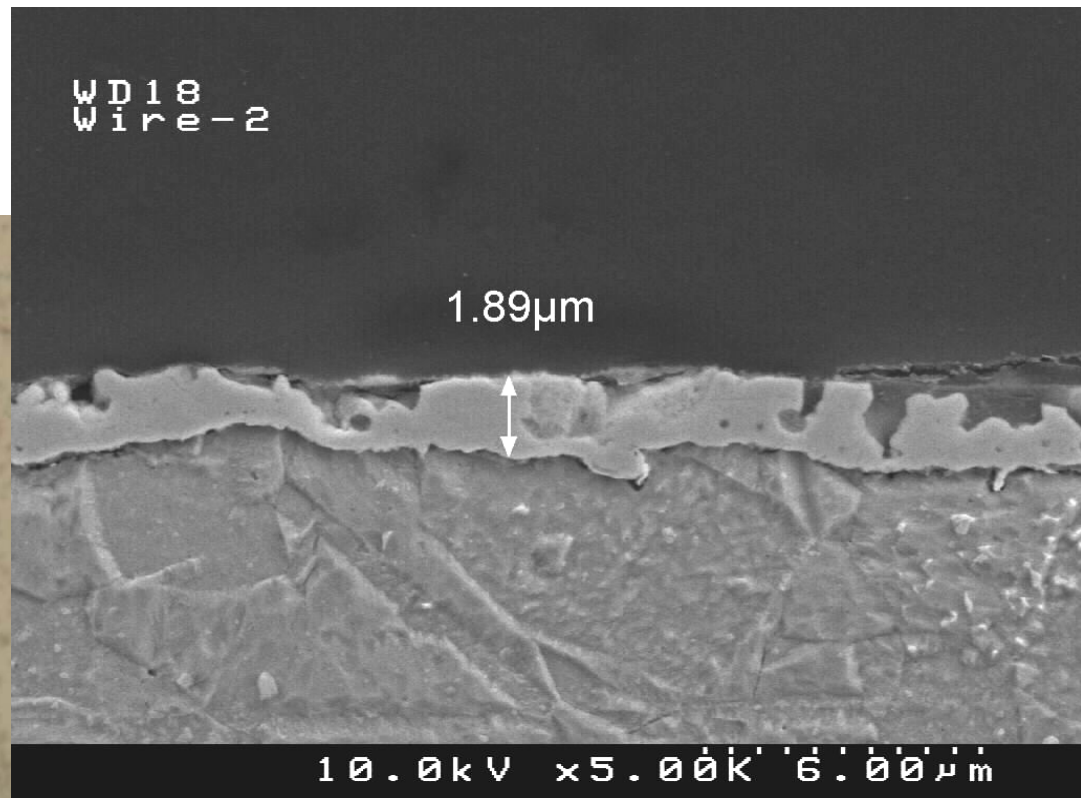
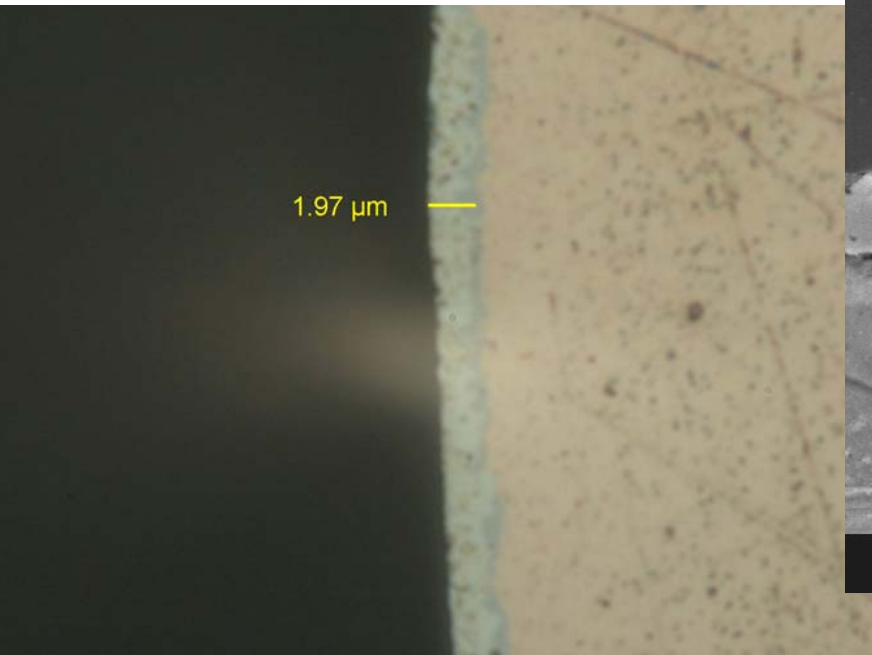
Cross Sections



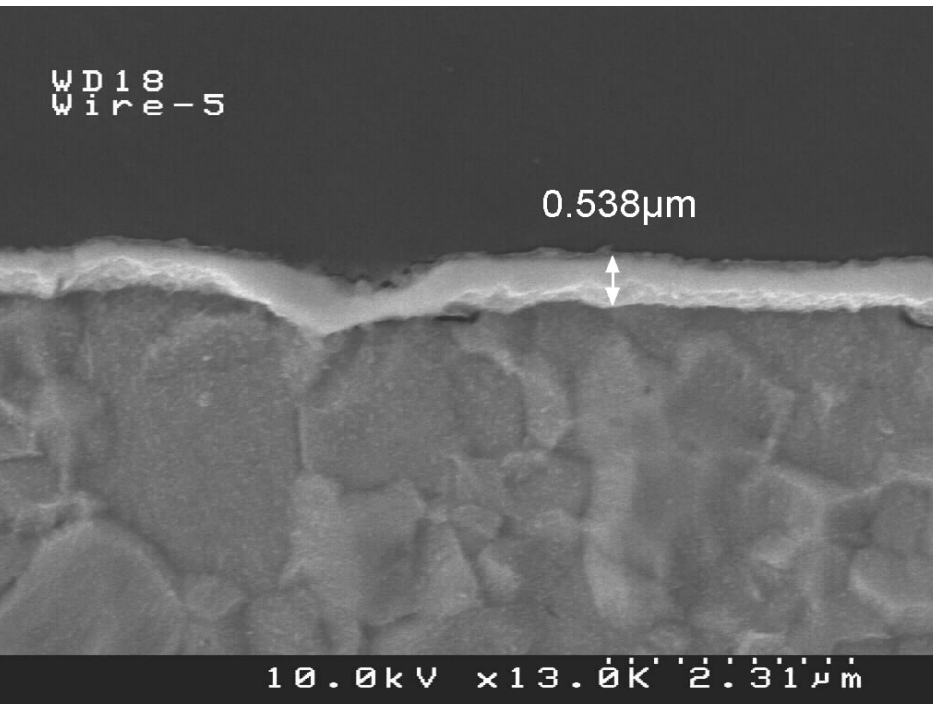
Sample 2

7 year old bus wire

IMC consumes 30 to 100% of tin layer



Cross Sections



← Sample 5

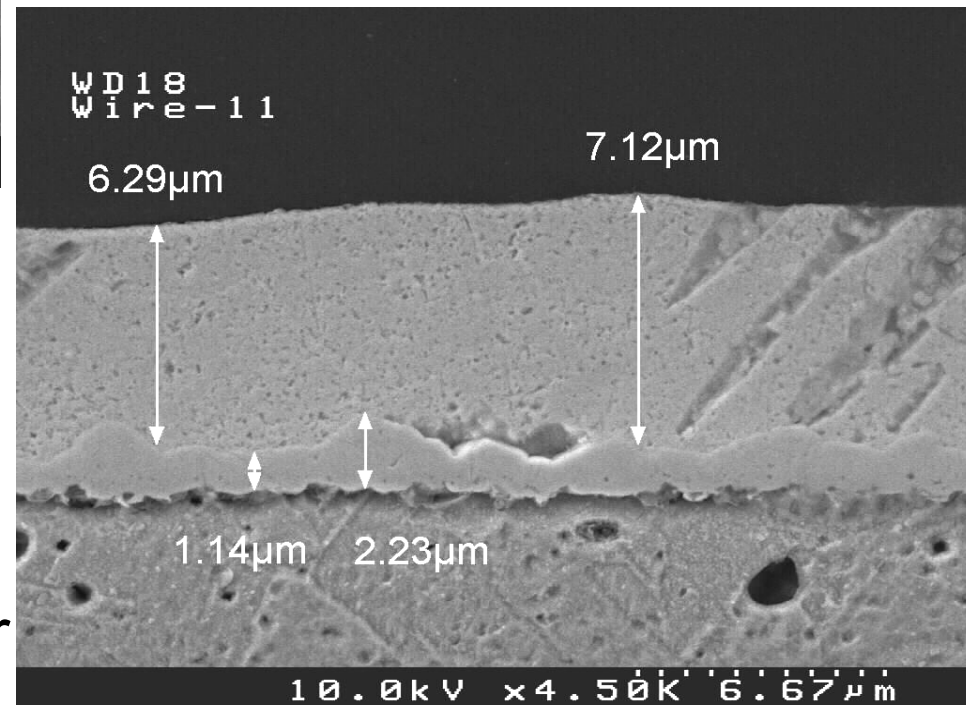
23 year old braid (type S wire)

IMC consumes 100% of tin layer

Sample 11 →

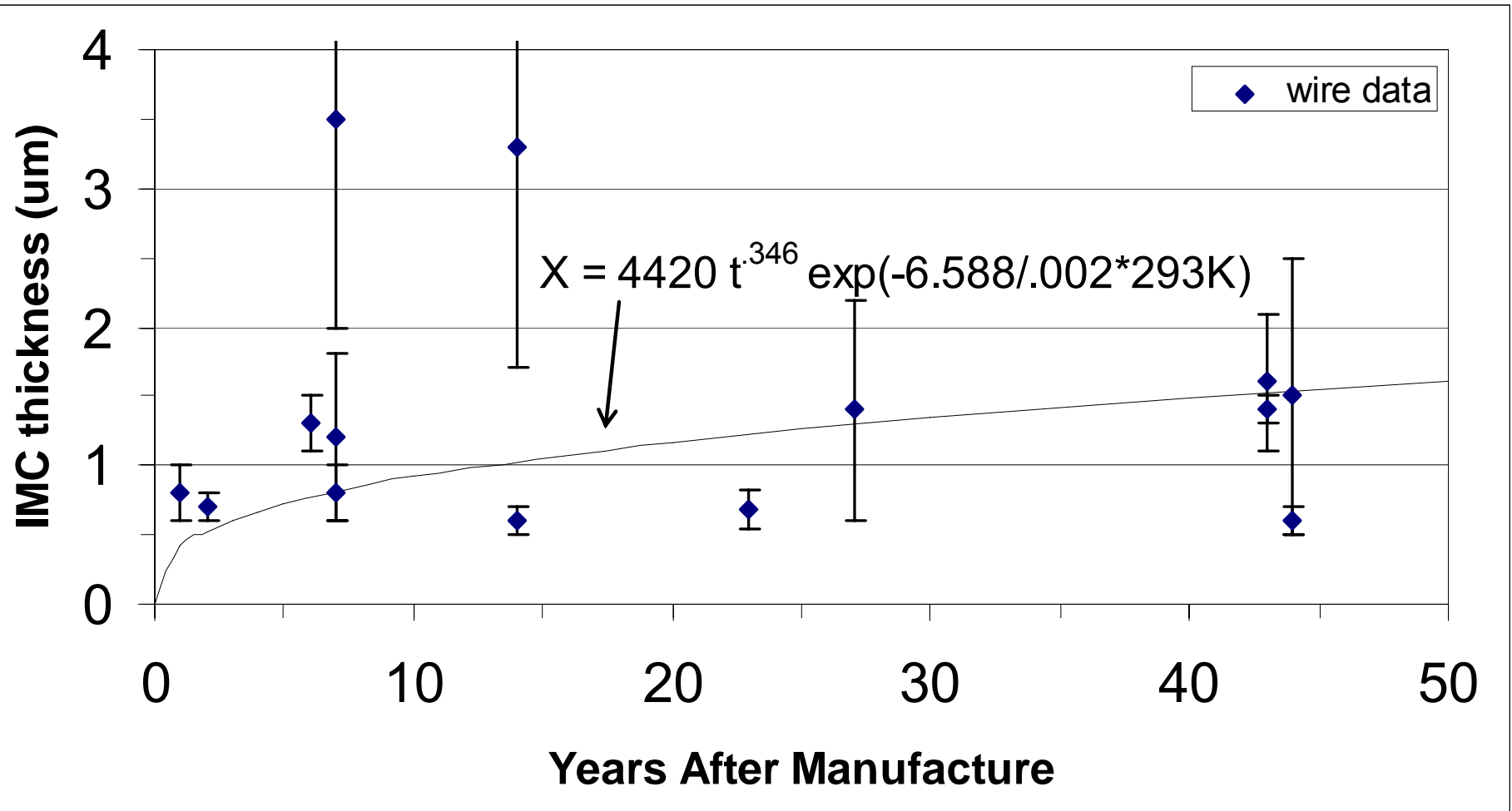
43 year old type H wire

IMC consumes 20% of tin layer



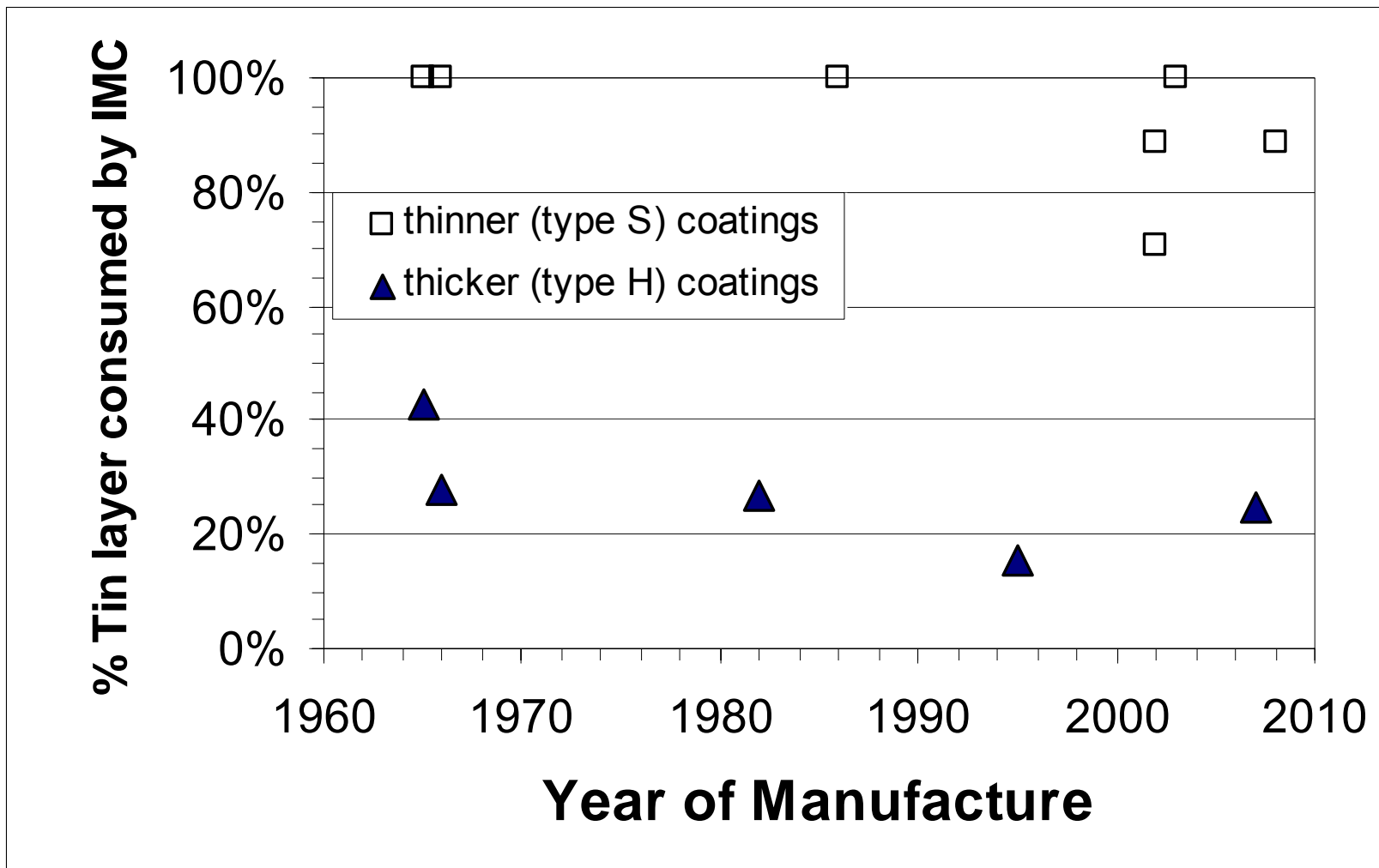
IMC Thickness

- General trend of increasing IMC thickness with age.
- Outliers (samples 17 and 23) have much thicker tin layer



IMC Thickness

- Type S coatings are consumed by IMC in first years
- Type H coatings retain 50-75% of nascent pure tin



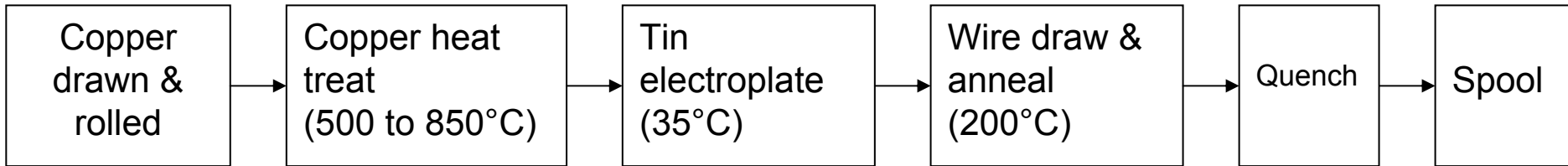
Cross Sections

Sample i.d.	Total wire diameter	Surface layer thickness	Tin-copper IMC thickness
2	.025"	1.5 to 1.9 um	0.5 to 1.9 um
4	.0043"	2.7 to 2.9 um	0.4 to 0.9 um
5	.0059"	0.5 to 0.8 um	0.5 to 0.8 um
11	.051"	4.4 to 7.1 um	1.1 to 2.2 um
12	.033"	3.2 to 3.8 um	0.8 to 3.4 um
14	.020"	5.1 to 5.3 um	0.7 to 3.5 um
15	.032"	0.5 to 0.7 um	0.6 to 0.7 um
17	.117"	18 to 21 um	1.6 to 5.1 um
18	.025"	0.8 to 1.1 um	0.8 to 1.1 um
19	.064"	1.3 to 1.5 um	1.3 to 1.5 um
20	.016"	3.5 to 4.2 um	0.5 to 0.7 um
21	.0059"	1.1 to 1.5 um	1.1 to 1.5 um
22	.0094"	0.8 to 1.1 um	0.8 to 1.1 um
23	.018"	18 to 25 um	2 to 5 um

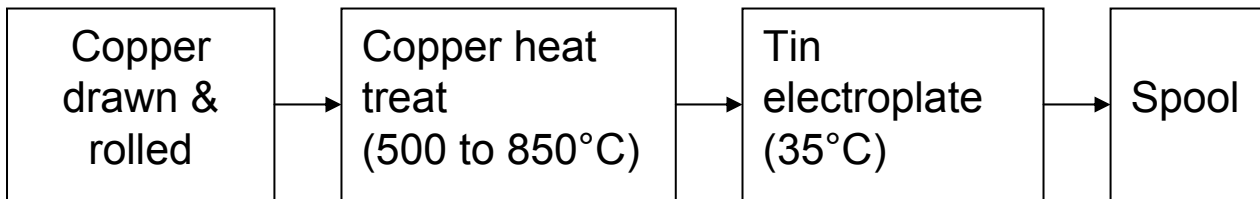
Wire Manufacturing Processes

- **Two processes used to coat bare copper wire with tin: electroplating (aka electrodeposit) and hot dipping.**
 - **Plating = electrochemical process**
 - **Hot dipping = physical process**
- **Regardless of the coating process, the bare copper wire is processed the same**
 - **Copper rods or bars heated and drawn through a series of dies to reduce diameter**
 - **Drawing is similar to extrusion except that the wire is pulled through the die rather than pushed**

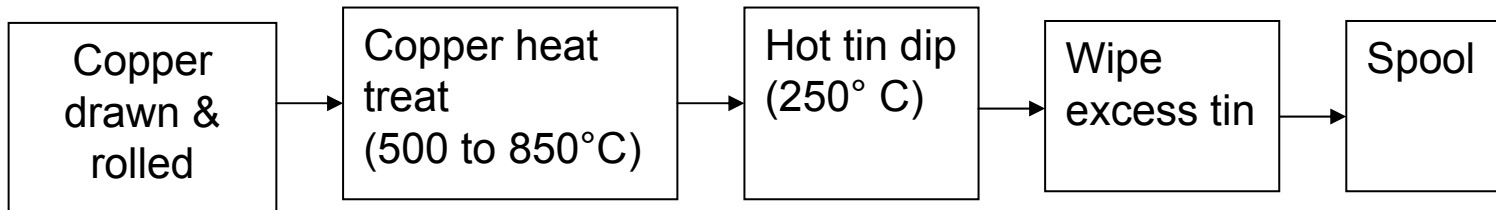
Wire Manufacturing Processes



Type S electroplated tin coated copper wire



Type H electroplated tin coated copper wire



Type S hot dipped tin coated copper wire

■ **Significant differences between hot dipping and electroplating:**

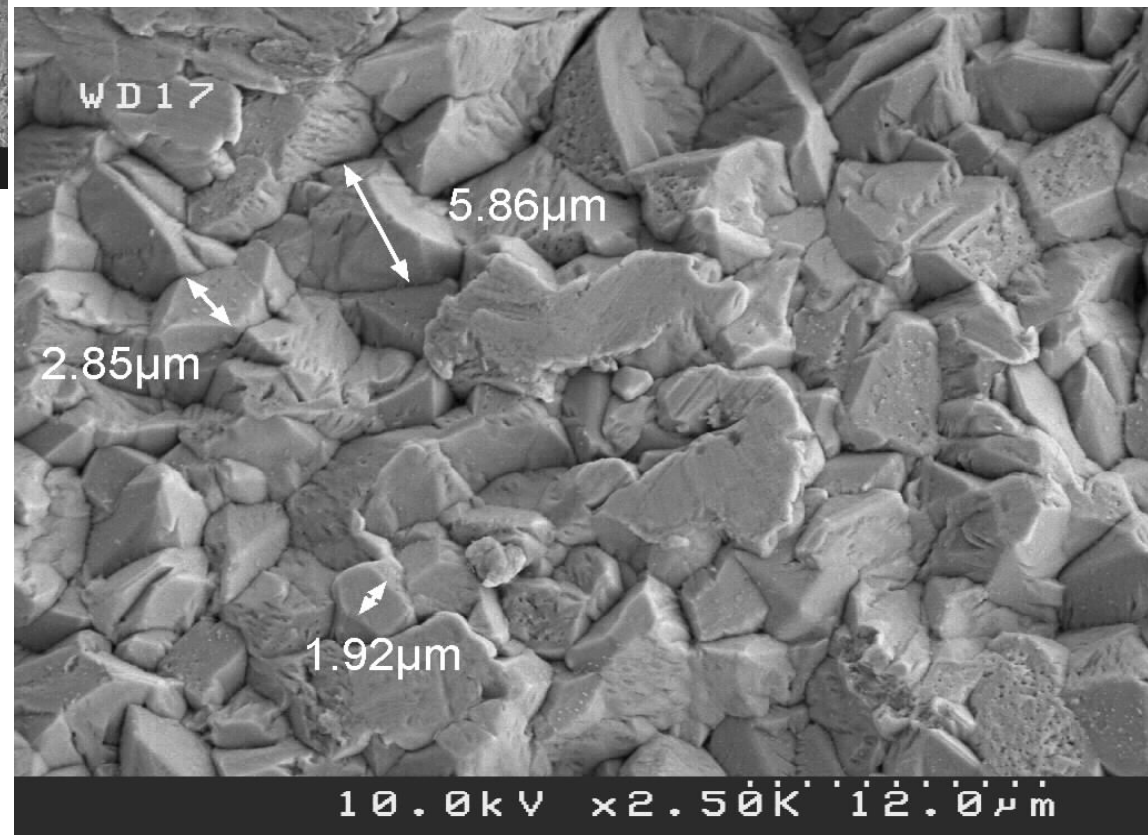
- **Hot dipping takes place at much higher temperature, therefore resulting in thicker initial IMC.**
- **Hot dipped wire is handled in the molten state to remove excess tin; processes may be variable.**
- **Hot dipped wire produces smaller, less distinct grains**
- **Type S electroplated wire is drawn through a die after plating**

Grain structure & size- sample 23 (plated lug)



Electroplated wire shows larger, more distinct grains with sharp ridges.

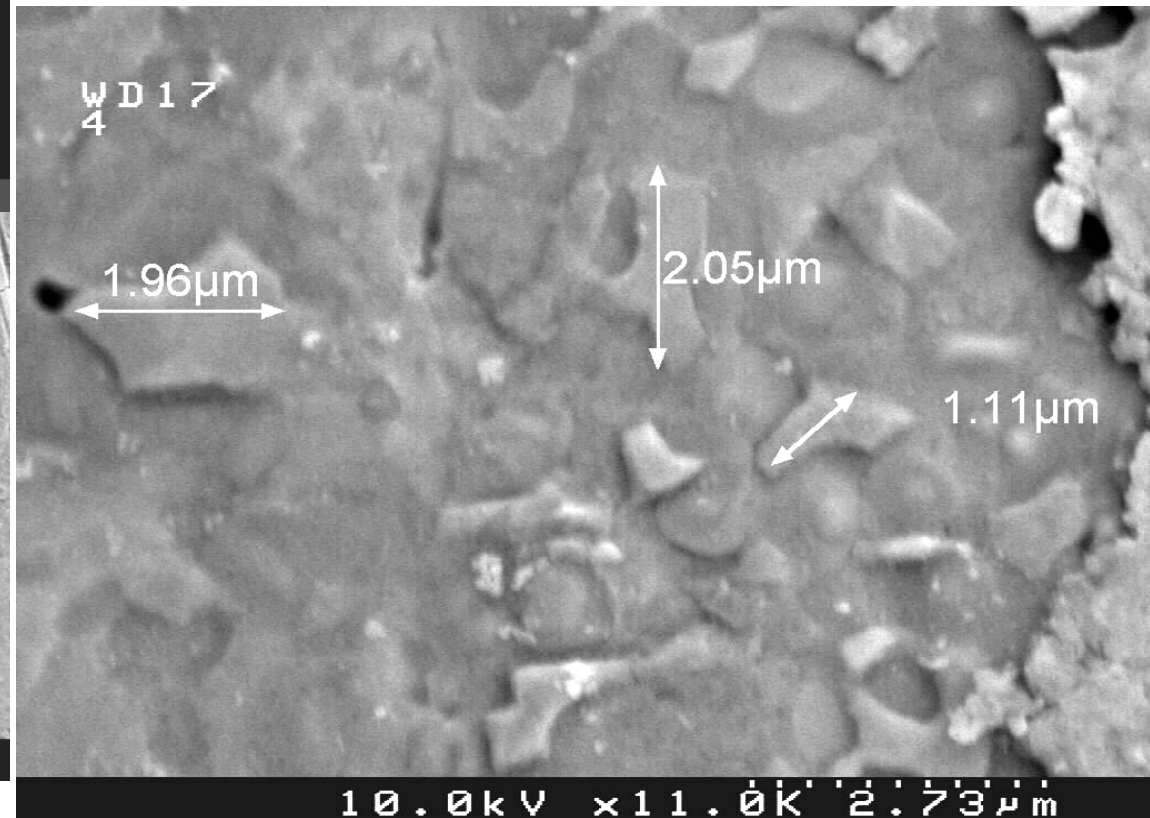
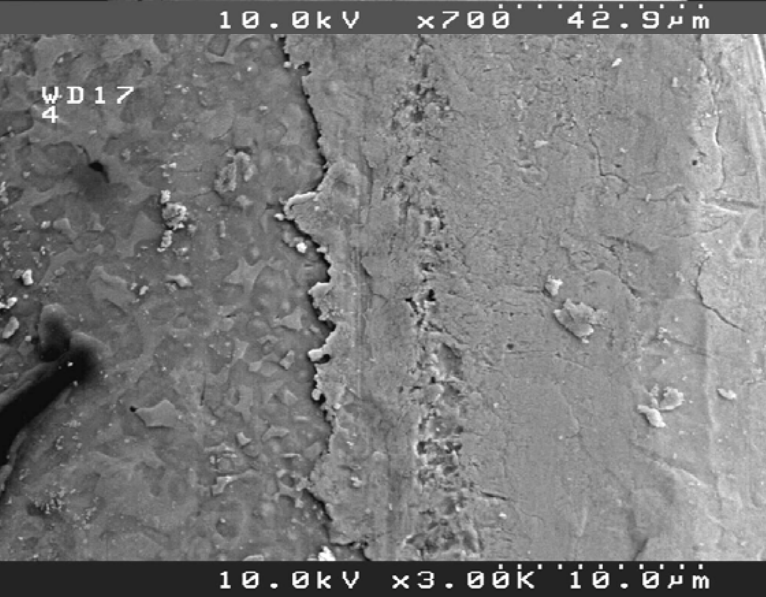
Grain size is $3.9 \pm 1.8 \mu\text{m}$



Grain Structure & Growth-Sample 4 (hot dipped braid)

Hot dipped wire shows relatively smooth, shows signs of reflow with less structured grains.

Grain size $1.3 \pm 0.6 \mu\text{m}$



Pure tin on wire vs. Components

Factor	Wire	Component terminations
Base material	Copper	Copper, alloy 42, Kovar, etc
Geometry	Round, no edges	Typically rectangular with sharp edges & corners.
Coating thickness and underplate	Type S < 2 um, Type H 5-10 um Tin directly over copper	5 to 20 um Nickel diffusion barrier
Coating process	Hot dip or electroplate followed by wire draw-- controls vary by supplier	Electroplated
Heat exposure /anneal	Yes, copper is annealed prior to plating. Type S and H annealed after plating.	Most cases: no
Cold working	Yes, copper is repeatedly drawn prior to plating. Type S wire is drawn after plating	Most cases: no. Some leads are formed after plating
IMC growth	Thicker for hot tin dipped tin coatings. Thinner for electroplated coatings.	Thinner for electroplated coatings. Thicker if part is reflowed or annealed. ²⁴

Conclusions

- **Three factors work to suppress whisker growth on wires**
 - **Post-plating drawing steps cold work the wire**
 - **Annealing relieves stresses in the plating**
 - **Larger IMC layer in hot dipped wire results in less pure tin material available for whisker growth.**
- **Thus type S wires (hot dipped or electroplated) would tend to be at lower risk for whisker growth than wires with thicker plating (type H).**
- **According to QQ-W-343 & AA-59551, Type H wire is preferred as hookup wire on electrical assemblies because of its solderability**
- **In terms of whisker mitigation, however, type S wire is preferred to type H.**

Conclusions

- No tin whiskers were observed on any samples; 20 samples from 10 suppliers, aged between 1 and 44 years.
- No correlation between whisker growth and age of sample, intermetallic compound thickness, supplier or coating process (hot dipped vs. electroplated).
- Significant differences between tin plated wire (no whiskers) and tin plated component terminations (whiskers) include geometry, thickness of tin layer, and post plating annealing and cold working processes. None of these factors alone appear to be completely successful in suppressing whiskers; rather it is likely a combination of factors.
- Literature contains four reports of whisker growth on tin plated copper wire or wire leads (refs 8,9,10,11)
- Interviews with wire manufacturers revealed isolated reports of tin whiskers on wire over the past 20 years.
- Several data-based references state that there is little to no risk for substantial whisker growth on tin-plated wire and cable.