IEC TR 60068-3-82

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TECHNICAL REPORT

colour
inside

Environmental testing –
Part 3-82: Supporting documentation and guidance – Confirmation of the performance of whisker test method

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ENVIRONMENTAL TESTING –

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IEC TR 60068-3-82 has been prepared by IEC technical committee 91: Electronics assembly technology. It is a Technical Report.

The text of this Technical Report is based on the following documents:

Draft	Report on voting
91/1957/DTR	91/1967/RVDTR

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 60068 series, published under the general title *Environmental testing*, can be found on the IEC website.

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ENVIRONMENTAL TESTING –

Part 3-82: Supporting documentation and guidance – Confirmation of the performance of whisker test method

1 Scope

This part of IEC 60068, which is a Technical Report, provides technical background information on the whisker test methods from IEC 60068-2-82 and guidance on test selection.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60068-2-82:2019, *Environmental testing – Part 2-82: Tests – Test XW1: Whisker test methods for components and parts used in electronic assemblies*

IEC 61190-1-1, *Attachment materials for electronic assembly – Part 1-1: Requirements for soldering fluxes for high-quality interconnections in electronics assembly*

IEC 62483, *Environmental acceptance requirements for tin whisker susceptibility of tin and tin alloy surface finishes on semiconductor devices*

ISO 9454-2:2020, *Soft soldering fluxes – Classification and requirements – Part 2: Performance requirements*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1
whisker

metallic protrusion that grows spontaneously during storage or use

Note 1 to entry: Whiskers typically do not require any electrical field for their growth and are not to be confused with products of electrochemical migration. Signs of whiskers include:

- striations in growth direction;
- typically no branching;
- typically constant diameters.

Exceptions are known but are rare and can require detailed investigation.

For the purposes of this document, whiskers are considered if:

- they have an aspect ratio (length/width) greater than 2;
- they have a length of 10 µm or more.

Note 2 to entry: For the purposes of this document, whiskers have the following characteristics:

- they can be kinked, bent, or twisted; they usually have a uniform cross-sectional shape;
- they may have rings around the circumference of the column.

Note 3 to entry: Whiskers are not to be confused with dendrites, which are fern-like growths on the surface of a material, which can be formed as a result of electro(chemical)-migration of an ionic species or produced during solidification.

Note 4 to entry: Whiskers are not to be confused with slivers as generated by mechanical metal processing. Whiskers are not to be confused with tubular SnO structures, which may develop under damp-heat test conditions. These structures are hollow and are typically lacking striations occurring on Sn whiskers.

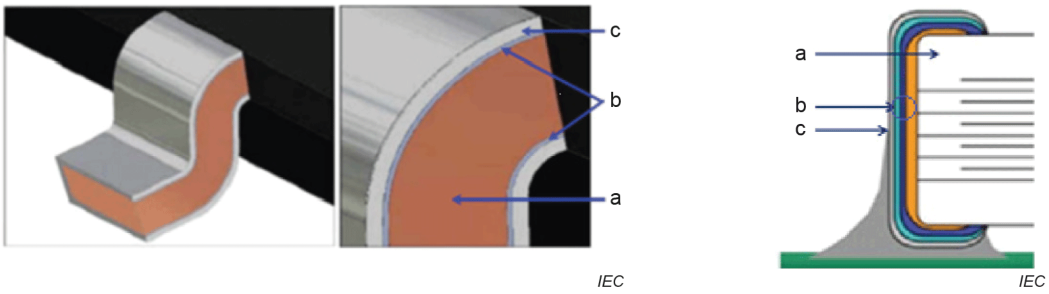
[SOURCE: IEC 60068-2-82:2019, 3.1]

3.2
termination

solderable element of a component consisting of the following elements:

- base material;
- underlayer (or underlayer system, if more than one underlayer is present), if any, located under the final plating;
- final Sn or Sn alloy finish.

See Figure 1.



a) Gull wing termination **b) Chip termination**

Key

a base material;

b underlayer (or underlayer system, if more than one underlayer is present), if any, located under the final plating;

c final tin or tin alloy finish.

Figure 1 – Cross-sectional views of component termination surface finishes

3.3
∆CTE
CTE mismatch
coefficient of thermal expansion mismatch

coefficient calculated by taking the absolute after subtracting the CTE of the base material from the CTE of the surface finish layer:

$$\Delta CTE = | C_f - C_b |$$

where

C_f is the coefficient of thermal expansion of the surface finish layer;

C_b is the coefficient of thermal expansion of the base material

Note 1 to entry: No underlayer system (e.g. Ni, Cu) has any influence on the CTE mismatch.

3.4
mechanical load
load related to the intended mounting/assembly condition of a particular specimen (e.g. press-fit application: stress exerted by the plated through-hole on the press-fit pin), or as a transitional load related to a mechanical process in a trim and form operation to adapt the shape of the specimen to the intended use condition (e.g. bending of a connector pin)

Note 1 to entry: Mechanical load in the context of these test methods is not related to external factors, e.g. thermo-mechanical loads arising from the mismatch of the coefficients of thermal expansion of the various constituents of a particular test specimen upon temperature change.

3.5
classification

3.5.1 Level A
<general electronics products> consumer products, some computer and computer peripherals, and hardware suitable for applications where the major requirement is function of the completed assembly

3.5.2 Level B
<dedicated service electronics products> communications equipment, sophisticated business machines, and instruments where high performance and extended life is required, and for which uninterrupted service is desired but not mandatory

Note 1 to entry: Typically, the end-use environment would not cause failures.

3.5.3 Level C
<high performance electronics products> equipment where continued performance or performance-on-demand is mandatory; equipment downtime cannot be tolerated, end-use environment can be uncommonly harsh, and the equipment shall function when required, such as life support systems and other critical systems

Note 1 to entry: The classification of levels A, B and C is based on IEC 61191-1 [1][1].

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[1] Numbers in square brackets refer to the Bibliography.

4 Whisker growth mechanisms

4.1 General

4.1.1 Sn whiskers

4.1.1.1 Features of Sn whiskers

Sn whiskers are metallic protrusions, which can grow spontaneously during storage or use from Sn or Sn alloys. For information on whisker characteristics and their various forms, refer to 3.1 and in IEC 60068-2-82:2019. They can grow up to millimeters, even centimeters long, which is long enough to branch over to a neighboring electrical contact. Being metal growths, this has often led to short circuit failures and system malfunctions. They are not produced during plating (e.g. electrochemical effects during galvanic deposition or dendrite growth), but instead grow afterwards, during storage or use.

4.1.1.2 Sn whiskers growth rate and mechanism

Depending on the conditions, Sn whisker have been observed growing within hours after deposition or first found creating a system failure after 10 years in service, which is why they are often referred to as spontaneous growths. Sn whiskers were already reported as early as 1951 by Compton [2] including the investigation of other metals. Over the last 70 years many contradictory findings have been reported in the literature as well as several whisker theories formed, but still no universal model exists today [3]. However, it is commonly agreed that compressive stress in the Sn film is the fundamental driving force behind whisker growth [4], [5], making whisker growth a stress relief mechanism for the surface finish. Compressive stress sources within the film or applied on the film lead to stress gradients within the deposit, generating atomic migration, which promotes the transportation of atoms to a whisker nucleation site. Migration takes place over long-range diffusion [6] throughout the film, predominately along the grain boundaries, however, also along the surface and interface. As atoms continue to build-up at a nucleation site, a whisker, in return, can grow out of the film, reducing the stress state. In general, all factors that create stress gradients within the film or promote diffusion increase the whiskering tendency.

4.1.1.3 The role of this document on Sn whiskers

Although Sn is not the only metal known to whisker, it is the surface finish of focus for this technical report, since Sn whiskers have been the culprit for many system malfunctions throughout the past and Sn is commonly used in industry due to its beneficial characteristics. Its low melting temperature (231,9 °C) makes it very attractive for soldering applications and its contact resistance, corrosion resistance and low cost has made it, in general, one of the more favorable platings of choice for electronic finishes. The incorporation of lead (Pb) as an alloying element in Sn is the most universally successful prevention method against Sn whisker induced failures. However, due to mandated regulations restricting the use of Pb in electronics [7], [8], the risk of electrical shorts due to Sn whisker growth remains. Still to this day whisker growth characteristics, such as propensity, length and rate are unpredictable, and vary from plating to plating as well as with substrate material. Therefore, it is important to define a set of tests as guidelines to be able to compare and assess the whiskering propensity of different surface finish/substrate combinations in a structured manner. To effectively do this one must first have an understanding for the basic Sn whisker growth mechanisms.

4.1.2 Sn surface finishes

4.1.2.1 General

For all practical industry purposes, Sn is plated through galvanic deposition or hot-dip tinning. Due to the ease using these plating options for Sn and its low material cost, it generally does not deem appropriate to use other more expensive plating techniques such as chemical or physical vapor deposition. Sn alloys are also used depending on application. For information regarding Sn alloys, see also [9].

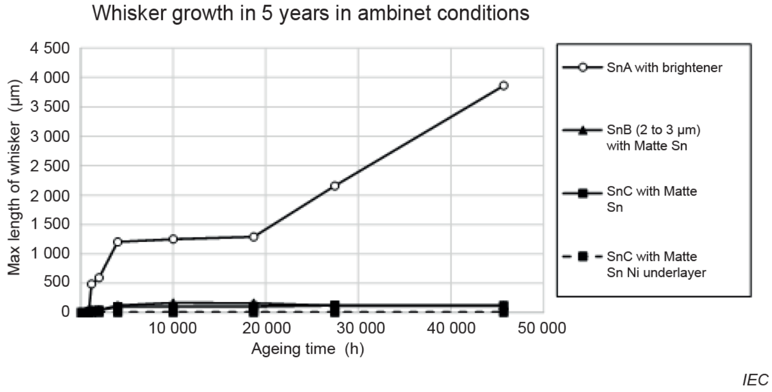
4.1.2.2 Galvanic Sn plating

Galvanic Sn plating is often the method of choice since it offers a larger spectrum of plating possibilities, especially selective plating for other surface finish options on the mating side. The plating can be applied for different geometries as individual piece parts through barrel or rack plating, or in a strip format on a plating line. The electrolytes and therefore, their finishes are mainly divided into two different types: bright or matte. Other than just appearance, the main differences between the two deposit types are smaller grain size and higher carbon (C) content for the bright Sn, typically < 1 µm and > 1 000 ppm C respectively, whereas matte Sn generally has an average grain size of a few microns and < 150 ppm C in the finish, as stated in Table 1 of IEC 60068-2-82:2019. Though bright Sn has an excellent cosmetic appearance, the higher amount of co-deposited C, as a result of the organic brighteners used in the electrolyte, end up creating a higher internal stress in the Sn finish. Carbon in a Sn deposit can be measured using different methods, such as Glow Discharge Optical Emission Spectroscopy [11] or Auger-electron spectroscopy in combination with sputter-depth profiling.

Furthermore, the smaller grain sizes in bright Sn do not help against whisker growth. Smaller grains in general lead to more grains on the surface and the probability for more low index grains, which make for great whisker nucleation sites. Smaller grains also mean additional grain boundaries, which promotes diffusion and easier acccess to a whisker root. For example, a layer with an average grain size of 1 µm has a 1 000x higher diffusion rate than a layer with approximately 10 µm grains. An example of grain size and whisker growth from a bright Sn ("SnA" sulfuric acid base) vs. matte Sn finish ("SnC" MSA base) is given in Figure 2. Here the maximum whisker lengths are compared after 5 years of incubation at room temperature / relative humidity (RT/RH) conditions, where the impact on whisker growth from a bright Sn finish is clear.

Bright Sn **Matte Sn**

a) grain size/orientation



b) whisker growth between a bright Sn deposit and a matte Sn both approximately 2 µm to 3 µm thick

Figure 2 – Grain size and whisker growth on bright Sn and matte Sn finishes [10]

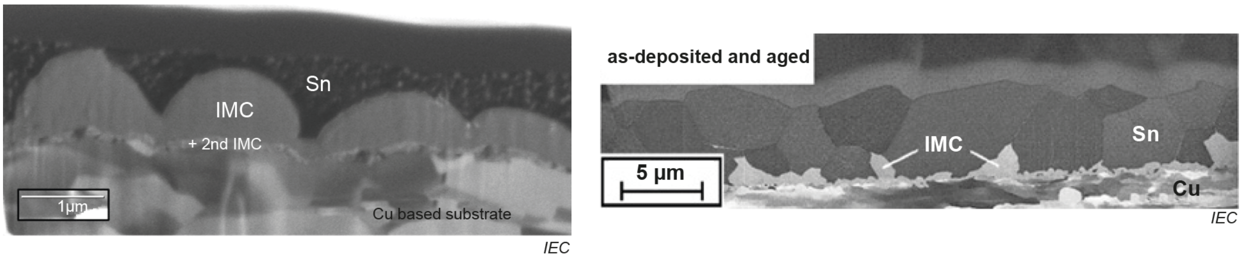
Consequently, matte Sn is usually used for electronic finishes to reduce the internal film stresses and thus, the whisker risk. All galvanic surface finishes discussed throughout the remainder of this chapter will therefore, be based on matte Sn deposits.

There exist numerous different matte Sn electrolytes available on the market today with the majority of them using a methanesulfonic acid (MSA) base. In order to achieve a homogeneous layer thickness throughout the surface and to reduce the redox reaction, different additive systems and an antioxidant are utilized. The design of the electrolytes can be optimized for certain plating "purposes" such as complicated geometry, high plating speed, low plating speed, appearance, plating distribution, etc. To achieve different demanding targets the concentration of the electrolyte components (e.g.: Sn, MSA, and additives) as well as the plating parameters can also be adjusted (e.g.: temperature, current density, and agitation). The whisker propensity for galvanic Sn platings strongly depend on the electrolyte chemistry, process parameters and plating method. Therefore, every component-geometry, plating method, electrolyte and set-up of plating parameters requires a specific assessment and qualification.

4.1.2.3 Hot-dip tinning

Due to the low melting point of Sn (231,9 °C), it can be hot-dip plated. Hot-dip plating is the immersion of the base material into the molten Sn after the surface has been first appropriately prepared (e.g.: cleaning, fluxing), which means that selective plating is not an option for tinning. The molten bath can be easily alloyed, often with Ag and/or Cu and the temperature typically varies between 250 °C and 290 °C depending on alloying elements and process set-up. It is broadly used for mechanical components as pre-plated material, but also for various electronic components. The resultant surface tends to be smooth and shiny.

A significant difference between a Sn finish which is hot-dip plated compared to galvanic plated, especially when regarding whisker growth, is the intermetallic compound (IMC) formation between Sn and Cu based substrate materials, due to the high temperatures needed for tinning, see Figure 3. IMC formation is automatically present in hot-dip Sn deposits, in the as plated state, but not in galvanic plated finishes, which are plated at much lower temperatures typically between approximately 20 °C to 40 °C depending on the electrolyte. The various IMCs between Sn and Cu at different temperatures and their effects on whisker growth are explained below, in 4.2.1.



a) **a hot-dip plated Sn finish**

b) **an electroplated Sn finish**

Figure 3 – Example comparison of IMC formation between a Sn surface deposit and Cu based substrate

4.2 Basic Sn whisker mechanisms

4.2.1 General remarks

As stated in 4.1.1, whiskers grow as a result of compressive stress gradients within the film, which promote Sn atom migration. In the past, the focus tended to lie mainly on the macroscopic stress of the Sn finish. However, macroscopic stress is not the only relevant driving force for whisker formation. In fact, it is the microscopic compressive stress sources, creating microscopic stress gradients throughout the film, which play a significant role in whisker growth [12]. If these factors are present within a certain range, whisker growth can be expected.