Ecolife 2 - Lead-free assembly

Introduction

Lead has been used for thousands of years in a wide range of applications and it continues to be a vital material in many areas. However, the fact that the potential health hazards and toxicity of lead have become more widely understood and appreciated has encouraged alternatives to be employed in many fields such as fuel additives, piping and paints. Lead is still widely used in the electronics industry, principally as a costituentent of solders but also in certain components and in the Printed Circuit Board (PCB) manufacturing process. Conventional eutectic or near eutectic tin-lead solder compositions have been used for virtually all soldering applications in electronic product assembly. However, as with the desire to remove lead from other applications, there has also been a more recent move to proscribe the use of lead in electronics. Soon to be implemented European Legislation, in the form of the Waste from Electrical and Electronic Equipment (WEEE) and Restriction of Hazardous Substances (RoHS) Directives, focussed attention on the use of a number of undesirable materials in electronics manufacturing and the result is that, for many applications, the use of lead will be proscribed from mid-2006. The implications of this need to move to so called lead-free electronic assembly are immense and not yet widely appreciated, yet there are only three years remaining before the use of lead will be proscribed.

Current Situation

The WEEE directive was originally conceived as a tool to help address the growing problem of end-of-life electronics and to reduce the large amount products that were consigned to landfill. The WEEE directive's overarching aim is to encourage the recycling and reuse of components and materials found in end-of-life electronics. In one of its early iterations the WEEE directive also sought to proscribe the use of certain materials such as lead, hexavalent chromium and some brominated flame-retardants in electronics. Part of the reason for the desire to ban lead was due to concerns about its fate in products placed in landfill. There was concern that heavy metals such as lead might, under certain conditions, migrate with the possibility that they might cause a local pollution problem or even find their way into the water course, thus presenting a more substantial health related problem. Since its conception some ten years ago the WEEE directive has evolved through several iterations and more recently the part of it which sought to proscribe the use of lead and other materials has been incorporated into a separate piece of legislation; the RoHS directive.

The development of this legislation, particularly over the last five years has raised many concerns with electronics manufacturers, especially with respect to the fact that lead will effectively be banned in electronics from 2006. To date, there has been much work done to identify suitable alternative lead-free solder compositions and to address some of the assembly process and equipment issues associated with the use of these materials. Although this legislation affects only products manufactured in or entering the European market place, it has global ramifications since many manufacturers wishing to sell their goods in Europe will have to adopt a lead-free approach. Consequently, major efforts have been made by, for example, Japanese consumer electronics companies to develop lead-free processes and products. It is true to say that in many areas the Japanese are well ahead of their European and American counterparts in the adoption of lead-free assembly in their products. The Japanese have also been able to demonstrate that there can be sound commercial benefits to be gained from moving to lead-free and consumers have shown a willingness to purchase 'lead-free' products because of their belief that these are ultimately less harmful to the environment.

Current electronic assembly methods rely on the use of tin-lead based solders. These are alloys of the two elements and typically they have tin to lead compositional ratios of 60:40 or 63:37 and melt at or around 183°C. (The eutectic composition for tin-lead solders is 63:37 and this has a true melting point of 183°C, whilst the 60:40 alloy has a melting range in the same region). These solders and temperatures have proved ideal for electronics assembly in that the soldering temperature is high enough to enable product operation over a relatively wide temperature range without requiring a soldering temperature that is high enough to cause damage to the components and circuit board materials exposed to these temperatures during soldering operations.. There are many alternative solder systems that have been proposed as potential replacements for conventional lead based solders and they have melting ranges from much lower than conventional solders too much higher.

Example lead-free solders

Solder Alloy	Composition/Wt %	Melting Range/°C
Sn-In	Sn-52In	118
Sn-Bi	Sn-58Bi	138
Sn-Pb	*Sn-37Pb*	*183*
Sn-Zn	Sn-9Zn	198.5
Sn-Ag-Cu	Sn-4Ag-0.5Cu	217
Sn-Ag	Sn-3.5Ag	221
Sn-Cu	Sn-0.7Cu	227
Sn-Sb	Sn-5Sb	232-240

The problem is that these solders each have potential advantages and disadvantages and various companies have developed different processing solutions for each type of solder and composition. In an attempt bring some degree of conformity to lead-free assembly in Europe, various organisations (eg Intellect and Soldertec) have recommended that the industry minimises its choice of solders as much as possible. To this end, recommendations have been made that two specific alloy types are suitable for meeting the requirements of most applications likely to be encountered in general electronics assembly. These recommendations are that a tin silver copper alloy be used where a reflow operation is required and a tin copper alloy for wave soldering. The tin silver copper tenary alloy recommended has a composition that gives a melting range in the region of 215 to 220°C(eg Sn-3.8Ag-0.7Cu, mp 217°C) whilst providing a combination of good processing and reliability performance. For wave soldering the tin copper eutectic alloy (Sn-0.7Cu) has a melting point of 227°C and represents one of the cheapest lead-free alloys available. It therefore provides a relatively attractive lead-free alloy when setting up a new lead-free wave solder bath.

Issues

Although there are numerous alternative lead-free solder compositions that can be used to replace conventional tin-lead alloys, there are also a large number of issues which need to be addressed if lead-free soldering is to be achieved successfully, reliably and efficiently. One major concern actually centres on the fact that there are so many possible alternative solders available utilising a wide range of elements and alloy formulations. Instead of having just one type of solder in widespread use, there is the possibility that dozens of solders may be encountered in service each with its own benefits, disadvantages and varying process assembly requirements and conditions. This means that assemblers will have to establish specific procedures for each type of solder. In Europe it is hoped that the electronics industry will focus on the use of the two alloys mentioned above but there will still be the issue of servicing electronics manufactured outside the European Union and the need to identify the solder composition used. It will be essential to use the correct solder for rework and repair because there are known incompatibilities between certain solder compositions that can for example compromise reliability.

Another key issues related to the use of lead-free solders is that the recommended alternative solders have melting points higher than their lead based counterparts. The exact increase in temperature required for soldering with lead-free solders can vary significantly and depends on the alloy type used and the type of board being assembled, but it seems clear that if solders with melting points/ranges around 30 degrees higher than their lead based analogues are used the processing temperatures will also need to increase by a similar amount. Exposure to higher temperatures can result in issues of compromised stability and reliability for both the boards and components. It is known, for example, that some electrolytic capacitors may need to be hand assembled after reflow. Certain low-end PCB laminates are also unsuitable for reflowing at these higher temperatures, although the widely used FR4 type laminates are generally not affected. The key point here is that many organic materials are sensitive to the elevated temperatures that could be encountered in lead-free soldering operations. A possible solution is to solder under an inert atmosphere such as nitrogen, although this might lead to increased costs for capital equipment modifications, as well as increased overheads. Soldering at higher temperatures also leads to higher energy consumption and it is likely that many existing soldering machines will not be able to operate at the required higher temperatures without significant modification or even replacement.

Another important issue that needs to be addressed relates to the visual inspection of soldered joints. Solder joints formed with lead-free solders have a very different appearance to those formed with lead based solders. Joints formed in lead-free solders can often have a different geometries and appearances that could lead to them being rejected if they were judged by the inspection criteria used for lead based solders. There will thus need to be an education and training process for operators carrying out visual inspection on lead-free solder joints. X-ray inspection is widely used to assess the quality of solder joints and in the absence of lead, this requires greater control and guidelines for inspection may need to be changed in order to accommodate the type of lead-free solder being inspected.

The final finish on the circuit boards being soldered must be compatible with lead-free solders. One of the most common finishes is the so called tin-lead based Hot Air Solder Levelled (HASL) finish. It will not be possible to use tin-lead based finishes when lead is proscribed and alternative finishes will have to be considered. It has been demonstrated that both vertical and horizontal lead free HASL is possible with no, or only slight, changes to the production process and the performance of the coatings is equivalent to tin-lead HASL. There are many other planar surface coatings already in commercial use which are both lead-free and compatible with lead-free solders. These include the Organic Solderability Preservatives (OSPs) and various metallic finishes such as nickel-gold, tin, silver and palladium. The solderability of these finishes with lead-free solders has been thoroughly investigated and there are few problems. However, solderability will vary with solder type and conditions, so it is important to choose the correct combination of solder/surface finish/flux and soldering conditions to ensure optimum performance.

When moving to lead-free assembly, in addition to lead-free PCB finishes and solders, it will be necessary to ensure that components are also lead-free. Lead-free components have been slow to arrive in the market and the need to ensure there is a wide and adequate supply remains a challenge for the industry as it prepares to become lead-free. Components are traditionally tinned with a tin-lead finish in order to impart good solderability. Components with lead based finishes can be successfully soldered with many lead-free alloys, although a phenomenon known as fillet lifting can occur in some circumstances. Many lead-free component finishes exist today and their wider use will become possible when component manufacturers receive more demand.

From an environmental perspective, it will be important to consider the wider implications of moving to lead-free. For example, some of the elements used in replacements for lead based solders may be more toxic and harmful than the lead they replace. Also, it will be important to consider the recyclability of lead-free solders in end-of-life electronics. Silver can be recovered economically but concerns have been expressed over the costs of recovering alloy elements such as bismuth from copper containing scrap.

Future Perspectives

There is no doubt that the electronic goods manufactured or used within the European Union will soon have to be assembled using lead-free solder. At the very latest, manufacturers will have to switch to lead-free assembly by the middle of 2006. Although the principal legislation driving the move to lead-free soldering has originated in Europe, there has already been much work carried out by major Japanese companies to enable them to convert their production to lead-free. Some Japanese manufacturers have already changed to lead-free assembly on many of their products and others have announced plans to convert well in advance of the European legislative deadline. European and North American manufacturers still have some way to go and it is important, in view of the many issues which must be addressed during such a conversion, that manufacturers do not wait too long to begin the changeover.

Martin Goosey
Shipley Europe Ltd
6th March 2003