A Study of Lead-Free Wave Soldering

Discussion: As lead-free wave soldering becomes increasingly prevalent, questions have arisen about copper dissolution into lead-free alloys. Concerns have arisen over the use of alloys that may require more solder pot maintenance due to their high copper dissolution rates.

The first part of this study was performed to determine if there is any significant difference between Sn/Ag/Cu alloys. The study compared Sn/Ag3/Cu0.5 (LF218) to Sn/Ag2.5/Cu0.8/Sb0.5 (CASTIN). The purpose was to determine if at wave soldering temperatures one alloy will absorb less copper than the other alloy.

Test Procedure: Two pots of each alloy holding approximately 500 grams of metal were heated to 530°F (276°C). Copper strips were weighed, fluxed and then placed into the lead-free alloys. The temperature and strips were monitored every 5 minutes for any visual change. After 30 minutes changes were noticed. The copper coupons were then removed and weighed.

	CASTIN	**Sn/Ag3/Cu0.5**
Coupon Weight Loss	.8992	1.8415
	.8067	1.8157
	.8767	1.8523

Observation: The Sn/Ag3/Cu0.5 appears to dissolve almost twice the amount of copper as the CASTIN does at the same temperature over the same short period of time. From this it is inferred that CASTIN is more stable in a wave solder pot when soldering circuit boards and should require less initial alloy maintenance.

In order to determine the upper limits of copper contamination, the testing continued over a 24 hour period. The bath was subjected to excessive copper. At the end of the second 24 hour period it was found that the Sn/Ag3/Cu0.5 and CASTIN absorbed very similar amounts of copper.

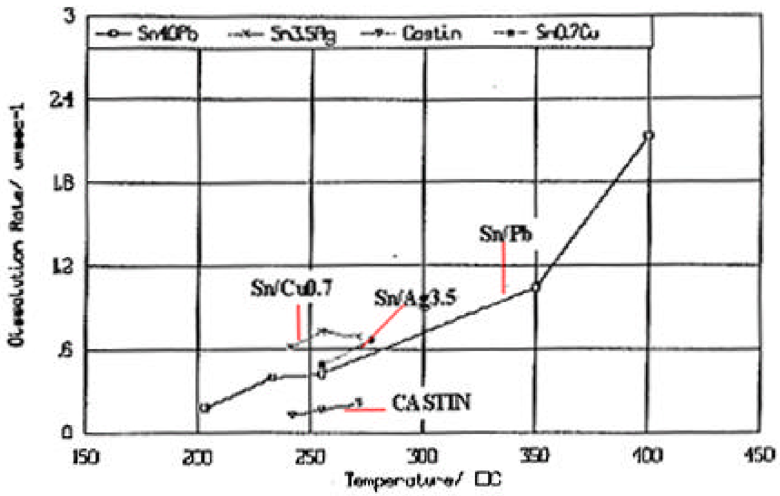
	CASTIN	**Sn/Ag3/Cu0.5**
Percent of Copper	1.85	1.99
	1.84	1.98
	1.89	2.05

Lead-Free Wave Solder Pot Maintenance Issues: During this second 24 hour period the solder in the pots started to exhibit sluggish flow. The pots were then emptied and large amounts of Cu6Sn5 intermetallics were found at the bottom of each pot. This was a problem that had not been anticipated since with a standard Sn63/Pb37 wave pot the Cu6Sn5 will float and can be removed easily.

Different proposals have been suggested for lead-free wave soldering. One option is to use the Sn/Cu0.7 alloy for wave soldering and Sn/Ag/Cu for surface mount. However, this method is very difficult to control, inventory can be hard to manage and eventually the alloys would get mixed on the circuit board. Another idea is to use a low silver (< 3.0Ag) Sn/Ag/Cu alloy for all applications. A third is to use a high silver content (> 3.8Ag) Sn/Ag/Cu alloy. Unfortunately, it appears that whichever process is implemented, wave solder pot maintenance is going to be problematic.

In a standard Sn63/Pb37 wave pot, as impurities such as copper build up they form intermetallics with the tin. This intermetalic build up can be systematically removed by reducing the temperature of the solder pot to 370°F (188°C) and allowing the pot to sit undisturbed for > 8 hours. The density of the Cu6Sn5 intermetallic is 8.28, while Sn63/Pb37 is 8.80, allowing most of the Cu6Sn5 to float to the top of the pot after a few hours of cooling. After this the top of the pot is skimmed and new solder is added to bring up the level. This typically will maintain copper levels below 0.3% and can maintain the copper level in the 0.15% range. This is a simple gravimetric separation of Cu6Sn5.

Unfortunately, whether Sn/Cu or Sn/Ag/Cu is implemented for wave soldering, the density of both alloys is less than Sn63/Pb37. The densities for these lead-free alloys are approximately 7.39, versus 8.80 for Sn63/Pb37 and 8.28 for Cu6Sn5. Therefore, instead of the intermetalic floating off and easily being removed as when in Sn63/Pb37, the intermetallics sink and are dispersed through the lead-free alloy in the pot. To make matters worse, as is shown in fig. 1, some lead-free alloys dissolve copper at a faster rate than Sn63/Pb37.[1] The end result of this is copper build-up in the pot.



To add to these problems, as lead-free electronics assembly becomes increasingly popular, more organic coated (OSP) copper boards will be utilized. This will result in more copper exposure to the wave. The question of copper limits for the wave then arises. This is dependent on wave temperature. The higher the temperature, the more the intermetalics will stay molten. However, eventually these intermetallics will build to a point where they can plug the wave pump's baffles. As discussed above, some alloys pick up copper at different rates than others. Over time, however, all the alloys seem to reach approximately 2% copper at 530°F (276°C). At this copper concentration the alloy will exhibit needle-like dendrites of Cu6Sn5 and will become sluggish as it relates to capillary flow.

The result and biggest problem of all of the above is that solder pots will need to be dumped more often, leading to a complete change over of the wave pot. The pot dump specification will most likely be around 1.55% copper, since above this point the alloy becomes sluggish and at 1.9 to 2% precipitation in the pot starts to occur, which can lead to damage to the wave pump and baffles.

Conclusion

In order to minimize copper dissolution into lead-free wave solder pots, the boards will have to be designed to have solder barrier material on them. Nickel is typically used for this. However, when utilizing gold-over-nickel boards the gold will build up in the pots. Regardless of the solder alloy or barrier metal chosen, waste and changeover costs will dramatically increase with lead-free wave soldering.

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[1] Testing performed by ITRI/UK