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PUBLICLY AVAILABLE SPECIFICATION

PRE-STANDARD

colour inside

Process management for avionics – Aerospace and defence electronic systems containing lead-free solder –
Part 3: Performance testing for systems containing lead-free solder and finishes

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Following publication of this PAS, which is a pre-standard publication, the technical committee or subcommittee concerned may transform it into an International Standard.

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INTRODUCTION

The implementation of Lead-free (Pb-free) interconnection technology into electronics has resulted in a variety of reactions by designers, manufacturers, and users. While the prime motivation for Lead-free (Pb-free) technology was to address the social concern of improving the environment by limiting the amount of toxic and dangerous substances used in products, the ramifications of this initiative have provided a state of uncertainty regarding the performance – in this context, defined as operation and reliability, i.e. the expected life cycle of a product – of aerospace and defence systems. For over fifty years, Tin-Lead solder was the benchmark for electronics assembly and generations of research baselined its performance under a variety of operating conditions including the harsh settings of aerospace and defence equipment. However, with the integration of Lead-free (Pb-free) technology, aerospace and defence companies are faced with questions as to whether these new materials will provide, as a minimum, the same degree of confidence during the life cycle of critical systems and products.

In evaluating performance, two approaches are used: analysis/modeling and test. This document addresses the latter, providing guidance and direction in the development and execution of performance tests for Lead-free (Pb-free) electronic interconnections. The user of this document needs to be aware of the following: This document does not give answers as to how to perform a specific test. Products and systems applications vary immensely, so designers need to understand use conditions and the entire life cycle. Once this is understood, then this document can be used to give designers an understanding of how to develop a suitable test, e.g., ascertain the type of platform in which a product will be used, comprehending all the environmental effects on the platform, and learning why material characterization is key to deciding upon test parameters, etc.

Sound engineering knowledge and judgment will be required for the successful use of this document.

The global transition to Lead-free (Pb-free) electronics has a significant impact on the electronics industry; it is especially disruptive to aerospace and other industries that produce electronic equipment for high performance applications. These applications, hereinafter described as AHP (Aerospace and High Performance), are characterized by severe or harsh operating environments, long service lifetimes, and high consequences of failure. In many cases, AHP electronics must be repairable at the soldered assembly level. Typically, AHP industry production volumes may be low and, due to low market share, may not be able to resist the change to Lead-free (Pb-free). Furthermore, the reliability tests conducted by suppliers of solder materials, components, and sub-assemblies cannot be assumed to assure reliability in AHP applications. This document provides guidance (and in some cases direction) to designers, manufacturers, and maintainers of AHP electronics in assessing performance of Lead-free (Pb-free) interconnections.

Over the past several decades, electronics manufacturers have developed methods to conduct and interpret results from reliability tests for lead-bearing solder alloys. Since these alloys have been used almost universally in all segments of the electronics industry, and since a large body of data, knowledge, and experience has been assembled, the reliability tests for Pb-bearing solder alloys are well-understood and widely accepted.

When it became apparent that the use of Pb-bearing alloys would decline rapidly, programs were implemented to evaluate the reliability of the Lead-free (Pb-free) replacement alloys. Those programs have generated a considerable database. To date, however, there is no reliability test method that is widely accepted in the AHP industries. Reasons for this include:

a) No single Lead-free (Pb-free) solder alloy has emerged as a replacement for lead-bearing alloys; instead, a number of alloys are being used in various segments of the electronics industry.

b) The physical, chemical, and metallurgical properties of the various Lead-free (Pb-free) replacement alloys vary significantly.

c) Due to the many sources of solder alloys used in electronic component termination materials or finishes, assembly processes, and repair processes, the potential number of combinations of alloy compositions is nearly unlimited. It is an enormous task to collect data for all these combinations.

d) The test methods developed by other segments (References [1] and [2]) are directed toward shorter service lives and more benign environments. Also, there is still a question of suitable dwell times and acceleration factors. (However, the intent of this document is to provide a mean of coordinating the information from References [1] and [2] into a basic approach for AHP suppliers.)

e) The data from reliability tests that have been conducted are subject to a variety of interpretations.

In view of the above facts, it would be desirable for high-reliability users of Lead-free (Pb-free) solder alloys to wait until a larger body of data has been collected, and methods for conducting reliability tests and interpreting the results have gained wide acceptance for high-reliability products. In the long run, this will indeed occur. However, the transition to Lead-free (Pb-free) solder is well under way and there is an urgent need for a reliability test method, or set of methods, based on industry consensus. While acknowledging the uncertainties mentioned above, this document provides necessary information for designing and conducting performance tests for aerospace products. In addition, when developing test approaches, the material in question needs to be suitably characterized. Such material properties as ultimate tensile strength, yield strength, Poisson's ratio, creep rate, and stress relaxation have been shown to be key attributes in evaluating fatigue characteristics of Lead-free (Pb-free) solders.

Because of the dynamic nature of the transition to Lead-free (Pb-free) electronics, this and other similar documents must be considered provisional. While this document is based on the best information and expertise available, it must be updated as future knowledge and data are obtained.

The intent of the document is not to prescribe a certain method, but to aid avionics/ defence suppliers in satisfying the reliability and/or performance requirements of IEC/PAS 62647-1 (GEIA-STD-0005-1) [5] as well as support the expectations in GEIA-HB-0005-1 [6]. Accordingly, it includes

- a default method for those companies that require a pre-defined approach and
- a protocol for those companies that wish to develop their own test methods.

Also, this PAS will focus on testing the Lead-free (Pb-free) interconnections, i.e., the "system" comprised of the solder alloy as well as the component and board finishes. While the bulk of this introduction has discussed reliability testing of Lead-free (Pb-free) assemblies, this document will direct attention to test guidelines to evaluate the performance of the Lead-free (Pb-free) interconnection. The guidelines presented in this document do not suggest methods for reliability testing of product. That is left to each individual user. The document provides insight as to what approaches should be used as part of a performance test when Lead-free (Pb-free) interconnection is of prime interest.

In summary, the purpose of this PAS is threefold:

1. It is meant to provide a means to acquire sound, accurate data regarding the performance of a Lead-free (Pb-free) interconnection under harsh conditions (aerospace, military, medical, etc.,)
2. It is usable for further design assessment and operation of a product, and
3. It is usable as part of a process development study.

Finally, any portion of this document may be used to develop a Lead-free (Pb-free) assembly test program, i.e., *this PAS is tailorable* and provides room for flexibility. For those situations in which results are used for reliability, verification, or qualification, it is strongly recommended that stakeholder concurrence be sought and documented so that expectations are understood and addressed.

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

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1 Scope

This PAS defines for circuit card assemblies (CCA)

– a default method for those companies that require a pre-defined approach and

– a protocol for those companies that wish to develop their own test methods.

The default method (Section 4 of the PAS) is intended for use by electronic equipment manufacturers, repair facilities, or programs that, for a variety of reasons, may be unable to develop methods specific to their own products and applications. It is to be used when little or no other information is available to define, conduct, and interpret results from reliability, qualification, or other tests for electronic equipment containing Lead-free (Pb-free) solder. The default method is intended to be conservative, i.e., it is biased toward minimizing the risk to users of AHP electronic equipment.

The protocol (Section 5 of the PAS) is intended for use by manufacturers or repair facilities that have the necessary resources to design and conduct reliability, qualification, or process development tests that are specific to their products, their operating conditions, and their applications. Users of the protocol will have the necessary knowledge, experience, and data to customize their own methods for designing, conducting, and interpreting results from the data. Key to developing a protocol is a firm understanding of all material properties for the Lead-free (Pb-free) material in question as well as knowledge of package- and board-level attributes as described in Section 4.1.1. As an example, research has shown that the mechanisms for creep can be different between Tin-Lead and Tin-Silver-Copper (SAC) solders. Understanding these mechanisms is key to determining critical test parameters such as dwell time for thermal cycling. The protocol portion of this document provides guidance on performing sufficient characterization of new materials in order to accurately define test parameters.

Use of the protocol is encouraged, since it is likely to yield more accurate results, and to be less expensive than the default method. Reference [7] provides a comprehensive overview of those technical considerations necessary in implementing a test protocol.

This PAS addresses the evaluation of failure mechanisms, thru performance testing, expected in electronic products containing Lead-free (Pb-free) solder. One failure mode, fatigue-failure thru the solder-joint, is considered a primary failure mode in AHP electronics and can be understood in terms of physics of failure and life-projections. Understanding all of the potential failure modes caused by Lead-free (Pb-free) solder of AHP electronics is a critical element in defining early field-failures/reliability issues. Grouping of different failure modes may result in incorrect and/or misleading test conclusions. Failure analysis efforts should be conducted to insure that individual failure modes are identified, thus enabling the correct application of reliability assessments and life-projection efforts.

When properly used, the methods or protocol defined in this PAS may be used along with the processes documented in compliance to Reference [3], to satisfy, at least in part, the reliability requirements of References [3] and [4].

This PAS may be used for products in all stages of the transition to Lead-free (Pb-free) solder, including:

- Products that have been designed and qualified with traditional Tin-Lead electronic components, materials, and assembly processes, and are being re-qualified with use of Lead-free (Pb-free) components
- Products with Tin-Lead designs transitioning to Lead-free (Pb-free) solder; and
- Products newly-designed with Lead-free (Pb-free) solder.

For programs that were designed with Tin-Lead solder, and are currently not using any Lead-free (Pb-free) solder, the traditional methods may be used. It is important, however, for those programs to have processes in place to maintain the Tin-Lead configuration including those outsourced or manufactured by subcontractors.

With respect to products as mentioned above, the methods presented in this document are intended to be applied at the level of assembly at which soldering occurs, i.e., circuit-card assembly level.

2 Normative references

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

1) IPC-9701A, “Performance Test Methods and Qualification Requirements for Surface Mount Solder Attachments”, IPC, February 2006
2) IPC/JEDEC-9703, “Testing Methodologies for Solder Joint Reliability in Shock Conditions”, DATE TBD
3) IPC-SM-785, “Guidelines for Accelerated Reliability Testing of Surface Mount Solder Attachments”, IPC, November 1992
4) JESD22-B110A, “JEDEC Standard Subassembly Mechanical Shock”, November 2004
5) IEC/PAS 62647-1, Program management for Avionics – Aerospace and defence electronic systems containing lead-free solder – Part 1: Lead-free management
6) GEIA-STD-0005-1, Performance Standard for Aerospace and High Performance Electronic Systems Containing Lead-free (Pb-free) Solder. Government Engineering and Information Technology Association, 2006
7) IEC/PAS 62647-2, Process management for Avionics – Aerospace and defence electronic systems containing lead-free solder – Part 2: Mitigation of the deleterious effects of tin
8) GEIA-STD-0005-2, Standard for Mitigating the Effects of Tin whiskers in Aerospace and High Performance Electronic Systems. Government Engineering and Information Technology Association, 2006
9) IEC/PAS 62647-21, Aerospace and defence electronic systems containing lead-free solder – Part 21: Program management – Systems engineering guidelines for managing the transition to lead-free electronics
10) GEIA-HB-0005-1, Program Management / Systems Engineering Guidelines For Managing The Transition To Lead-free (Pb-free) Electronics, 2006
11) IEC/PAS 62647-22, Aerospace and defence electronic systems containing lead-free solder – Part 22: Technical guidelines
12) GEIA-HB-0005-2, Technical Guidelines for Aerospace and High Performance Electronic Systems Containing Lead-free (Pb-free) Solder, 2007
13) MIL-STD-810, “Department of Defence Test Method Standard for Environmental Engineering Considerations and Laboratory Tests”, revision F, January 1, 2000.
14) MIL-HDBK-217F, “Military Handbook, Reliabilty of Electronic Equipment”, 2 December 1991.

15) NASA-DoD LFE Test Protocol, 19 September 2007

16) Shigley, Joseph Edward, Mechancial Engineering Design, THIRD EDITION, McGraw-Hill Book Company, New York, NY, 1977, pp. 185-188.

17) Collins, J.A., Failure of Materials in Mechanical Design, John Wiley and Sons, New York, NY, 1981, pp. 240-269.

18) "Fatigue (Material)", Wikipedia, http://en.wikipedia.org/wiki/Metal_fatigue

19) Joint Group on Pollution Prevention, "Lead-free (Pb-free) Solder Testing for High Reliability", Project Number S-01-EM-026, (A full report on the JG-PP effort can be found at the JG-PP Web site).

20) NASA-DoD Lead-free (Pb-free) Project, http://www.teerm.nasa.gov/projects/NASA_DOD LeadFreeElectronics_Proj2.html

21) Directive 2002/95/Ec of the European Parliament and of the Council of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment (commonly known as the RoHS or Restriction of Hazardous Substances Directive)

22) Communication with W. Engelmaier, January 7, 2006

23) Communication with W. Engelmaier, January 7, 2006 and Follow-up communication with A. Dasgupta on September 28, 2007

3 Terms and definitions

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

3.1
AHP
Aerospace and High Performance, referring to a generalized level of equipment use in harsh and stringent operating conditions.

3.2
coupon
a test sample representing a scaled-down or proportional version of an actual product or higher level test vehicle.

3.3
CTE
Coefficient of Thermal Expansion

3.4
DSC
Differential Scanning Calorimeter.

3.5
JCAA
Joint Council on Aging Aircraft.

3.6
JG-PP
Joint Group on Pollution Prevention, referring to the Department of Defence initiative that sponsored a project to obtain design data from testing Lead-free (Pb-free) assemblies under a series of military environments.

3.7
lead
term associated with the termination of an electronic component, i.e., the structure that makes electrical contact with a printed wiring board.

3.8
lead-free (Pb-free)
meaning that the content of the element lead is < 0.1 % by weight. [The chemical symbol for the element is used so as to not confuse the reader when the term “lead,” meaning the electrical connection of a component, is used.]

3.9
PSD
Power Spectral Density; describes how the power of a signal or time series is distributed with frequency.

3.10
RoHS
Restriction on Hazardous Substances (Directive 2002/95/EC of the European parliament and of the Council of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment).

3.11
tin-lead
solder bearing the elements tin and lead, respectively, in the by weight amounts of 63-37 unless otherwise specified.

3.12
vehicle
a test sample such as a populated circuit card assembly.

4 Default Test Methods

Use of the default method *shall* be limited to circuit-card assemblies (CCA). Also, the use of test coupons may also be used provided the concerns listed in Section 4.1.1 are considered.

4.1 Test Vehicles

4.1.1 Test Vehicle type

Test vehicles used in testing of electronic systems containing Lead-free (Pb-free) solder *shall* consist of soldered assemblies that are representative of the materials and processes used in the assembly and/or repair procedures used by the AHP manufacturer or repair facility. Characterization and documentation of the test vehicle attributes (both design and manufacturing) is recommended. Test vehicle attribute documentation *shall* include, at a minimum, the following data:

- Board type, material, size, finish, thickness, Copper content
- Piece-part material, package size, package type, termination finish
- Assembly solder alloy
- Assembly processes including fluxes and cleaners
- Thermal management materials
- Underfill and staking materials
- Other mechanically attached structures
- Environmental coatings
- Repair history/process (including solder alloys)

The utilization of electrically functional assemblies/units or representative test vehicles is permitted provided full characterization of the electronic assembly materials, test vehicle configuration, and assembly processes are documented. The IPC-9701A specification