

## Lead-Free wave soldering Root causes of common defects

Wave soldering using RoHS compliant lead-free alloys is no longer a new concept. Lead-free wave soldering has been in practice for many years now, and the process has been implemented by thousands of circuit board assembly operations. However, many defects that are well understood in tin/lead wave soldering (such as poor hole fill, bridging, skipping, and blow-holes) become more prevalent in lead-free soldering environments. These defects are even more common when high complexity, thick, multiplayer printed circuit boards (PCB's) are being assembled. The purpose of this paper is to examine the causes of these problems so that steps can be taken to reduce the frequency of defects.

Some characteristics of lead-free wave soldering that create challenges are:

- Tighter Operating Parameters
- Wetting Time
- Lower Fluidity
- Fillet Lifting and Shrinkage Void
- Copper Erosion
- Copper Contaminating

## Tighter Operating Parameters

In lead-free wave soldering processes the pot temperatures are significantly higher than traditional tin/lead soldering. Higher soldering temperatures may cause potential problems such as board warpage, discoloration, delamination, degassing, component cracking, and excessive copper dissolution. In addition to the higher pot temperature, some lead-free wave soldering processes increase the total contact (dwell) time for complex and thick boards. This will put additional strain on the board and component reliability.

Lead-free wave soldering processes also have much narrower operating temperature windows. For SAC305 (Sn96.5Ag3.0Cu0.5) the melting range is 217-220°C. If the pot temperature is 260°C the temperature window is about 40°C. For tin-copper based lead free alloys (Sn99.3Cu0.7, Sn99.5Cu0.5Co, Sn99.5Cu0.5Ni etc.) the liquidus temperature is around 227°C. Even if the pot temperature is set at 270°C (some manufacturers may use as high as 275°C, which is not recommended) the temperature widow is still only about 40°C. For tin-lead eutectic solder, the operating temperature windows are usually at least 70°C (183 – 255°C).

This narrow temperature widow will cause the molten solder to exhibit slower drainage and faster solidification, which makes the solder joints more prone to bridging, icicling, and flag formation. Using higher activity fluxes, higher preheat temperatures, smoother flow at the point of peel-off, and lower clearance of the leads can minimize these defects.



*Fig. 1. Bridging*



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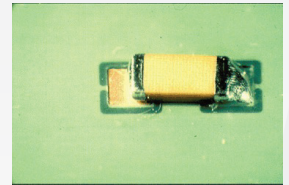
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## Wetting Time

All of the commonly used lead-free alloys exhibit slower wetting speeds (at their normal operating conditions) than the eutectic tin/lead solder system, although the wetting speed varies among the lead-free solder alloys. In addition, lead-free wave soldering processes require higher preheat and pot temperature settings, which cause the PCB and the components to become more heavily oxidized in comparison to the tin/lead process. The slower wetting speed and the heavier oxidation will cause more tendencies of skips on SMT devices and poor fillet filling. These problems can be overcome by higher flux activity and increasing the contact time. If it is feasible, a higher pot temperature will help to reduce the defects created by the slower wetting.



*Fig. 2. Skipping*

## Lower Fluidity

At their operating temperatures all lead-free alloys exhibit less fluidity than Sn63Pb37 solder. This is not only due to the intrinsic properties of the alloys, but also due to the narrower operating temperature windows as mentioned earlier. Solder that is less fluid fills the fillets more slowly increasing the likelihood of shadowing effects, solder bridging, and icicle formation. Some lead-free alloys use a small amount of transition metals such as Co and Ni as a grain refiner, which significantly improves the fluidity of the solder during the molten stage. Higher pot temperature and better wetting flux chemistry will improve the hole-fills and reduce any bridgings.

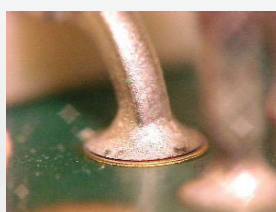


*Fig. 3. Solder Icicle*

## Fillet Lifting and Shrinkage Void

Through hole fillet lifting is a phenomenon in which the solder joint will lift off the pad surface. It is believed that the wide pasty range (the temperature range from fully solid to totally liquid) and the uneven solidification shrinkage due to the phase segregation of the lead-free alloys are the root causes. High surface tension of the liquid state and low ductility at the solid state of the lead-free alloys also contribute to the problem.

During solidification the tin rich primary phase in lead-free solder will start to nucleate and grow as dendrites from the outer surface and in through hole barrels due to the heat sink effect of the component leads. The lower-melting point phases will stay as liquid at the interface area during the early stage of the solidification. This will cause uneven solidification shrinkage of the solder and will pull the solder away from the PCB pads along the intermetallic layer. Contaminations from certain metal elements such as bismuth, indium and lead are believed to aggravate the fillet-lifting problem due to the formation of lower melting temperature phases, which will concentrate on the interface during the solidification of the molten solder and make the solder joint more prone to fillet lifting. Uneven solidification shrinkage of lead-free alloys also causes hot tearing and voids on the solder joints. These defects, as well as minor fillet lifting, are normally considered benign by the industry. However, in some severe cases they will raise a reliability concern. To avoid these problems some transition metal impurities should be avoided. Lead-free alloys with grain-refining elements such as Co and Ni are faster cooling after soldering and may help to prevent the potential issues.



*Fig. 4. Fillet Lifting*  
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*Fig. 5. Poor Hole Fill*

## Cooper Erosion

In Lead-free wave soldering processes copper dissolution rates are higher than that in tin/lead processes. This is not only because of the higher pot temperatures, but also because of the higher concentration of tin content in the alloys. Alloys with higher silver contents, such as SAC305, are believed to have a higher copper dissolution rate than the lower silver containing alloys. In most electronics assembly processes copper erosion that occurs on the copper track of a PCB is not a serious issue. However, repeated heating on a narrow copper trace, especially during rework, may cause a reliability concern. Therefore, during the board design a wider trace should be used for the vulnerable locations.

## Copper Contamination

When copper content increases the liquidus temperature of the alloy will also increase. At the same pot temperature the molten solder will become less fluid. Higher copper content also changes the grain structure of the alloy, which will carry over to the liquid state making the molten solder more sluggish. This will translate to more bridging, skipping and poor hole-fill. The density of the intermetallic compound (IMC,  $\text{Cu}_6\text{Sn}_5$ ) is 8.25 and the densities of lead-free alloys are from 7.30 to 7.39. As a result, the heavier IMCs tend to sink to the bottom of the pot and accumulate in the system as opposed to a tin/lead environment where IMCs float on the surface of the solder bath to be skimmed off with the dross. This will not only increase the tendency of defects (such as poor hole fill, bridging and skipping), but also may cause clogging in the wave solder machine from the needles of the crystalline IMC. Therefore the copper level in the pot needs to be monitored frequently. One way of removing the IMCs is by lowering the pot temperature (about 20%) and let the IMCs crystallize out at the bottom the pot. These needle shaped IMC crystals can be removed by a fine mesh stainless steel colander. The most common way of lowering the copper content is to replenish the pot by corresponding copper-free alloys.

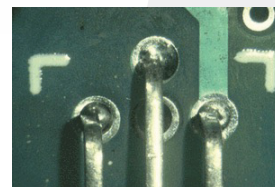


Fig 6. Poor Hole Fill

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