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Lead Free Material Requirements - and Options - for Fast UL Qualification

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About the Author

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By Crystal Vanderpan

Introduction

Lead-Free manufacturing is a process change involving the OEM (Original Equipment Manufacturer), EMS (Electronics Manufacturing Service), Assembler, PWB Fabricator, and Material Supplier. Communication across the supply chain is necessary to determine if lead-free is the appropriate direction for the product. Due to the conditioning time involved for UL PWB testing, identifying the need for UL certification should not be left to the last minute. Lead-Rich and Lead-Free processes are significantly different based on the reflow temperatures and possible cross contamination issues. Therefore, evaluation of the revised PWB manufacturing and assembly process may be required. Since many manufacturers will not find it cost effective to support two PWB production processes, manufacturers not intending to send the product to Europe may still choose to recertify their product with Lead-Free processing.

This paper examines the literature on the Lead-Free movement and describes the applicable UL requirements for PWBs, as well as possible risk issues for other components and OEMs.

The Legislation

The absorption of lead through contact and inhalation is known to be unhealthy. Lead adversely affects the central and peripheral nervous system, digestive tract, blood production, blood vessels, and metabolism. The increasing short product life cycles and new technology developments in the electronics industry are leading to large volumes of electronic products being discarded. The volume of waste generated increases nearly 5% each year. Electronics waste may be a major source of hazardous substances such as heavy metals and organic pollutants which lead to soil and ground water contamination. In addition, there is concern that valuable materials, which may be recycled and reused, are being thrown in the trash. In an attempt to protect human health and reduce environmental impacts, the EU has adopted two legislative Directives: Waste from Electrical and Electronic Equipment (the WEEE Directive), and Restriction of Hazardous Substances in Electrical and Electronic Equipment (the RoHS Directive). Japan, China, and the US are in the process of implementing similar legislation.

The WEEE Directive, deliberated on over the last decade, was published February 2003. The WEEE Directive was developed to reduce the levels of electronic waste dumped in landfills and encourage resource recovery through recycling and reuse. The WEEE Directive covers almost all consumer electronic products. A manufacturer of electronic equipment will be required to organize and finance the collection of materials targeted in the Directive for recycling and recovery no later than December 31, 2006.

The RoHS Directive was developed to support WEEE through the elimination of hazardous substances during the disposal and recycling of electronic waste. The targeted materials to be phased out by July 1, 2006 include heavy metals (mercury, lead, cadmium and hexavalent chromium) and specific halogenated flame retardants (polybrominated biphenyls, PBBs and polybrominated diphenyl ethers, penta-PBDEs and octa-PBDEs).

The RoHS Directive includes exemptions if a suitable substitute is not available or not technically feasible. The current exemptions include:

1. Lead in high melting temperature type solders (ie. solder alloys containing more than 85% lead),
2. Lead in solders for servers, storage and storage array systems (exemption granted until 2010),
3. Lead in solders for network infrastructure equipment for switching, signaling, transmission as well as network management for telecommunications,
4. Lead in electronic ceramic parts (ie. piezoelectronic devices).

Automotive, aerospace, and military equipment are outside the scope of RoHS. Medical equipment systems other than implants or monitoring and control instruments are temporarily exempt. Equipment covered under RoHS includes large and small appliances, portable tools, IT and telecommunications equipment, lighting, toys, and sports equipment. Terms commonly used by industry to refer to products or materials compliant with the WEEE/RoHS Directives are "Lead Free", "Halogen Free", "Non-Halogen", "RoHS Compliant", "Green", and "Environmentally Friendly".

Industry Research and Testing

The PWB and Assembly industry has been researching, testing and using Lead Free solder alloys for over 10 years. Research in the early 1990's concentrated on the development of alternate alloys and the assessment of basic properties such as toxicity, wetting, and strength behavior when compared to tin/lead solder. Later research concentrated on recommending standard alternative alloys and researching the fatigue properties, production behavior, and process optimization. A database containing an extensive list of projects along with a brief summary of each is located at Electronics Industries Alliance (EIA) website www.tintechnology.biz/soldertec/soldertec.aspx.

Material Choices

Lead has been in the solder used for electronic product assembly for more than 50 years. Historically, solder consisted of eutectic tin-lead 63Sn/37Pb or its equivalents, 60Sn/40Pb and 62Sn/36Pb/2Ag. The electronics industry with backing from key PWB supply chain companies, third party laboratories, and universities have researched alternative materials to determine the best Lead-Free solder material for use as a PWB surface finish and in the assembly process. Many Lead-Free alternatives are available, however each material must be evaluated for its benefits and challenges.

The available Lead-Free alternatives include:
- Immersion Finishes (Gold, Silver, or Tin),
- Electroless Nickel-Immersion Gold (ENIG),
- Organic Solderability Protectants (OSP - Benzimidazoles),
- Tin-Silver-Copper (SAC) alloy pastes, and
- Hot Air Solder Leveling (HASL Non-Lead containing – Tin/Copper and Tin/Silver).

The majority of the electronic industry associations are recommending the SAC alloy as the standard Lead Free soldering material.

Processing – Manufacturing and Assembly

Lead-Free materials require 30 to 45 C higher melting temperatures when compared to tin-lead solder (see Table 1) Even though the melting point for tin-lead is 183C, the optimal tin-lead reflow processing temperature has actually been identified as being between 225 and 238 C. These higher processing temperatures may allow the lower melting point lead free materials to be used without any temperature modifications. Many manufacturers have benefited from the large tin-lead reflow window by using one or two thermal profiles to process a wide range of board assemblies. However, the process window for lead-free materials is much smaller due to the component maximum exposure temperature of 250C (this limitation is primarily due to plastics deformation).

The higher melting temperatures required during the lead free reflow process can cause delamination within the PWB and damage a wide variety of components such as plastic connectors, relays, light emitting diodes (LEDs), electrolytic and ceramic capacitors. Precise temperature control during lead free processing may include a ramp stage in the temperature profile in order for the temperature rate of rise not to harm components that may be thermally sensitive. PWB warping, thermal shock-induced cracks, and differences in adjacent materials' coefficient of thermal expansion (CTE) are additional potential problems.

Material	**Melting Range (C)**	**Solder Pot Temp. (C)**
Sn-Pb	183 – 188	250
Sn-Cu (98Sn/0.7Cu)	227	270 – 280
Sn-Ag-Bi	206 – 213	260
Sn-Ag-Cu	217	260 – 270
Sn-Ag (96.5Sn/2.5Ag)	221	265 – 275

Table I Soldering Material Melting Points and Associated Solder Pot Temperatures(1)

Additional modifications to the reflow temperature profile for lead free solders are required for proper wetting and solder joint formation. The peak temperature and time above liquidous must be achieved without overheating the assembly or components. A longer preheat section is needed to reach the higher temperatures and avoid thermal shocking the PWB during the solder reflow process. Two common types of profiles used for lead free solders are known as the soak/spike and tent profiles. The soak/spike profile subjects the assembly to a temperature just below the liquidous point to achieve a uniform assembly temperature. The tent profile is a continuous ramp up of temperature from the time the assembly enters the oven until the assembly reaches the desired peak temperature. Figure 1 shows a typical lead free reflow temperature profile and Figure 2 shows typical lead free reflow parameters.

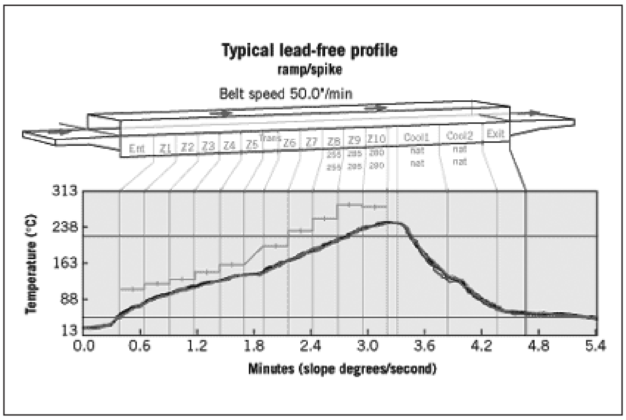

Figure 1. Typical Lead Free Reflow Temperature Profile(2)

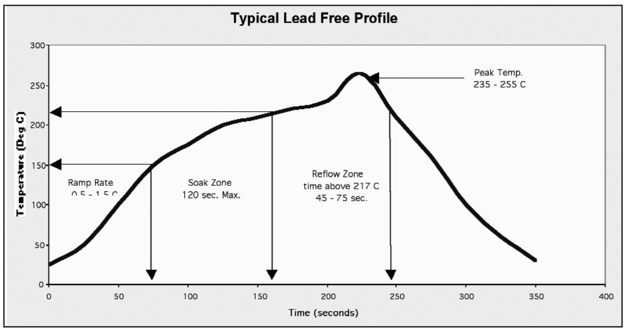

Figure 2. Typical Lead Free Reflow Parameters

Lead free soldering makes it increasingly important to identify the components, board finishes and the solders used to assemble them. Keeping the materials identifiable throughout the assembly process is critical as is identification of the final assembly for reliable rework. Inventories must be separated to ensure lead free components are not mixed with leaded components due to the varying material melting points and possibility of creating metallic alloys which may cause premature failure of the board.

Tin Whiskers

The lead-free movement in the electronics industry has caused many component manufacturers to change from tin-lead alloys to pure tin and high-tin content alloys for the final finish of solderable surfaces. Pure tin and high-tin content alloys are susceptible to tin whiskers. These whiskers (Figure 3) can cause electrical shorts in tightly spaced electronic circuitry. Finding whiskers more than 300 – 400 microns in length is unusual. Unfortunately, no consensus exists on an accelerated reliability test for whisker growth, so qualifying tin plated terminations is virtually impossible. NEMI has active projects working to develop accelerated testing techniques and is working with groups in Japan and Europe to develop acceptable global solutions. Any high tin content plating finish has some risk of tin whisker formation. The photos of whiskers and additional information regarding tin whiskers may be found in the NEMI RoHS/Pb-Free Summit Proceedings, October 2004(3b).

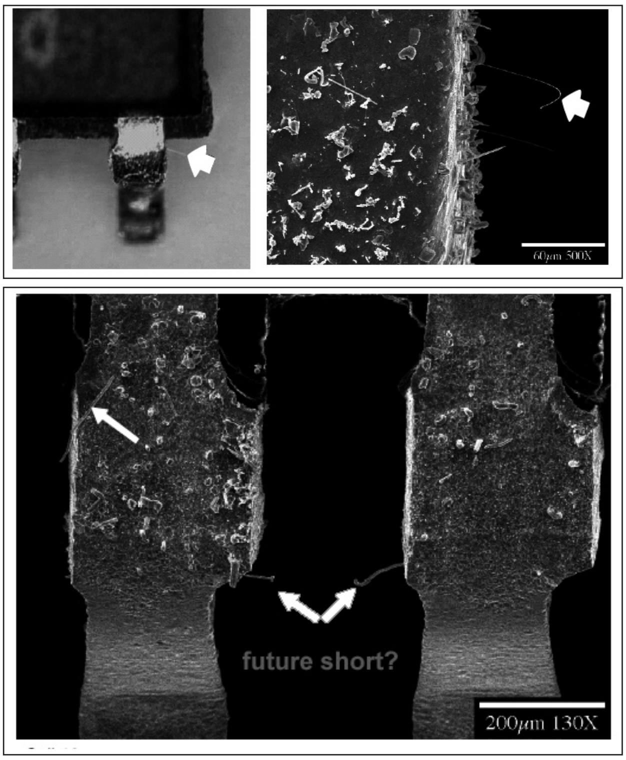

Figure 3

UL Requirements – PWB and End Product

The UL PWB certification program monitors the manufacturing process including maximum temperature and exposure times and the materials used to produce the PWBs. As board manufacturers begin using alternate surface finishes, these materials will be included in the process description. Currently, most process descriptions list "solder" which is intended to be tin/lead solder. Lead free solders will be described by their material constituents to clearly identify the type of solder. In addition, testing is required if the lead free board process or assembly process includes higher temperatures. Flammability, conductor adhesion, blistering, and delamination will require re-evaluation if increased processing temperatures are involved. These product evaluation tests typically require either 4 weeks or 12 weeks to complete, depending on whether 10 day conditioning receives compliant test results (if not, 56 day conditioning is required).

At a minimum, UL end product certification programs monitor the board flammability and maximum operating temperature (MOT) rating. A change to lead free solder on the PWB may not have an impact on UL certified end products assuming the PWB manufacturer has completed the appropriate testing with compliant results.

The time required to update the PWB certification for lead free materials and processing can be minimized when manufacturers take the following actions.

1. Submit requests to UL to modify the PWB certification as early as possible based on the required testing conditioning time.
2. Use the current FUS Procedure Description pages (Table I and II, Solder Resist table, and Process description) as a template to describe the proposed modifications being made.
3. Request process temperature and times reflecting the maximum possible exposure so the updated process description will allow for tolerance ranges and/or multiple reflow steps.
4. Sample preparation should be verified with UL staff such that appropriate samples are submitted for testing.
5. Notify the UL project handler of the manufacturer's expected shipping date by considering the required testing conditioning time.

Summary

The term "Solder" cannot be assumed to refer only to the eutectic tin/lead alloy (63Sn/37Pb) during the electronics manufacturing and assembly processes. The PWB and assembly industry are recommending 2 –3 lead free solders as the standard alloy to replace eutectic tin/lead, and intend to assign unique part designations to distinguish the alloys from one another. The higher required melting temperatures of lead free solders may damage boards or board assemblies, requiring certain board performance characteristics (flammability, delamination, and conductor bonding) to be re-evaluated. However, unless field problems associated with lead free materials manifest, the impact on UL end product certifications should be minimal. Implementing the suggested actions will help to expedite the PWB re-evaluation process.

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6. Standard for Printed Wiring Boards, UL 796, Underwriters Laboratories Inc.