Test and Inspection of Lead-Free Assemblies

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Major industrial nations, around the world, are rapidly moving to eliminate lead from the electronic manufacturing processes. While some companies are taking advantage of the situation and are using "lead-free" as a major marketing initiative in the consumer market, others are delaying the inevitable, because of the world wide lead-free legislation.

Lead-Free Legislation

Europe

- OECD: Lower the lead content limit in underground water from 0.05mg/L to 0.025mg/L in 2000.
- Total abolition of lead, cadmium, hexa-chromium, and non-flammable agent halogen starting 2005/6, according to the EU directive (WEEE & Rosh).

USA

- 1990: Introduced a bill prohibiting use of solder containing over 0.1% lead. (However, this excludes the electronics industry.)
- 1999: Industrial organization NEMI, formed by the USA electronic parts manufacturing industry, government organizations and universities, started research and development targeting the total abolition of lead products by 2004.
- 2002: Proposition 65 California.
- End Of Life legislation pending in 20 plus states.

Japan

- 1991: The Waste Disposal Law requires disposal within the facility when the detected lead amount is over 0.3mg/L by eluting test of industrial waste.
- 1994: The Water Pollution Prevention Law lowers the lead content of rivers from 0.1mg/L to 0.01mg/L.
- 2001-4: The Consumer Electronics Recycle Law requires manufacturers to recover harmful materials.

The move to lead-free solder has an impact on all phases of PCB assembly, including test and inspection. Let's take a look at some of the technical issues involved and the impact of lead-free solder on the major test and inspection technologies: automated optical inspection (AOI), automated X-ray inspection (AXI), in-circuit test (ICT) and functional test.

New Solder Formulations

The upcoming ban on the use of lead has prompted electronics manufacturers and industry organizations such as NEMI (National Electronics Manufacturing Initiative) and IPC to consider several alternatives to the traditional tin-lead solder chemistry. Teradyne has participated in NEMI's "Roadmap of Lead free Assembly in North America," the "Lead-Free Hybrid Assembly and Rework Project," and in the IPC 7-32 solder inspectability standards committee. (See Web URL's in Online Resources sidebar.)

New lead-free formulations include tin-silver-copper and tin-copper. The majority of the electronics industry seems to be moving toward the tin-silver-copper family of alloys for lead-free soldering. NEMI has recommended an "industry standard" lead-free alloy of Sn3.9Ag0.6Cu (+/- 0.2%) for reflow and Sn0.7Cu for wave solder. However, as with any process change, you should carefully consider the most appropriate mix for a broad range of applications, along with the logistics and economics of specifying a particular alloy.

Reflow Temperature

Lead-free solder mixes have higher melting points, which can lead to possible component and/or board damage. With lead-free solder formulations, melt temperatures rise from 183°C to approximately 217°C for SnAgCu, with temperature spikes as high as 260°C. The high temperatures can be somewhat reduced by longer pre-heat times. Rework temperatures also are affected, with some parts reaching 280° C.

Components need to be qualified for these higher temperatures, and some non-qualified components may actually require hand assembly.

Optical Inspection Issues

Inspecting lead-free solder terminations is fundamentally no different from inspecting a conventional leaded joint. The image of a lead-free joint is similar in appearance to that of a traditional tin-lead joint. The key to inspecting either type of solder is an inspection mechanism that can correctly measure the visual attributes of each image type.

However, there are some differences in the visual appearance between lead-free and leaded solder joints that can affect AOI systems. Lead-free solder joints are typically more striated and rough than corresponding lead joints, due to the phases transition from liquid to solid. As a result the joints may appear slightly duller and uneven. Also, lead-free solder has a higher surface tension and does not flow as readily as leaded solder, causing a slightly different-shaped fillet. These visual differences will probably require that you recalibrate AOI equipment and software. For example, automatically learned pass levels in some AOI systems may be slightly different for lead-free joints.

If you are currently using human inspectors and considering moving to AOI systems, now may be a logical time to deploy AOI systems because human inspectors will need “recalibration” at this time anyway.

Results of Industry Study on Lead-Free Solder Inspection

In 2002 Teradyne helped fund the National Physical Laboratory (NPL) to independently evaluate the ability of AOI systems to inspect lead-free solder joints. The NPL is the United Kingdom’s national standards laboratory, an internationally respected and independent center of excellence in research, development and knowledge transfer in measurement and materials science.

The NPL performed a study and published the results in July 2002 under the title "A Comparison of Automated Optical Inspection Systems for Use with Lead-Free Surface Mount Assemblies." The goal of the project was to determine if lead-free assemblies presented any problems for automatic optical inspection systems.

The test vehicle used in the study was a single board type developed specifically for the study. A number of boards were produced, some with defects, and some defect free. The board included many different solder termination types. Each assembly contained nearly 100 components with a total of over 1400 lead-free solder joints. The component types incorporated into the design included 0.4mm pitch 256-pin QFPs, 0.5mm pitch TSOPs, and 0402 resistors. The defect categories covered included missing components, misaligned components, components of correct size but wrong value, poor quality solder joints; components with wrong polarity, solder bridges, and poor component planarity.

The study evaluated AOI systems from six different manufacturers, including Teradyne. Identical software algorithms were used for lead-free inspection and for inspection of conventional lead-solder assemblies. The study found that results were similar to or better than those found with lead PCBs. False detect rates were also similar for both sets of results. Test times were unaffected by the lead-free nature of the test vehicle.

Although results did vary slightly among the different machines, the study concluded that most AOI systems can be used to inspect of lead-free surface mount assemblies. Some systems that use color-based algorithms and systems that rely on single cameras have experienced problems in evaluating lead-free solder joints. As a practical matter, a color image is not needed by an AOI system to analyze a solder joint; a monochrome image contains all the necessary information required for solder-joint analysis. Angled camera systems normally performed better at some J-leads defects such as bridges and insufficient solder joints.

Automated X-Ray Inspection Issues

With lead-free solder ball joints, we can expect an increase in voids. Lead-free solders have similar densities to lead based solder, allowing cracks and voids in the solder joint to be detected. Copper, tin and silver are still "dense" materials and therefore, like lead, impede X-rays. Some recalibration of the X-ray system maybe be required, but all the X-ray inspection companies--whether they produce manual X-ray or automatic X-ray inspection systems-- have concluded that lead free has no inspection issues but does offer an opportunity for increased inspection requirements on the manufacturing line to characterize good joints, monitor the assembly process and, most importantly, analyse the structural integrity of joints.

Impact of Lead-Free Solder on ICT

As we have documented, tin alloys are the lead-free choice; however, tin has demonstrated a "whisker" phenomenon--small protrusions of metal that "grow" out of a solder joint or pad. These whiskers can become large enough to short across two lands and can carry sufficient current to cause equipment malfunction. This can found easily with in-circuit test, but tin whisker growth can take time and may be a long-term reliability issue. Efforts are underway in organizations such as NEMI to try and minimize this phenomenon with different tin alloys.

To help with the reflow process for lead-free, we do see an increase use of flux, which in a no-clean environment can have a detrimental effect on fixture performance with increased contact resistance and a buildup of probe tip contamination. This will require increased maintenance of fixtures and maybe a change to more aggressive probe tip styles. But more aggressive probe tip may conflict with the brittle nature of lead-free solder and cause damage. The brittle nature of lead-free also means that more care will have to be taken to limit the flexing of boards in the test fixture.

Impact of Lead-Free Solder on Functional Test

Excess flux can also have a detrimental effect on “RF” circuits which can mean any modem PCB with the introduction of high speed serial communication protocols. This may put more pressure on the functional test to detect PF related problems due to board contamination.

Rework & Repair Issues

A final area to consider is the impact of lead-free solder on rework and repair. Higher temperatures are needed to melt lead-free alloys. If you have larger components on a board, you may need to pre-heat the component because of the larger heat dissipation. With the introduction of lead-free solder and the elimination of certain fire-retardants within the bare PCB, the higher temperatures required for rework may damage the component and/or board. These problems are being investigated by the NEMI “Lead-Free Hybrid Assembly and Rework Project” mentioned earlier. Many companies may find that they need to minimize or eliminate defects from the PCB assembly line, and the “zero-defect” line may become a reality. Also there will be increasing demands for accuracy diagnostics for device and pin level failures and an elimination of any false fails from the inspection systems.

References for additional information:-

www.leadfree.org
www.lead-free.org
www.ipc.org
www.nemi.org
www.npl.co.uk