GUIDE TO TESTING LEAD-FREE PRODUCT

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To comply with recent international governmental mandates, electronics manufacturers are moving to eliminate lead in their products. This push to more environmentally friendly manufacturing techniques, has raised many questions about the quality and durability of products produced without lead. Lead-containing solders and lead-containing finishes of components and circuit boards have been used for decades in the production of electronic assemblies. Typical strength and durability characteristics of joints with lead-containing solders/finishes have been long known. However, there is very little data of these same properties for joints made lead-free solders/finishes.

Lead-free solders require different processing than standard lead-containing solders. The most common lead-free solders have a higher melting point and higher liquidus temperature. Additionally, the time required at liquidus is typically longer for lead-free solders than lead-containing solders. All this means that the soldering process parameters must be altered from what was commonly used with lead-containing solders. If the parameters are not adjusted properly, the lead-free joints may be defective or weaker than is required. Additionally, boards and components will now be exposed to higher temperatures for longer periods of time.

For these reasons, new lead-free solder joints must be examined and specialized testing is required to validate the assemblies produced using lead-free processes.

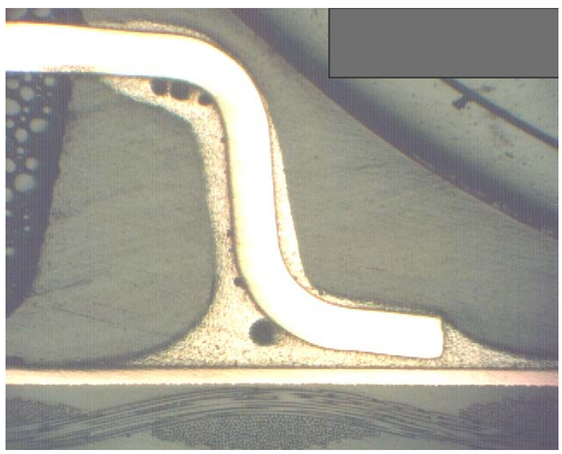

Figure 1 – Cross-section of a lead-free solder joint

Lead or No-Lead

The first step in verification is to confirm that the materials are truly lead-free. This is easiest accomplished on the solder before it is used in assembly. There are many analytical techniques to examine solder for the presence of lead. Some involve digesting the metal in acid and testing via Atomic Absorption Spectroscopy (AAS) or Inductively Coupled Plasma (ICP). Others involve making the metal into a slug and testing via Optical Emissions Spectroscopy (OES) or X-Ray Fluorescence (XRF). Though the analytical techniques differ and have differing detection limits, all will provide adequate reliability in results.

Testing the printed circuit board and components can be accomplished in a similar manner but do pose more difficulties. The problems mainly center on the large sample size and determining what is truly a homogeneous sample. When testing metals for composition, only a 5-gram sample is needed (approximately $1cm^3$ for solders). Typical PCB or PCA are much bigger than this and testing a sampling will not satisfy many of the governing agencies. For components or assemblies, the entire product must be tested. This means, the entire product must be digested. The most common method used in the digestion is US EPA Method 3050B. Once the sample is digested, it is tested via AAS in accordance with US EPA Method 7420. This will provide the percentage of lead in the entire product.

Mechanical Strength

Beyond the simple verification that lead is not present in the product, the integrity of lead-free solder joints must be determined. Most of the testing is based on standard methods, but all need to be modified to accommodate the particular product. Because the methods are altered, the absolute values obtained for new product are often times not as important as how they compare to values of known product. For this reason, it is best to use boards with lead-containing solder joints as a control. The new lead-free joints can be compared side-by-side with their lead-containing counterparts.

Common mechanical tests are Lead Pull Strength and Lead Shear Strength. These can be performed on individual leads or the component as a whole (testing all leads at once).

The Pull Strength measures the force required to pull the lead from the board. The pull is conducted perpendicular to the board surface. Once the leads are pulled, it is significant to note the mode of failure. Common modes of failure include lead separating from the joint, joint cracking, joint separating form the board, or pad pulling from the board.

The Shear Strength measures the force required to shear the lead from the board. The shear is conducted parallel to the board surface. Again, the mode of failure should be noted.

Additional to strength and force data, cross-sectioning the joints is essential. The joints should be examined for voiding, cracking, wetting, and a variety of other features and anomalies, via Optical Microscopy

Once sectioned, the joints should be examined at high magnification via Scanning Electron Microscopy (SEM). SEM analysis will allow for inspection of the grain structure, intermetallic formation, and many more minute details not ready apparent via standard Optical Microscopy. With Energy Dispersive X-Ray Spectroscopy (EDS) coupled to the SEM, the elemental distribution through the joint should be determined. These mechanical integrity qualities will ultimately determine the strength, reliability, and robustness of the joints.

Reliability Testing
The most common reliability tests are thermal shock and temperature cycling while monitoring continuity through the solder joints. Again, this testing is ideal when comparing old proven processes to new lead-free processes. This requires boards with daisy-chained circuits connected to dummy daisy-chained components.

The basic premise is to stress the boards until solder joint failure. An event detector applies current to the circuits and continually monitors continuity through the joints. The event detectors will isolate opens that last mere nanoseconds.

Unlike PCB interconnects or copper plating cracks that open and stay open, the common failure mode of solder joints is to open for very short periods of time. When first occurring, the open is usually temperature dependent and will not manifest itself unless the temperature is changing. At constant temperature, particularly ambient conditions, the joints appear fine. Eventually, the joints will worsen and the failures will be apparent at ambient or constant temperature conditions. However, this could be 100s or 1,000s of cycles after the initial open occurred. For this reason, it is essential to monitor the circuits with an event detector as opposed to taking discrete resistance measurements at certain intervals. The joints may have long since failed by the time a discrete resistance measurement detects high resistance.

The failure mode described above, is one of the reasons assemblies have intermittent failures long before they completely stop working.

Tin Whiskers
Most of the above has dealt with the lead-free solder. The other main concern is PCB surface finish. Tin is quickly becoming the lead replacement of choice. The testing mentioned above will help determine the strength and reliability of assemblies those boards were tin-plated. However, tin finish can cause additional problems, namely whiskers.

Figure 2 –SEM photograph of whisker formed on tin plated leads

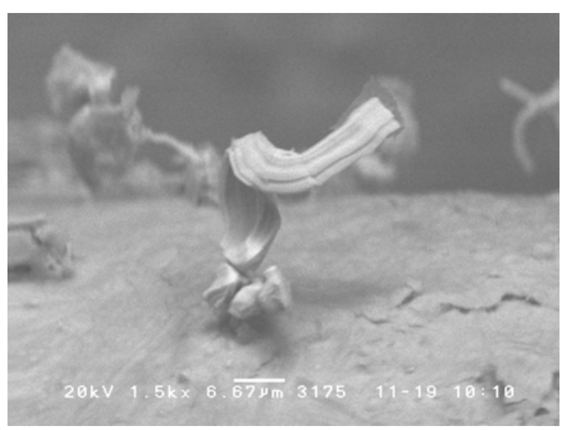

Figure 3 - SEM photograph of whisker formed on tin plated leads

It has long been documented that tin has a propensity to form whiskers. There are several tests that should be conducted to determine the plating's tendency to form whiskers. As with the testing detailed previously, this testing is best used as a comparison, but in this case a comparison of new potential finishes.

The following are the recommendations of Trace Laboratories – East for determining the likelihood of tin whisker formation on pure tin platings and soldered assemblies. The test samples can be bare printed circuit boards with pads plated in tin or new tin-plated components before they are soldered to a board or a finished soldered assembly or part (harness assembly, cable, etc.)

- Initially examine each of the pads/leads/joints for tin whiskers.
- Perform Scanning Electron Microscopy (SEM) on parts at approximately 300X to locate whiskers.
- Photograph at approximately 3000X to measure and record the maximum length of whiskers.
- General requirement is that whiskers shall not exceed 10µm for high reliability products and 25µm for consumer products before or after being subjected to the following conditions.

<u>Air-Conditioned Facility Testing</u>
Condition samples at 25°C ± 5°C and 30 – 80% RH for 4,500 hours (approximately six (6) months). Remove 1/3 of the samples for examination at 750, 2250, and 4500 hours. Examine for tin whisker growth as listed above.

<u>High Constant Temperature Testing</u>
Condition samples at 60°C and 85 – 95% RH for 4,500 hours (approximately six (6) months). Remove 1/3 of the samples for examination at 750, 2250, and 4500 hours. Examine for tin whisker growth as listed above.

<u>Temperature Cycling</u>
Condition samples at +85°C to -40°C for 1,000 cycles with three (3) cycles per hour. Remove ½ of the samples for examination at 500 and 1000 cycles. Examine for tin whisker growth as listed above.

Conclusions
As new processes are implemented, new means of testing must be employed. At Trace Laboratories – East, we specialize in taking existing standard test methods and modifying them to better suit our customer's needs.

For more information concerning these topics or any other testing needs, please contact me at (410) 584-9099 (traceeast@tracelabs.com) or (303) 683-4806 (tracedenver@tracelabs.com). Visit us on the web at www.tracelabs.com/east.aspx.