Tin-copper based solder options for lead-free assembly

As the transition to lead-free progresses a substantial percentage of assemblers have either implemented less costly solder alloys or are investigating them. Tin-copper solder by itself without dopants has limitations however the addition of certain elements helps out in the deficiencies normally seen with tin-copper.

This paper discusses several options and the advantages they offer when compared with SAC based solders. It compares tin-copper based solders with SAC305 and describes results being obtained by large assemblers.

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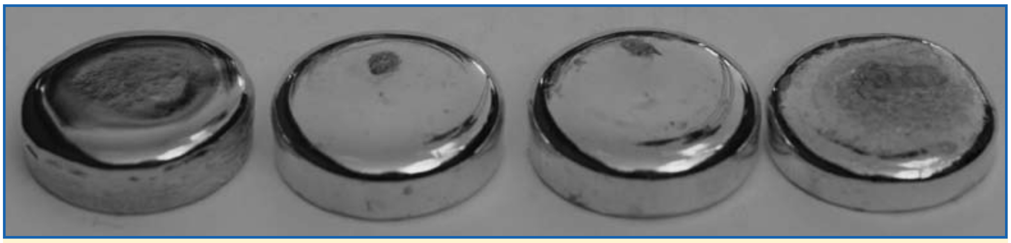

Figure 1. Comparative solder button showing differing surface finishes.

Tin-silver-copper has received much publicity in recent years as the lead-free solder of choice. The IPC Solder Value Product Council SAC305 (Sn96.5 Ag3.0 Cu0.5) was endorsed by as the preferred option for SMT assembly, and most assemblers have transitioned to this alloy for their solder paste requirements. However, due to the 3.0% silver content, the SAC305 is expensive when compared to traditional Sn63Pb37. For this reason, many wave assemblers are opting for less costly options, such as tin-copper based solders, for their wave, selective and dip tinning operations.

In recent years, tin-copper based solders with a variety of elemental dopants have emerged and have improved the overall properties and performance of tin-copper solders. Tin-copper solder without the incremental additions of certain elements is rarely used, but the addition of nickel or nickel and bismuth (as found K100 and K100LD, respectively) do offer improvements in wetting, joint cosmetics and in some cases solder joint reliability. K100LD is a Kester patent pending alloy.

Cost advantage of SnCu based solders

The approximate cost of solder alloys is indicated in *Table 1*, showing clearly that filling wave solder pots is less expensive with tin-copper based materials. Top-off costs are also less, making the overall operation much less expensive.

Properties of SnCu based solders

If the properties of SAC305 and tin-copper based solders are compared, the melting point of SAC305 is lower; this is one reason why it is not a popular choice for reflow soldering. Tin-copper based solder would require a slightly higher peak temperature in this operation. If wetting speeds are compared, tin-copper based solders would show lower values than SAC305 when weaker fluxes are used. So although tin-copper based solders are an option, they do require careful optimization of the soldering process to achieve complete hole-fill in a wave or selective process.

The other difference is cosmetics of solder joints. Tin-silver-copper based alloys give joints with a rougher, non reflective surface. SAC joints also exhibit hot tears as detailed in IPC-610D, Section 5. Tin-copper based solders with certain additives, such as nickel and bismuth, do not show as much surface shrinkage effects or hot tears and are usually smoother and more reflective. The solder joints with these alloys can be as cosmetically appealing as Sn63Pb37 joints.

Figure 1 shows three cast buttons showing the differences in solder surface. The rougher surface of SAC solder, far right, is evident when compared to the two center buttons which are tin-copper based solders with additives.

Table 1. Approximate relative costs of various solder alloys.

Alloy	Composition	Relative Cost (approx)
Sn63	Sn63Pb37	1x
K100LD	Sn99.3Cu0.7 + Ni + Bi	1.5x
K100	Sn99.4Cu0.6 + Ni	1.5x
SAC305	Sn96.5Ag3.0Cu0.5	3x

Figure 2. SAC305 Wave Soldered Joint Top-side.

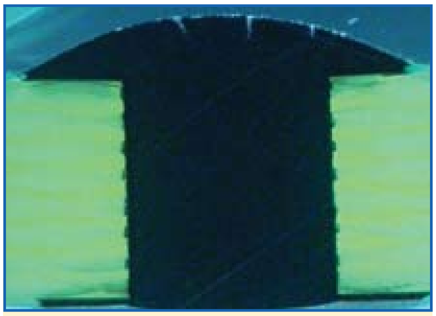

Figure 3. Cross-sectional SAC305 with fissures.

The cast button on the left is Sn63Pb37 leaded solder.

It is not unusual to see surface shrinkage effects with SAC solders when they are used in wave and selective soldering, and also in hand-soldering. *Figures 2 and 3* demonstrate this phenomenon; SnCu based solders with certain additives reduce this issue. Work is still ongoing to determine the reliability impacts of these soldering abnormalities.

Lead-free wave soldering also may increase the dross or oxide rate. Many lead-free solders do contain a dros- reducing additive to prevent excessive oxides at slightly elevated solder pot temperatures. Avoiding the higher extremes in pot temperature, keeping the solder pot full and reducing the frequency of dross removal will normally keep oxides in control.

A summary of the properties of SAC versus tin-copper based with the required additives solders are detailed in *Table 2*. The reactivity to iron is lessened with both tin-copper based solders; this is a serious issue with SAC where solder pots are recommended to be lead-free compatible, constructed with titanium, cast iron, and ceramic coated or coated steels.

The other advantage these tin-copper based solders have is the lower copper dissolution; relative to SAC solder, Sn-Cu-Ni-Bi alloy has substantially less dissolution potential. Lower dissolution is important since high tin alloys tend to erode base metals, such as copper, from boards and terminations. Dissolution leads to increased solder pot testing and maintenance, but in some cases removal of the metallization can also lead to de-wetting and loss of joint reliability. Copper dissolution is particularly important in the rework process of lead-free boards where solder temperatures are more elevated. This also applies to selective soldering systems where soldering temperatures are also higher.

Optimizing the wave solder machine for SnCu based solders

Lead-free soldering differs from Sn63Pb37, particularly in wetting speed, and this translates to reduced wetting speeds up the barrel of the through-hole. Using the correct flux for the job is critical. If the parts to be joined are easily solderable and free of heavy oxidation,n no-clean fluxes do well. In some cases, where the boards or components are difficult to solder or storage and handling have not been optimal, higher-solids no-clean or water washable fluxes will perform better.

Slower conveyor speeds and longer contact times at the solder also help insure good hole-fill. Slightly higher pot temperatures are normally used with SnCu based solders as indicated in *Table 2*.

Recent implementations of SnCu based solders K100 and K100LD at customer sites indicate that excellent hole-fill without soldering defects can be achieved. An important parameter that was common to all the successful builds was the ratio of contact of the solder to the board thickness. The minimum contact should be 1/2 the board thickness and if 1/4 of the board thickness is used this will further insure adequate hole-fill on assemblies of poorer wetability. Contact times of 3-5 seconds were used to give good void-free hole-fill.

Typical wave process parameters are indicated in *Table 3*. These settings were used at a contract assembler on three assemblies with board thicknesses ranging from 0.063 to 0.093 inches. The boards were ENIG and tin-copper HASL finishes and a water washable flux that was designed for lead-free was spray-applied. The preheat top-side temperature was set to the manufacturer's recommended range.

Figures 4, 5 and 6 show typical results achieved with the SnCu based solder K100LD using the above parameters on a tin-copper HASL finished board 0.093 inches thick. Usually thicker boards can show incomplete hole-fill, but in this case, complete hole-fill was observed with solder impinging at about 3/4 the thickness of board.

On another assembly with bottom-side SMDs, tin-copper solder performed equally well. With the parameters indicated in *Table 3*, the SMD parts were free of solder flagging. Complete wetting was noted. The solder cosmetics were as good as traditional Sn63Pb37 solder. The board in this case was ENIG finished and 0.063 inches thick.

Hand soldering with SnCu based solders

For the sake of consistency, many assemblers using SnCu based solders in

Table 2. Properties of SAC versus tin-copper-based solders.

	Sn-Cu-Ni-Bi	Sn-Cu-Ni	SAC305
Melt Point	~227°C	~227°C	217 - 220°C
Pasty Range	0	0	3C
Appearance	Shiny	Shiny	Dull
Shrink Holes	No	No	Yes
Copper Dissolution (Sn63 = 1)	0.8	1.0	2.1
Pot Management	Easiest	Easy	Difficult
Reactivity to Equipment	Low	Low	High
Suggested Pot Temperature	255 – 265°C	255 – 265°C	250 – 260°C

Table 3. Typical wave process parameters.

Wave Solder Parameter	Setting
Solder Pot Temperature	265 °C
Conveyor Speed	3.0 to 3.5 feet per minute
Contact Time	3.3 to 4.0 seconds
Contact Width	2 inches
Flux Type	Water washable, alcohol based, ORH1
Solder Impingement on Board at Wave	3/4 of board thickness
Flux Preheat	93 to 102 °C Top-side

wave, selective or dip operations will use the same alloy for hand assembly.

Tin-copper based solder wire will require similar settings as SAC solder wire. The soldering tip temperature will need to be between 700-800°F. As with SAC hand soldering, SnCu based solder wire requires the selection of the correct tip, one with adequate thermal transfer.

Tin-copper based solders with certain additives do not exhibit the shrinkage effects seen with SAC solder wire. The cosmetics of solder joints are more uniform and quite reflective.

Figure 8 shows solder joints accomplished using SnCu based solder wire with a water washable flux core. The operator used 750°F as the temperature setting on the soldering iron and increased contact time only slightly to achieve excellent solder flow.
The boards were ENIG finished at a thickness of 0.063 inches and as can be seen the solder flowed around the annular rings top-side very well.

Over 20,000 boards were assembled using SnCu based K100 solder bar and solder wire. The defect rate was extremely low and comparable to a traditional Sn63Pb37 process.

Figure 4. Bottom-side, bright joints with SnCu based solder K100LD.

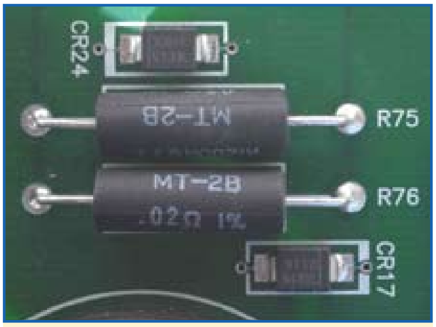

Figure 5. Good hole-fill 0.093 inch thick board.

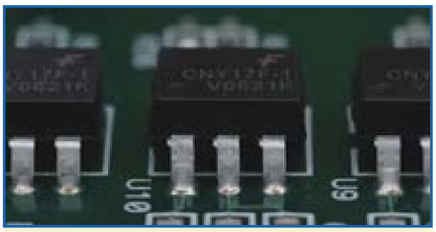

Figure 6. Complete hole-fill of 0.093 inch thick board with 3/4 inch thickness solder impingement.

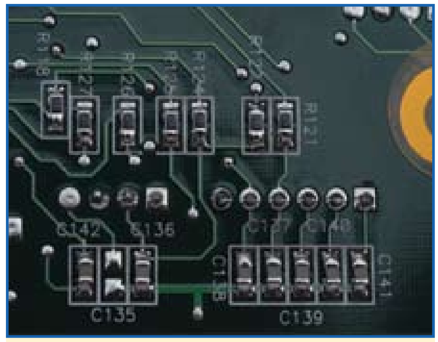

Figure 7. Through-hole and SMD components wave soldered using SnCu based K100LD.

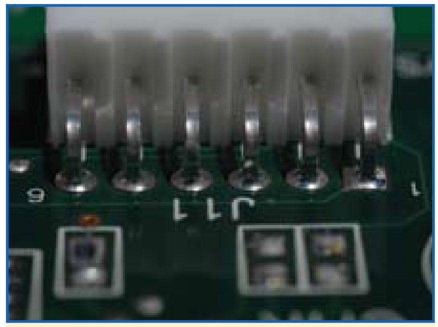

Figure 8. Connector hand-soldered with K100 solder wire using 750°F tip temperature.

Conclusion

Lead-free wave soldering with SnCu based solders can offer cost advantages if the alloy is chosen carefully. Not all SnCu based solders function equally well in a soldering operation. The additives make the difference, and these enhance both cosmetics and function, giving lower dross, lower copper dissolution and better solder fluidity. Some tin-copper based solders also reduce shrinkage effects normally seen with SAC lead-free wave, selective or hand soldering.

Once an alloy with good properties is chosen, the functionality of the flux needs to be carefully assessed as its ability to help solder a variety of board thicknesses and in some cases differing board finishes. Choosing a liquid flux designed for lead-free applications is crucial since lead-free fluxes must withstand longer contact times and higher solder temperatures. A flux with sustained activity after exiting the wave will reduce both bridges and flagging.

Optimization of the wave process is also important. Understanding that lead-free solders wet more slowly than Sn63Pb37 is a good start in understanding why conveyor speed, contact time and impingement of the board at the wave are critical parameters to good hole-fill.

SnCu based solders are compatible with all popular board finishes, such as ENIG, OSP, Ag Imm, Sn Imm and lead-free HASL. In some cases OSP boards in thicknesses in excess of 0.093 inches solder flow-through can be an issue if low solids no-clean fluxes are used. In cases where solderability is poor or board thickness is larger than 0.093 inches, a higher solids flux can assist the hole-fill process. Water washable fluxes do well because they are much more active fluxes but will require cleaning after soldering.

At present, the vast majority of assemblers are using SAC305 or patented SnCu based solders. For many applications SnCu based solders do offer advantages over SAC solders and their use is likely to increase in the next few years.

Case studies that highlight successful trials of tin-copper based alloys will be detailed in future issues. The customers that have started using these alloys have recognized a substantial cost advantage and also were able to optimize their process and create a reliable defect-free process with SnCu based solders.

Peter Biocca is Senior Market Development Engineer with Kester in Des Plaines, Illinois. He is a chemist with 23 years experience in soldering technologies. He has presented around the world in matters relating to process optimization and assembly. He has been working with lead-free for over 8 years. He has been involved in numerous consortia within this time and has assisted many companies implement lead-free successfully. He is an active member of IPC, SMTA, and ASM. He is the author of many technical papers delivered globally. He is also a Certified SMT Process Engineer.

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