人们提出了关于铜在无铅合金中溶解的问题，特别是关于使用可能需额外焊锅维护的合金的问题。本研究了解是否有可能满意地控制无铅HASL过程。本研究的第一部分确定在用于HASL的锡/银/铜合金之间是否存在任何在系统中铜累积方面的明显区别。研究发现，“锡/银3.0/铜0.5”合金在相同温度和相同（短）时间内的铜溶解量是“锡/银2.5/铜0.8/铅0.5”合金的几乎两倍。本研究还对焊锅的维护和从无铅锅中分离铜的金属互化物提出建议。

A Study of Lead-Free Hot Air Leveling

David Suraski

Controlling copper buildup in automatic soldering equipment using lead-free solder.

Questions have arisen about copper dissolution into lead-free alloys, particularly in alloys that may require added solder pot maintenance. This study investigates whether satisfactory control of the lead-free hot air leveling process is possible.

The Sn/Ag/Cu family of alloys is a leading candidate as a lead-free alternative. The first part of this study was to determine any significant difference between Sn/Ag/Cu alloys for HAL in terms of copper buildup in the system. The study compared Sn/Ag3.0/Cu0.5 and Sn/Ag2.5/Cu0.8/Sb0.5 to determine if, at processing temperatures, one alloy would absorb less copper than the other.

Coupon	Sn/Ag2.5/Cu0.8/Sb0.5	Sn/Ag3.0/Cu0.5
1	0.8992	1.8415
2	0.8067	1.8157
3	0.8767	1.8523

TABLE 1: Coupon Weight Loss

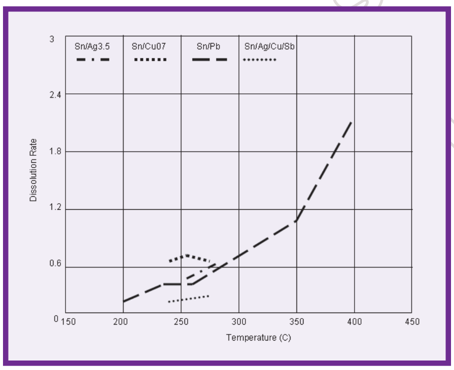

FIGURE 1: Copper dissolution rates of various lead-free alloys.

Two pots of each alloy holding approximately 500 grams of metal were heated to 275°C. Copper strips were weighed, fluxed and then placed into the lead-free alloys. The temperature and strips were monitored every five minutes for any visual change. After 30 minutes, changes were noticed. The copper coupons were then removed and weighed.

As shown in **Table 1**, Sn/Ag3.0/Cu0.5 dissolves almost double the amount of copper as Sn/Ag2.5/Cu0.8/Sb0.5 does at the same temperature over the same (short) period of time. Thus, Sn/Ag2.5/Cu0.8/Sb0.5 is more stable in a wave solder pot when soldering boards and should require less initial alloy maintenance. This result is corroborated by studies[1] showing the lower copper dissolution of Sn/Ag2.5/Cu0.8/Sb0.5 versus other lead-free alloys (**Figure 1**). Also note that extensive third-party testing[2] indicates that this alloy is a viable choice for the HAL process, demonstrating good coverage and solderability with flatter pads than Sn/Pb. For these reasons, Sn/Ag2.5/Cu0.8/Sb0.5 was used in the second part of this study to determine how to control the copper level in a lead-free HAL process.

Copper is a well-understood contaminate in the Sn63/Pb37 alloy for pre-solder applications. If the copper level in pots becomes too high, solder may suffer from poor flow and exhibit embrittlement. Presently, HAL manufacturers have limited the copper in a solder bath by precipitating the copper out using a simple gravimetric separation of Cu6Sn5. In a standard tin-lead pot, as impurities such as copper build, they form intermetallics with the tin. This intermetallic buildup can be systematically removed by reducing the solder pot temperature to 370°F (188°C) and leaving the pot undisturbed for more than eight hours. Because the density of the Cu6Sn5 intermetallic is 8.28, while that of Sn63/Pb37 is 8.80, most of the Cu6Sn5 will float to the top of the pot after a few hours of cooling. After this occurs, the top of the pot is skimmed and new solder is added to raise the level. The process typically will maintain copper levels below 0.3%, generally in the 0.15% range.

However, the density of high-tin lead-free alloys is lower than that of Cu6Sn5: approximately 7.40 versus 8.28. Therefore, the Cu6Sn5 inter-

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metallics sink and are dispersed through the lead-free alloy in the pot, instead of floating off and being easily removed after cooling.

Furthermore, an increase in lead-free electronics will likely bring a corresponding increase in organic-coated (OSP) copper boards. The added copper exposure to the wave may eventually cause the intermetallics to build to a point where they plug the wave pump's baffles.

Yet another issue is the lack of an industry specification for lead-free pot maintenance. Clearly, a guideline for the users of these alloys will be needed. Therefore, **Table 2** has been developed from empirical studies and metallurgical evidence. As shown, the upper limit for copper in the pot is 1.5%. Above this point, the alloy becomes sluggish; at 1.9 to 2%, precipitation in the pot starts to occur, which can damage the wave pump and baffles.

Ag	Al	As	Au	Bi	Cd
4.5	0.006	0.03	0.20	0.25	0.005
Cu	**Fe**	**Ni**	**Pb**	**Sb**	**Zn**
1.5	0.02	0.01	0.5	0.50	0.005

TABLE 2: Lead-Free Pot Specification, Maximum Impurity Levels (%)

	PPT 260	PPT 240	Ingot
Ag	2.264	2.328	2.45
Al	<0.001	<0.001	<0.001
As	<0.003	<0.003	<0.003
Au	<0.003	<0.003	<0.003
Bi	0.011	0.013	0.013
Cd	<0.001	<0.001	<0.001
Cu	5.061	3.6	1.412
Fe	0.002	0.002	<0.001
Ni	<0.001	<0.001	<0.001
Pb	0.030	0.034	0.026
Sb	0.479	0.474	0.507
Sn	Balance	Balance	Balance
Zn	<0.001	<0.001	<0.001

TABLE 3: Analyses of Pot Precipitates

Separating Copper Intermetallics from Pb-Free Pots

Although separating the copper intermetallics from lead-free pots is more complicated than when using Sn/Pb, it is still achievable. To do so, a second pot capable of holding the volume of alloy from the HAL machine should be used. This should be a round-bottom pot open to the atmosphere, preferably with a beach built into the top lip of the pot. The beach permits the crystalline structure that works like a sponge to permit the alloy to drain back to the pot.

When separating copper intermetallics from lead-free pots, first transfer the used alloy into the second pot at an elevated temperature (400°C). After solder transfer, the pot should be cooled to 260°C. At this point, precipitate will form at the bottom of the pot. A ladle with holes in it or a rake that can pull the material up onto the beach on the sidewall of the pot should be used to remove this precipitate. A sample of the precipitate should be removed and labeled "PPT 260." Then, the pot should be further cooled to 240°C and a sample of the alloy cast into ingot form and labeled as "Ingot." Any additional precipitate in the bottom of the pot should also be removed, with a sample labeled as "PPT 240." Then, all three samples should undergo laboratory analysis. These actions should reduce the copper content of the existing solder to an acceptable level of 1 to 1.4%. **Table 3** shows the results of the analyses on these materials.

Cooling the pot and removing the precipitate lowered the copper level to an acceptable level. Therefore, salvaging lead-free solder is possible using a similar method as used with Sn/Pb, except that the SnCu intermetallics now sink instead of float, and instead of being skimmed now need to be dragged from the bottom of the pot. The result is a reduction of copper in a lead-free soldering pot to within acceptable levels. ■

References

1. Studies performed by ITRI (now Soldertec), lead-free.org.
2. Mark Racic and Sherry Goodell, "No-Lead and Horizontal Hot Air Leveling," *Nepcon West Proceedings*, February 1995.

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