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AEROSPACE INFORMATION REPORT

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Investigation of Whisker Formation on Tin Plated Conductors

1. SCOPE:

This SAE Aerospace Information Report (AIR) shall be limited to general information about tin whisker formation on tin plated conductors. It summarizes the mechanisms of metal whisker formation and describes possible conclusions as related to tin plated conductors. It also provides a number of reference documents that describes research and observations of the whisker phenomena, recommendations to prevent its formation and conclusions.

The investigation by this task group of AE-8D was initiated by a request of the Naval Air Warfare Center, Indianapolis, Indiana, to determine if the phenomenon of tin whiskers is a problem in aerospace wire and cable.

1.1 Purpose:

This document provides some brief information about tin whisker formation and a list of reference documents that can provide more detailed information.

2. APPLICABLE REFERENCES:

AMP Products and Industries, Lead-Free, Whiskerless Tin, Internet web site-http://www.amp.com/product/articles/dd50.html

Arnold, S. M., A Hidden Cause of Failure in Electronic Equipment: Metal Whiskers, Electrical Manufacturing, November 1954, 110, Proceedings 1954 Electronic Components Symposium, p. 38

Arnold, S. M., Growth and Properties of Metal Whiskers, American Electroplaters' Society Proceedings, 43rd Annual Convention, 1956, p. 26

Arnold, S. M., Growth of Metal Whiskers on Electrical Components, Proceedings 1959 Electronic Components Conference, p. 75-82

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2. (Continued):

Arnold, S. M., Repressing the Growth of Tin Whiskers, Plating, January 1966, 53, p. 96

ASTM B 545-92, Standard Specification for Electrodeposited Coatings of Tin, American Society for Testing and Materials

Britton, S. C., Spontaneous Growth of Whiskers on Tin Coatings: 20 Years of Observation, Tin Research Institute, 1974

Britton, S. C., Spontaneous Growth of Whiskers on Tin Coatings: 20 Years of Observation, Transactions - Institute of Metal Finishing, 1974, 52, p. 95

Britton, S. C. and Clarke, M., Transactions - Institute of Metal Finishing, 1963, 40, p. 205

Britton, S. C. and Clarke, M., Transactions - Institute of Metal Finishing, 1964, 42, p. 195

Cobb, H. L., Cadmium Whiskers, Monthly Review, American Electroplaters' Society, 1946, 33, p. 28

Compton, K. G., Mendizza, A., and Arnold, S. M., Filamentary Growth on Metal Surfaces - 'Whiskers', Corrosion, 1951, 7, p. 327

Diehl, R. P. and Cifaldi, N. A., Proceedings 8th Annual Connector Symposium, Electronic Connector Study Group, Inc., Cherry Hill, NJ, October 1957, p. 327

Despain, Frank J., Tin Whiskers - Final Report, Lockheed Martin Astronautics, June, 1993

Dunn, B. D., A Laboratory Study of Tin Whisker Growth, European Space Agency ESA STR-223, September 1987

Dunn, B. D., The Fusing of Tin-Lead Plating on High Quality Printed Circuit Boards, Transactions - Institute of Metal Finishing, 1980, 58, p. 26-28

Dunn, B. D., Mechanical and Electrical Characteristics of Tin Whiskers with Special Reference to Spacecraft Systems, ESA Journal 1987, Vol. 11/1988, Vol. 12, p. 1-17

Dunn, B. D., Metallurgical Assessment of Spacecraft Parts and Materials, Ellis Horwood Limited, p. 316-346

Dunn, B. D., Whisker Formation on Electronic Materials, ESA Science Technical Review, 1976, 2, p. 1-22

Ellis, W. G., Transactions of the Metallurgical Society - AIME, 1966, 236, p. 872

Eschelby, J. O., A Tentative Theory of Metallic Whisker Growth, Physics Review, 1953, 91, p. 755

Eschelby, J. O., Journal of Applied Physics, 1953, 24, p. 176

2. (Continued):

Fisher, R. M., Darken, L. S., and Carrol, G. K., Accelerated Growth of Tin Whiskers, Acta Metallurgica, 1954, 2, p. 370

Frank, F. G., On Tin Whiskers, Philosophical Magazine, 1953, 44, p. 854

Franks, J., Growth of Whiskers in the Solid Phase, Acta Metallurgica, 1958, 6, p. 103

Gabe, D. R., Whisker Growth on Tin Electrodeposits, Transactions - Institute of Metal Finishing, 1987, 65, p. 115

Glazunova, V. K. and Kudryavtsev, N. T., An Investigation of the Conditions of Spontaneous Growth of Filiform Crystals on Electrolytic Coatings, J. Appl. Chem. USSR (Zhur Prikl Khim), 1933, 36, (3), p. 543

Glazunova, V. K., Zhur Prikl Khim, 1964, 37, p. 2387

Hedges, Ernest S., Tin and Its Alloys, Edward Arnold (Publishers) Ltd., 1960, p. 71-77

Herring, C. and Galt, J. K., Elastic and Plastic Properties of Very Small Metal Specimens, Physics Review, 1952, 85, p. 1060

Jafri, A., Fighting Whisker Growth in the Communications Industry, Plating, 1973, 60, p. 358

Jennings, Charles W., Filament Formation on Printed Wiring Boards, IPC Technical Review, February, 1976, p. 9-16

Kehrer, H. P. and Kadereit, H. G., Tracer Experiments on the Growth of Tin Whiskers, Applied Phys. Lett., 1970, 16, No. 11, p. 411-412

Key, P. L., Surface Morphology of Whisker Crystals of Tin, Zinc, and Cadmium, Inst. Elec. & Electronic Engr. Proc. 20th Electronic Component Conf. May 1970, p. 155

Koonce, S. E. and Arnold, S. M., Metal Whiskers, Journal of Applied Physics, 1954, 25, p. 134

Leidheiser, Henry, Jr., The Corrosion of Copper, Tin, and Their Alloys, J. Wiley and Sons, Inc., 1971, p. 334-340

Marchand, W., Transactions - Institute of Metal Finishing, 1961, 38, p. 112

Marcus, R. B. and Rottersman, M. H., Journal of the Electrochemical Society, 1967, 114, No. 3, p. 59c

McCrone, W. C., Insight, 1973, 4 (2), p. 4

Metal Finishing Guidebook, Metals and Plastics Publications, 1965, p. 265

2. (Continued):

Modern Electroplating, 2nd Edition, Ed.: F. A. Lowenheim, John Wiley and Sons, 1963, p. 249

Mott, N. F., Proceedings of the Physics Society, 1951, B64, p. 379

Nabarro, F. R. N. and Jackson, P. J., Growth and Perfection of Crystals, John Wiley and Sons, 1958, p. 13

Neutron Bombardment and the Growth of Metal Whiskers, American Metal Market, December 18, 1956

Nordwall, B. D., Air Force Links Radar Problems on Growth of Tin Whiskers, Aviation Week and Space Technology, 30 June 1986, p. 65-69

Parker, M. T., Proceedings 4th SEM Symposium, (1), ITT Research Institute, April 1971, p. 217

Peach, M. O., Mechanism of Growth of Whiskers on Cadmium, Journal of Applied Physics, 1952, 23, p. 1401

Pitt, C. H. and Henning, R. G., Journal of Applied Physics, 1964, 35, p. 459

Politycki, V. A. and Kehren, H. P., Z. Metallkunde, 1968, 59, p. 309

Problem Advisory, Transistors, Whisker Growth, Tin, Alert/safe-Alert No. 8Y-P-90-01

Rozen, M., Plating, 1968, 55, p. 1155

Sabbagh, N. A. J. and McQueen, H. J., Metal Finishing, 1975, 73 (3), p. 27

Seitz, F. C., Physics Review, 1950, 79, p. 1003

Selcuker, Ahmet & Johnson, Michael, Microstructural Characterization of Electrodeposited Tin Layer in Relation to Whisker Growth, CARTS 91, p. 196

Semiconductor Reliability News, Tin Whiskers, October 1990

Smith, J. F., Whisker Growth on Electrodeposited Tin, Trans. Inst. Metal Finishing, 1967, 45, p. 9

Zakraysek, L., Whisker Growth From a Bright Acid Tin Electrodeposit, Plating and Surface Finishing, March 1977, p. 38-43

3. GENERAL:

3.1 Background:

Whiskers are metal filaments having a diameter of the order of 1 µm (10^{-4} cm), although they have been observed as small as 6 nm (10^{-7} cm) and as large as 6 µm. Tin whiskers have been measured in excess of 2.5 mm in length and can conduct electrical current in excess of 32 mA. Whiskers generally grow straight from the substrate, however some curved examples have been reported.

Documented research of whisker formation in metals dates back to the mid 1940's. One of the earliest observations of whisker formation was during an investigation for electrical failure in densely packed electronic assemblies. It was observed that conductive zinc filaments had bridged across the spacing between components causing failures. Whiskers have the potential of causing short circuit failures in low voltage, low current circuits as a current path of a few milliamperes can seriously affect these systems. Conversely, whiskers do not seem to affect high voltage, high current circuits as the filaments simply "burn out" if they cause a short.

Later investigation revealed that other metals such as cadmium and especially tin was susceptible to whisker growth. Whisker growth has only been observed to form on pure metal surfaces. Tin whiskers can develop on solid tin, tin plating that is applied by electrodeposition or evaporation, fused tin coatings, reflowed tin, etc.

3.2 Whisker Composition and Structure:

As whiskers grow from the pure metal surface, they retain the same composition and have been analyzed to be single crystal in structure.

3.3 Whisker Growth Mechanism:

The growth of tin whiskers has been investigated and documented by several researchers, however, there are no definitive theories regarding the growth mechanism, conditions necessary, prediction of growth sites, or methods to completely prevent its formation.

Observations have shown that whiskers grow from their base outward. There seems to be a general consensus that diffusion and mechanical stress are related to nucleation and rate of growth. However, many observations of whiskers have shown no depressions or depletion of the tin surface surrounding the filament which may indicate more than localized diffusion. Controlled experiments varying the amount of stress application, both tensile and compressive, has shown varying results. Therefore, confirmation of localized stress affecting whisker formation has not been established.

3.4 Mechanisms That Affect Whisker Growth:

Surface composition has been observed to affect the number and rate of whisker growth. On tin surfaces, lead alloyed in a few percent with the tin has greatly reduced the nucleation sites for whiskers. Other alloying elements such as antimony, cobalt, copper, germanium, gold and nickel have similar effects.

Mechanical barriers such as coatings can also affect whisker growth. Thin barriers such as chromate coatings, oils, greases, silicones, waxes and thin lacquer coatings do not prevent whisker growth. Thicker barriers such as resin coatings greater than 1/16 in or more have successfully prevented whisker growth.

3.5 Variability of Whisker Growth:

Most of the researchers performing investigative work on the subject of whiskers have experienced onen common conclusion, that whisker formation is not consistent or predictable. Experiments have resulted in the extremes of rapid whisker growth after a short period of time to no visible growth after extended periods on different samples prepared under similar conditions. Variations in temperature and humidity conditions has shown both increased growth rate and no effect.

4. DISCUSSION:

4.1 Whisker Growth on Tin Coated Copper Conductors:

In industry, the occurrence of tin whisker growth is a concern in electronic equipment containing exposed tin coated surfaces such as printed circuit boards, chassis components, and connector terminations. Under these circumstances, the phenomena of whisker formation has been well documented and recommendations have been presented by many researchers to eliminate its growth.

There have been several instances of whisker growth on tin plated copper conductor. These instances have been limited to bus wire applications where the conductor had no surface insulation.

No documented observations of tin whisker growth on insulated tin plated copper wire was found in published literature.

The SAE AE-8D subcommittee was surveyed requesting information and known cases or problems caused by tin whisker formation on wire and cable. Of the 19 respondents:

a. 8 had prior knowledge of the tin whisker phenomenon
b. 1 had references to literature
c. NO respondents had direct information on cases of whiskers in wire and cable

5. HYPOTHESES:

5.1 Insulation as a Barrier:

It is conceivable that the insulation placed on tin plated copper conductor serves as an effective barrier to whisker formation. Therefore, if conditions are conducive for whisker formation, it would be limited to exposed areas where the insulation has been stripped, such as conductor strand surfaces adjacent to a termination.

5.2 Limited Free Tin on Tin Coated Conductors:

Tin coated copper conductors usually contain a relatively thin coating of electroplated tin on the surface of the conductor strands. It is a well documented phenomena that diffusion of copper and tin forms a copper-tin intermetallic that eventually consumes all the free tin on the conductor surface. This is also characterized by the loss of solderability of tin plated copper wire after time. It is conceivable that this change in composition of the surface from pure tin to intermetallic tin effectively removes the conditions necessary for whiskers to form.

PREPARED BY SAE SUBCOMMITTEE AE-8D, WIRE AND CABLE
OF COMMITTEE AE-8, AEROSPACE ELECTRICAL/ELECTRONIC DISTRIBUTION SYSTEMS

APPENDIX A

A.1 SCANNING ELECTRON MICROSCOPE IMAGES OF TIN WHISKERS:

The SEM images were reproduced with the permission of Lockheed Martin Astronautics, Denver, CO (see Figure A1).