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Lead Elimination from Printed Wiring Assemblies

(Get the Lead Out!)

Lead is commonly used in solders and finishes required for the manufacture of printed wiring assemblies for electronics. Lead is a neurotoxin, a haematotoxin, a teratogen, and is possibly carcinogenic. Concerns have been raised in Europe and Japan about lead leaching out of electronics that have been disposed of in landfills. These concerns have led to efforts in Europe and Japan to limit the amount of lead that goes into landfills. This reduction will be accomplished by eliminating lead use in the design of new electronics and by imposing penalties on those manufacturers that fail to comply.

Recently, legislation has been proposed in Europe to ban the use of lead (and other materials) in electronics by 2008. This legislation is called the Waste from Electrical and Electronic Equipment (WEEE) Directive and is currently in a draft form that is being evaluated by the European Union. It is almost a certainty that this Directive will become law.

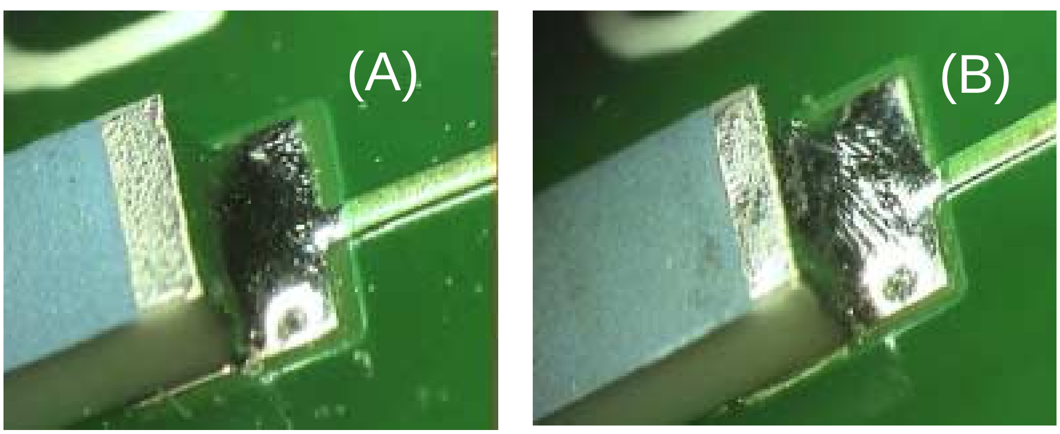

Figure 1. (A) Solder Joint Produced Using Tin/Lead Solder and Finishes; (B) Tin/Silver/Copper Solder Joint On An Immersion Silver Board Finish

Japan also has become focused on lead-free electronics. Many of the major electronics companies have announced lead reduction targets (Hitachi, NEC, NTT, Panasonic) and the move to lead-free electronics is supported by the Japan Electronic Industry Development Association (JEIDA). These companies view lead-free as a marketing tool that will allow them to gain market share from their foreign competitors.

The European and Japanese restrictions on lead in electronics do not currently include aerospace applications. The United States is not contemplating restrictions on lead in electronics. However, there is no question that the international restrictions are going to largely eliminate lead in consumer products, either directly or through market forces. The U.S. based IPC-Association Connecting Electronic Industries held an international summit on lead-free electronics assemblies (IPCWorks '99) where they began the creation of a lead-free roadmap for American industries. The overwhelming consensus at this summit was that lead-free electronics will soon be the norm overseas and that the US electronics industry must catch up or risk losing business in those markets.

Consumer products drive global production of electronics. Industries still requiring leaded electronics will be marginalized, with reduced sources and higher costs. Availability of components for use on leaded boards may also become an issue. Eventually, aerospace electronics

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	Control Specimens	Lead-Free Specimens		
Board Finish	Tin/Lead	Silver	OSP	Nickel/Gold
Reflow Solder	Tin/Lead	Tin/Silver/Copper	Tin/Silver/Copper	Tin/Silver/Copper
Component Finish	Tin/Lead	Tin/Copper	Tin/Copper	Tin/Copper
Wave Solder	Tin/Lead	Tin/Copper	Tin/Copper	Tin/Copper

Table 1. Combinations of Finishes and Solders Used on the Test Vehicles

will have to transition to lead-free, even if direct regulation is not passed. The challenge is to manage the transition to control our risks while maintaining maximum cost advantage. As a first step, we must be assured that alternative lead-free solders and finishes will yield electronics that are reliable. Boeing is conducting research in-house on lead-free solder joint reliability and working with an international consortium (the No-Lead Solder JG-PP) that will answer the many other questions facing this transition.

A solder joint is formed when an electronic component is attached to a printed wiring board with solder. The finish on the component and on the board also contribute to the composition of the final solder joint. Two types of soldering operations are normally used to create solder joints. In **reflow soldering** a solder paste is used to create the solder joint. The paste is applied by a screening operation; components are robotically placed into the paste; and the paste is melted (or reflowed) in an oven. The second type of soldering operation is called **wave soldering**. In wave soldering, the components are adhesively bonded to the board and the board is then passed through a wave of molten solder to form the solder joint attachments. The solders currently used for reflow and wave soldering normally have a high lead content as do the finishes on the components and on the pads of the printed wiring boards. Lead-free solders and finishes have only recently become available and are not yet fully characterized.

A test program was started in 2000 at Boeing for the evaluation of the reliability of lead-free solder joints. One lead-free solder was tested for reflow operations (tin/3.8%silver/0.7%copper) and one solder was tested for wave soldering operations (tin/0.7%copper). These solders are considered the leading candidates for replacement of eutectic tin/lead solder by many in the U.S.

Of course, to produce truly lead-free solder joints, the circuit board finish and the component finishes also have to be lead-free. Circuit board finishes are used to prevent the copper pads on the board from oxidizing which would make the copper unsolderable. Tin/lead alloys are currently the most widely used finish for circuit boards but lead-free alternatives have emerged in recent years. Three lead-free circuit board finishes were tested by Boeing in combination with the lead-free solders mentioned above, i.e., immersion silver; electrolytic gold on top of nickel; and an OSP (organic solderability preservative). The immersion silver and the gold are very thin metallic coatings that dissolve in the solder of the solder joint during processing. OSP's are organic chemicals that chemically bond to the copper of the circuit board and inhibit oxidation.

The components used on the Boeing test vehicles were chip resistors whose end terminations were finished with tin/0.7%copper. A chip resistor is a small rectangle of aluminum oxide that has a resistive element sandwiched between two metallized end terminations. Test vehicles were assembled by reflow soldering chip resistors to the top of each test vehicle and wave soldering chip resistors to the bottom side of each test vehicle. The combinations of solders and finishes used on each test vehicle are shown in Table 1. Solder joints produced using lead containing solders and finishes (63%tin/37%lead) were used as a control. The test vehicles were then thermally cycled and the failure rates of the lead-free solder joints were determined by electrically monitoring the solder joints during the test. The thermal cycle was from –55°C to +125°C with 15 minute dwells at each temperature extreme and a ramp rate of 7°C per minute. The test vehicles were exposed to 4380 thermal cycles in order to get enough failures for statistical analysis. Thermal cycling has long been recognized as a realistic test for the accelerated aging of solder joints.

Pictures of a typical lead-based solder joint and a lead-free solder joint are shown in Figure 1. The lead-based solder joint is generally smooth and shiny while the lead-free solder joint is typically grainy and striated. This implies that inspection criteria currently in use will have to be changed before lead-free solders can be implemented at manufacturing sites.

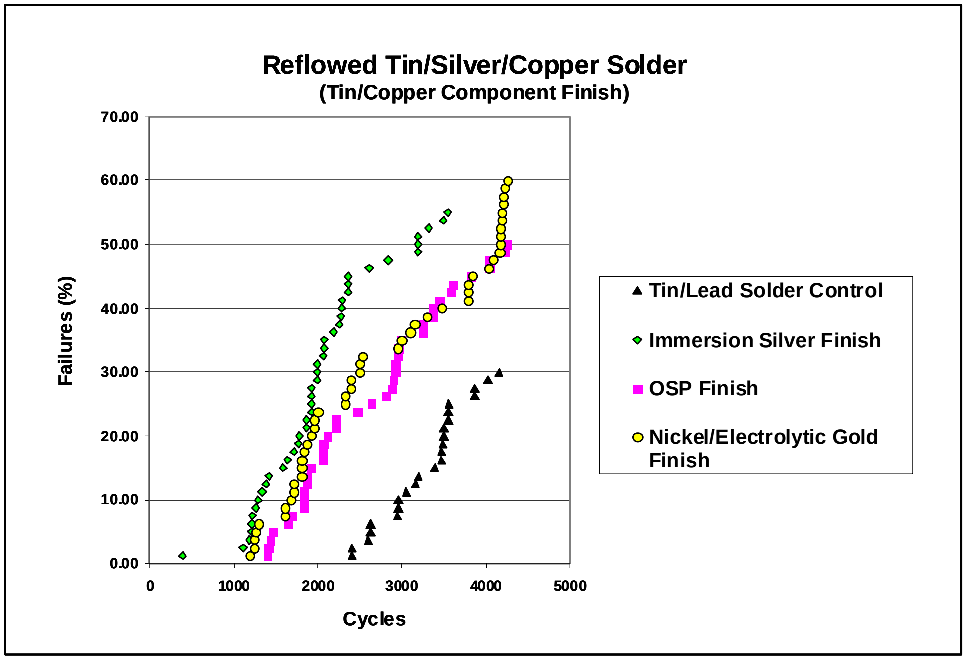

Figure 2. Reliability Data for Reflowed Solder Joints

The Boeing reliability results for the lead-free reflowed solder joints are shown in Figure 2. The percentages of failed solder joints were plotted against the number of thermal cycles accumulated. The failure rates of tin/silver/copper solder on three different board finishes (silver, gold, and OSP) are shown. The failure rate of the reflowed tin/lead control solder joints is also shown. The lead-free solder joints began to fail much earlier than the tin/lead controls which suggests that this lead-free solder is not a good choice for electronics that must have high reliability. These findings have recently been verified independently by Dr. R. Wayne Johnson at Auburn University. It has been suggested that tin/silver/copper solder performs better than tin/lead when the component has a coefficient of thermal expansion (CTE) similar to that of the circuit board but does not perform as well when the CTE of the component differs from that of the circuit board. The CTE of ceramic components, such as chip resistors, is much less than the CTE of most circuit boards and the mismatch between the component and the board applies a lot of stress to the solder joints. Since chip resistors are used on many circuit boards, they may be the "weakest link" where lead-free solders are concerned.

The reliability results for the lead-free wave soldered joints are shown in Figure 3. The failure rates of a tin/copper solder on three different board finishes (silver, gold, and OSP) are shown. The failure rate of the wave soldered tin/lead control solder joints is also shown. In this instance, the lead-free solder joints began to fail at about the same number of cycles as the tin/lead controls which suggests that this lead-free solder is a suitable replacement for tin/lead in wave soldering operations.

In addition to doing reliability studies, Boeing conducted leachate testing (EPA's Toxicity Characteristic Leaching Procedure and The State of Texas Seven-Day Distilled Water Leachate Test) on the lead-free solder joints to determine if toxic metals could be leached out under conditions found in landfills. Any alternative materials used for lead-free solder joints must not leach out elements that could be even more toxic than the lead that they are replacing. For example, silver is relatively non-toxic to mammals but is very toxic to marine life. The leachate testing conducted showed that the lead-free solder joints did not leach detectable amounts of toxic metals (i.e., silver) but the lead-containing control solder joints leached amounts of lead in excess of that allowed by Federal law (5.0 mg/liter from 40 CFR 261).

In summary, Boeing's test program was able to identify a suitable replacement for the solder used in wave soldering operations. The lead-free candidate for reflow soldering operations, however, was not as reliable as tin/lead solder and further testing will be required to identify a suitable material for reflow soldering of high reliability electronics.

In addition to its in-house test program, Boeing is a member of the No-Lead Solder Joint Group on Pollution Prevention (JG-PP). JG-PP is an organization whose charter is to coordinate joint the pollution prevention activities of the armed services. JG-PP's primary objectives are:

1. To reduce or eliminate the use of hazardous materials (HazMats) by fostering cooperation between the branches of the armed services

2. To avoid duplication of efforts to reduce or eliminate HazMats and to foster the sharing of technology.

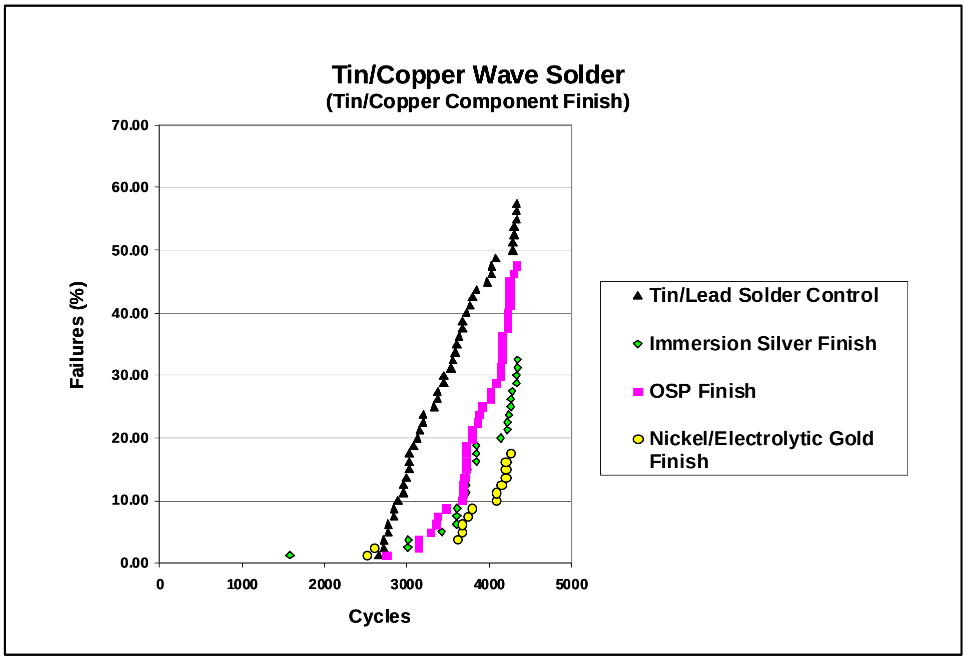

Figure 3. Reliability Data for Wave Soldered Joints

JG-PP focuses on implementing pollution prevention processes at defense contractor design, manufacturing, and re-manufacturing locations, with subsequent technology transfer to the U. S. Department of Defense Sustainment Community. JG-PP is managed by the Joint Pollution Prevention Advisory Board.

The goal of the No-Lead Solder JG-PP is to identify, test, and promote the use of environmentally acceptable materials and processes for circuit card manufacturing and maintenance. Currently, the No-Lead Solder JG-PP is testing lead-free solders and board finishes. Two test programs are currently in the planning stage. The first is focusing on the use of lead-free materials in new designs. The second is focusing on the use of lead-free solders for repair. Each test plan will be documented in a Joint Test Protocol (JTP). Test vehicles are being designed and these test vehicles will be exposed to stress testing (e.g., vibration; shock; thermal shock) to determine if lead-free materials can survive these conditions. Long term reliability testing (such as that being done by Boeing) is not currently a part of the test programs, however. Other JTP's will be created to address new lead-free issues as they arise. All test results will be documented in Joint Test Reports that will be available to the public. Extensive information on the JG-PP and its various projects can be found at http://www.jgpp.com .

Before the U.S. electronics industry can switch from lead containing materials to lead-free solders and board finishes, many questions remain to be answered. As discussed above, reliability concerns must be addressed and the long-term environmental impacts of the alternative materials must be characterized to ensure that they are indeed less hazardous than the materials they are replacing. Repairing existing leaded electronics after most production has transitioned to lead-free materials is another thorny area. Large test programs will need to be conducted and electronics manufacturers must form consortia so that the tremendous costs involved can be shared.

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