Conclusions

The legislation chapter reviewed the emerging wave of environmental regulations around the globe, which present technical, administrative, and procedural compliance challenges to producers. Failure to comply with these requirements also carries significant business, financial and legal implications. Companies must pay close attention to these evolving regulations and work with diverse experts to bring all the elements of sustained compliance together.

The alloy chapter reviewed various lead-free solder alloys with a focus on SnAgCu. It guided the reader to where future research on Pb-free alloys would be needed, which included:

- high reliability applications – server, military, aerospace, medical – for which exemptions are going away or where the lack of availability of tin-lead components will force a switch to lead-free soldering
- understanding whether there are any significant differences between different SAC alloy compositions in terms of reliability
- acceleration factors for SnAgCu and SnCu based alloys
- interactions of lead-free solder alloys and board/component surface finishes (containing gold, nickel, bismuth, silver, copper)
- effects of lead-free soldering time above liquidous temperature and peak soldering temperature on intermetallic formation and solder joint microstructure and its effect on reliability
- effect of lead-free cooling rate and subsequent aging on intermetallic compound and solder joint microstructure and their effect on reliability
- copper dissolution studies with different lead-free solder joint alloys and reliability of the resulting solder joint
- effect of CuSn, NiSn, NiCuSn, AgSn, AuSn intermetallic on lead-free solder joint reliability
- effect of lead-free surface mount, wave and rework (BGA/CSP, Wave, Hand) processing on intermetallic formation and solder joint microstructure with the resultant effect on reliability
- effect of lead-free wave solder holefill on reliability

- effect of ATC and mechanical testing (bend, shock, vibration) on lead-free solder joint reliability
- effect of ATC dwell time and temperature ranges on lead-free solder joint reliability

The SMT reflow chapter discussed the printability of lead-free SAC solder pastes which were shown to be equivalent to that of SnPb in most cases. With more production experience with lead-free assembly, solder paste suppliers would make more improvements in their flux formulations. There had been no real placement issues associated with lead-free components. Lead-free reflow soldering affected the visual appearance of soldered joints which was indicated in the IPC-610D standard. It also affected the temperature of the reflow profile which could cause issues for assembled components and boards due to the higher soldering temperatures. The surface mount component temperature rating standards had been adjusted to reflect these higher temperatures, but more work was needed for board temperature ratings for lead-free. X-ray images were fairly similar for lead-free and tin-lead soldered components.

The lead-free wave soldering chapter discussed the migration from the traditional tin-lead (Sn37Pb) alloy to lead-free solder with Sn3.0Ag0.5Cu as the main lead-free wave alloy alternative to align with the lead-free surface mount paste. Due to cost issues, alloys containing reduced or no silver, such as SN100C (Sn0.6Cu0.05Ni), could also be an alternative. The wave solder machine would need to be adapted to lead-free soldering to avoid erosion of all its machine parts that were in contact with the molten alloy which should be considered to be retrofitted.

Materials segregation to control lead-free solder from being mixed with tin-lead solder would be one of the most challenging items to implement moving forward. Frequency of bath alloy analysis would need to be reinforced with careful analysis of the elements such as lead, copper and iron. The lead-free wave process window would be narrowed and the risk of damage of components and/or PCB increased. Higher solids content no-clean fluxes would give good results for lead-free wave soldering but there would be an issue with test pin probeability results. If assemblers were not used to VOC-free fluxes, they would need education as they were typically preferred for lead-free soldering as they offered a complete green solution. With these water based fluxes, increased preheat would be more critical to ensure water removal prior to the wave soldering. Lead-free solder joints had a grainy appearance and some anomalies or defects may increase with lead-free soldering, including voiding, hot tearing and shrinkage grooves, fillet lifting, pad lifting and reduced hole fill. More studies would need to be performed on the final product application as the effect of these potential anomalies/defects on solder joint long term reliability was not well known.

The lead-free rework chapter discussed the choice of Sn3.5Ag for lead-free hand solder rework, although there had been movements to Sn3Ag0.5Cu to be the same alloy as used for surface mount and wave soldering. Typical soldering iron tip temperatures were found to be around 371°C (700°F), which was slightly higher than those used for tin-lead. The soldering tip would usually apply localized heating so that the component would be less likely to increase in temperature sufficiently to cause concern compared with lead-free BGA/CSP component rework. Good training would be needed to avoid excessive board and component damage. Soldering iron tip life would typically be degraded with lead-free high tin based solders with more care needed by the operators for solder iron tip maintenance.

For lead-free BGA/CSP Rework, temperatures being experienced were found to be higher than during 1st pass reflow. The peak temperature of the component during rework was found to be 15-25°C above that of the solder joint. A good temperature rating for components for lead-free soldering would be 260°C. The margin of error to maintain a lead-free minimum solder joint temperature of 230-235°C with a maximum body temperature of 245°C-250°C was very tight during BGA/CSP rework with the J-STD-020C standard helping to address this (260°C). In many cases, adjacent component temperatures were exceeded at 3.8mm (150mils) during rework on the board for tin-lead and lead-free BGA/CSP rework, which gave cause for concern for adjacent component temperatures and subsequent joint reliability. Rework equipment and nozzles were still in the process of development for lead-free with it generally being more difficult to control temperatures in rework than reflow with a need for more lead-free process manufacturing margin.

Bottom-side heat and thermal uniformity of BGA/CSP rework machines were critical to bring the board to proper lead-free rework temperatures. Rework machines needed more development with emphasis on optimized lead-free rework profiles, optimized rework machine development and machine repeatability. These were under investigation in the new iNEMI lead-free rework optimization project.

For lead-free hand PTH rework, there had been limited work done. The testing done so far indicated soldering temperatures and time may be slightly higher than for lead-free SMT hand soldering rework. In some cases, pre-heat of the board would be preferred. More work would be needed to develop the rework process with a general soldering iron tip temperature guideline of 371°C (700°F) to 427°C (800°F) for lead-free.

For lead-free PTH mini-pot rework, this area had minimal development. There were issues due to increased solder mini-pot temperatures and dwell times using lead-free high tin containing solders which lead to issues such as copper dissolution and reduced holefill. Alternative alloys such as Sn0.6Cu0.1Ni (SN100C) were being investigated to reduce the copper dissolution issue, but more work needed to be done investigating the type of copper plating used by the board supplier to understand if this could also reduce the amount of copper dissolution.

The lead-free reliability chapter indicated that along with SnPb assemblies, the assessment of lead-free solder joint reliability required detailed, quantitative investigations of the thermo-mechanical response of solder alloys under a wide range of stress, strain and temperature conditions. Lead-free solder joint reliability similar to SnPb reliability remained product- and application-specific. The case study indicated that lead-free solder joint life for a given product board relied on a large number of parameters describing thermal conditions, board and component geometry, and material properties. Significant progress had been made to quantify the thermo-mechanical behavior of SAC387/396 solders and board assemblies, including the development of test databases, life prediction models, and acceleration factors, and more work would be needed. Similar efforts would also be needed for each new solder alloy composition being considered for lead-free product assembly.

The backward compatibility and forward compatibility chapter reviewed the process and reliability implications of the mixing of tin-lead solder alloy and lead-free components and lead-free solder alloy with tin-lead components, with emphasis on the reliability of tin-lead solder and lead-free BGA/CSP backward compatible assemblies. There were conflicting experimental results on the reliability of BGA/CSP backward compatible assemblies. The majority of forward compatibility studies showed few or no issues, although excessive voiding of tin-lead BGA/CSP components with lead-free solder was a concern. The effect of lead content in mixed assemblies (forward compatibility and backward compatibility) was still questionable in terms of reliability. Data showed that the backward compatibility assemblies of chip components and lead-frame components were reliable in terms of solder joint integrity. The estimation of the liquidous temperature of mixed compositions in backward compatibility was presented for BGA/CSP, lead-frame and chip components. The estimation for BGA/CSP components could be used to guide the development of a reflow profile, but it needed to be noted that the estimation was an approximation and further experimental study would be needed to validate the accuracy of the method.

Both the backward and forward compatibility situations would need to be considered as transitional processes only with a full movement to lead-free solder with lead-free components being the general goal to avoid any reliability issues associated with the two transition assembly situations. For lead-free press-fit components, due to the press-fit material changing from SnPb coated to lead-free coated, the process would need to be re-characterized. Currently there were only limited studies done by OEM/EMS/suppliers. No conclusion could be drawn yet in terms of the selection of the best PCB surface finish, PCB laminate material, and compliant pin plating. It was recommended that OEM and EMS providers and connector suppliers work together to make the lead-free press-fit interconnection transition smooth, without compromising quality and reliability.

The PCB laminate chapter discussed several laminate material properties that were critical for evaluating laminate material choices for higher temperature lead-free assembly processing. Laminate material decomposition temperature was the newest test method for evaluating thermal robustness, and along with the overall Z-axis CTE test method was the most indicative of what was required for both surviving higher temperature lead-free assembly processing and ensuring subsequent product reliability.

The PCB surface finishes chapter discussed the lead-free board surface finishes which were commercially available to meet the requirements of Pb-free electronics manufacturing. It gave a description of the most technically feasible alternatives. Benefits and concerns specific to each finish (or group of finishes) were discussed. It was noted that no surface finish had yet been developed that met the requirements of Pb-free assembly while eliminating all of the well known processing, storage and operational concerns. To some extent each finish was adversely affected by one or more technological or cost issues. In addition, there were some processing, performance or reliability problems that affected all or many of the available finishes. For example, it was well known that Pb-free solders were more aggressive to copper in comparison to eutectic SnPb solder. Pb-free soldering on Pb-free HASL, OSP, immersion silver, immersion tin and immersion gold resulted in the formation of a Cu-Sn IMC, which reduced the underlying pad and through-hole copper thickness. With no barrier layer, any further thermal exposure would continue to dissolve copper into the solder joint, forming more IMC. Such dissolution was of particular concern where the initial copper was thin, such as controlled impedance applications. Lead-free wave soldering could be very aggressive, particularly during rework soldering, causing drastic reductions in copper thickness, most notably at the through-hole entrance or “knee”.

Voiding was another example of an issue that affected soldering on all board surface finishes to some extent. The specific issue of microvoiding with respect to immersion silver was examined with more work needed in this area. It was important to note that IPC design standards had not currently changed in response to Pb-free requirements. Land patterns in the newly released IPC-7351A met requirements for surface-mount assembly with either SnPb or Pb-free solders. Selection of the proper PCB surface finish would be more critical with increasing demands, particularly in light of the continuing drive to reduce costs. As a result, each finish needed to be examined and evaluated based on its recognized functional capabilities and known potential weaknesses.

The lead-free standards chapter reviewed some of the most common standards, which had been affected by the transition to lead-free soldering. Critical issues such as temperatures for lead-free surface mount soldering and visual inspection of lead-free soldered joints had been addressed to a certain extent but there were many more standards that need updating and this was being done as more data was becoming available.

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