Tin Whiskers Remain A Concern

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The elimination of lead in electronic equipment due to governmental regulations (European Union End of Life Vehicle Directive and European Union Restriction of Hazardous Substances Directive) has increased the risk of electrical shorting due to the formation of tin whiskers in electronic products. Tin whiskers are hair-like tin structures that grow sporadically on surfaces coated with tin. Whiskers are often difficult to detect due to their small cross-sectional dimensions, typically ranging between 1 and 5 micrometers, which may be 10 to 50 times finer than a human hair. While their cross-sectional dimensions are small, whiskers can grow to lengths greater than a millimeter. Such lengths are sufficient to bridge the distance between tightly spaced electronic parts. Despite the difficulty of detecting them, tin whiskers have been identified as a cause of failure in medical, aerospace, power, and automotive equipment. In particular, control systems, such those found in automotive applications, have been found to have significant tin whisker failure risks [1]. Further, coupled with the increased use of tin as a surface finish in electronics, the continued trend towards higher interconnect densities and compact electronics is expected to increase the failure risk presented by the formation of tin whiskers.

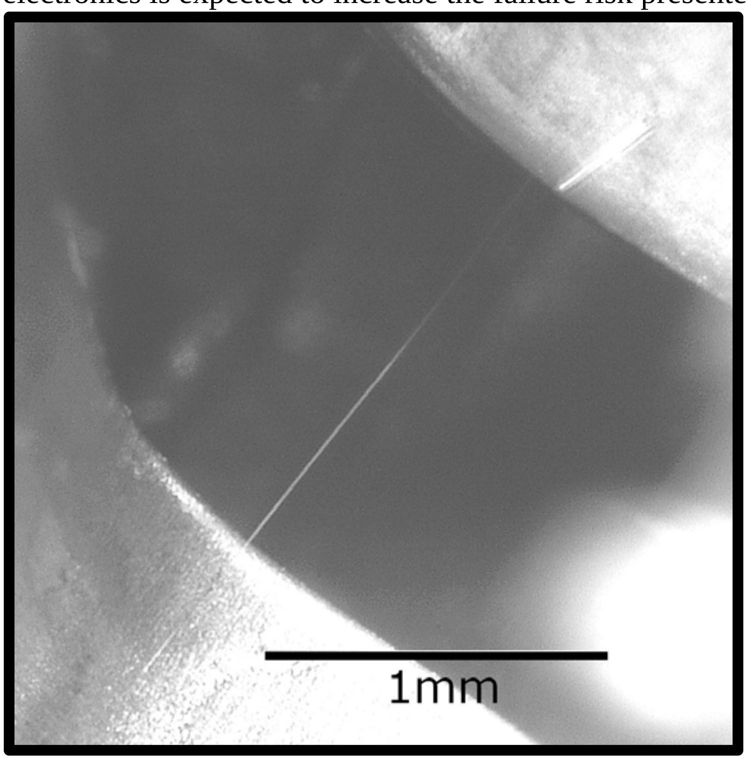

Figure 1: Tin whisker bridging adjacent terminals on feedthrough tin-plated connector of an accelerator pedal position sensor that led to intermittent resistance between the two terminals [2].

With the use of tin-based solder materials for creating electrical connections, tin is used extensively in electronics. With regards to electronics, advantages of tin include low cost and excellent engineering properties, including high corrosion resistance and solderablity. With the elimination of lead, tin has become a common surface finish for plated package terminations used on electronic devices. Research dating back to the 1950's has demonstrated that the addition of lead to tin significantly mitigates the occurrence of tin whiskers. While quality control tests for tin whiskers have been established, no tests are available to assess the long-term elimination of the tin whisker failure risk [3]. Tin whiskers are electrically conductive and can carry, depending on their cross-sectional area, sustained electrical current up to 10 mA without fusing. At higher current levels, the tin will melt and break the electrical circuit. In the presence of a high in-rush current (>1000A/s) and with voltages at or above 12 V, tin whiskers can strike a metal vapor arc operating at temperatures in excess of 1000°C. Once initiated, a metal vapor arc can be sustained with continued voltage, current, and material [4]. For electronics, the formation of an unintended electrical short can cause a product to malfunction. For control systems, such as an automotive engine control or automotive stability control system, a tin whisker–induced malfunction can create unsafe operating conditions.

While extensive research has been conducted into whisker formation, methods to effectively assess the propensity of tin-finished surfaces to form whiskers in long-term service applications remain elusive. Research indicates that tin whiskers form in response to stress imbalance in the tin film. Vianco et al. have recently reported that tin whiskers form through dynamic recrystallization when the strain within the tin film is greater than a critical value [5]. Even as our understanding of the processes promoting whisker formation increases, the challenge of finding effective test methods to predict long-term tin whisker growth remains. This challenge stems from a variety of factors, both external and internal, which can change the stress state in the tin film, giving rise to whisker growth. For instances, contact forces in connector applications have been shown to give rise to rapid whisker growth. In field applications, environmental factors such as corrosion and surface oxidation can promote whisker formation. Further, temperature cycling of tin-plated systems can give rise to stress states within the tin film due to the mismatch of temperature expansions rates between the tin and substrate to which the tin is applied. Internally, the formation of intermetallic compounds between the tin and the substrate material to which it is plated can also overtime create a stress state favorable for whisker formation. Further, grain structure and plating thickness have been demonstrated to play a role in whisker growth.

For part manufacturers, the use of matte tin plating, high temperature annealing, and the application of a nickel underlayer have become common approaches for mitigating tin whisker formation. With regard to matte tin plating, this specification typically denotes a dull surface appearance that arises from larger (approximately 1 to 5 micrometer) surface grains. As whiskers form from new grains at or near the free surface of the tin layer, the larger grain size means fewer locations for tin whiskers to form compared to bright tin with finer (less than 1 micrometer) surface grains for the same surface area. However, matte tin should not be interpreted as being whisker-free. With regard to high temperature annealing, this process provides relief from whisker formation by promoting a uniform and enlarged interfacial intermetallic layer between the tin film and the substrate and reducing stress in the tin film. However, research indicates that the stress state continues to evolve, delaying, but not eliminating, whisker growth. With regard to a nickel underlayer, the porosity of the nickel layer may still allow for an evolving stress state favorable to whisker formation. Further, neither annealing nor a nickel underlayer prevents external stress sources from promoting whisker formation. As a result, equipment manufacturers should not consider part manufacturer mitigations to be sufficiently effective, particularly in electronic systems where failure can result in significant losses. However, advancements in tin plating and treatment of substrates prior to plating continue to show promise as further reducing whisker growth.

To assist equipment manufacturers of high performance systems with mitigating the potential risks associated with tin whisker formation, the GEIA-STD-0005-2:2012, **Standard for Mitigating the Effects of Tin Whiskers in Aerospace and High Performance Electronic Systems**, has been developed. For mitigation strategies, this document identifies the use of hard non-conductive barriers, encapsulation, and conformal coating. The document also identifies the separation of tin-finished surfaces as a strategy as well as the use of tin-lead solder–covered tin surfaces with solder occurring in the reflow and wave soldering process. For the reasons previously discussed, GEIA-STD-0005-2:2012 does not consider part-manufacturer-applied tin whisker mitigation methods to be sufficiently effective to stand alone. However, the document does indicate that tin-finished parts that have been subjected to part-manufacturer-applied tin whisker growth mitigation methods are preferred over tin-finished parts with non-defined tin whisker growth mitigation methods. In addition to mitigation strategies, the document identifies program control levels for handling tin-finished materials in electronic products. The control levels are created to allow organizations to consider the consequences of failure and the use of appropriate tin whisker mitigation strategies, with the highest level, Level 3, calling for the complete prohibition of lead-free tin.

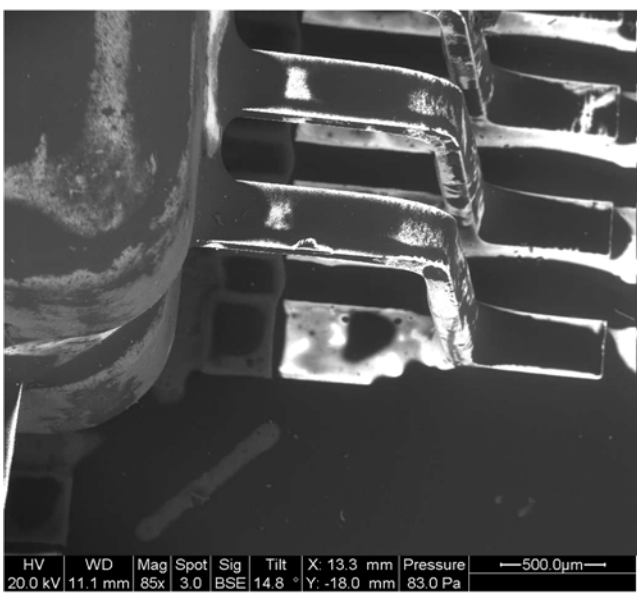

Figure 2: Poor coverage of acrylic conformal coating (bright areas on lead wire represent little to no coating). Courtesy of CALCE/University of Maryland.

While a complete ban on the use of tin, particularly for safety-critical applications, would be preferred, the cost and potential risks of eliminating tin-finished parts may be prohibitive. Further, manufacturer mitigation methods, such as encapsulation, conformal coating, and fault tolerant circuit analysis, may be sufficient for safe operation. However, any mitigation strategy should be assessed for its effectiveness prior to implementation and should be audited to ensure that the proscribed mitigation method meets the defined requirements. For instance, the coverage of tin-finished surfaces provided by current conformal coating processes may be insufficient to prevent whisker-induced failure [9]. Figure 2 depicts an acrylic conformal coating that does not completely encapsulate the lead wires of a quad-flat package. To address this issue, the IPC 5-22ARR J-STD-001/Conformal Coating Material and Application Industry Assessment Task Group has conducted a round-robin study to characterize the coverage provided by commonly used conformal coating materials with existing application processes. The study includes 26 different material combinations, and the results are expected to be used for updating measurement and evaluation standards.

In designing safety and control electronics, the risks of using tin must be carefully assessed. To this end, methods for assessing failure risk have been developed [6]. For example, the risk of a tin whisker–induced short can be estimated by identifying tin-finished surfaces, distances from the identified surface to surfaces at a different electrical potential, and knowledge of whisker growth statistics. Tin whisker lengths can vary dramatically; however, they have been found to follow a lognormal distribution [7]. The density of whisker growth can also vary dramatically. For assessment, software [8] using measured whisker growth statistics has been published in the open literature. With these methods, a probability of failure can be assigned to the tin whisker failures, and the effect of tin whisker failure mitigation strategies that rely on separation and coating coverage can be assessed.

Thus far, the ban on the use of lead in most electronics has not resulted in public concern about tin whiskers. This result is likely is due in large part to the development of industry standards, research by industry and academic groups, engineering functions within organizations to address this reliability threat, as well as closed discussion related to product failures, in general. However, this does not mean the risk to electronics posed by tin whiskers has been eliminated. Research into whisker mitigation strategies and the tests for assessing whisker risk should continue to be supported. As long as the electronic industry continues to use tin, tin whisker risk must be addressed. Tin whiskers are a known problem, and forgetting to account for their potential failure risk will cost organizations dearly.

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