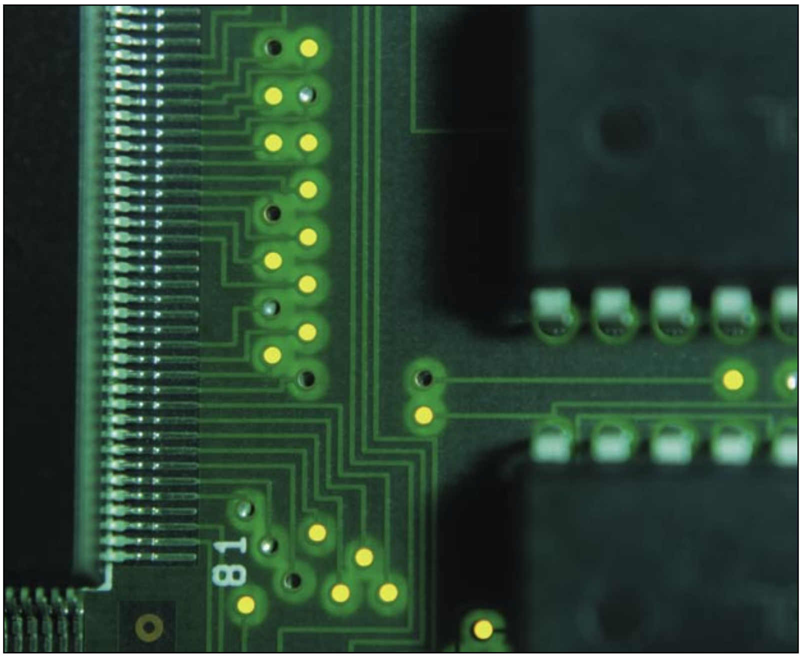
Lead-Free Wave Soldering: Lessons Learned

by Steve Brown and Chrys Shea, Cookson Electronics Assembly Materials

Wave soldering, or flow soldering as it was called in its early days, has been around for about 50 years. Over the span of its lifetime, the originally "simple" process has been continuously improved and refined, bringing it to the high level of sophistication it operates at today. Many would argue that wave soldering is the most complex of all soldering processes. Now it faces the biggest change in its history - new alloys with different flow behaviours and processing characteristics.

When wave solder alloy conversion issues began emerging a few years ago, a number of rumours about the new process began circulating. Some were based on fact, some were early speculation, and some were just pure fiction. Two years later, with many mainstream assembly processes having converted to lead-free, the authors were surprised to find that many of the myths regarding lead-free wave soldering are still in circulation. It's time to examine some of these rumours more closely and set the record straight.



Lead-free dross sinks to the bottom of the solder pot

Fiction. As with tin-lead or any metal oxide, the dross becomes less dense than the molten metal and rises to the top. All over the world, tens of thousands of wave solder operations have been converted to lead-free alloys, and none of them have demonstrated the issue of dross sinking to the bottom of the solder pot. Similar to tin-lead, it is typical to have some dross circulating in the melt, and a portion of it will cling to the internal parts of the solder pot. Following an alloy conversion, equipment preventive maintenance should be performed in the same manner and frequency as a tin-lead solder pot, and maintenance intervals can then be adjusted based on production experience with the new process.

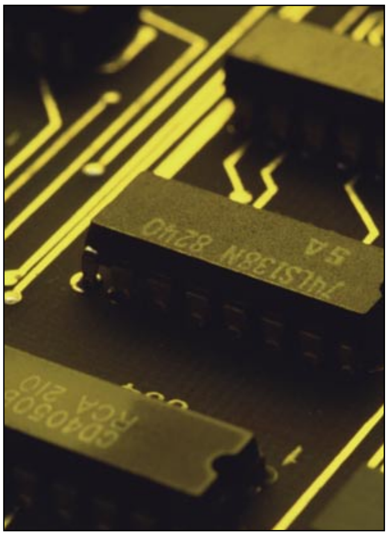
Avoiding OSP surface finishes will limit copper dissolution

Fiction (mostly). Copper dissolution is a very large concern for assemblers, because it has serious implications on both the soldering process and the reliability of the final product. Whether the surface finish is OSP, Immersion Silver, or Immersion Tin should not make a substantial difference. These final finishes immediately enter into solution when wetted by molten solder. The only finish that should not lose copper to the solder bath is Electroless Nickel-Immersion Gold, because the nickel provides a barrier layer, shielding the copper from the wave. Remember that in the case of an ENIG finish, the solder is not attaching to copper, but to nickel instead, which brings with it a separate set of concerns for the engineer.

Bismuth embrittles lead-free solder joints and should be avoided

Fiction. Quite to the opposite: bismuth included in the alloys in amounts up to 3% actually improves the fatigue strength of the alloy. Pure bismuth is a brittle metal and when alloyed with tin at 42%Sn-58% Bi, it makes a very brittle alloy with a melting point of 138°C. We assume that this is the root of one of the fears regarding bismuth inclusion. The other rumoured fear concerning bismuth:

Bismuth from solder can combine with tin-lead to form an alloy that melts at 96°C. If any one of the many components on a PWB is plated with tin-lead, the entire assembly may be unreliable if service temperatures exceed 96°C



Fiction. While it is true that an alloy containing 52% bismuth, 16% tin, and 32% lead will melt at 96°C, it would be physically impossible to arrive at this concentration of bismuth, given that the bismuth component of solder alloys are typically 3% or less. And although bismuth-containing solders may appear new to the average user, they have been in use for a long, long time. Bismuth has a well established history in both tin-lead and lead-free soldering. It is likely that the average consumer owns electronic devices that contain bismuth in their tin-lead (62/36/2) solder joints, because it is used in one of the most popular consumer brands. Of three large-scale studies by major OEMs, the most conservative results recommend bismuth in quantities less than 0.3% - compare this with the concentration of a typical bismuth containing lead-free alloy at 0.1%.

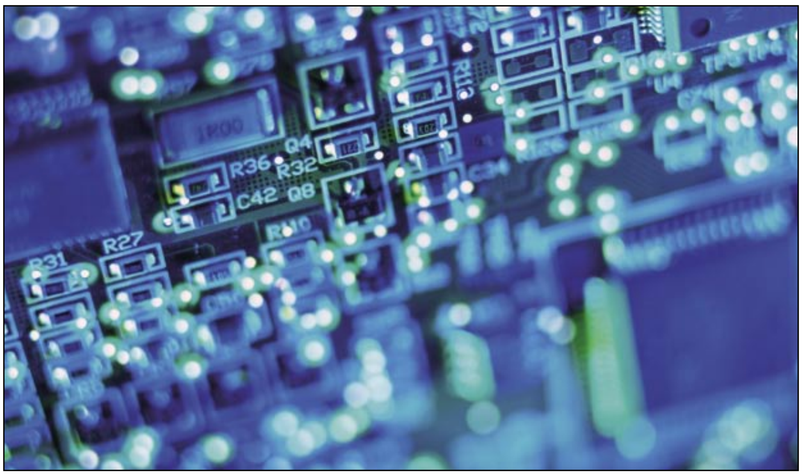
If this is not convincing enough, take a look at the spec sheets for tin-lead solder. Standard electronics grade tin-lead solders allow up to 0.1% bismuth to be included in the alloy. In this case, history can provide some sound guidance. If bismuth inclusion presented reliability issues, these issues would have been seen in the last few decades. The engineering community would be well aware of the reliability risks by now, and tighter specification limits would be in force for tin-lead alloys.

From fiction to fact

Now that we have looked at non-truths surrounding the wave solder process we will take a look at some of rumours from the lead-free transition that are true. To gain a better understanding of the stories in the field, we consulted with some well-respected experts on the topic from Electrovert.

Lead-free solder pots need analysis more frequently than tin-lead solder pots

Fact. The tin-rich lead-free alloys erode copper faster than their tin-lead counterparts. This means that copper from PWB pads and through-hole pins will be picked up faster than in tin-lead solder pots. As copper content increases in the solder bath, the fluidity of the solder decreases, and this can cause more soldering defects.



Furthermore, the RoHS limit for lead is 0.1%; if more lead is present in the bath, the final assembly will not be RoHS compliant. It is generally suggested that solder pot analysis be performed more often with lead-free than with tin-lead solder pots. Current guidance is to begin the lead-free wave solder process with pot analyses approximately every 8000 PWBs, track the results, and adjust sampling frequency accordingly.

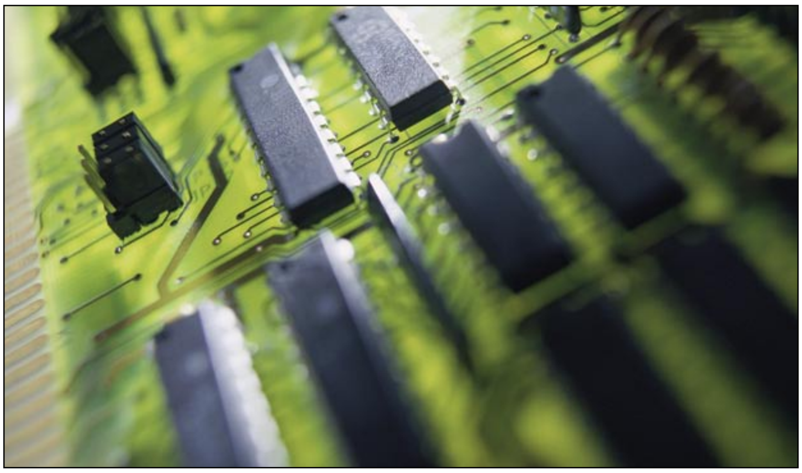
Stainless steel solder pot components need to be treated to protect them from tin-rich corrosion

It depends. Most tin-rich alloys do attack stainless steel, but all attack them at different rates. SAC305 and 405 are known to be particularly aggressive. The rate of attack depends on the alloy constituencies of both the solder melt and the stainless steel itself, and the temperature of the melt. The best way to determine if protection is required is to discuss your process with the manufacturer of your wave solder equipment.

PWB designs with high thermal mass and poor thermal relief that are difficult to solder with tin-lead alloy may be nearly impossible to solder with lead-free alloys

Fact. This is one of those areas where the engineering community anticipated that the challenges would get worse, but I don't think any of us knew how much worse until we began soldering and saw it with our own eyes!

Hole fill is one of the areas that bring the biggest challenge. Most tin-lead solder pots operate roughly 55°C above the freezing temperature of the solder. Compare that to lead-free solder pots that operate at about 30-40°C above the freezing point, and couple it with alloys that don't wet as readily as tin-lead. Not only will the solder wick up the barrel more slowly, an internal ground plane



that is not properly connected can stop it dead in its tracks.

Ways of improving hole fill include running longer contact times and deeper immersion depths, both of which can impair peel-off mechanics and create more solder bridges. Given this scenario, it would not be unreasonable to update DFM guidelines to add increased solder bridges to the list of potential defects that poor internal ground connections can cause. Back in the days of tin-lead, we could overcome bridging problems with hot gas de-bridging knives. But now that we are running lead-free, that brings us to another rumour regarding the lead-free process:

Hot gas de-bridging knives do not work with lead-free solder

It depends. To me, this is one of the biggest downsides of going lead-free with wave soldering. I have always regarded de-bridging knives as the "great forgivers." Engineers could crank up the wave (to get hole fill on thermally challenging designs, climb up into the apertures of selective solder pallets or overcome shadowing on densely populated layouts) and the knife would efficiently blow away all those pesky bridges before the board exited the solder process. We just can't count on that anymore. In some cases, such as when using selective pallets, the knives may be able to provide some relief to solder bridging, but it is not likely in mainstream production. This is because the wider throats on the wave nozzles that provide more contact also create a longer distance between the point of separation and the knife itself. Given that lead-free alloy is running closer to the freezing point than tin-lead alloy, by the time the knife can act on the bridges, they are either frozen solid or very close to it. In order to get good de-bridging action, the knife would need to be turned up to temperatures and pressures that could adversely affect the reliability of the final assembly.

We know that lead-free solders have lower fluidity than tin-lead, and that the drainage is worse, so in many cases we can expect more solder bridges to begin with. When we lose the effectiveness of our de-bridging tool, we have to rely solely on peel-off mechanics to remove the bridges. Because peel-off is now more critical than ever, it is important to take advantage of the best possible setup. The three things to look for when setting up the wave are:

- Smooth flow at the point of peel-off. Look at the peel-off region as a PWB exits the wave. Turbulence should be minimal. Since we are relying on surface tension to snap the solder bridges apart, we want it to be as uniform as possible, in both magnitude and direction.
- To get the smoothest flow possible, run the lowest lead clearance and lowest effective pump speed possible. Notice that this contradicts some of the options to improve hole fill like deeper immersion depths, so a trade-off may be required.
- Just enough backflow that when no PWB is crossing the wave, a mere trickle flows over the back gate, but when the PWB does enter the wave, the leading edge initiates typical back flow. This will push accumulated dross off the surface of the wave and provide fresh, oxide-free metal for soldering.

Notice that all three tips require watching the wave. Our eyes are the probably the most useful diagnostic tool we have in wave soldering.

The lesson

So what is the lesson learned? The alloy is the cornerstone of the wave soldering process, and when it changes, many process considerations change with it. We mentioned that the wave soldering process has been around for 50 years, and until recently, 99% of all the wave soldering processes in the world used tin-lead. From the primary considerations of hole fill and solder bridges to the ancillary process concerns of maintenance and hardware protection, we need to look at everything that the alloy change can affect. Unfortunately, the investigation of every possible main and side effect is likely not a viable option in today's business environment, so we need to rely on our suppliers to do much of the leg work for us.

The rumours on surface finishes and bismuth inclusion required consultation with metallurgists for clear-cut explanations, the concerns on dross buoyancy can be reasoned out with some very basic principles we learned in high-school chemistry and physics classes. While it is true that we can expect the behaviours of the new alloys to change as their constituents change, we cannot expect the laws of nature to change along with them.