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BSI Standards Publication

Process management for avionics — Aerospace and defence electronic systems containing lead-free solder

Part 23: Rework and repair guidance to address the implications of lead-free electronics and mixed assemblies

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National foreword

This Published Document is the UK implementation of IEC/TS 62647-23:2013. It supersedes DD IEC/PAS 62647-23:2011 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee GEL/107, Process management for avionics.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Process management for avionics – Aerospace and defence electronic systems containing lead-free solder – Part 23: Rework and repair guidance to address the implications of lead-free electronics and mixed assemblies

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ELECTROTECHNICAL
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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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FOREWORD

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Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC 62647-23, which is a technical specification, has been prepared by IEC technical committee 107: Process management for avionics.

The text of this technical specification is based on the following document: IEC/PAS 62647-23[1].

This technical specification cancels and replaces IEC/PAS 62647-23, published in 2011. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) Coherence with IEC/TS 62647-1, IEC/TS 62647-2 and IEC/TS 62647-21 definitions.

b) Reference to IEC 62647 documents when already published.

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
107/206/DTS	107/219/RVC

Full information on the voting for the approval of this technical specification can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 62647 series, published under the general title *Process management for avionics – Aerospace and defence electronic systems containing lead-free solder*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- transformed into an International Standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

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[1] IEC/PAS 62647-23, which served as a basis for the present document, is also known as GEIA-HB-0005-3.

INTRODUCTION

0.1 General

The global transition to lead-free (Pb-free) electronics impacts the aerospace, defence and high performance (ADHP) industry and other industries having high reliability applications in various ways.

This document is intended to facilitate the development of procedures and processes for use when undertaking the rework/repair of aerospace, defence, and high performance (ADHP) electronics systems. It is intended to contain sufficient information to support the processing of equipment that incorporates either tin-lead (Sn-Pb) or lead-free (Pb-free) solder alloy, Sn-Pb or lead-free (Pb-free) piece parts and printed circuit board (PCB)/printed wiring board (PWB) finishes, or a combination thereof.

This document may be used by original equipment manufacturers (OEMs), contract manufacturers (CMs) and commercial depots. This document may also be used by personnel performing rework/repair at the organizational (O) level, intermediate (I) back shop level, and depot (D) overhaul level.

0.2 Pb-free and legislation

Recent directives and legislation by nations around the world mandated elimination of lead and other hazardous material usage in sectors of the electronics industry by 2006. In electronics, lead (Pb) has been a primary component of tin-lead (Sn-Pb) solder used in piece part attachment and PCB/PWB finishes for over 50 years, and more recently in the solder spheres for attachment of ball grid array (BGA) packages. Since there is no “drop-in” replacement for Sn-Pb solder alloys, multiple Pb-free alloys have emerged in the manufacturing industry as replacements. These multiple replacement alloys are being used in printed circuit boards (PCBs)/printed wiring boards (PWBs) finish, piece part termination finish and as solder alloys, leaving the rework/repair technician with literally hundreds of possible combinations of metallurgy in the finished repair.

The majority of the Pb-free alloys being considered have melting temperatures 34 °C to 44 °C (61 °F to 79 °F) higher than that of tin-lead (Sn-Pb) eutectic solder. These higher Pb-free processing temperatures require significant changes to convective rework/repair procedures and minor adjustments in conductive hand soldering procedures to ensure that quality products will be produced.

Another major concern is the potential re-emergence of tin whiskers as an additional equipment failure mechanism. Tin whiskers are electrically conductive, crystalline structures of tin (Sn) that grow under compressive force from surfaces where tin (Sn) (especially electroplated tin (Sn)) is used as a final finish. Tin whiskers have been observed to grow to lengths of several millimeters (mm). Numerous electronic system failures have been attributed to short circuits caused by tin whiskers that bridge closely-spaced circuit elements. Tin whiskers have been successfully suppressed for decades by the addition of lead (Pb) to tin (Sn) plating used in high reliability applications. With the global shift to Pb-free solders, tin whiskers have re-emerged as a major concern to reliability. IEC/TS 62647-2:2012 further discusses tin whisker issues and mitigation techniques.

Procedurally, conductive Pb-free rework/repair is similar to that of Sn-Pb. However, adjustments should be made to accommodate the generally poorer wetting ability of Pb-free solders as well as differences in appearance and inspection criteria. Convective rework/repair will require redevelopment of profiles to accommodate the higher melting temperature of Pb-free alloys. Also, Pb-free rework/repair has a tighter process window leaving a smaller margin for error in comparison to Sn-Pb. With the proper materials, preparation, skill, and the use of fundamentally sound procedures, Pb-free rework/repair can be successfully and reliably accomplished [28][2].

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

PROCESS MANAGEMENT FOR AVIONICS – AEROSPACE AND DEFENCE ELECTRONIC SYSTEMS CONTAINING LEAD-FREE SOLDER –

Part 23: Rework and repair guidance to address the implications of lead-free electronics and mixed assemblies

1 Scope

This part of IEC 62647 provides technical background, procurement guidance, engineering procedures, and guidelines to assist organizations reworking/repairing aerospace and high performance electronic systems, whether they were assembled or previously reworked/repaired using traditional alloys such as Sn-Pb or Pb-free alloys, or a combination of both solders and surface finishes. This document contains a review of known impacts and issues, processes for rework/repair, focused to provide the technical structure to allow the repair technician to execute the task.

This document focuses on the removal and replacement of piece parts. For the purposes of this document, the term “rework/repair” is used as defined in 3.1.29 and 3.1.30.

The information contained within this document is based on the current knowledge of the industry at the time of publication. Due to the rapid changing knowledge base, this document should be used for guidance only.

NOTE 1 For the purposes of this document, if the element “lead” is implied, it will be stated either as Pb, as lead (Pb), or as tin-lead. If a piece part terminal or termination “lead” is referred to, such as in a flat pack or a dual-inline package, the nomenclature lead/terminal or lead-terminal will be used.

NOTE 2 Processes identified in the document apply to either rework or repair.

This document may be used by other high-performance and high-reliability industries, at their discretion.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC/TS 62647-1:2012, *Process management for avionics – Aerospace and defence electronics systems containing lead free solder – Part 1: Preparation for a lead-free control plan*

IEC/TS 62647-2:2012, *Process management for avionics – Aerospace and defence electronic systems containing lead-free solder – Part 2: Mitigation of deleterious effects of tin*

IEC/TS 62647-22:2013, *Process management for avionics – Aerospace and defence electronic systems containing lead-free solder – Part 22: Technical guidelines*

3 Terms, definitions and abbreviations

3.1 Terms and definitions

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

3.1.1
alloy composition
whole ingredients of an alloy whose weight is defined in percent

Note 1 to entry: For instance 63Sn-37Pb corresponds to a mixture of 63 % by weight of tin (Sn) and 37 % by weight of lead (Pb).

[SOURCE: IEC/TS 62647-22:2013, 3.1.1]

3.1.2
assemblies
electronic items that require electrical attachments, including soldering of wires or component terminations

EXAMPLE: Circuit cards and wire harnesses.

[SOURCE: IEC/TS 62647-1:2012, 3.1]

3.1.3
backwards compatibility
Pb-free materials compatible with an Sn-Pb process

3.1.4
CTE
coefficient of thermal expansion
degree of expansion of a material divided by the change in temperature

Note 1 to entry: PCB/PWB CTE (x-y axis) is measured in the direction in the plane of the piece part mounting surface and is used to quantify the stresses in the solder joint arising from the differences in CTE between the piece parts and the PCB/PWB during thermal cycling. CTE (z axis) is measured in the “thickness” direction and is typically used to quantify plated through hole stress.

[SOURCE: IEC/TS 62647-22:2013, 3.1.8]

3.1.5
conductive
use of a contact heat source such as a soldering iron, hot bar, or resistance to transfer heat to the assembly

3.1.6
convective
use of a non-contact heat source, usually heated air, nitrogen or infrared light to transfer heat to the assembly

3.1.7
copper dissolution
excessive loss of copper from plated through hole barrels and pads caused by wave or solder fountain processing primarily with high tin (Sn) content solders

3.1.8
critical
state of an item or function, which if defective, will result in the system’s inability to retain operational capability, meet primary objective, or affect safety

[SOURCE: IEC/TS 62647-1:2012, 3.2]

3.1.9
customer
entity or organization that (a) integrates a piece part, soldered assembly, unit, or system into a higher control level system, (b) operates the higher control level system, or (c) certifies the system for use

EXAMPLE: This may include end item users, integrators, regulatory agencies, operators, original equipment manufacturers (OEMs), and subcontractors.

[SOURCE: IEC/TS 62647-1:2012, 3.5]

3.1.10
delamination
separation between plies within a base material, between a base material and a conductive foil, or any other planar separation with a printed board that may propagate under thermal stress

3.1.11
D
depot level maintenance
maintenance requiring major overhaul or a complete rebuilding of parts, assemblies, subassemblies, and end items, including the manufacture of parts, modifications, testing, and reclamation as required.

Note 1 to entry: Depot maintenance serves to support lower categories of maintenance by providing technical assistance and performing that maintenance beyond their responsibility.

3.1.12
dissolution
process in which one substance is dissolved in another by chemical action

3.1.13
eutectic
mixture of two or more metals at a composition that has the lowest melting point, and where the phases simultaneously crystallize from molten solution at this temperature

Note 1 to entry: A non-eutectic mixture will exhibit a pasty range during cooling where both liquid and solid phases are present prior to reaching the mixture’s solidus temperature.

[SOURCE: IEC/TS 62647-22:2013, 3.1.12]

3.1.14
high performance
continued performance or performance on demand where an application (product, equipment, electronics, system, program) down time cannot be tolerated in an end-use environment which can be uncommonly harsh, and the application must function when required

EXAMPLE: Examples of high performance applications are life support or other critical systems.

[SOURCE: IEC/TS 62647-1:2012, 3.7]

3.1.15
I
intermediate level maintenance
repair operation of aircraft and engine components, WRAs, and LRUs forwarded to the intermediate level by the organizational level flight-line activities

Note 1 to entry: This consists either in limited repair operation of commodity-orientated piece parts and end items, job shop, bay, and production line operations for special mission requirements or in repair of printed circuit boards (PCBs)/printed wiring boards (PWBs), software maintenance, and fabrication or manufacture of repair parts, assemblies, piece parts. WRA and LRU repair is accomplished by the removal, troubleshooting, and replacement of faulty SRA and SRU, pieces, and parts within the WRA/LRU.

3.1.16
lead-free
Pb-free
less than 0,1 % by weight of lead (Pb) in accordance with reduction of hazardous substances (RoHS) guidelines

[SOURCE: IEC/TS 62647-1:2012, 3.8]

3.1.17
lead-free control plan
LFCP
aerospace or military system supplier's document that defines the processes that assure the Plan owners, their customers and all other stakeholders that aerospace, defence and high performance high-reliability electronics systems containing Pb-free solder and Pb-free piece part and PWB finishes will continue to be reliable, safe, producible, affordable, and supportable

[SOURCE: IEC/TS 62647-1:2012, 3.9]

3.1.18
liquidus
minimum temperature at which all components of a mixture (such as an alloy) can be in a liquid state

Note 1 to entry: Below liquidus, the mixture will be partly or entirely solid.

3.1.19
measling
condition that occurs in laminated base material in which internal glass fibers are separated from the resin at the weave intersection

Note 1 to entry: This condition manifests itself in the form of discrete white spots or "crosses" that are below the surface of the base material.

3.1.20
organization
organizational structure typically consisting of program management, procurement, process engineering, bench technicians, and quality assurance personnel

3.1.21
O
organizational level maintenance
maintenance normally performed by an operating unit on a day-to-day basis in support of its own operations

Note 1 to entry: Organizational level maintenance typically includes "inspections", "servicing", "handling" and "preventive maintenance" and is limited to the replacement of electronic assemblies at the WRA and LRU (black box) level of major aircraft and engine components. There can be an exception when troubleshooting and piece parts level repair are accomplished at the organizational level.

3.1.22
Pb-free tin
pure tin or any tin alloy with $<$ 3 % lead (Pb) content by weight

Note 1 to entry: Some Pb-free finishes other than pure tin, such as tin-bismuth and tin-copper are considered to be “tin” for the purposes of this specification. Many of these alloys have not been assessed for whiskering behaviour.

[SOURCE: IEC/TS 62647-1:2012, 3.11]

3.1.23
Pb-free tin finish
final finishes or under-plates either external or internal to a device, board or other hardware, including all leads and surfaces, even those coated, encapsulated, or otherwise not exposed

Note 1 to entry: It may include finishes on electrical piece parts, mechanical piece parts, and boards. It does not include Pb-free bulk solders, assembly materials, solder balls, or those devices where the Pb-free tin finish has been completely replaced.

[SOURCE: IEC/TS 62647-1:2012, 3.12]

3.1.24
PCB
printed circuit board
PWB
printed wiring board
substrate using conductive pathways, tracks or signal traces etched from copper sheets laminated, and allowing to connect electrically a set of electronic components to realize a circuit card.

[SOURCE: IEC/TS 62647-21:2013, 3.1.10]

3.1.25
piece part
electronic component that is not normally disassembled without destruction and is normally attached to a printed wiring board to perform an electrical function

[SOURCE: IEC/TS 62647-1:2012, 3.14]

3.1.26
procurement
process of obtaining services, supplies, and equipment

3.1.27
PTH
plated through hole
plated through holes used on printed circuit boards (PCBs)/printed wiring boards (PWBs) for interconnecting between layers and for component attachment

[SOURCE: IEC/TS 62647-22:2013, 3.1.26]

3.1.28
quality assurance
planned and systematic set of activities to ensure that requirements are clearly established and that the defined process or product complies with these requirements

3.1.29
repair
act of restoring the functional capability of a defective article in a manner that precludes compliance of the article with applicable drawings or specifications

[SOURCE: IEC/TS 62647-1:2012, 3.17]

3.1.30
rework
action taken to return a unit (SRU/LRU/system) to a state meeting all requirements of the engineering drawing, including both functionality and physical configuration by making repairs

Note 1 to entry: Also used to define the act of reprocessing non-complying articles, through the use of original or equivalent processing in a manner that assures full compliance of the article with applicable drawings or specifications.

[SOURCE: IEC/TS 62647-1:2012, 3.16]

3.1.31
SAC
family of Pb-free alloys containing tin, silver and copper used in surface mount technology or sometimes in wave solder processes

Note 1 to entry: The alloys typically have a composition near the eutectic (95,6Sn-3,5Ag-0,9Cu)

[SOURCE: IEC/TS 62647-22:2013, 3.1.29]

3.1.32
SRA
shop replaceable assembly
SRU
shop replaceable unit
component assembly inside a black box (LRU or WRA) typically consisting of individually replaceable circuit card assemblies

3.1.33
Sn-Cu
solder or alloy referring to Pb-free alloys that are comprised of tin-copper (Sn-0,7Cu)

[SOURCE: IEC/TS 62647-22:2013, 3.1.32]

3.1.34
Sn-Cu-Ni
solder or alloy referring to tin-copper with nickel trace (Sn-0,7Cu-0,05Ni)

Note 1 to entry: Some formulations also include other minor additions such as germanium (Ge).

[SOURCE: IEC/TS 62647-22:2013, 3.1.33]

3.1.35
Sn-Pb
solder generally referring to the family of tin-lead alloys at or near the eutectic composition with or without silver added (Sn-37Pb, Sn-40Pb, or Sn-36Pb-2Ag)

[SOURCE: IEC/TS 62647-22:2013, 3.1.34]

3.1.36
soldered assembly
assembly of two or more basic parts interconnected by a solder alloy

Note 1 to entry: A lead (Pb)-based soldered assembly is one in which the solder alloys are solely lead (Pb)-based. A lead-free soldered assembly is one in which the solder alloys are solely lead-free.

[SOURCE: IEC/TS 62647-22:2013, 3.1.36]

3.1.37
system
one or more units that perform electrical function(s)

[SOURCE: IEC/TS 62647-1:2012, 3.24]

3.1.38
termination
area to be soldered of the piece part termination, castellations, or metallized surface(s) of an electronic device

3.1.39
ternary alloy
solder alloy containing three component metals

3.1.40
T_g
glass transition temperature of laminate material

3.1.41
high T_g
glass transition temperature of laminate material ≥ 170 °C (338 °F)

3.1.42
tin whisker
spontaneous crystal growth that emanates from a tin (Sn) surface and which may be cylindrical, kinked, or twisted

Note 1 to entry: Typically tin whiskers have an aspect ratio (length/width) greater than two, with shorter growths referred to as nodules or odd-shaped eruptions (OSEs).

[SOURCE: IEC/TS 62647-1:2012, 3.26]

3.1.43
under-plating
plating made as a base of a surface over-plating usually required as a barrier to prevent leeching of two dissimilar metals into one another

3.1.44
WRA
weapons replaceable assembly
black box of electronics, replaced at the flight-line level

3.1.45
XRF
X-ray fluorescence
form of metallurgical analysis that uses X-rays to identify composition of solder alloys and termination finishes

3.2 Abbreviations

ADHP	Aerospace, defence, and high performance
Ag	Silver
AHP	Aerospace and high performance
Au	Gold
Bi	Bismuth

BGA	Ball grid array (related to electronic component package)
C4 Ball	Controlled collapse component connection ball
CALCE	Center for Advanced Life Cycle Engineering
CBGA	Ceramic ball grid array
CCA	Circuit card assembly
CM	Contract manufacturer
CTE	Coefficient of thermal expansion
Cu	Copper
D	Depot maintenance level
ENIG	Electroless nickel immersion gold (related to PCB/PWB surface finish)
EU	European Union
Fe	Iron
I	Intermediate maintenance level
Imm Ag	Immersion silver
In	Indium
iNEMI	International Electronics Manufacturing Initiative
JG-PP	Joint Group on Pollution Prevention
GEIA	Government Electronics and Information Technology Association
HASL	Hot air solder leveling (related to PCB/PWB surface finish)
LFCP	Lead-free control plan
LRU	Line replaceable unit
MSD	Moisture sensitive devices
Ni	Nickel
O	Organizational maintenance level
OEM	Original equipment manufacturer
OSP	Organic solderability preservative (related to PCB/PWB surface finish)
Pb	Lead
Pb-free	Lead-free
PCB	Printed circuit board
Pd	Palladium
PTH	Plated through hole
PWB	Printed wiring board
QFN	Quad flat no leads (related to electronic component package)
Sn-Ag-Cu	Pb-free solder alloy of tin (Sn), silver (Ag), and copper (Cu)
SAC	Pb-free solder alloy of tin (Sn), silver (Ag), and copper (Cu)
SACB	Pb-free solder alloy of tin (Sn), silver (Ag), copper (Cu) and bismuth (Bi)
SMT	Surface mount technology (related to circuit card assembly technology)
SMTA	Surface Mount Technology Association
Sn	Tin
Sn-Bi	Pb-free solder alloy of tin (Sn) and bismuth (Bi)
Sn-Cu	Pb-free solder alloy of tin (Sn) and copper (Cu)
Sn-Cu-Ni	Pb-free solder alloy of tin (Sn), copper (Cu), and nickel (Ni)

Sn-Pb	Tin/lead (normally 63 % tin/37 % lead)
SRA	Shop replaceable assembly
SRU	Shop replaceable unit
WRA	Weapons replaceable assembly
XRF	X-ray fluorescence

4 Pb-free concerns

4.1 General

The transition from Sn-Pb to Pb-free rework/repair raises a variety of concerns. IEC/TS 62647-1:2012 identifies five major areas that should be considered. Those areas include reliability, configuration control, risk management, effects of Sn in the system, and rework/repair. If the concerns in the first four areas are not properly identified, planned for, assessed, managed, and documented, rework/repair of those assemblies becomes extremely difficult. A quality lead-free control plan (LFCP) will identify and mitigate potential concern areas and provide the technician with clear requirements for rework/repair.

4.2 Reliability

4.2.1 General

The program manager should understand how the transition to Pb-free solder and piece part termination finishes or mixing Sn-Pb and Pb-free solders may affect the reliability of the assembly. Additionally, the effects on package types/geometry, piece part termination finish, and laminate materials and finishes, should be clearly understood when authorizing and introducing the use of alternate materials.

The reliability of the original solder joint is dependent upon the integrity of the solder in the joint and the metallurgical interfaces to the terminations and PCB/PWB lands. The solder joint reliability is influenced by the final solder alloy composition and microstructure, the shape of the solder surface and the termination-to-solder interfacial strength. The initial composition of the solder used to form the joint is typically modified to some extent during the soldering process as the pad metallization and finish are dissolved into the solder joint. The amount of dissolved piece part and pad metal typically does not significantly alter the initial alloy composition. The exceptions to this rule are ball grid array (BGA) type devices where the ball solder volume represents a significant amount of the total solder volume, and pad interface finish elements that have a tendency to segregate to either the piece part or the PCB/PWB pad interfaces or grain boundaries such as gold (Au) and bismuth (Bi) alloys contaminated with trace amounts of lead (Pb).

4.2.2 Mixed metallurgy reliability

4.2.2.1 General

In a reworked/repaired solder joint, metallurgy mixing is a major reliability concern to electronics equipment suppliers and users. As Sn-Pb BGA ball metallurgy and Sn-Pb finished piece parts are being quickly replaced by Pb-free alternatives, Pb-free solders may be either intentionally or unintentionally mixed with Sn-Pb solder and/or Pb-bearing finishes throughout their service life and during repair activity. Annex A lists a number of the termination finishes that potentially could be encountered. Annex B provides a summary of the tin whisker propensity for the various elemental additions to Sn.

4.2.2.2 Pb-free terminations in Sn-Pb joints

One result of the WEEE/RoHS directives and the responding piece part fabricator initiative is the introduction of piece parts with Pb-free surface finish terminations into existing traditional Sn-Pb soldering processes. The variety and compositions of the Pb-free surface finishes being delivered into the electronics industry is extensive. Many of these piece parts materials will find their way into the inventory of aerospace and defence assembly processes under government acquisition reform initiatives. Electronics assembly design teams should be knowledgeable on the potential impact of the Pb-free surface finish piece part and pad interface on solder joint integrity. The impact is not universal – solder joint integrity degradation can range from slight to severe depending upon the use environment.

4.2.2.3 Sn-Pb terminations in Pb-free joints

The introduction of Sn-Pb terminated piece parts in a Pb-free solder system is likely during the early stages of Pb-free assembly processing while the piece part supply stream still contains Sn-Pb terminated piece parts.

4.2.2.4 Bismuth (Bi)

4.2.2.4.1 General

The addition of Bi to SAC has been shown to yield a solder joint that has improved durability. However, the principal concern is that when Bi and Pb are intermixed, a low melting point Sn-Bi-Pb ternary alloy can form, particularly at the grain boundaries. The melting point of the ternary alloy is 96 °C (205 °F) and the solder can lose strength during hot mission environments.

4.2.2.4.2 Sn-Pb finish in Sn-Bi solder alloy

Trace amounts of lead (Pb) were found to have a detrimental effect (e.g. Kirkendall voiding, embrittlement, etc.) on solder life of bismuth (Bi) containing solders (91,8Sn-3,4Ag-4,8Bi and 92,3Sn-3,4Ag-1,0Cu-3,3Bi). Also Sn-58,0Bi solder joints may become contaminated with lead (Pb) as a result of rework leading to catastrophic failure. Since ADHP products have a 20-year service life, a repair depot infrastructure will have both Sn-Pb and Pb-free alloy configurations for a significant amount of time.

4.2.2.4.3 Sn-Bi finish in Sn-Pb solder alloy

Bismuth bearing solder alloys are noted as a concern in IEC/TS 62647-1:2012. However, there are some piece parts that are only available with an Sn-Bi termination finish. Preliminary testing suggests that trace amounts of Bi in Sn-Pb joints are not detrimental to solder life. For further information see IEC/TS 62647-22:2013.

4.3 Configuration management

The need for configuration management is paramount to the Pb-free transition. Studies have shown that mixing Sn-Pb and Pb-free solders or the mixing of Pb-free solders of different alloys and/or piece parts (solders or finishes of different alloys) may have a detrimental impact on the long-term reliability under high stress (e.g., defence, commercial aerospace, or space) environments. All parties involved in the rework/repair process should understand the appropriate configuration controls (e.g., traceability) that are necessary for the program’s environment.

There are applications within ADHP systems where acceptance of alternate materials may be acceptable. Any deviation from the assembly drawings should be approved and promulgated by the responsible engineering authority or the delegated representative.

Introduction of alternate solder alloys and piece part termination finishes that deviate from the assembly drawing may or may not affect the user’s configuration management process. The use of Pb-free termination finishes in Sn-Pb assemblies may not be considered a configuration change. However, the use of alternate solder alloys on that assembly may result in a configuration change. The authorized deviation to assembly drawing requirements should be accompanied by clear, well documented rework/repair procedures.

NOTE Commercial part suppliers are in the position to modify or not part numbers when converting to Pb-free or changing existing Pb-free finishes.

4.4 Risk management

Risks need to be identified early and a mitigation strategy engaged. The appropriate systems engineering process of risk identification, risk analysis, and risk mitigation should be followed. Risk identification and risk assessment should be performed for any deviation (transition to Pb-free or mixed assembly, etc.) for the particular end-use conditions of the assembly. The program manager has the responsibility to conduct an analysis and complete a risk management plan that identifies risk and provides mitigation methods. This plan should include impacts to rework/repair and provide revised procedures as necessary.

4.5 Tin whiskers

Whiskers are elongated single crystals of pure tin (Sn) that have been reported to grow to more than 10 mm in length (though they are more typically 1 mm or less) and from 0,3 μm to 10 μm in diameter (typically 1 μm to 3 μm). Whiskers grow spontaneously without an applied electric field or moisture (unlike dendrites) and are independent of atmospheric pressure (they grow in vacuum). Whiskers may be straight, kinked, hooked, or forked and some are reported to be hollow. Their outer surfaces are usually striated. Whisker growth may begin soon after plating. However, initiation of growth may also take years. The unpredictable nature of whisker incubation and subsequent growth is of particular concern to systems requiring long term, reliable operation. More information is available in Annex B of this document and in IEC/TS 62647-2:2012.

4.6 Copper dissolution (erosion)

The high Sn content of the common Pb-free alloys (those typically > 95 wt % Sn) used in through hole wave soldering has created rework/repair issues with solder fountain methods. Solder fountain rework/repair of connectors and other multi-termination piece parts is causing excessive dissolution of the PCB/PWB pad and barrel. In some cases where prolonged time in the solder wave can occur, one Pb-free rework/repair can completely dissolve the plated hole at the knee. Under common conditions, the dissolution rates may be so high that traces are almost completely dissolved within 20 s to 30 s. Stabilized alloys composed of Sn, Cu, and small amounts of Ni have proven to offer several advantages for wave soldering applications, including brighter solder joints, low copper dissolution rates comparable to Sn-Pb, good flow characteristics, and reduced defects such as bridges and icicles.

Due to the high probability of copper dissolution in high Sn content Pb-free alloys, solder fountain rework/repair using these alloys should be avoided. Continuous vacuum extraction methods should be employed to maximize plated through hole integrity allowing for potential future rework/repair.

Separate solder fountains should be maintained in situations where rework/repair is being performed on legacy Sn-Pb and Pb-free assemblies. See 6.3 for additional solder fountain details.

5 Materials

5.1 Solder

5.1.1 General

Some examples of solder alloy types are listed below.

5.1.2 Solder alloys

IPC/JEDEC J-STD-609A designations (e0 to e9) are listed after some of the common Pb-free solder alloys:

- e0: contains intentionally added Pb6;
- e1: tin-silver-copper (Sn-Ag-Cu) with silver content greater than 1,5% and no other intentionally added elements;
- e2: tin (Sn) alloys with no bismuth (Bi) nor zinc (Zn), excluding tin-silver-copper (Sn-Ag-Cu) alloys in e1 and e8;
- e3: tin (Sn);
- e4: precious metal (e.g. silver (Ag), gold (Au), nickel-palladium (Ni-Pd), nickel-palladium-gold (Ni-Pd-Au) (no tin (Sn));
- e5: tin-zinc (Sn-Zn), tin-zinc-other (Sn-Zn-X) (all other alloys containing tin (Sn) and zinc (Zn) and not containing bismuth (Bi));
- e6: contains bismuth (Bi);
- e7: low temperature solder (≤ 150 °C) containing indium (In) (not containing bismuth (Bi));
- e8: tin-silver-copper (Sn-Ag-Cu) with silver content less than or equal to 1,5 %, with or without intentionally added alloying elements. This category does not include any alloys described by e1 and e2 or containing bismuth or zinc in any quantity.
- e9: symbol – unassigned.

NOTE IPC/JEDEC J-STD-609A is merging JESD97 and IPC-1066 standards.

5.1.3 Solder forms

5.1.3.1 General

Pb-free solder is available in many of the same forms as Sn-Pb solder including wire, paste, spheres, ribbon or foil, ingot or bar, and preforms. Pb-free solders may not be easily distinguishable from Sn-Pb solders or other Pb-free alloys so it is important for technicians to keep all solder alloy materials clearly marked in the manufacturer’s original packaging. Wire solder or solder paste with missing labels may render the material unidentifiable without testing. It is especially important to maintain 100 % control of solders where multiple alloys are present at the rework/repair station and cross-contamination could occur if mixed.

5.1.3.2 Solder wire

A wide range of solid and flux-cored Pb-free solder wire is commercially available. The solder wire diameters for rework/repair have not changed with standard sizes between 1,574 mm and 0,381 mm being common. Due to the inherent stiffness of Pb-free solder wire, some Pb-free alloys are difficult or impossible to extrude in the 0,254 mm diameter.

5.1.3.3 Solder paste

In appearance Pb-free and Sn-Pb solder paste look identical. At least one manufacturer has tinted the flux chemistry in the paste green as a method to identify it as Pb-free. In general, paste application methods using a syringe or stencil have not changed. To enhance solderability, the rework/repair site lands or pads should be properly tinned especially when reworking/repairing OSP, which oxidizes rapidly, making rework/repair difficult. Although flux formulations are vastly different and wetting may be reduced, the application and use of Pb-free solder paste is very similar to Sn-Pb paste.

5.1.3.4 Solder preforms

Solder preforms are used in a variety of manufacturing and rework/repair applications that require precise amounts of solder. Pb-free solder preforms have few notable differences from Sn-Pb preforms. When there are reduced solderability and wetting, an inherent difference in Pb-free soldering can be expected. This can be minimized through proper site preparation during rework/repair.

5.2 Fluxes

The transition to Pb-free solders has driven the requirement for new fluxes formulated for the higher melting temperature and slower wetting characteristics of Pb-free solders. Compatibility of Pb-free alloys with the flux chemistry is critical for acceptable results in both assembly and rework/repair. Fluxes contained in wire solder, flux pens, and dripper bottles should be fully compatible with the assembly fluxes and cleaning materials. All fluxes should be labelled properly for positive identification at the bench. Fluxes used for Pb-free are available in the same liquid, paste, and gel forms as used in Sn-Pb rework/repair.

NOTE See IPC J-STD-004 for additional information on flux composition and activity level categories.

5.3 Piece parts

5.3.1 General

The transition to Pb-free solder affects the piece part termination finish, not the function of the part. Pb-free through hole and surface mount piece parts still require the same practices and precautions for receiving, storage, handling, preparation, and use. At facilities that rework/repair Sn-Pb and Pb-free assemblies, parts bins, staging locations and piece part packaging should be clearly marked and segregated to prevent unintentional mixing of material.

5.3.2 Termination finishes

Some of the Pb-free finishes being applied to piece part terminations include the following:

- tin (Sn), including matte tin (Sn) and bright tin (Sn);
- tin silver (Sn-Ag);
- tin copper (Sn-Cu);
- tin silver copper (Sn-Ag-Cu);
- nickel palladium (Ni-Pd);
- nickel palladium gold (Ni-Pd-Au);
- tin bismuth (Sn-Bi).

Piece part manufacturers typically offer few, if any, finish alternatives for each part type. When soldered, some of the piece part finish dissolves into the solder, and may cause detrimental intermetallic phases in the finished solder joint. In some cases, a small percentage of an incompatible piece part finish can significantly reduce reliability. An Sn-Pb finished piece part introduced into a SACB soldered assembly is a prime example of this potential for reduced reliability in mixed rework/repair. Annex A lists piece part termination finishes and their corresponding compatibility with solder alloys. Table B.2 lists various termination finishes and their risk for whisker growth.

5.3.3 Area arrays (BGA, CSP, etc.)

One of the most technically challenging issues in the transition from Sn-Pb to Pb-free assembly is the compatibility of the Pb-free BGA placed in an Sn-Pb assembly. There are two areas of concerns: solder joint yield and reliability. If an ordinary Sn-Pb reflow profile is used, the Pb-free balls are not fully melted, producing a non-homogenous mix of Pb-free balls and Sn-Pb solder paste resulting in an unreliable solder joint. The lack of ball collapse may also result in open solder joints. IEC/TS 62647-22:2013 provides more information on area array reliability.

Industry studies have shown that automated X-ray inspection systems can be effectively used to evaluate Pb-free array package solder joints deformities, defects, and irregularities. The X-ray inspection systems may have to be optimized to take into account the contrast differences of the Pb-free solder and the differences in solder fillet shape and length.

5.4 Printed circuit boards/printed wiring boards

5.4.1 Laminate material

PWBs are constructed out of different laminate materials depending on application. PCBs/PWBs (heritage/low T_g) may be damaged during rework/repair using the higher Pb-free processing temperatures. Both high glass transition temperature and high decomposition temperature are important to prevent damage to PCBs/PWBs during rework/repair processes. If these properties are not known, careful heating application (both in temperature and soldering time) during the rework/repair process is critical to prevent damage to the PCB/PWB.

5.4.2 Surface finish

Many PCB/PWB Pb-free surface finishes are available including:

- tin (Sn);
- electroless nickel immersion gold (ENIG);
- immersion silver (Imm Ag);
- organic solderability preservatives (OSP);
- hot air solder leveling (HASL) finishes with SAC and Sn-Cu alloys are also available.

While the surface finish is outside the control of the technician, it may be a factor in determining compatibility with specific termination finish and solder alloys. In addition, ensure that PCB/PWB materials can withstand reflow temperatures without warpage or other damage.

IEC/TS 62647-22:2013 provides more information on Pb-free surface finishes.

5.5 Conformal coatings

Conformal coatings have been used for many years to protect printed circuit board (PCB)/printed wiring board (PWB) assemblies used in many high-reliability applications. Conformal coatings are used in military and aerospace equipment to primarily provide a moisture barrier for electrical circuits including piece part terminations and PCB/PWB traces. It also provides secondary benefits such as protecting the assembly from mechanical damage, dust, fungus, humidity, and other contaminants that may cause corrosion or current leakage.

With the advent of Pb-free materials and processes, conformal coating has an additional positive attribute when used as part of a formal tin whisker mitigation strategy. Unfortunately, the more aggressive fluxes associated with Pb-free solders also mean that greater care should be taken in cleaning the board prior to the application of any coating. This is especially the case after rework/repair, where only limited cleaning facilities may be available.

Conformal coatings may provide one or more of the following features:

- tin whisker mitigation;
- thermal heat conductivity to dissipate heat from piece parts;
- low shrinkage factors during application and curing to prevent coatings from applying stress to laminates or piece parts;
- resilience, hardness, and strength to support and protect piece parts;
- low moisture absorption;
- inorganic composition to prevent fungus growth;
- qualities of electrical insulation.

6 Soldering equipment

6.1 General

Given the concerns with lead contamination and the incompatibility of inter-mixing some Pb-free alloys, each solder alloy, as designated in 5.1.2, should have its own unique set of equipment. This recommendation is to preclude cross-contamination of assemblies through use of common soldering and de-soldering equipment. Segregation of soldering equipment includes but is not limited to: soldering iron tips, extractor tips, sponges, tip cleaning tools and dressings, wire solder, and solder paste. This list should also include hand and supporting tools that cannot be effectively cleaned of all residual solder and might include acid brushes and wooden alignment tools.

6.2 Hand soldering equipment

6.2.1 General hand soldering equipment considerations

Hand soldering equipment for Pb-free soldering is no different than equipment used for Sn-Pb soldering. The same equipment can be used for either application requiring only a tip change to prevent cross-contamination of alloys and process modifications for the slower wetting Pb-free alloys. Improvements in soldering iron technology directly benefit Pb-free soldering, although they were not specifically designed for that purpose.

One equipment consideration is the use of fixed temperature or variable temperature models. Fixed temperature equipment uses heater cartridges that provide better thermal management at the joint by applying additional power to maintain tip temperature under load. Hand soldering equipment with a fixed temperature rating makes it a good choice for rework/repair to minimize process variations. Variable temperature equipment is well suited for rework/repair applications where thermal load requirements vary from CCA to CCA. Many variable temperature equipments have a password-protected lockout feature enabling management to disable the temperature adjustment feature, making them well suited for production and touch-up as well.

The use of nitrogen-assisted soldering irons is another consideration as they help to mitigate problems associated with reworking/repairing Pb-free solders. Nitrogen creates an inert environment around the soldering tip and work area, slowing the oxidation rate. The use of nitrogen can open the process window, reduce flux usage, improve wetting, and produce a shinier, less grainy, finish. On equipment where nitrogen is passed through or near the heater, the nitrogen will be warmed by the heater and this will provide some preheat capability. This may allow the use of lower soldering temperatures further minimizing oxide formation.

For Pb-free rework/repair, power for thermal management and tip protection safeguards are also important features. Equipment used for Pb-free soldering should have enough power to maintain tip temperature under load without extreme swings below and then above the set temperature. Because Pb-free tips oxidize rapidly and wear out much quicker than Sn-Pb tips, features that turn the solder iron on/off as the iron is removed/replaced in the tool stand are highly desirable. Auto set-back/off features that idle or turn the iron off after a period of non-use are also important features for equipment used in Pb-free applications.

6.2.2 Tip selection

Maximum heat transfer to the work area is essential in Pb-free soldering. Selection of a soldering iron tip with the largest mass tip practical for the application is critical to maximize heat transfer. Using equipment with high power and fast thermal recovery is highly recommended. Whenever possible, use the same soldering temperature as with an Sn-Pb solder. Most tip manufacturers have transitioned to 100 % Sn finished soldering iron tips. These tips, when new, are compatible with both Sn-Pb and Pb-free processes. Once tips are used with a specific solder alloy, they should be used only with that alloy.

6.2.3 Soldering iron tip life

Tip life will be substantially reduced with Pb-free solders. Tin is an active metal and interacts with the iron (Fe) plating on the soldering iron tip. Iron leaches more quickly into the higher tin (Sn) content of the Pb-free alloys. Soldering tips used for Pb-free soldering erode approximately three to four times faster than tips used with Sn-Pb. To enhance tip life, most tip manufacturers have increased the thickness of the iron plating on their soldering tips (see Figure 1). Tip inspection should be performed on a daily basis to ensure copper (Cu) washing of the tip core into the solder connection does not occur. Any soldering tip that shows plating cracks, wear areas, or exposed copper (Cu) core should be discarded (see Figure 2). Cleaning oxidation from a Pb-free tip can be a difficult task. Flux-cored solder and sponge or soft brush is recommended. Steel wire brushes, files and other abrasive methods should be avoided as they will wear out tip plating quickly. Chemical methods stronger than authorized fluxes, including tip tinners, should be avoided, especially if they contain zinc chloride, which is an acid.

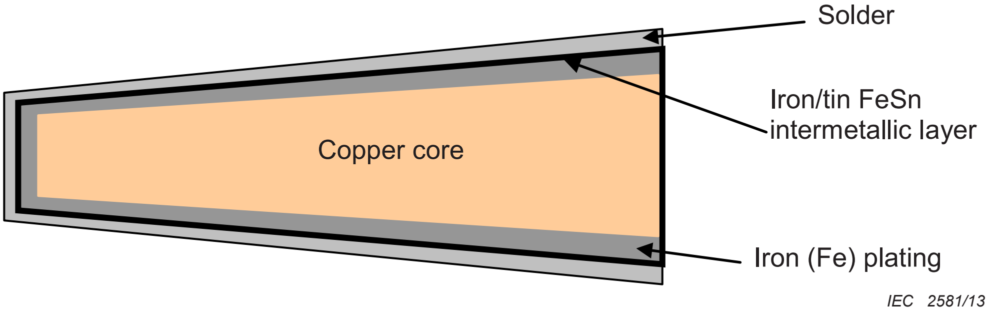


Figure 1 – Soldering iron tip construction

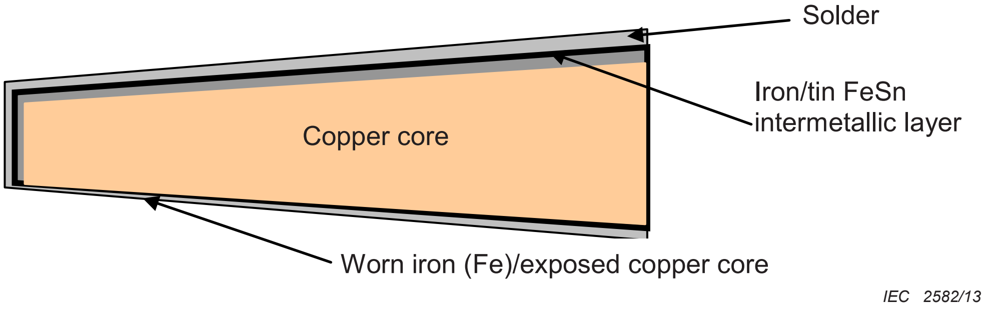


Figure 2 – Worn soldering iron tip

The following recommendations will help increase the longevity of soldering tips:

- Use the lowest possible soldering temperature:
  - 315 °C to 343 °C (600 °F to 650 °F) for SMT applications,
  - 343 °C to 371 °C (650 °F to 700 °F) for through hole applications.
- Keep the tip clean during use by dressing it with a coating of solder.
- Always apply fresh solder to the tip before placing the soldering iron back into the tool stand.

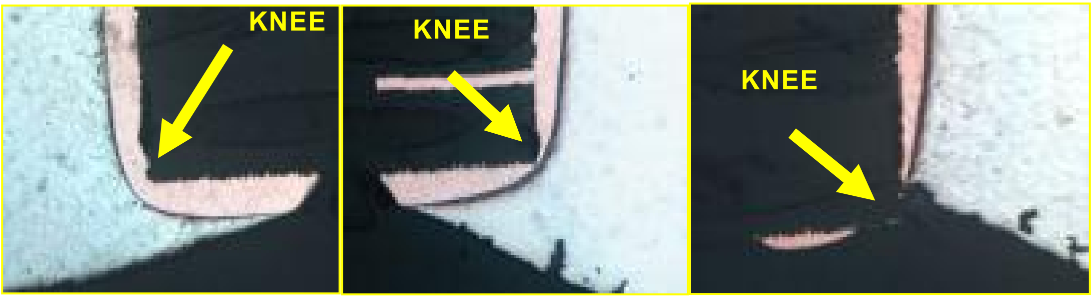
Turn off the soldering iron when not in use for 10 min or longer. If the soldering iron is equipped with a temperature setback feature it should be enabled.

6.3 Fountain soldering

Rework/repair requirements for large through hole piece parts and connectors, high density circuit boards, or piece parts with heat sinks can be accomplished with the use of a solder fountain system. During the rework/repair activity, only the desired specific circuit board areas are subjected to the direct contact of the molten solder and the associated thermal energy.

The increased copper dissolution rate is the most critical issue faced when performing Pb-free solder fountain rework/repair of plated through hole (PTH) connectors and large through hole devices. A known characteristic of solder fountain rework/repair with traditional Sn-Pb alloys is the amount of copper dissolution from the pads and barrel walls of PTH. The introduction of Pb-free alloys, specifically those with high Sn content, including the SAC family and Sn-Cu alloys, dissolve copper (Cu) from PTH pads and barrels faster than Sn-Pb alloys. Studies conducted to date generally support processing guidelines allowing only a single solder fountain rework/repair cycle using SAC and Sn-Cu alloys.

The area of greatest concern for copper dissolution is the point, called the “knee,” where the pad and barrel wall connect. This area of the copper (Cu) pattern typically has the thinnest initial volume of plated copper (Cu). Solder fountain rework/repair of multi-termination or multi-pin devices with Pb-free solder can have significant impact on the reliability of the solder connections. A single rework/repair attempt can completely dissolve all or portions of the copper (Cu) interfacial connection at the knee. Solder may flow over this dissolved area at the knee and may form an acceptable looking solder joint. This hidden defect would place the solder joint at increased risk for premature failure. Figure 3 shows copper dissolution of a PTH measured at 20-, 22- and 36-second fountain dwell time with A30C5 solder.



IEC 2583/13

NOTE Images reproduced courtesy of Flextronics.

Figure 3 – Copper dissolution

Contact time with the flowing solder fountain, preheat temperature and increased solder pot temperature are inter-related factors influencing the rate of copper dissolution during Pb-free fountain rework/repair. Contact time with the flowing solder from the fountain nozzle has the greatest impact on copper dissolution rates. Nozzle design also plays an important role in the rate of dissolution between PTHs near the center of the nozzle (turbulent flow) versus the ends of the nozzle (laminar flow). Higher density PCB/PWB and thick laminates will be more susceptible to the impacts of copper dissolution due to their increased thermal mass and subsequent longer contact time with the solder fountain.

A group of Pb-free solders called “stabilized Sn-Cu” have been identified as alternatives to SAC and Sn-Cu alloys because of their favorable copper dissolution rates. These alloys are doped with small amounts of nickel (Ni) and may include other trace elements. Stabilized Sn-Cu alloys reduce copper dissolution to near Sn-Pb rates and produce shinier, more traditional, solder joints than SAC or Sn-Cu alloys. Stabilized Sn-Cu alloys typically cost less as they contain no Ag.

All PCBs/PWBs have unique and varying characteristics of PTH plating quality and initial thickness. The initial Pb-free alloy used to manufacture the assembly, laminate thickness, base material of the piece part terminations, and ground and power plane connections to the

PTH all have an effect on copper dissolution rates. Therefore, Pb-free solder fountain rework/repair processes will be unique for each assembly and require validation through testing. In cases where an assembly cannot support fountain rework/repair, alternative methods, including convective hot gas, infrared or vacuum extraction methods, should be considered.

All Pb-free solder fountain rework/repair processes and procedures should be validated by engineering to identify the risks and concerns related to laminate damage, piece part damage, and solder joint reliability. IEC/TS 62647-22:2013 provides information on copper dissolution. The following guidelines should also be considered for solder fountain rework/repair of Pb-free assemblies:

- avoid SAC and Sn-Cu alloys;
- use “stabilized” Sn-Cu for rework/repair of SAC and Sn-Cu manufactured assemblies, if possible;
- optimize preheat and solder fountain temperatures to reduce contact time and improve solder mobility;
- reduce the rate of solder flow through the fountain nozzle;
- select nozzle configurations with baffling to minimize solder turbulence;
- identify and record the solder contact time for all solder fountain rework/repair activities;
- increased solder pot temperature required for Pb-free solders requires specific plating finishes for all fountain system surfaces contacting the molten solder, typically a dedicated system is used for Pb-free rework/repair operations;
- increase the monitoring of solder bath alloy contaminate levels as a result of increased pot temperature and higher copper dissolution rates;
- potential for reflow of solder or damage to adjacent piece parts as a result of increased temperature and dwell times should be considered;
- inspect for cracking of vias and piece part barrel walls in the molten solder contact area due to z axis expansion of the laminate material;
- inspect for lifting of pads as a result of higher temperatures and contact time;
- develop alternate procedures for convective, infrared, and vacuum extraction methods.

6.4 Convective soldering equipment

6.4.1 General

Thermal profile issues are discussed in 6.4.2.

6.4.2 Thermal profile issues

Convection reflow processes are the most popular of the operations currently used. Typically, these processes provide a lower temperature difference across a PCB/PWB and the installed piece part solder joints. As with all other reflow systems, uniform temperature across the PCB/PWB is the primary goal. Any thermal profile developed will contain several distinct phases, including but not limited to ramp up, dwell time, maximum temperature, and a ramp down or cooling phase. The critical parameters in the development of an effective convective soldering process involve the determination of the appropriate point where the temperature required to initiate and maintain reflow of all applicable devices is reached versus the rapid heating of the assembly to reduce the effects of oxidation, while protecting the installed parts. Parameters such as ramp rate, peak reflow temperature, dwell time above liquidus, soak time, and temperature gradients across the PCB/PWB should be closely monitored and strictly maintained.

Once the thermal profile for a given process is developed, it is vital that the heater and gas flow rates are constantly monitored to ensure repeatability. Process repeatability requires relating the specific set points to the solder processing rates and then constantly monitoring these zones. Time and temperature rates through the reflow process directly affect repeatability.

Pb-free soldering processes pose additional concerns that should be addressed when selecting the appropriate reflow equipment. These concerns are associated with the higher temperatures involved to maintain the required soak and peak temperature levels associated with various Pb-free solders.

7 General rework/repair considerations

7.1 General

All rework/repair of CCAs should be performed with the solder alloy and piece part finish composition used to manufacture the original assembly unless assembly drawings or rework/repair documentation authorize use of alternate materials. Where alternate materials are authorized for use, they should be clearly identified on all rework/repair documentation. Each electronic assembly should be evaluated on its own reliability concerns and rework/repair options available prior to any rework/repair activities being performed.

As piece part manufacturers transition to Pb-free termination finishes, introducing alternate materials into Sn-Pb assemblies, engineering has the responsibility to establish acceptable procedures that provide for the reliable rework/repair of these assemblies. This may require re-tinning parts to mitigate tin whiskers and specifying alternate flux and cleaning processes to address higher process temperatures, if required.

Engineering studies to date show general backwards compatibility of Pb-free solder alloys and termination finishes with legacy Sn-Pb. Pb-free solder alloys, with the exception of bismuth (Bi) containing Pb-free alloys, show general compatibility with trace amounts of Sn-Pb contamination. Industry still has concerns regarding the soldering of Pb-free area array packages with Sn-Pb solder. It can be accomplished, but at Pb-free soldering temperatures instead of the soldering temperatures of the Sn-Pb solder paste. There are long term solder joint reliability concerns resulting from the mixing of solder alloys (Pb-free and Sn-Pb).

Deviation from the original assembly materials may in some cases result in the mixing of incompatible materials reducing the reliability of the assembly. Alternate materials should be thoroughly assessed for compatibility with the original assembly materials prior to authorization for use in rework/repair. Positive identification of the solder cannot be made through visual inspection alone. While most Pb-free solder joints exhibit steeper wetting angles, reduced wetting and less shiny appearance when compared to Sn-Pb, these visual characteristics will not identify the solder type used.

In OEM and CM facilities, solders used in assembly should be well documented with information available to make informed rework/repair decisions. In situations where the repair technician does not have access to assembly documentation, the solder alloy used in assembly may be very difficult to determine. Technicians should always consult with the technical documentation of the assembly to determine solder alloy used in assembly.

7.2 Rework/repair procedure order of precedence

The order of precedence in rework/repair procedure selection should be as follows:

a) rework/repair procedures identified in applicable documentation (i.e., commercial maintenance manuals, tech orders, product specific documentation, FAA’s ARINC Project Paper 671);
b) rework/repair procedures described in the applicable lead-free control plan (LFCP) identified in IEC/TS 62647-1:2012;
c) rework/repair procedures identified in IPC-7711/21.

NOTE At the time of the preparation of this document, it is believed that the procedures contained within IPC-7711/21 need not be changed or modified based solely on the presence of a Pb-free alloy.

7.3 Technician training

Formal classroom training in through hole and surface mount technology (SMT) rework/repair techniques including specific training in Pb-free rework/repair to IPC-7711/21 or equivalent internal documents is recommended. This training program should provide both theory and substantial hands-on application. Prospective rework/repair candidates should have advanced soldering experience.

Technician training should provide an overview of the following information:

- PCB/PWB land and pad finishes;
- hand soldering of through-hole and SMT Pb-free piece parts;
- rework/repair of Pb-free assemblies;
- cleaning issues;
- Pb-free visual inspection guidelines;
- X-ray inspection of hidden interconnects (BGA, QFN, etc.);
- documentation for Pb-free operation.

7.4 Pb-free rework/repair considerations

7.4.1 General

The processes used to rework/repair CCAs assembled using Pb-free solders are similar to Sn-Pb solder. The same type of equipment and process steps used for Sn-Pb soldering can be used for Pb-free soldering. Proper training is required to understand the process and appearance differences when using Pb-free solders to ensure the quality and reliability of the assembly is maintained. When multiple alloys are present on the production floor, multiple rework/repair lines should be established and kept separate. All materials and equipment used should be segregated to preclude contamination of either line. Not all of the materials used for Pb-free rework/repair are compatible with Sn-Pb solder and could degrade the solder joint reliability. While specific alloy compositions have specific traits, several general process and solder processing considerations of Pb-free solder apply in the rework/repair process.

7.4.2 General process considerations

General process considerations are discussed in the following items:

- All assemblies should be preheated prior to any rework/repair activity.
- Higher processing temperatures may cause measling, delamination, and/or lifted pads.
- Higher processing temperatures may cause plastic parts to melt or deform.
- Higher melting temperatures may cause thermal shock to the piece part.
- Piece part termination finish as well as PCB/PWB finish should be compatible with the solder alloy.
- When convective hot gas rework/repair is to be established, specific profiles should be developed and used for the alloy type and thermodynamics of the assembly.
- Higher processing temperatures affect the applied stresses or strains due to the coefficient of thermal expansion (CTE) mismatch between the laminate material, the glass fiber, and copper (Cu).
- Moisture sensitive devices (MSDs) in Pb-free soldering should be properly preconditioned.
- Piece part maximum core temperature ratings should not be exceeded.

7.4.3 Solder processing considerations

Solder processing considerations are discussed in the following items:

- Pb-free solders have a higher melting point.
- Soldering iron tips will oxidize much faster with Pb-free solders.
- Conductive soldering may require longer dwell times at higher process temperatures. This is especially true on high mass through-hole piece parts and assemblies with large thermal ground planes.
- Pb-free soldering has a tighter process window.
- Pb-free solder joints may be more difficult to rework/repair.
- Solderability indicators such as wetting, wetting angles, and joint appearance will generally be different. Inspection criteria such as those contained in the IPC A-610 can be used to help establish acceptance.
- Higher temperatures and extended dwell times may increase oxidation, hindering the soldering process.
- Solder fountain rework/repair attempts of Pb-free assemblies may be limited due to copper dissolution.
- Segregation of Sn-Pb and Pb-free solder materials and equipment should be exercised.
- Rework/repair should minimize excessive heating of adjacent piece part solder joints.

7.4.4 Flux considerations

While Pb-free flux formulations are different from Sn-Pb flux formulations, their use remains essentially unchanged. All flux applied by flux pen or dripper bottle should be applied in small controlled quantities (sparingly) to prevent intrusion into unwanted areas and match (or be compatible with) the flux formulation used in the flux cored wire solder. Any remaining inactivated residual flux may cause corrosion or other unwanted issues and should be cleaned off.

The amount of thermal energy applied to a connection affects the flux performance. Significant increases in soldering iron temperatures should be avoided. Too high a soldering iron temperature will cause the flux to evaporate before it can properly activate, remove oxidation, and promote solder wetting. Pb-free rework/repair will usually require an increase in the solder wire flux core from 1,0 % common in Sn-Pb, to amounts in excess of 3 %. Pb-free formulated fluxes designed to withstand higher process temperatures, higher oxidation rates and the poor wetting ability of Pb-free, may also require some modifications in rework/repair cleaning processes. See 10.1.

General guidance on flux considerations:

- Use flux sparingly to prevent intrusion under adjacent parts.
- Higher melting points of Pb-free solder will require higher activation temperature flux chemistry to achieve adequate wetting.
- Use flux formulated for Pb-free processing.
- The flux should not spatter or fume excessively at Pb-free soldering temperatures.
- The flux should have activator systems designed to solder a variety of Pb-free PCB/PWB and piece part finishes.
- The flux should be active enough and remain active during tip contact to compensate for the reduced wetting of Pb-free alloys.
- Due to the higher processing temperatures, flux residues may be more difficult to remove and require modifications in cleaning processes.

8 Pre-rework/repair processes

8.1 Alloy identification

8.1.1 IPC/JEDEC J-STD-609A

IPC/JEDEC J-STD-609A identifies an industry approved marking and labelling method to identify materials (laminate material, CCA surface finish, solder alloy (Pb-free or Sn-Pb solder)) and conformal coating family used in the manufacturing process. IPC/JEDEC J-STD-609A also identifies a marking system for individual piece parts termination finish identification and a labelling system for piece parts packaging. The use of IPC/JEDEC J-STD-609A whether invoked voluntarily or by contract, can aid in the rework/repair process by providing valuable information on:

- the laminate material used in the CCA construction per IPC-4101;
- CCA laminate material halogen content;
- CCA surface finish;
- solder alloy or alloys (Pb or Pb-free) used in reflow, wave or other soldering process;
- the conformal coating type applied during the assembly process;
- piece parts termination finishes when assembled parts are marked;
- piece parts termination finish when identified on exterior label of replacement component packaging;
- the maximum piece part temperature rating when identified on exterior label of replacement component packaging.

Table 1 provides a guide to the IPC/JEDEC J-STD-609A assembly and piece part marking methods used to identify laminate type, halogen presence, CCA surface finish, solder(s), and conformal coating. Refer to IPC/JEDEC J-STD-609A for additional information on board marking and labelling requirements.

Table 1 – Assembly and piece part marking methods

PCB/PWB base material HF = Halogen free	**Bare board plating finish**	**Assembly solder used (reflow, wave, other)** These codes also identify piece part termination finishes	**Conformal coating type**
/ 92 HF	b0	e0 Contains Pb	ER Epoxy resin
/ 95 HF Aluminum hydroxide Flame retardant T_g 110 °C to 150 °C	b1 Pb-free HASL Sn alloys (with no bismuth (Bi) or zinc (Zn) content)	e1 Tin – silver –copper Sn-Ag-Cu “SAC” types	UR Urethane resin
/ 99 HF Bromine Flame retardant with inorganic fillers T_g 150 °C min.	b2 Immersion silver (Imm Ag)	e2 Sn alloy combinations (with no Bi or Zn content) Excludes Sn-Ag-Cu	AR Acrylic resin
/ 126 HF Bromine Flame retardant with inorganic fillers T_g 170 °C min.	b3 Tin (Sn) Electrolytic or immersion	e3 Tin (Sn)	SR Silicone resin
Other types are available	b4 Gold (Au) Electrolytic or immersion Electroless nickel immersion gold (ENIG) Nickel-gold (Ni-Au)	e4 Precious metal (with no Sn content) Silver (Ag) Gold (Au) Nickel-palladium (Ni-Pd) Nickel-palladium-gold (Ni-Pd-Au)	XY Paraxylylene
Base material “slash” # is followed by “HF” if laminate is halogen free	b5 Screened carbon ink	e5 Other alloys containing Sn (with no Bi content) Tin-zinc (Sn-Zn) Tin-zinc-“other” (Sn-Zn-xx)	
For PCBs/PWBs made with more than one grade of laminate – identify the material with the lowest temperature rating	b6 Organic solderability preservative (OSP)	e6 Alloys containing Bi	
		e7 Low temp solders (≤ 150 °C) containing indium (In) (with no Bi content)	
	b7, b8, b9 Unassigned	e8, e9 Unassigned	
Example: / 95 – HF – b2 – e1 – e2 – AR		Multifunctional epoxy laminate, halogen free, immersion silver PCB/PWB finish, SAC solder used for reflow and a tin alloy (with no Bi or Zn content) used for wave, acrylic resin conformal coating	

8.1.2 X-ray fluorescence (XRF)

XRF is a technology used in industry to positively identify the constituent metals of solder alloys, termination finishes, and PCB/PWB land/pad finishes. XRF exposes the material under test to high energy X-rays. The reflected energy is used to identify the elemental characteristics of the item under test.

XRF equipment is available in both handheld and desktop models and varies widely in features, targeting methods, software, and accuracy. While there is variation amongst manufacturers' models and types, desktop models are usually more accurate as they have smaller column sizes, better software, more advanced targeting and aiming ability, motorized stages for accurate positioning, and better resolution. Desktop units are typically more expensive than handheld units. Handheld units offer affordability and portability but lack the refinements and accuracy of desktop units. In general terms, handhelds and desktops can handle homogenous bulk solder joint identification with reasonable accuracy, but accurate identification of piece part terminations is better suited for desktop units due to their more advanced aiming and targeting features.

8.1.3 Pb swabs

Pb swabs are an inexpensive method of providing a go/no go test for Pb presence. This test method has an accuracy, claimed by the swab Supplier, of 0,1 %. Pb swabs identify only Pb, so it may be a useful tool for determining whether a solder alloy or termination finish is Pb-free, but is not useful to determine the constituent metals in a Pb-free alloy.

Pb swabs are based on the reactivity of Pb with certain compounds capable of forming strongly colored complexes with Pb. When Pb swabs are used, a pink color that is specific for Pb develops within 30 s and is stable for hours. Pb swabs have an indefinite shelf life, provide rapid results, are low cost, and are non-destructive and non-hazardous.

Pb swabs can introduce risks as they may leave chemical residues. It is currently not known if these residues will interact with circuitry materials causing short and/or long-term reliability issues. Testing should be performed to validate compatibility of Pb swabs with assembly materials before implementation in any assembly or rework/repair process.

Because of the above risks, the use of Pb swabs is not recommended for determining Pb content.

8.2 Piece part and CCA preparation

8.2.1 General

The cleanliness of terminals, piece part terminations, conductors, and printed circuit board (PCB)/printed wiring board (PWB) surfaces should be sufficient to ensure solderability. When required, the surfaces should be cleaned by either chemical methods or tinning. Cleaning should not damage the piece part, piece part terminations, or conductors. Knives, emery cloth, sandpaper, sandblasting, braid, erasers, or other abrasives should not be used.

8.2.2 Piece part preparation

8.2.2.1 Dry bake of moisture sensitive piece parts

Many electronic parts, especially surface mount parts, have a moisture sensitivity level (MSL) rating that identifies a parts susceptibility to moisture absorption. IPC/JEDEC J-STD-020 provides MSL ratings and identifies conditioning requirements for each MSL level. Refer to IPC/JEDEC J-STD-033B.1:2007 for bake out requirements and floor life for each MSL rating.

8.2.2.2 Hot solder dip for tin whisker mitigation

When hot solder dipping for tin whisker mitigation, use an approved, documented process.

8.2.3 CCA preparation

8.2.3.1 Conformal coating removal

The conformal coating should be removed and replaced in accordance with IPC-7711/21 or other applicable documentation. Methods of coating removal vary depending on the coating type used and may include use of chlorinated solvents, heat application, mechanical abrasion, and micro-abrasive blasting techniques.

8.2.3.2 Preheating of CCAs prior to rework/repair

Preheating is recommended for every SMT rework/repair process. Preheating minimizes the risk of thermal shock to the laminate and piece parts. The technician should employ a preheat method which heats the rework/repair areas of the assembly as evenly as possible.

Preheating is typically accomplished by either a temperature controlled conductive heating plate, a controlled convective heating device, or a system that combines both conductive and convective heating.

Controlling both the rate of temperature ramp up as well as the soak temperature is critical to avoiding damage and optimizing the piece part installation or removal process. The assembly is ramped at an acceptably safe rate until it reaches a target temperature at which it is thermally soaked or evenly heated. To avoid thermal shock, the ramp rate should be between 2 °C to 4 °C (4 °F to 9 °F) per second until the appropriate temperature is reached. Replacement piece parts should be preheated along with the CCA to the recommended levels. Recommended soak temperatures are as follows:

- 80 °C (176 °F) for simple, single and double-sided CCAs;
- 100 °C (212 °F) for epoxy/glass and SMT through hole CCAs with up to six internal layers;
- 120 °C (248 °F) for ceramic, polyimide, and high mass CCAs with seven or more internal layers.

NOTE If the preheater does not have a temperature readout, a thermocouple and digital thermometer can be used to determine CCA surface temperature.

Preheating accomplishes the following objectives:

- it minimizes thermal shock by elevating the assembly temperature to a level closer to solder melt temperature;
- it minimizes solder reflow time;
- it overcomes the heat dissipation characteristics of the assembly;
- it avoids adjacent solder connection reflow on densely populated assemblies.

9 Rework/repair processes

9.1 General

Conformal coating removal, piece part removal, and pad preparation should be executed as per approved procedures. See 7.2.

9.2 Conductive hand soldering

There are some notable differences between Sn-Pb and Pb-free hand soldering:

- Sn-Pb eutectic solder melts at 183 °C (361 °F);
- the leading group of Sn-Ag-Cu and Sn-Cu Pb-free solders melts between 217 °C (423 °F) and 227 °C (440 °F);
- higher Pb-free melting points (compared to Sn-Pb) may require:

  - higher initial soldering iron temperatures;
  - longer dwell times on the termination;
  - increased thermal build-up in the laminate and land/pads;
  - increased potential for laminate or conductor damage;
  - increased “Z” axis expansion of the assembly may cause cracking of plated through holes;
- a process should be established requiring designated Sn-Pb and Pb-free soldering irons or changing soldering iron tips in order to prevent cross-contamination.

Higher Pb-free solder melting temperatures do not automatically equate to higher solder tip temperatures. With a clean tip of the proper mass and shape, 315 °C (600 °F) to 343 °C (650 °F) should meet most SMT soldering requirements. The higher solder melting temperatures require more of the tip’s available heat to be transferred to the work surface. This is accomplished by paying close attention to tip mass and shape to provide maximum contact area, not by automatically turning up the soldering iron temperature. When CCA thermal dynamics require using higher temperatures, tip oxidation becomes an issue, making it more difficult to maintain a properly wetted tip. The soldering iron should remain clean and coated with the solder alloy. Pb-free solders are more sensitive to the effects of a dirty soldering iron. Higher soldering temperatures can result in the soldering iron tip becoming oxidized if not cleaned and coated. The soldering performance can be improved by more active solder flux and soldering in a nitrogen atmosphere.

The Pb-free soldering process, just as in traditional eutectic Sn-Pb soldering, requires proper materials selection, preparation, and execution. The Pb-free soldering process still requires the formation of a heat bridge for rapid heat transfer, application of solder, and the removal of the solder and heat source at the same time. In Pb-free rework/repair, the process may require additional time to achieve adequate wetting, but has a tighter process window to achieve adequate results.

Pb-free solders typically do not wet as well as Sn-Pb solders. Wetting speeds will vary among different Pb-free alloys due to differences in surface tension, flux type, and melt temperatures. Due to the higher surface tension of most Pb-free solders, icicles and bridging may be more prominent until technicians become comfortable with the nuances of Pb-free rework/repair. These issues can be minimized or avoided using the following techniques:

- ensure the tips are designed for Pb-free soldering;
- the soldering iron should remain clean and “tinned” with the solder alloy;
- use the same alloy originally used for production assembly;
- minimize the use of additional liquid flux during the piece part installation;
- select the lowest possible working temperature for any application;
- when applicable, preheat the circuit board before reworking/repairing to improve soldering efficiency;
- choose the largest possible soldering tip to allow for full coverage of the solder pad to allow for the best thermal control of the process with minimum time on the termination to perform the application;
- the use of higher “thermal capacity” tools, especially in Pb-free applications, will allow the use of lower temperatures and better quality workmanship;
- ensure the flux content in the wire is at least 2 % to 3 % by weight;
- avoid prolonged contact times;
- avoid needless rework/repair of the connection;
- enable the “Setback” or “Auto-Off” features of your soldering stations to help extend tip life;
- remove all flux residues using approved procedures.

9.3 Convective soldering process

9.3.1 General

For convective hot gas rework/repair specific profiles should be developed and used for the alloy type and thermodynamics of the assembly. Sn-Pb profiles should not be used with Pb-free assemblies and vice versa. Conversion of Sn-Pb profiles to Pb-free profiles is more complicated than adding 27 °C (80 °F) (typical) to the temperature limits of the Sn-Pb profile. Specific concerns are detailed herein.

9.3.2 Solder paste handling

Proper identification and segregation of Pb-free solder paste is required to prevent cross-contamination.

9.3.3 Paste printing

The printing process for Pb-free pastes is equivalent to the process used for Sn-Pb solder pastes. It is important to follow guidelines recommended by the paste manufacturers to accommodate paste specific requirements. In general, the Pb-free paste characteristics yield similar performance in terms of stencil life, aperture release, print definition, and repeatability. One important factor that should be considered in purchasing stencils is that Pb-free pastes have higher surface tension and do not wet or spread on the surface of pads as easily as eutectic solder pastes. This can lead to exposed pad finish material after reflow soldering, which can be rectified by modifying the stencil aperture designs to increase the paste coverage on the pads. Stencils used with Pb-free pastes should not be used with Pb-bearing pastes due to possible cross-contamination.

9.3.4 Reflow process

9.3.4.1 Process considerations

The most demanding thermal process in a manufacturing environment is hot gas rework/repair. The high temperatures required in small, localized areas for long periods of time create several impacts that should be monitored on the assembly, including maximum piece part body temperatures, PCB/PWB laminate survivability, and maximum temperatures of both adjacent and bottom-side piece part solder joints. The objective of the rework/repair process is to mimic, as closely as possible, the primary attachment SMT reflow process to ensure that solder joint formation (and reliability) are similar. There are several challenges in making assembly reflow and hot gas rework/repair processes identical. The main difference between the two processes is that assembly reflow is a full heat excursion, while the hot gas rework/repair process is a local heat excursion. This localized heat creates local stresses within the piece part and the PCB/PWB.

In general, there are some differences of BGA rework/repair with Pb-free solder balls compared to that with Sn-Pb solder balls:

- the melting temperature of Pb-free solder increases to 217 °C (423 °F). As a result, longer heating times are required compared to conventional Sn-Pb joints. The expected total process time will vary from one product to another, but a rework/repair cycle time range of 7 min to 10 min per piece part is not uncommon;
- to reach proper wetting of the Pb-free solder on the pad, the temperature at the solder joint has to reach approximately 230 °C (446 °F);
- the alignment of new BGA parts should be as accurate as possible, because unlike Pb BGAs, there is less self-centering with Pb-free BGA parts.

9.3.4.2 Prebake

Prebake the PCB/PWB to remove the absorbed moisture content. The typical prebake temperature range is from 90 °C to 125 °C (194 °F to 257 °F). The time and temperature are dependent on assembly exposure and thickness. Refer to IPC/JEDEC J-STD-033B.1:2007 for further guidance.

9.3.4.3 Machine configurations

Higher thermal profiles require more support from bottom heaters. In general applications, 4 000 W is the minimum wattage for bottom heaters. Nozzle designs with some form of turbulence generator can help to reduce temperature deltas across the package. Nitrogen atmospheres reduce solder viscosity, but are not required for low and medium complexity assemblies.

9.3.4.4 Profile development

An improper profile may result in the lifting of pads if the solder is not fully molten before removal is attempted. On the other hand, if the piece part is heated extensively, damage can occur to surrounding piece parts on the PCB/PWB. When soldering any piece part, a suitable thermal profile ensures that the piece part and PCB/PWB are not overheated and all the solder joints are reflowed.

It is necessary to monitor the temperatures at critical locations on the assembly to ensure that the temperature of the solder joints, the temperature difference across the site, and the temperature of the adjoining piece parts are within acceptable limits. A common method of monitoring employs the use of a portable data logging device that monitors thermocouples mounted onto the assembly at various locations during the reflow process. It is recommended that the thermocouples be attached as close to the corners and in the center of large piece parts (i.e. BGAs) as possible.

The maximum peak temperature delta across the part should be in the range of 5 °C to 10 °C (41 °F to 50 °F). This requires allowance for sufficient preheat “soak” time for the heat to be absorbed across the product assembly. Soak times are dependent on the organic component of the paste. Higher flux percentages require longer soak times.

Thermocouples should also be placed to ensure that adjacent piece parts do not exceed safe temperatures. The maximum allowable rework/repair temperature limits for Pb-free parts is regulated by the IPC/JEDEC J-STD-020 standard.

Thermal protection/screening may be required to meet specifications and to avoid unintentional reflow. There are many deflective methods available, ranging from metal foil to ceramic containing materials to gypsum based putty that assist in protecting adjacent piece parts from excessive heat exposure.

A set of best practices created for Pb-free BGAs requires that the peak temperature be between 230 °C and 245 °C (446 °F and 473 °F). Time above liquidus should be between 35 s and 65 s. Excessive thermal exposure can damage the PCB/PWB material and create thicker inter-metallic compounds.

9.3.4.5 Site preparation

The piece part attach site should be dressed by using copper wick, constant vacuum removal, or other approved method to prepare the attach pads for receiving the rework/repair piece part. A smooth, level, solderable surface is desired. Any damage incurred during site preparation should be resolved.

9.3.4.6 Rework/repair concerns

Piece parts to be used for rework/repair should be handled in accordance with the IPC/JEDEC J-STD-033B.1:2007, Tables 4-1, 4-2, 5-1 and 7-1 requirements.

Replacement of the piece part occurs using the same profile after the PCB/PWB has cooled to baseline temperature.

Localized rework/repair site cleaning may be required per individual product specifications.

9.3.4.7 Process validation

Successful replacement verification should include automated or manual visual inspection and X-ray confirmation for any “hidden” solder joints. Electrical test should also be performed where applicable to confirm successful rework/repair operations.

10 Post-rework/repair processes

10.1 Cleaning

The cleaning effort conducted after completing the rework/repair activities should consider the method of cleaning to be used and ensure the cleaning chemistry is compatible with the flux residues present. Typically, rework/repair activities are executed on completed assemblies, and cleaning of the flux residue is isolated to the area of repair. When other piece parts or devices on the finished assembly are not tolerant of “system” cleaning, the cleaning effort is conducted using “localized” cleaning techniques. This type of cleaning is commonly done by brushing the cleaning chemistry onto the flux residue to dissolve the material followed by rinsing the area to remove contaminates. These efforts may require the area to be masked off to contain the cleaning chemistry preventing contaminants dissolved in the cleaning media to spread into other areas of the assembly. Multiple cleaning sequences may be required to ensure all flux residues have been successfully removed from the area of repair and other piece parts in proximity. All masking materials, if used, should be removed and any adhesive residue cleaned from the assembly.

The entire assembly, including the area of repair, should meet the documented cleanliness requirements and should be inspected to determine the presence of any particulate matter, flux residue, or any residual cleaning chemistry.

10.2 Inspection

The resulting Pb-free solder joints from rework/repair are often dull and exhibit a grainy surface. Solder joints may also have higher wetting angles as Pb-free solder does not flow as easily as Sn-Pb solder and may not form the typical concave fillet. The IPC J-STD-001 and the associated Space Addendum requires 100 % inspection of all reworked/repaired solder joints and allows dull, matte, or grainy appearances, provided that such appearance is normal for the materials and processes involved. Technicians and inspectors will have to adjust their visual criteria for an acceptable solder joint to allow for these differences. Although the visual criteria may be somewhat different than Sn-Pb, the acceptability requirements of IPC-A-610 have not changed.

The inspector should receive formal classroom training to applicable standards and methods for disposition of defects. Training should include the differences in appearance between Pb-free solder joints and Sn-Pb solder joints. Additional inspection criteria will be required when multiple solder alloys are used in the rework/repair process.

10.3 Reapplication of conformal coating

During rework/repair, the conformal coating is removed in accordance with applicable documentation such as IPC-7711/21 and replaced per manufacturer’s instructions. See 5.5 related to conformal coating and 8.2.3.1 related to conformal coating removal for additional information.

Annex A
(informative)

Termination finishes

Table A.1 – Piece-part terminal and BGA ball metallization solder process compatibility risk (see IEC/TS 62647-22:2013)

Terminal or PCB/PWB metallization [a]	**Sn-Pb solder**	**SAC solder (SMT and wave)**	**Sn-Cu or Sn-Cu-Ni wave solder**	**Sn-Ag solder**
Sn-(3 wt % to 5 wt %)Pb	None	Low [b,c]	Low [c]	Low [b,c]
Sn-(37 wt % to 40 wt %)Pb	None	Medium [b,c]	Medium [c]	Medium [b,c]
Sn, reflowed/fused/dipped [d]	None	None	None	None
Sn, bright electro-deposit – avoid [e]	Shelf life [f,g] Solder voids [h]	Shelf life [f,g] Solder voids [h]	Shelf life [f,g] Solder voids [h]	Shelf life [f,g] Solder voids [h]
Sn, matte electro-deposit [d]	Shelf life [f,g] Solder voids [h]	Shelf life [f,g] Solder voids [h]	Shelf life [f,g] Solder voids [h]	Shelf life [f,g] Solder voids [h]
Sn-Bi (2 wt % to 5 wt % Bi content in terminal plating, which results in ~0,2 wt % to 0,5 wt % in most final SMT solder joints); Bi finishes are not recommended for wave solder [i]	SMT low to medium [j]	None SMT	None SMT	None SMT
Antimony bearing	No data	No data	No data	No data
SAC dipped [k]	None	None	None	None
Sn-Cu electro-deposit – avoid [l]	None	None	None	None
Sn-(0,5 wt % to 0,9 wt %)Cu-0,05Ni plated or dipped avoid [l]	None	None	None	None
Ni-Pd-Au electro-deposit	Low [m]	Medium	Medium	Medium

[a] All alloy percentages are given in weight percent.

[b] Some investigators have found that an Sn-Ag-Pb alloy can form having a melting point of 178 ºC, which may impact processing. See [23], [24].

[c] Pb from the finish can contaminate the wave solder bath.

[d] Organic co-deposited compounds are typically removed from the Sn coating during the reflow/fusing process.

[e] Bright Sn finish is not recommended due to tin whisker propensity of bright tin plating. Bright Sn is defined as having 0,2 % to 1,0 % carbon content with 0,5 μm to 0,8 μm grain size. Matte Sn is a film with lower internal stresses and larger grain sizes than bright Sn. Matte Sn plating is defined as having 0,005 % to 0,050 % carbon with 1 μm to 5 μm grain size. See [25].

[f] Co-deposited organics can limit shelf life and/or solderability.

[g] Insufficient coating thickness can result in reduced shelf life. Recommended thickness is 10 μm nominal (8 μm minimum) when no Ni under-plating is used. The minimum thickness should be 2 μm when a Ni under-plate is used to ensure shelf life. See [25]. The lower rate of Ni diffusivity retards Ni-Sn intermetallic formation thus limiting the stresses which would drive tin whisker growth.

[h] In right Sn or thicker matte Sn coatings, co-deposited organics can yield solder voids during solder reflow for some solder joint geometries.

[i] Not recommended for pin through-hole, Bi may accumulate in wave solder pot.

[j] Environmental reliability should be substantiated on the programs considering small amounts of total Bi in the final solder joint.

[k] There may be tin whisker risk with SAC alloy dipped finishes where they become thin around corners and edges. Note that thicker coatings tend to isolate the intermetallic layers and dissipate whisker formation inducing stresses.

[l] Avoid Sn-Cu due to the tin whiskering propensity of this plating. Sn-Cu provides all of the raw materials for generating the intermetallics that drive Tin whisker formation. Tin whiskering propensity is high. Hot solder dipped Sn-Cu is being used in some applications. See [25].

[m] Electrodeposited plating should be analyzed to ensure that the final solder joints will not be susceptible to strength reduction associated with Au embrittlement.

Table A.2 – BGA piece parts risk

CBGA/CCGA/ BGA/C4 ball metalization	**Sn-Pb solder**	**SAC solder**	**Sn-Cu or Sn-Cu-Ni**	**Sn-Ag solder**
Sn-37Pb (includes Sn-36Pb-2Ag metallization)	None	Unlikely combination	Unlikely combination	Unlikely combination
Sn-90Pb	None	High [a]	Unlikely combination	High [a]
Sn-Cu	No data	None	None	None
SAC	Medium [b]	None	None	None
Cu wire column [c]	Low	Low	Low	Low

[a] See [26]. In some cases, tilting of CCGA columns was observed after Pb-free reflow.

[b] Mixed alloy (SAC ball/Sn-Pb paste or Sn-Pb ball/SAC paste) combinations are not as reliable as the unmixed (SAC ball/SAC paste or Sn-Pb ball/Sn-Pb paste) combination.

[c] The Cu wire column typically uses a wire that is 254 μm in diameter, 1 524 μm long and having a finish of 0,05 μm Sn. See [27].

Annex B
(informative)

Tin whiskers

B.1 Tin whisker growth mechanisms

The mechanism(s) by which tin whiskers grow has(have) been studied for many years. No single, widely accepted explanation of this mechanism has been established but there are some commonly agreed factors involved in tin whisker formation. Tin whisker growth is primarily attributed to stresses in the Sn plating. These stresses may be from many sources including:

- residual stresses in the Sn resulting from the plating process. Electrodeposited finishes are considered most susceptible due to stresses built into the finish as a result of the plating process;
- formation of intermetallic compounds (i.e. Cu_6Sn_5) especially within the tin (Sn) grain boundaries;
- compressive stresses such as those introduced by applying torque to a nut or a screw;
- bending or stretching of the surface after plating;
- scratches or nicks in the plating introduced by handling;
- coefficient of thermal expansion mismatches between the plating material and substrate;
- historically, elevated temperature storage (typically 50 °C (122 °F)) has been reported to be the optimum environment for whisker growth to occur. However, very recent studies by international consortia have produced contradictory findings. Further studies are attempting to quantify the effects of environmental conditions such as temperature cycling, elevated temperature and humidity and even prolonged ambient storage. Bright tin (Sn) finishes seem to be worse than matte finishes due to some influence of the organic compounds used as brighteners and/or their smaller grain size structure.

B.2 Tin whisker mitigation techniques

Mitigation methods for tin whiskers are implemented during the design and manufacturing of an assembly and include: hot solder dip reprocessing, conformal coating, specification of piece part termination finish, under-platings, annealing, and piece part termination pitch. At the rework/repair bench, mitigation methods are typically limited to hot dip tinning of parts and replacement of conformal coatings.

B.3 Hot solder dip

Reprocessing of piece part terminations is defined as a method for removing the Pb-free alloys from the termination surfaces and replacing the Pb-free with an Sn-Pb solder coating. This can be an effective mitigation of tin whiskers in the areas of the terminations that have been reprocessed. However, if the reprocessing does not extend all the way to the body of the piece part, the area left with Pb-free solder finish can grow tin whiskers. The risk is greatly minimized by hot solder dipping, but not eliminated. So, additional mitigation techniques should be employed for critical (i.e., flight safety) situations.

B.4 Conformal coatings

Conformal coatings can be a mitigation technique for tin whiskers if used with the appropriate precautions and piece part termination spacing. Because of the variances described in 5.5, each coating type should be evaluated for performance and effectiveness as a tin whisker mitigation process for a given application. See 5.5 and 8.2.3.1 for additional information.

B.5 Specification of piece part termination finish

Specification of piece part termination finishes occurs during the assembly's design. The assembly's parts list should be specific as to what alloy the termination finish is. Unfortunately, this is not always the case and the finish needs to be determined. The technicians often do not have this information available to them.

B.6 Under-platings/annealing

Many alternative platings have been used or proposed for use either as a singular application or in combination with other materials as finishes with nickel (Ni)-palladium (Pd)-gold (Au). The use of nickel (Ni) is also frequently used as an under-plating (underlay) on copper (Cu) by at least one piece part manufacturer with good success and no reports of tin whisker growth. However, under-plating does not ensure tin whiskers will not grow. Some recent experiments have shown that tin whiskers will grow on Sn-Ni-Cu assets subjected to elevated storage temperatures and humidity such as 60 °C / 95 % RH. Alternate platings should be evaluated on a case-by-case basis depending upon the intended application and environments.

At least [27] reports that annealing treatments have been found to be promising in mitigating tin whisker growth on matte Sn platings. It should be noted however, that matte Sn, without further mitigation, is not recommended for high reliability electronics or authorized for military applications. Exposure to temperatures from 150 °C to 200 °C (302 °F to 392 °F) for one hour or more is required for proper annealing of matte Sn. However, this publication also indicates that bright Sn platings do not accept annealing very well as bright tin (Sn) tends to blister when exposed to the required temperatures. Whether or not annealing is to be used should be evaluated on a case-by-case basis depending upon the intended application and environments.

B.7 Piece part lead pitch

Although numerous experiments and research conducted by academia and various consortiums, OEMs and different working groups (CALCE, iNEMI, JG-PP) have shown that whisker growth is typically less than 100 μm and usually less than 10 μm, some experiments have proven that whiskers can grow to lengths over 100 μm in length with some approaching (and surpassing) the current termination pitch of 125 μm used on many piece parts. Termination pitch versus whisker length will become an ever increasing dilemma as piece parts and their associated termination pitches continue to shrink in size. As the termination pitch decreases, the propensity for shorting between terminations will increase. Increased vigilance and attention to detail should be imposed during the designing of future electronics assemblies.

Table B.1 gives tin whisker information and Table B.2 presents piece part termination tin whisker risks.

Table B.1 – Tin whisker information (see IEC/TS 62647-22:2013)

Lead finish	Solder alloy compatibility	Note
Bright Sn		Bright acid Sn contains co-deposited organic materials to produce the "bright" appearance. These co-deposited organic materials have a detrimental impact on solderability and have been shown to be more prone to produce tin whisker phenomena.
Matte Sn		Industry studies have shown that matte Sn can produce tin whisker phenomena under some conditions. Matte Sn also has a greater potential of having solderability problems due to the formation of Sn oxides in comparison to Sn-Pb surface finishes.
Sn-Cu		
Sn-Ag		
Sn-Ag-Cu (SAC) 305 – 407 and variations Sn-Ag-Cu-Bi[a] Sn-Ag-Cu-Sb		The interaction of a SAC surface finish and Sn-Pb solder is not fully understood although initial solder joint reliability studies have not revealed any major solder joint integrity problems.
Palladium (Pd)		Pd has been shown to be flux sensitive and has a relatively slow diffusion rate into Sn-Pb solder alloys in comparison to other metals. A slight increase in solder process temperatures (e.g. 5 °C to 10 °C (9 °F to 18 °F)) and extending the solder process dwell time have been used to compensate when using Pd surface finishes in Sn-Pb soldering processes. Pd thicknesses in the 0,51 μm to 0,76 μm (20 μinch to 30 μinch) range have been shown to cause solder joint embrittlement due to the formation of $PdSn_4$ microstructure phase.
Ni-Pd	Compatible with Sn-Pb as well as industry preferred Pb-free solders	No whiskering concerns.
Ni-Pd-Au	Compatible with Sn-Pb as well as industry preferred Pb-free solders	No whiskering concerns.
Palladium/silver (Pd-Ag) or palladium/platinum/silver (Pd-Pt-Ag)	Compatible with Sn-Pb as well as industry preferred Pb-free solders	Pd-Ag and Pd-Pt-Ag surface finishes common on ceramic bodied piece-parts such as surface mount chip capacitors or piece-parts utilizing castellations. These finishes can be "leached" off the piece-parts due to dissolution of the surface finish into the solder joint during the Sn-Pb solder process resulting in degradation of the piece-part termination/solder joint interface. Pd-Ag and Pd-Pt-Ag surface finishes are also less robust than Sn-Pb surfaces finishes in terms of solderability characteristics.
Gold (Au)	Compatible with Sn-Pb as well as industry preferred Pb-free solders 3 % or less	Au embrittlement due to the formation of the $AuSn_4$ microstructure phase when the Au content of the solder joint exceeds approximately three percent by weight when Sn-Pb solder is used is well established. Au plating thicknesses in the 0,025 μm to 0,51 μm (1 μinch to 20 μinch) range can be prone to solderability problems in some storage environments for some piece-part types. Fine pitch parts are more susceptible to solderability issues due to thin Au plating. For Pb-free solder systems the intermetallic compound formation is more complex. In addition to Au-Sn intermetallic, Ag-Sn and Cu-Sn intermetallics are also present.

Lead finish	Solder alloy compatibility	Note
Sn-Bi Sn-Cu-Bi [a]	Compatible with Pb-free processes; compatible with Sn-Pb alloys up to 6 %	Tin, lead and bismuth can form low melting microstructure phases, which would have a detrimental impact on solder joint reliability. The industry is currently conducting solder joint integrity investigations to determine the severity and consequences of the interaction of Bi and Sn-Pb solder in high performance electronics use conditions. Testing suggests that a small amount of Bi introduced into Sn-Pb solder joints from an Sn-Bi electroplated termination finish does not present a reliability issue. Increasing the Bi content in an Sn-Pb solder joint can result in solder joint integrity degradation.
Sn-Pb	Not compatible with Bi alloys	

[a] Concern exists with Bi mixed with Pb that form a low melt point alloy that can result in early failure of a solder joint. Test results have shown poor performance with Sn-Pb solder alloys mixed with Bi in low cycle fatigue during thermal cycling.

Table B.2 – Piece part termination tin whisker risks (see IEC/TS 62647-22:2013)

Terminal or PCB/PWB metallization [a]	Whisker propensity [b,c,d]
Sn-(3 % to 5 %)Pb	Low [e]
Sn37-Pb or Sn-40Pb	Low [e]
Sn reflowed	Medium – high [f]
Sn bright electro-deposit	High [g]
Sn matte electro-deposit	Medium – high [f,h]
Sn matte electro-deposit with Ni under-plating	Low
Sn-Bi (2 % to 4 % Bi content in terminal plating) [i]	Medium – high [f]
Antimony bearing [j]	No data
SAC dipped	Medium [f]
Sn-Cu plated finish	High [g]
Sn-Cu dipped finish	High [g]
Ni-Pd-Au electro-deposit	None
CBGA/BGA/C4 ball	
Sn-37Pb ball alloy (includes Sn-36Pb-2Ag)	None
Sn90-Pb	None
Sn-Cu ball alloy	Low [k]
SAC ball alloy	Low [k]
Cu wire column [l]	No data

[a] Alloy percentages given as weight percent.

[b] IEC/TS 62647-2:2012 provides guidance on finishes and risk mitigation methods. There is presently significant effort being directed toward understanding the tin whisker growth mechanism. Generally, the substrate material, plating parameters, the presence of Ni under-plating, annealing, and reflowing the finish also influence the whisker growth but long term testing is still underway. For the purposes of this table, the base termination material is taken to be Cu. Base materials such as brass (Cu-Zn) have a high propensity for tin whisker formation and have actually been used to create tin whiskers in very short times. Ni under-plating is recommended if brass termination material is used.

[c] See [25].

[d] See IEC/TS 62647-22:2013, Tables 2 and 3.

[e] The risk is considered low for the heritage Sn-Pb finishes. Small Pb whiskers have been observed on the JCAA/JG-PP –55 °C to + 125 °C thermal cycle testing.

[f] Medium-high risk corresponds to those finishes that iNEMI recommends be tested in accordance with JEDEC JESD 201 to verify that the finish has a relatively low tendency for whisker growth. In some cases, other mitigations such as Ni under-plating may be necessary to reduce whiskering to a low risk level.

[g] [25] suggests that dipped Sn-Cu finish may or may not be effective reducing Tin whiskers. In electrodeposited layers, Cu in Sn promotes rapid whisker formation. See Table 2.

[h] [25] recommends a matte Sn plating thickness greater than 8 µm for whisker mitigation however, thick matte platings may be susceptible to voiding during soldering.

[i] Bi finishes may need to be restricted on low volume Sn-Pb solder joints in cases where the total Bi content of the joint becomes 0,2 wt % to 0,5 wt % in typical SMT solder joints. Bi also can accumulate to undesirable levels in wave solder pots.

[j] Antimony greater than 1 000 ppm needs to be reported in accordance with HAZMAT as referenced in IPC-1752.

[k] Tin whiskers have not been identified to be an issue on bulk Pb-free alloys like BGA balls or solder joints.

[l] The Cu wire column typically uses a wire that is 254 µm in diameter, 1524 µm long having a finish of 0,05 µm Sn. See [27].

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