

IPC/PERM-2901

2018 - February

Pb-free Design & Assembly Implementation Guide

An international standard developed by IPC

Association Connecting Electronics Industries



Copyright Association Connecting Electronics Industries
Provided by IHS Markit under license with IPC
No reproduction or networking permitted without license from IHS
Full document details: [IPC PERM-2901 2018](#)



Licensee=/, User=,
Not for Resale,

The Principles of Standardization

In May 1995 the IPC's Technical Activities Executive Committee (TAEC) adopted Principles of Standardization as a guiding principle of IPC's standardization efforts.

Standards Should:

- Show relationship to Design for Manufacturability (DFM) and Design for the Environment (DFE)
- Minimize time to market
- Contain simple (simplified) language
- Just include spec information
- Focus on end product performance
- Include a feedback system on use and problems for future improvement

Standards Should Not:

- Inhibit innovation
- Increase time-to-market
- Keep people out
- Increase cycle time
- Tell you how to make something
- Contain anything that cannot be defended with data

Notice

IPC Standards and Publications are designed to serve the public interest through eliminating misunderstandings between manufacturers and purchasers, facilitating interchangeability and improvement of products, and assisting the purchaser in selecting and obtaining with minimum delay the proper product for his particular need. Existence of such Standards and Publications shall not in any respect preclude any member or nonmember of IPC from manufacturing or selling products not conforming to such Standards and Publication, nor shall the existence of such Standards and Publications preclude their voluntary use by those other than IPC members, whether the standard is to be used either domestically or internationally.

Recommended Standards and Publications are adopted by IPC without regard to whether their adoption may involve patents on articles, materials, or processes. By such action, IPC does not assume any liability to any patent owner, nor do they assume any obligation whatever to parties adopting the Recommended Standard or Publication. Users are also wholly responsible for protecting themselves against all claims of liabilities for patent infringement.

IPC Position Statement on Specification Revision Change

It is the position of IPC's Technical Activities Executive Committee that the use and implementation of IPC publications is voluntary and is part of a relationship entered into by customer and supplier. When an IPC publication is updated and a new revision is published, it is the opinion of the TAEC that the use of the new revision as part of an existing relationship is not automatic unless required by the contract. The TAEC recommends the use of the latest revision. Adopted October 6, 1998

Why is there a charge for this document?

Your purchase of this document contributes to the ongoing development of new and updated industry standards and publications. Standards allow manufacturers, customers, and suppliers to understand one another better. Standards allow manufacturers greater efficiencies when they can set up their processes to meet industry standards, allowing them to offer their customers lower costs.

IPC spends hundreds of thousands of dollars annually to support IPC's volunteers in the standards and publications development process. There are many rounds of drafts sent out for review and the committees spend hundreds of hours in review and development. IPC's staff attends and participates in committee activities, typesets and circulates document drafts, and follows all necessary procedures to qualify for ANSI approval.

IPC's membership dues have been kept low to allow as many companies as possible to participate. Therefore, the standards and publications revenue is necessary to complement dues revenue. The price schedule offers a 50% discount to IPC members. If your company buys IPC standards and publications, why not take advantage of this and the many other benefits of IPC membership as well? For more information on membership in IPC, please visit www.ipc.org or call 847/597-2809.

Thank you for your continued support.

©Copyright 2018. IPC, Bannockburn, Illinois. All rights reserved under both international and Pan-American copyright conventions. Any copying, scanning or other reproduction of these materials without the prior written consent of the copyright holder is strictly prohibited and constitutes infringement under the Copyright Law of the United States.



IPC/PERM-2901

Pb-free Design & Assembly Implementation Guide

Developed by the Research Coordination and Technical Guidance Task
Group (8-81D) of the PERM Council (8-80) of IPC

Users of this publication are encouraged to participate in the
development of future revisions.

Contact:

IPC
3000 Lakeside Drive, Suite 105N
Bannockburn, Illinois
60015-1249
Tel 847 615.7100
Fax 847 615.7105



Table of Contents

1 INTRODUCTION	1	5 DESIGN PROCESS FLOW	17
1.1 The European Union's Restriction of Hazardous Substances (RoHS) legislation	1	5.1 The Proposal Stage	18
1.2 Scope	1	5.2 The Requirements Stage	18
2 APPLICABLE DOCUMENTS	2	5.3 The Concept (Development) Stage	18
2.1 IPC	2	5.4 The Preliminary Design Stage	19
2.2 Joint Industry Standards	2	5.5 The Detailed Design Stage	20
2.3 Other Publications	2	5.5.1 Risk Management	20
2.3.1 SAE International	2	5.6 Documentation	22
2.3.2 International Electrotechnical Commission	3	5.7 Manufacturing (Production Readiness)	22
3 TECHNICAL INFORMATION	3	5.8 Validation & Qualification	22
3.1 Pb-free Solders and Solder Joints	3	5.9 Product Support	22
3.1.1 Pb-free Solders (Alloy Characteristics)	3	6 DEFINITIONS AND TERMS	23
3.1.3 Pb-free Solder Alloys – Design/Implementation Summary and Guidance	7	7 ACRONYMS	23
3.2 Tin Whiskers	7	8 REFERENCES	25
3.2.1 Tin Whiskers Design/Implementation Summary and Guidance	10	8.1 Cited References	25
3.3 Printed Board Defects	10	8.2 Normative References	27
3.3.1 Plating Defects	10	APPENDIX A EXAMPLE OF A PB-FREE TEST PLAN AND TEST PROCESS FLOW	28
3.3.2 Conductive Filament Formation (CFF)	11		
3.3.3 Printed Board Defects Design/Implementation Summary and Guidance	11	Tables	
3.4 Product Qualification	11	Table 3-1 Melting Points of SnPb and some Pb-free Alloys	5
3.4.1 Product Qualification Design/Implementation Summary and Guidance	12	Table 5-1 Notional Considerations in Concept Development with Respect to Pb-free Technology	19
3.5 Manufacturing Processes	12	Table 5-2 Preliminary Design Risks/Mitigations	20
3.5.1 Soldering	12	Table 5-3 Notional Listing of Risk Topic Areas	21
3.5.2 Component Storage	12	Table A.1 Test Plan Example	28
3.5.3 Cleaning	13		
3.5.4 Process-Induced Stresses	13	Figures	
3.5.5 Manufacturing Processes Design/Implementation Summary and Guidance	13	Figure 3-1 a) Shrinkage voids in a Pb-free BGA Solder Joint, b) Large Ag3SnSilver/Tin IMC Structures in a Mixed Metallurgy Solder Joint	4
3.6 Supply Chain Control	13	Figure 3-2 a) Tin/lead Solder Joint Microstructure, b) Pb-free Solder Joint Microstructure	5
3.6.1 Supplier Pb-free Flow-downs	14	Figure 3-3 a) Appearance of PbSn Solder Joints, b) SAC (Pb-free) Solder Joints	6
3.6.2 Supply Chain Control Design/Implementation Summary and Guidance	14	Figure 3-4 A SAC 305 solder joint with Silver dendrites	6
3.7 Obsolescence Management	14	Figure 3-5 Detail of a SAC 305 soldered joint growing Silver dendrites	6
3.7.1 Obsolescence Management Design/Implementation Summary and Guidance	15	Figure 3-6 A Tin whisker (right) compared to a human hair (left)	7
3.8 COTS Assemblies Selection and Use	15	Figure 3-7 a) Card guide growing whiskers, b) Whiskers, from card guide, contacting an electrical component	8
3.8.1 COTS Design/Implementation Summary and Guidance	15	Figure 3-8 Examples of Tin Whiskers	8
3.9 Configuration Management	16	Figure 3-9 Examples of Loose Tin Whiskers	9
3.9.1 Configuration Management Design/Implementation Summary and Guidance	16	Figure 3-10 Conductive Filament Formation Between Closely-Spaced PTHs	11
4 IMPLEMENTATION	16	Figure 3-11 The global military and aerospace supply chain	13
4.1 Product Design Risk Management (PDRM)	16	Figure 5-1 A Typical Product Development Cycle in a Design Process Flow Format	17
4.1.1 Pb-free Interconnections	16		
4.1.2 Tin Whiskers	16		
4.2 Customer Risk Management (CRM)	17		

Acknowledgment

Any document involving a complex technology draws material from a vast number of sources across many continents. While the principal members of the Research Coordination and Technical Guidance Task Group (8-81D) of the PERM Council (8-80) are shown below, it is not possible to include all of those who assisted in the evolution of this standard. To each of them, the members of the IPC extend their gratitude.

PERM Council

Executive Chair
David A. Pinsky
Raytheon Missile Systems

Vice-Chair (Government)
Paul S. Zutter
U.S. Army Aviation & Missile Command

Vice-Chair (Industry)
Ben Gumpert
Lockheed Martin Missile & Fire Control

Research Coordination and Technical Guidance Task Group

Chair
Anthony J. Rafanelli
Raytheon Missile Systems

Technical Liaison of the IPC Board of Directors

Bob Neves
Microtek (Changzhou) Laboratoris

Research Coordination and Technical Guidance Task Group

Martin Anselm, Rochester Institute of Technology
Mordechai Ben-Porat, Israel Defence Forces
James Blanche, NASA Marshall Space Flight Center
Jelena Bradic, Honeywell Aerospace
David Burdick, Boeing - Integrated Defense Systems
Ilie Cacipu, Bombardier
Chantal Cerret Gil, Airbus Helicopters
Peter Collier, MTC Operations Limited
Lloyd Condra, DfR Solutions
Richard Coyle, Nokia
Steven Davidson, Northrop Grumman Corporation
Scott Fiske, General Dynamics Land Systems
Dennis Fritz, MacDermid Enthone Electronics Solutions
Reza Ghaffarian, Jet Propulsion Laboratory
Graham Green, Rolls-Royce PLC
Ben Gumpert, Lockheed Martin Missile & Fire Control
Carol Handwerker, Purdue University
Joel Heebink, Honeywell International

David Hillman, Rockwell Collins
William Hoskins, NSWC Crane
Keith Howell, Nihon Superior
David Humphrey, newAspen Consulting
Joseph Juarez, Arizona State University
Milea Kammer, Honeywell Aerospace
Jeff Kennedy, Celestica
Jay Kokas, UTC Aerospace Systems
Frank-Peter Kriesch, Diehl Aerospace GmbH
Gary Latta, SAIC
David Locker, U.S. Army Aviation & Missile Command
Stephan Meschter, BAE Systems
Steven Middleton, Foresite, Inc.
Michael Miller, NSWC Crane
Terry Munson, Foresite, Inc.
Clifton Odom, General Atomics Aeronautical
Andre Oliveira, Embraer
David Penic, General Atomics Aeronautical
Jason Pham, General Atomics Aeronautical

David Pinsky, Raytheon Missile Systems
Carter Ralph, Southern Research Institute
David Redman, Aerospace Vehicle Systems Institute
Jeff Rowe, JR Consulting
Alexandre Santos, Embraer S.A.
Polina Snugovsky, Celestica
Ivan Straznicki, Curtiss-Wright Defense Solutions
Keith Sweatman, Nihon Superior Co., Ltd.
Robert Tipton, Mr. Robert L. Tipton
Anduin Touw, The Boeing Company
Mark Van Solkema, GE Aviation
John Williams, UTC Aerospace Systems
Barry Wood, Lockheed Martin Missiles & Fire Control
Linda Woody, LWC Consulting
Joe Zaccari, Zaccordix LLC
Paul Zutter, U.S. Army Aviation & Missile Command

This Page Intentionally Left Blank

IPC/PERM-2901

Pb-Free Design & Assembly Implementation Guide

1 INTRODUCTION

1.1 The European Union's Restriction of Hazardous Substances (RoHS) legislation [1], which went into effect July 2006, has had a profound impact on the electronics industry. One of the restricted substances, lead (Pb), is commonly used in alloys with tin for component finishes, printed board finishes and solders. While a great deal of historical knowledge exists relating to tin-lead (Sn-Pb) based electronic systems and products, the rapid transition of the electronics industries towards Pb-free (hereon denoted as Pb-free) has altered that experience base. Unless otherwise indicated, SnPb in this document refers to eutectic 63Sn37Pb solder systems.

Pb-free materials directly affect product performance, reliability and service life in many ways. There have been numerous, documented failures of electronics due to Pb-free materials in both commercial and Aerospace, Defense and High Performance (ADHP) products. The failure mechanisms for Pb-free materials are significantly different than SnPb based materials [2, 3]. Some failure mechanisms have not been experienced before. The ADHP industry has tried to avoid the use of Pb-free materials to the extent possible but the cost for doing so is increasing for product design, materials and manufacturing. It is currently cost prohibitive to require SnPb for all Commercial Off the Shelf (COTS) parts and assemblies used in ADHP products. Eventually it will become more affordable to incorporate Pb-free technology as the knowledge base improves. When Pb-free solders are used for ADHP electronics hardware, controls should be implemented in accordance with IPC J-STD-001 and its related Space Applications Electronic Hardware Addendum.

ADHP systems and products have a broad range of performance requirements, operating environments and service life. The guidelines presented in this document may not provide solutions for all products. Currently, not all Pb-free material risks have solutions that reduce the risk to acceptable levels. On-going research targeted for the ADHP industry and experience with Pb-free materials in commercial and industrial products continue to improve the knowledge base (see IPC-WP-012).

The significant differences between SnPb and Pb-free (many alloy types) solders has warranted the need for an industry guide to aid the electronic hardware design engineer in understanding and appreciating mechanical and physical behaviors and providing avenues for risk mitigation (see IPC-WP-014).

This guide is meant to be used by design engineers but may also be used by quality assurance, materials, components, and manufacturing engineers who contribute, in any way, toward the ultimate production of printed board assemblies and next level assemblies (e.g., power converters, controllers, or any other "box" containing multiple printed board assemblies).

NOTE: In accordance with IPC-T-50, the term "printed board assembly" will be used to denote a circuit card assembly.

Where applicable, a bulletized list of design suggestions is provided to aid the designer in identifying actions that can be taken to minimize risk.

1.2 SCOPE

1.2.1 The intent of this design guide is to assist design engineers in developing electronics that are completely Pb-free and meet the demanding requirements of ADHP systems and products. (For the present time, wiring/cabling is not included in the scope.) It is assumed that the design engineers using this guide are competent and experienced with SnPb based electronics but may not be fully conversant with the detailed vagaries of Pb-free materials, components or manufacturing processes or how these impact equipment reliability and longevity.

- a. This guide has been generated to address those 'delta' differences between SnPb and Pb-free solder technologies. Information/guidance that pertain to both technologies are not necessarily included. Any redundant information may be the result of completion or context.
- b. The "delta" differences are generally categorized as described in GEIA-HB-0005-3 as follows:
 - i) Typically poorer wetting ability
 - ii) Differences in appearance and inspection criteria
 - iii) Typically higher melting temperature
 - iv) Potential tighter process window for repair/rework

- v) Increased potential of tin whiskers
- vi) Solder joint life time under mechanical shock or vibration or under thermal cycling
- vii) Aging effects on strength properties

1.2.2 This design guide serves to address the following key areas affecting performance, reliability and service life and offers guidelines on dealing with the risks:

- Pb-free Solders and Solder Joints
- Tin Whiskers
- Printed Board Defects
- Product Qualification
- Manufacturing Processes
- Supply Chain Control
- Obsolescence Management
- COTS Assembly, Selection and Use
- Configuration Management

1.2.3 Presently, there are no industry-accepted reliability models for Pb-free interconnections. Until validated data and modelling methods are developed, projects considering Pb-free ADHP products and systems need to adopt additional steps, many of which will be based on specific applications of the product/system itself (see IPC-WP-014).

Background information will be provided for each of the areas to give the designer a basic understanding of the underlying issues. References (including GEIA resources) are included for those designers looking for more in-depth understanding (see 2.3.1). The design guide includes recommendations for addressing the limitations and risks associated with Pb-free materials.

2 APPLICABLE DOCUMENTS

2.1 IPC¹

IPC-WP-012 Pb-free Electronics Risk Management (PERM) Council Pb-free Research Priorities

IPC-WP-014 Pb-free Electronics Risk Management (PERM) Council Position on the Use of Pb-free Electronics in the Aerospace, Defense and High Performance Electronics Industries

IPC-T-50 Terms and Definitions for Interconnecting and Packaging Electronic Circuits

IPC-SM-785 Guidelines for Accelerated Reliability Testing of Surface Mount Attachments

IPC-7711/7721 Rework, Repair and Modification of Electrical and Electronic Assemblies

2.2 JOINT INDUSTRY STANDARDS¹

IPC J-STD-001 Requirements for Soldered Electrical and Electronic Assemblies

IPC-J-STD-001 Space Applications Electronic Hardware Addendum to IPC J-STD-001 Requirements for Soldered Electrical and Electronic Assemblies

IPC/JEDEC J-STD-020 Moisture/Reflow Sensitivity Classification for Nonhermetic Surface Mount Devices

IPC/JEDEC J-STD-609 Marking and Labeling of Components, PCBs and PCBAs to Identify Lead (Pb), Pb-free (Pb-Free) and Other Attributes

2.3 OTHER PUBLICATIONS

2.3.1 SAE International²

EIA-933B, Requirements for a COTS Assembly Management Plan

GEIA-STD-0005-1 Performance Standard for Aerospace and High Performance Electronic Systems Containing Pb-free Solder

1. www.ipc.org

2. www.sae.org

GEIA-STD-0005-2 Standard for Mitigating the Effects of Tin in Aerospace and High Performance Electronic Systems

GEIA-STD-0005-3 Performance Testing for Aerospace and High Performance Electronics Containing Pb-free Solder and Finishes

GEIA-HB-0005-1 Program Management / Systems Engineering Guidelines for Managing the Transition to Pb-free Electronics

GEIA-HB-0005-2 Technical Guidelines for Aerospace and High Performance Electronic Systems Containing Pb-free Solder

GEIA-HB-0005-3 Rework and Repair Handbook To Address the Implications of Pb-free Electronics and Mixed Assemblies in Aerospace and High Performance Electronic Systems

2.3.2 International Electrotechnical Commission³

IEC TS 62647-1 Process management for avionics – Aerospace and defence electronic systems containing lead-free solder – Part 1: Preparation for a lead-free control plan

3 TECHNICAL INFORMATION

This entire section is comprised of technical information retrieved from GEIA-HB-0005-2 as well as numerous other authoritative references (See Section 8). However, the user is encouraged to review any updates to these references as well as seek out publications regarding advances in the Pb-free knowledge base. Also, the user is reminded that this section has been streamlined to include only the “delta” concerns of Pb-free technology with respect to SnPb as stated in 1.2.1.

3.1 Pb-free Solders and Solder Joints The intent of this section is to provide a sufficient amount of information to give the user a working knowledge of Pb-free solders in supporting design decisions. As information to the designer, some manufacturing experiences and concepts (albeit some anecdotally) are presented (not inclusive) in order to illustrate design impacts (see also 3.5). The user is encouraged to augment his/her knowledge base by utilizing additional references on Pb-free materials such as GEIA-HB-0005-2 as well as several published texts and the data provided by many industry/academic consortia (e.g., University of Maryland-CALCE, Auburn University-CAVE3, Binghamton University, AREA Consortium, and NASA-DoD LFE). Several other SAE GEIA standards and handbooks identified in Section 2 are also useful.

3.1.1 Pb-free Solders (Alloy Characteristics)

3.1.1.1 General Background SnPb alloys differ from Pb-free materials with respect to material and physical properties. These changes manifest themselves under such service/environmental conditions as thermal cycling, mechanical shock, and vibration.

Tin-Silver-Copper (SAC) and Tin-Copper (Sn-Cu) Pb-free alloys have generally been found to exhibit higher yield strengths and are more creep resistant than SnPb alloys, but the mechanical strength is susceptible to a brittle failure mechanism and printed board pad cratering during rapid loading (see IPC-WP-012 and IPC-WP-014).

Depending upon the finishes, during reflow Pb-free solders may not spread as well as SnPb. Examples of Pb-free compatible finishes are ENIG, ImSn, and Pb-free HASL. The compatibility of printed board and component finish with the attachment solder alloy needs to be understood.

NOTE: An acceptable Pb-free solder joint will appear grainy or dull as opposed to an acceptable SnPb joint, which will feature a shiny or satin luster.

Pb-free solder joints, in assembly, have the potential to grow tin whiskers under certain conditions (see item 3 below). Published industry investigations/research have demonstrated that tin whiskers do initiate and grow from tin plated surfaces such as component leads or printed board metallization. There is a general industry consensus that the root cause of tin whisker initiation/growth of tin whiskers is to relieve stress in the tin plating or as a stress relief mechanism for the tin plating. Additional research/investigation is being conducted to characterize and understand the tin whisker initiation/growth potential of Pb-free solder alloys. Three specific conditions have been identified as having potential tin whisker initiation/growth concerns:

- 1) Tin Whisker Initiation/Growth Due to Corrosion** Industry investigation/research has documented tin whisker initiation/growth [8, 9] on Pb-free solder alloys due to corrosion mechanisms. High levels of ionic contamination, primarily from flux residues, have been shown to induce tin whisker initiation/growth in multiple regions of Pb-free solder joints. The ionic contamination levels were not typical of standard printed board assembly cleanliness and a temperature/humidity confounding effect was documented [10,11].

3. www.webstore.iec.ch

2) Inclusion of Rare Earth Element (REE) Additions in Pb-free Solder Alloys Rare earth element additions such as Y, Ce, and La in Pb-free solder alloys used to improve mechanical fatigue performance can significantly increase the whisker propensity. The surface-active nature of rare earth elements causes the Sn-REE intermetallics to segregate to the free surface of the solder joint during solidification. Upon exposure to oxygen, the REE in the Sn-REE intermetallics oxidize. The REE oxides have increased volume, causing compressive stress that promotes whisker growth from the tin matrix some distance from the Sn-REE intermetallic particle. SAC solder alloys with REE addition can result in significant whisker growth even at very low concentrations [12-15].

3) Solder Joint Regions with Thin Solder Fillet Edges Industry investigation/ research has shown that the edges of Pb-free solder joints – regions where the solder fillet is relatively thin, typically located at the circuit pad edges – can behave in a similar manner as thin tin plating. The tin whisker behavior observed was associated with high temperature and high humidity that may play a role in the initiation/growth characteristics. This solder joint tin whisker behavior has not been universally observed on Pb-free soldered printed board assemblies and is a continuing topic of industry investigation/research [16].

3.1.1.2 Melting Point The melting point of SnPb eutectic alloy solder is 183 °C [361 °F] whereas that of some Pb-free solders (SAC family of solders for example) can be 30+°C higher [221 to 227 °C]. Other families of Pb-free solders can have different melting point ranges as well. Be aware of the specific alloy and the effects of its melt temperature on components and printed boards. The melting points of the common eutectic solder alloys are collated in Table 3-1. When tin is added to lead, or lead to tin, the melting point of the original metal is lowered. The 63/37 tin/lead composition is called the eutectic alloy, since it becomes totally liquid at a single temperature of 183 °C [361 °F]. This solidification behavior of tin/lead solder was extremely beneficial from a manufacturing process perspective as it provided process robustness in terms of handling and temperature management. The commonly used Pb-free solder alloys, such as the SAC solder alloy family, melt over a temperature range where the solder is not completely melted and exists in a pasty or mushy state that requires additional manufacturing process due diligence, particularly during rework.

Understanding the solidification behavior of a solder alloy is important as it allows for the control/management of specific solder joint attributes such as voids and intermetallic phases (see Figure 3-1).

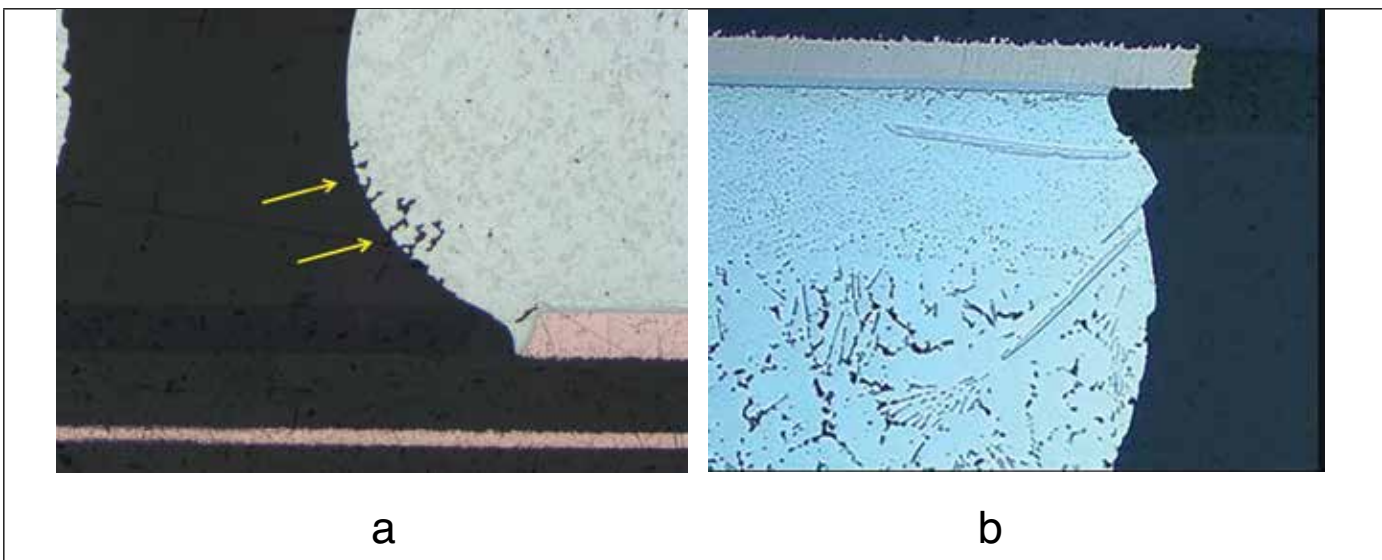


Figure 3-1 a) Shrinkage voids in a Pb-free BGA Solder Joint, b) Large Ag₃SnSilver/Tin IMC Structures in a Mixed Metallurgy Solder Joint [Figure courtesy of Rockwell Collins].

Table 3-1 Melting Points of SnPb and some Pb-free Alloys¹

Solder Alloy	Proportions	Melting point temperature
Sn-Pb	Sn63Pb37	183 °C [361 °F]
SAC 105	Sn98.5Ag1.0Cu0.5	215 °C to 227 °C [419 to 440 °F]
SAC 305	Sn96.5Ag3.0Cu0.5	217 to 220 °C [422 to 428 °F]
SAC 405	Sn95.5Ag4.0Cu0.5	217to 220 °C [422 to 428 °F]
Sn-Cu	Sn-0.7Cu	227 °C [441 °F]
Sn-Ag	Sn-3.5Ag	221 °C[429.8 °F]
Sn	Sn100	232 °C [449 °F]
Sn100C	Cu 0.5-0.7Ni 0.04-0.07Ge 0.008-0.01	227 °C

Note 1. This table is a partial listing for informational purposes and is not to be considered all inclusive.

The three main Pb-free solder alloy families are based on the Tin rich SnCu, SnAg or the SnAgCu (SAC) families of alloys. Sometimes small alloy additions of Ni, Ge, In, and Sb are made to these basic alloys in an effort to alter dissolution, solidification, mechanical properties or wetting characteristics. The melting point of pure Sn is 231.9 °C [449.4 °F] and the addition of 37% Pb to the Sn reduces the melting temperature to the eutectic point of 183 °C [361 °F]. Similarly, the addition of Ag and Cu to Sn reduces the melting temperature but not to the same extent as Pb. The higher melting temperature of Pb-free alloys, results in a 30 to 40 °C [54 to 72 °F] increase in processing temperature as compared to the temperatures used to process legacy SnPb alloys. Higher melting temperatures result in increased amounts of base metal dissolution (copper dissolution) and increased shrinkage stresses on components during cooling (see GEIA-HB-005-2 and [5]). An additional consideration is that the SAC alloys have generally been found to exhibit higher yield strength and are more creep resistant than the heritage Sn-Pb solders at typical electronic use temperatures. The microstructures of SnAg and SnAgCu alloys greatly drive the physical and mechanical characteristics described here and interested designers may wish to review the literature for detailed information on the various interactions [17].

3.1.1.3 Microstructure The solder joint microstructure of SnPb and Pb-free solder alloys are very different. The SnPb solder joint microstructure is an equal distribution of tin phase and lead phase (see Fig 3-2a). Pb-free solder alloy microstructure is typically composed of a tin dendrite matrix with a distribution of both a silver/tin (Ag₃Sn) and a copper/tin (Cu₆Sn₅) intermetallic phases (see Fig 3-2b). The microstructure of Pb-free solder alloys is significantly more influenced by the solder alloy elemental constituents and the thermal profile history in comparison to SnPb solder alloys.

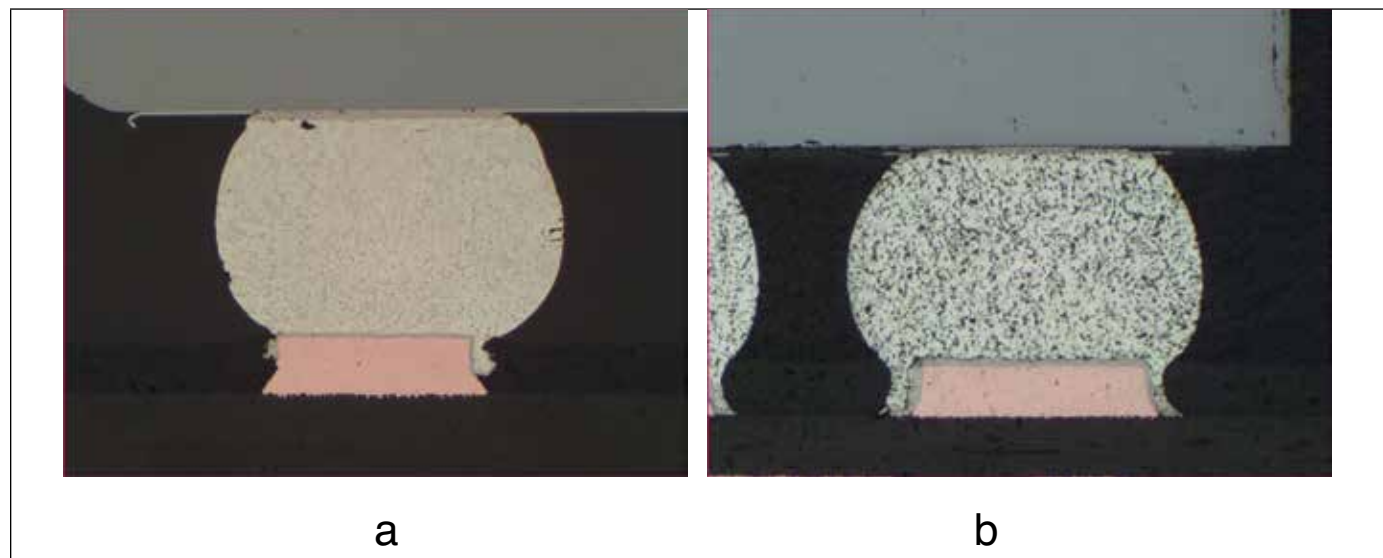


Figure 3-2 a) Tin/lead Solder Joint Microstructure, b) Pb-free Solder Joint Microstructure [Figure courtesy of Rockwell-Collins].

3.1.2 Pb-free Solder Joints There are many differences between eutectic SnPb and Pb-free solders. In particular, SAC solder joints will exhibit dramatically different visual characteristics with respect to their SnPb counterparts. Figure 3-3 shows differences between the two [2]. When properly reflowed, SnPb solder joints show a shiny, smooth appearance as shown on the left in Figure 3-3. Conversely, a properly reflowed SAC solder joint will show a dull, matte-like finish as shown on the right in Figure 3-3.

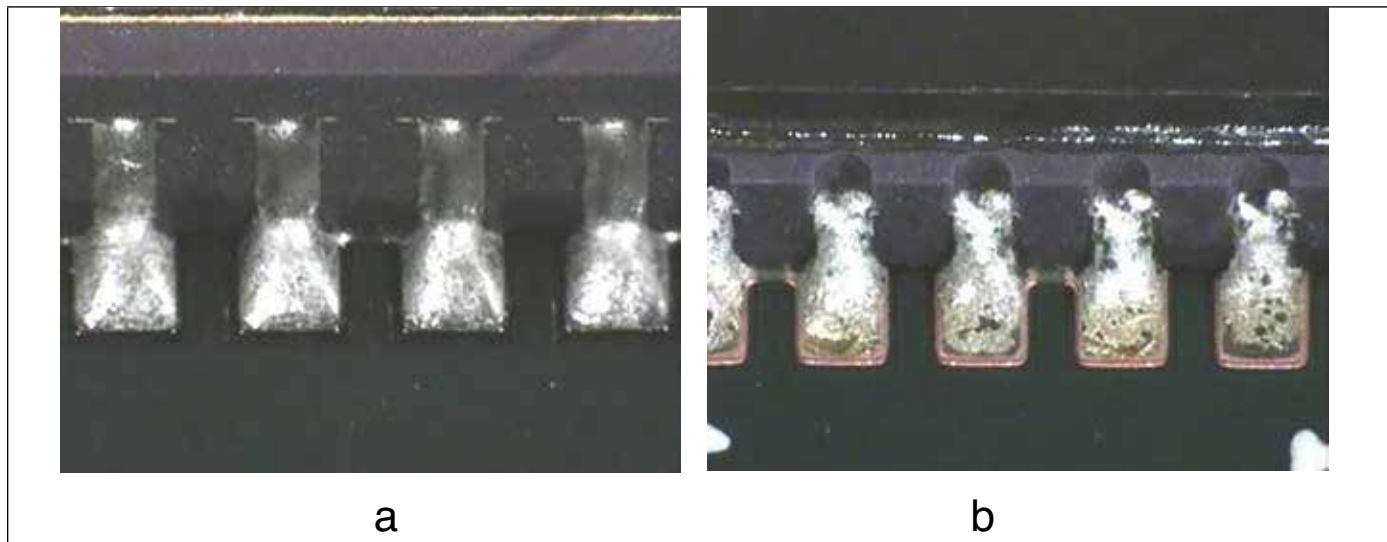


Figure 3-3 a) Appearance of PbSn Solder Joints, b) SAC (Pb-free) Solder Joints [Figure courtesy of ACI Technologies].

From a strength of materials perspective, Pb-free solders will exhibit different materials properties than SnPb. Therefore, it is imperative that a designer understand these differences for each Pb-free alloy. If one looks at the SAC family of solders, they see that the creep responses of these materials is drastically different from that of SnPb (e.g., for SAC, its higher stiffness results in a slower response to creep-inducing loads). SAC 305 tends to perform worse than SnPb under mechanical shock and vibration whereas it is superior to SnPb during thermal cycling (except at temperature extremes). Moreover, SAC 105 tends to perform better than SAC 305 under mechanical shock and vibration but not better than SnPb. Again, these examples are meant to emphasize the need to understand the characteristics of these materials.

The following subsections provide information on additional differences of which the designer should be aware.

3.1.2.1 Silver Dendrites Under certain conditions, SAC solders can grow silver dendrites. An example of this is shown in Figure 3-4 and Figure 3-5.

Dendrites are fern-like or snowflake-like patterns that form across a surface (x-y plane). They require a solvent capable of dissolving metal into a solution of metal ions and these ions are redistributed through electro-migration in the presence of a DC (direct current) electric field [18]. The presence of ionic contamination and moisture can exacerbate the growth of dendrites that can reduce the gap between two adjacent conductor traces leading to current leakage, intermittent shorts and consequently increases the chance of catastrophic failure [19, 20]. A detailed account of dendrites, their formation process, and their impact on performance, courtesy of Foresite, Inc. is located at www.ipc.org under “PERM Council”, located within the “Industry” tab.



Figure 3-4 A SAC 305 solder joint with Silver dendrites [Figure courtesy of Spur Electron and Ultra Electronics, UK].

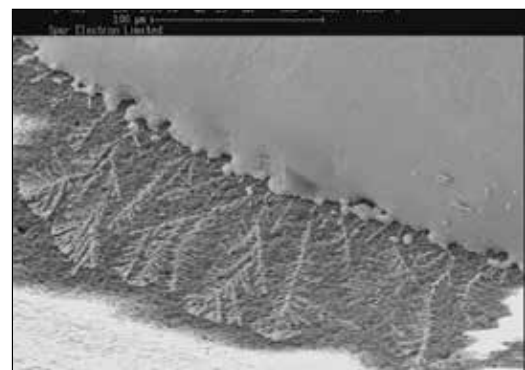


Figure 3-5 Detail of a SAC 305 soldered joint growing Silver dendrites [Figure courtesy of Spur Electron and Ultra Electronics, UK].