Case Study on the Validation of SAC305 and SnCu Based Solders in SMT, Wave and Hand-soldering at the Contract Assembler Level

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Abstract:
At the contractor level once a product is required to be soldered with lead-free solders all the processes must be assessed as to insure the same quality a customer has been accustomed to with a 63/37 process is achieved. The reflow, wave soldering and hand assembly processes must all be optimized carefully to insure good joint formation as per the appropriate class of electronics with new solder alloys and often new fluxes.

The selection of soldering materials and fluxes are important as to insure high quality solder joints with lead-free solders which tend to wet slower than leaded solders but also the process equipment must be lead-free process compatible. Components must be lead-free and able to meet the thermal requirements of the process but also the MSL (moisture sensitivity limits) must be observed. Board finish must be lead-free and the PCB must be able to sustain higher process temperature cycles with no physical damage but also good solderability to enable subsequent soldering at the wave or hand assembly.

Tin-silver-copper has received much publicity in recent years as the lead-free solder of choice. SAC305 was endorsed by the IPC Solder Value Product Council as the preferred option for SMT assembly and most assemblers have transitioned to this alloy for their solder paste requirements. The SAC305 alloy due to its 3.0% content of silver is expensive when compared to traditional 63/37 for this reason many contract manufacturers and PCBA assemblers are opting for less costly options such as tin-copper based solders for wave, selective, hand-soldering, dip tinning operations.

In recent years tin-copper based solders with a variety of elemental additives have emerged which improve 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 for example in K100 and K100LD respectively do offer improvements in wetting, joint cosmetics and in some cases solder joint reliability.

In this conversion SAC305 was used for the reflow process, tin-copper-nickel based solder K100 was used in the wave soldering operation and it was also used in solder wire form for hand assembly. This paper is a summary of the experience at a medium sized assembler in achieving the customer driven mandate to go lead-free and the maintenance of production yields and quality using both tin-silver-copper and tin-copper in the assembly of high end printer boards. Over 120,000 builds were achieved with A 99.6% first pass yield for the overall soldering process.

Alloy Selection
The solder alloys had to be selected for solder paste, solder bar and solder wire. For reflow soldering SAC305 was chosen since this alloy had the most data available but also had been endorsed by IPC SVPC as a good choice for reflow soldering.

With wave soldering and hand-soldering operations cost was a consideration since the initial cost of filling a solder wave machine is high at the start but also operating costs can be high depending on the alloy chosen. Cosmetics effects were also considered since both these operations tend to give hot tears with SAC type solders. A solder which was easy to inspect without concerns but also suitable to the customer was chosen. The K100 solder which is a tin-copper based solder with a small amount of nickel was chosen for wave and hand-assembly. The table below, Figure 1 summarizes the alloys chosen and their relative cost and cosmetics when compared to 63/37.

Alloy	Solder Composition	Shrinkage Effects	Overall Cosmetics	Relative Cost
Sn63	Sn63Pb37	Low	Good	1x
K100	Sn99.4Cu0.6 + Ni	Low	Good	1.5x
SAC305	Sn96.5Ag3.0Cu0.5	High	Fair	3x

Figure 1. Lead-free solder comparative to 63/37 Solders

The melting and process temperatures for the alloy were considered however the process temperature at the wave of 255-265°C was not considered significantly higher than SAC305. The advantages of lower dissolution of metallization were considered important since this reduced solder pot maintenance such as analysis frequency and dross formation. Dross or oxides tend to increase operating costs and also add to pot balancing issues. Below is a table, Figure 2 describing the properties of the wave alloy chosen to SAC305 which was not chosen in this case.

	Sn-Cu-Ni	SAC305
Melt Point	~227°C	217-220°C
Pasty Range	0	3C
Appearance	Shiny	Dull
Copper Dissolution (Sn63 = 1)	1.0	2.1
Pot Management	Easy	Difficult
Reactivity to Equipment	Low	High
Suggested Pot Temperature	255 – 265°C	250 – 260°C

Figure 2. Comparing Two Wave Solder Alloys

If wetting speeds are compared, tin-copper based solders would show lower values than SAC305 when weaker fluxes such as no-clean 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. Both flux selection and the optimization of the wave solder machine parameters are important to achieve the desired hole-fill. If this is not done then hole-fill and other types of defects such as flagging, and bridges are prone to increase. One of the main criteria in the selection of the solder alloy was the maintenance of production yields. Any impact here would have reduced the company's return but also could have impacted negatively the quality of the product. The K100 was chosen for both wave and hand-assembly.

Flux Selection

The flux was selected on the basis of the activity needed to solder parts and boards where their solderable was not always known. In this case the customer expected a board free of flux residues, making no-clean difficult to use. It was also known that tin-copper based solders have lower wetting speeds than SAC305. To get the full benefit of the cosmetics and cost associated with the wave alloy a water washable flux was chosen for all processes. Water washable fluxes due to their higher activity insured excellent wetting of SMD parts using reflow soldering, adequate hole-fill in the wave solder with K100 and good performance of K100 in hand-assembly.

The fluxes selected had the IPC Classification of ORH0 (R520A) for the solder paste; ORH1 (331) for the solder wire and ORH1 (2235) for the liquid flux. The flux chosen for the wave was alcohol based which worked very well with the convection heating system that is available in the wave solder machine.

The flux selected had also to be washed off completely in a hot di-ionized water in-line cleaning system. The ionic levels were not to exceed 14 micrograms NaCl/square inch of board. Some of the other reasons water washable fluxes were chosen is detailed below.

- Fluxes were specifically designed for lead-free soldering
- Board cosmetics were excellent
- Flux residue interference was eliminated, example connectors
- Board and component solderability was a non-issue
- Board and component storage and handling was less of an issue
- Process optimization for wetting behavior of lead-free alloys was easier
- Water cleaning equipment and ionic tester were available

Process optimization

To achieve the desired results the assembler used the assistance of the chemistry and equipment manufacturers. Thermal profiles were set-up using the data supplied. All equipment had been certified as lead-free capable; this also included the wave solder pot and the soldering irons.

Components and boards were lead-free and lead-free process capable. Certification to RoHs compliance was initially obtained by procurement. These parts were identified and labeled accordingly and kept segregated from other parts destined for leaded builds.

Board Description

The board soldered with lead-free is described below.

- Board Type: 0.062 inch thick ENIG, ground plane on connector J11
- Board OEM: Printer board for FutureLogic Inc., a leading world wide manufacturer of thermal printers
- Components: Pure tin, matte tin, lead-free type SMD and through-hole parts

Reflow process

The SMT process was modified for a lead-free SAC305 thermal profile. The printing was not affected and similar print parameters were used to a 63/37 solder paste process. A 6 mil laser cut stencil with 10% aperture reduction was used with a DEK 265 Horizon. The solder paste was designed for lead-free thermal profiling and therefore hot slump was excellent.

The thermal profile was measured using a Super M.O.L.E. Gold SPC Version 4.01 and the key points are summarized below for three thermo-couples. Nitrogen was not used in the reflow process. A copy of the thermal profile is also attached.

- Peak temperatures: 243.9, 245.0, 246.7 ºC, average was 254.2 ºC
- Time above liquidus: 1:07, 1:09, 1:12 minute: seconds
- Time to peak: 3:37, 3:31 minute: seconds
- Time to Liquidus: 3:00, 2:56, 2:55 minutes: seconds
- Slope to max: 3.82, 3.89, 3.54 minutes: seconds
- Slope cooling: 2.99, 2.43, 2.57 minutes: seconds
- Conveyor speed was set at 25 inches per minute.

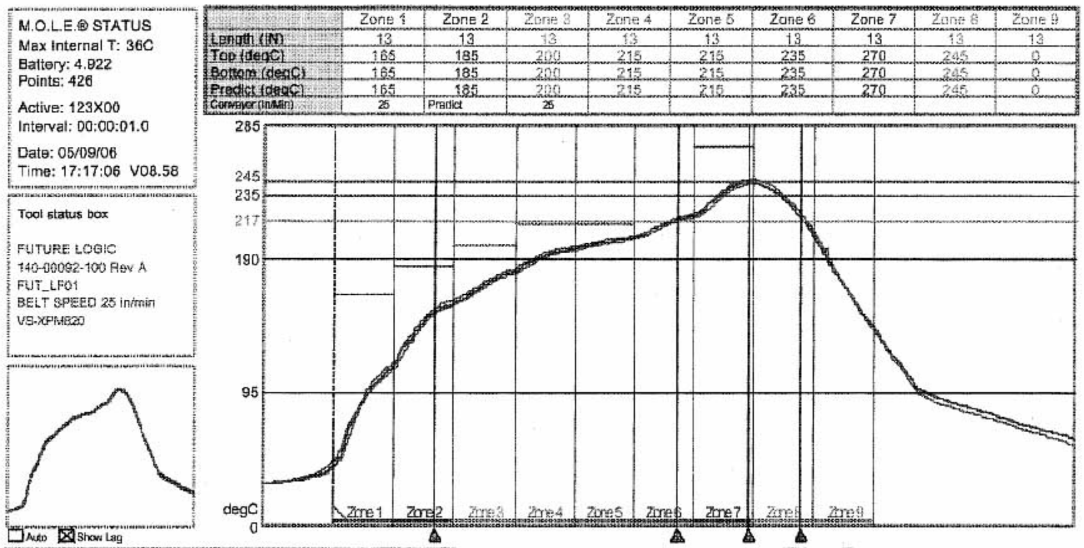

Figure 3. Lead-free SAC305 water washable paste thermal profile

Wave solder process

The wave solder was lead-free capable and after loading with K100 lead-free solder it was analyzed to verify the elemental concentrations but also for the presence of iron or lead. The analysis revealed it was acceptable. Solder analysis is recommended with lead-free wave soldering at least every 5000 board builds. A summary of the wave solder process is detailed below.

- Spray fluxing was used
- 5 sections of bottom-side convection heaters about 15 inches in width
- Quartz heater, before wave solder, width about 6 inches
- Chip wave, laminar wave
- Titanium solder pot and fingers
- No top preheaters
- 2 cooling blowers after wave solder pot
- 6° inclination used at the conveyor, adjustable
- No nitrogen blanketing was used

To achieve good hole-fill and low defects the wave process needed to be carefully optimized. Lead-free solders wetting speeds are slower so traditional speeds used with 63/37 are not always suitable. Contact time and width are critical with lead-free alloys. The board impingement thickness is also important and this was revisited. Flux application was optimized to insure the spray applied flux uniformly and throughout the through-hole. An air-knife after the sprayer was not used but this can be useful if flux application is restricted in thicker boards or tighter hole-to-lead ratios. With lead-free wave soldering flux application was found important. In this case alcohol based flux was used however VOC-free fluxes with higher surface tensions may benefit with the use on an air-knife.

The parameters used in this build and which continued with the production of 120,000 boards are defined below.

Wave Solder Process Parameters:

- Conveyor Speed: 61 centimeters per minute.
- Solder temperature 265°C, only laminar wave used.
- Preheater settings WS-450PC-LF specific: 135, 140, 150, 155, 160
- Top-side preheat board: 129-131°C.
- Solder contact width: 2 inches or 5.1 centimeters.
- Contact Time: 5 seconds
- Board thickness wave impingement: ½ to ¾

Hand-assembly process
The hand-assembly of some connectors was accomplished after SMD and through-hole soldering using K100 water washable flux wire. The flux percentage is a critical element in wire solder selection and in this case the flux percentage was 2% by weight. Lower flux percentages make soldering with lead-free more difficult due to their slower wetting behaviors. Although tin-copper was used the wetting speed and solder joint quality were to IPC-610D Class 3 and 100% hole-fill was obtained throughout.

Some of the basic criteria followed to obtain excellent lead-free hand-soldering are mentioned below.

- Lead-free compatible tips were used
- Correct tip geometry to achieve adequate thermal transfer
- Flux percent greater than 2%
- Soldering tip temperature 750ºF
- Marginally longer contact time
- No additional external flux was used

Hand-soldering was used particularly to solder a connector which was lead-free finished and RoHS compliant but not lead-free process capable. To avoid plastic damage this part was hand-assembled and soldered.

Cleaning process
An Electrovert AquaStorm 200 with DI water only, no chemical additives were used to clean-off all flux residues after soldering this included paste, liquid flux and wire flux residues. The water temperature used was 140°F. Cleanliness was measured using an ionic contamination tester and found to pass. In some cases residues tend to be more difficult to remove but in this case they removed well since the fluxes were lead-free process developed.

Lead-free Process Validation Prior to Mass Production
Initially five boards were completely assembled with lead-free solders. These were inspected visually to IPC-610D standards and found free of defects. SAC305 reflowed joints exhibited good wetting on all metallization and through-hole parts exhibited 100% hole-fill. Figure 4 shows the assembly.

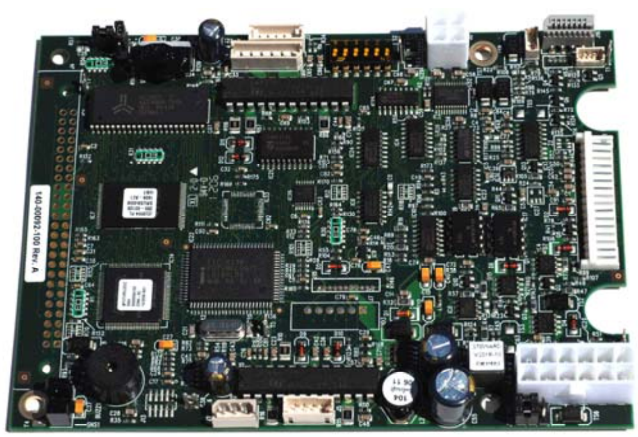

Figure 4. K100 and SAC305 PCB
Board soldered with SAC305 solder paste, K100 wave solder and K100 wire solder. Water soluble fluxes were used.

These types of fluxes due to the activators tend to give excellent wetting behavior and are therefore are well suited for lead-free soldering. No-clean could have been an option with VOC-free types but the activation would have required careful control to achieve hole-fill similar to that obtained here.

Tin-copper based K100 solder did give excellent soldering of through-hole parts with the process conditions used. The solder joints were reflective in nature and did not exhibit hot tears. Bridging and flagging sometimes noted with lead-free wave soldering were not present in all builds.

SAC305 solder paste with the ORH0 activation system did give excellent spread and wicking of solder on all metallization. The solder surface was less reflective than K100 but no tears were noticeable on the frosty surfaces. The SMD joints also met the IPC-610 criteria and the contact angles were shallow. Cleanliness of the assembly did indicate complete visual removal of flux residues.

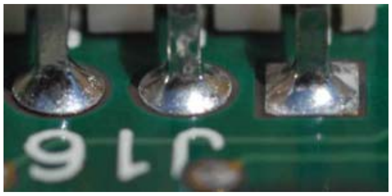

Figure 5. Top side joints

Figure 6. Bottom-side solder joints

The above photos Figure 5 and 6 show the typical solder joints obtained with Tin-Copper based solder in the wave operation. Top-side hole-fill was complete although the wetting behavior of the alloy is less than SAC305, process optimization was critical in obtaining this. In many cases lead-free solders offers a lesser degree of wetting when compared to 63/37.

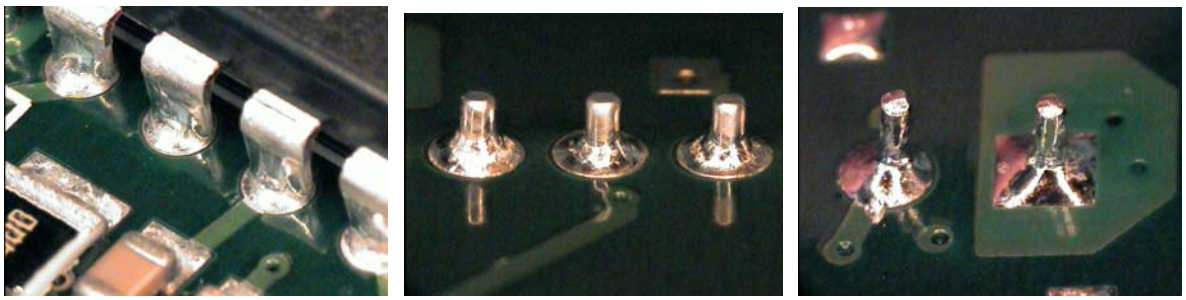

Figure 7. Various through-hole parts showing excellent wetting on top ands bottom-side

The board being ENIG plated and a thickness of 0.063" soldering with tin-copper based solder wave soldering was found to be repeatable, see Figure 7. In thicker boards such as 0.093" the hole-fill could have been more challenging. In fact it would have been challenging with both types of solders SAC and SnCu based. In some cases higher solids fluxes can be used which promote similar good wetting on thicker board assemblies.

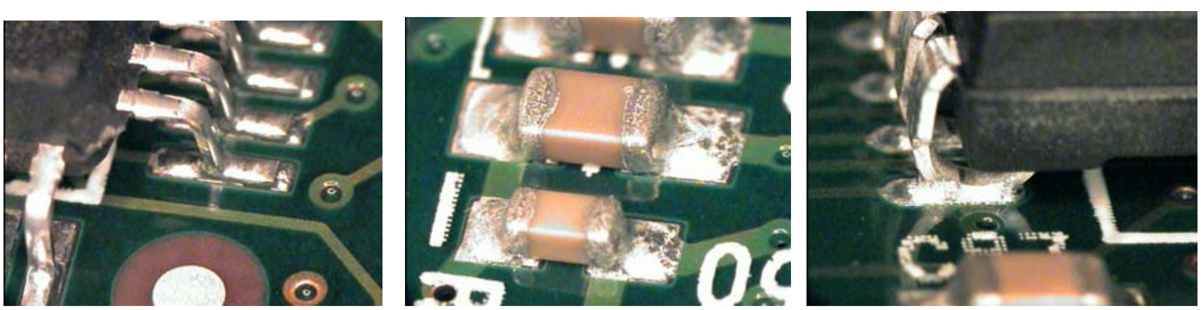

Figure 8. Various SMD parts soldered well with SAC305; all met IPC-610 Class 1, 2, 3

The above photographs, Figure 8 show typical reflowed joints with SAC305 on the printer board. Again the visual inspection indicated good joint formation. To further the lead-free validation study prior to production other tests were performed. The following tests were performed on 5 assemblies and the results were found acceptable.

- X-ray analysis
- Cross-sectional testing
- Intermetallic bond verification
- Outside laboratory visual confirmation

These tests were performed since lead-free solders tend to create more voiding than 63/37 solder. X-ray inspection of through-hole and SMD parts followed by select cross-sections of certain joints allowed the verification of joint meeting the voiding criteria established by IPC and the customer.

In some cases voiding can occur which would difficult to assess otherwise. Voiding can occur for a variety of reasons such as flux issues, plating issues, moisture pick-up and in the case of through-holes hole-to-lead ratio. X-ray and cross-sectional tests insure voids are not excessive but cross-sectional testing can also reveal the nature of the intermetallic bond. Combined with visual these tests insure the lead-free processes are performing optimally.

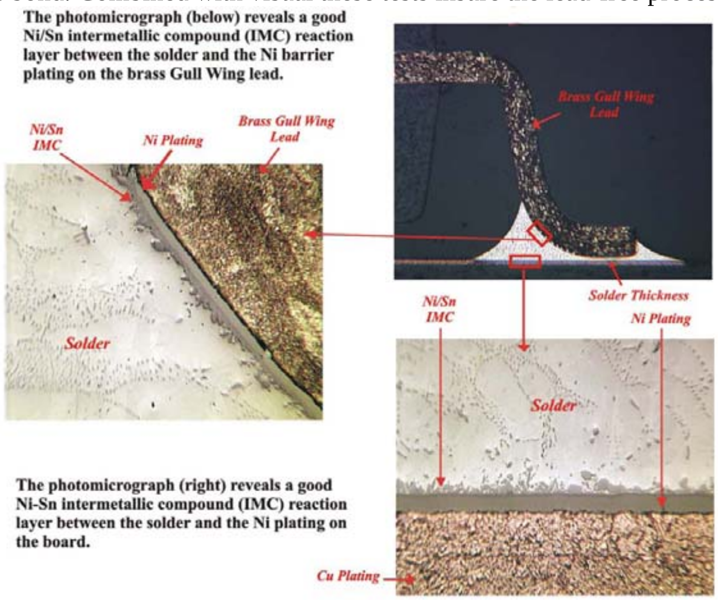

Figure 9. Cross-sectional tests for SMD parts

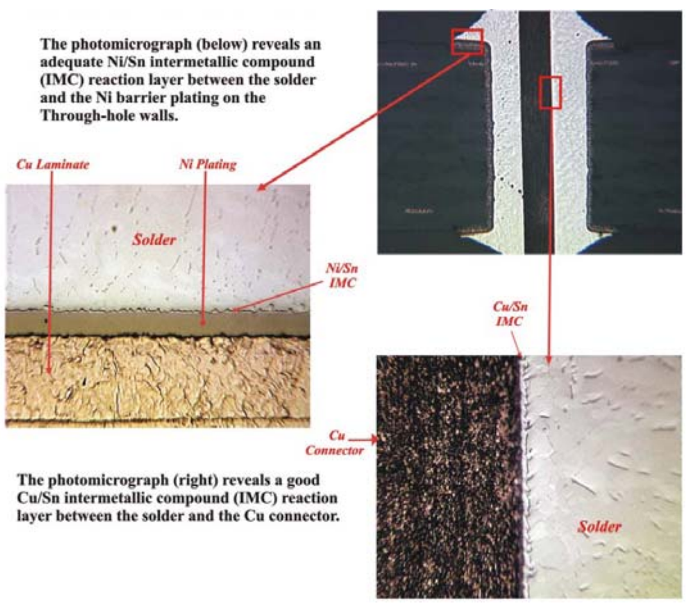

Figure 10. Cross-sectional tests wave soldered through-hole

Cross-sectional tests indicated complete hole-fill with the K100 alloy during wave soldering, as seen in the above Figure 10. Adequate Ni-Sn bond lines were noted on all tested parts.

The above is an extract from the full report in which numerous joints were examined but the results were the same on all wave joints and SAC305 joints. The connectors done with the water washable flux wire solder also exhibited complete hole-fill without voids as seen in Figure 10..

Overall the results obtained during the validation run indicated satisfactory joint formation using well defined processes and production was begun and followed through to the 120,000 assemblies.

Conclusions

Lead-free assembly can be achieved using different solder alloys taking into account cost savings associated with the alloys while maintaining good quality and production yields. The key was found to be careful control of all process parameters with each process optimized for the specific behavior of the alloys chosen.

Foremost the components and boards must be lead-free process capable. Early procurement involvement will insure RoHs regulations are met and traceability accounted for. This will also help prevent lead contamination; Lead contamination in wave soldering can result in lead levels beyond the established RoHs limits and increase the operating costs of this process. To further avoid pot contamination, procedures and training must be in place to avoid cross-contamination especially where dual lines are present leaded and lead-free.

Proper handling and storage coupled with good turn-over practices will help preserve solderability and reduce wetting issues with lead-free materials. Choosing fluxes designed for lead-free will also reduce defects and increase reliability by giving IPC class 3 solder joints.

Validation of any lead-free process must be verified for repeatability. Some addition tests may be required at first such as X-Ray analysis and cross-sectioning to insure the integrity of the lead-free joints.

SnCu based solders can be used in wave soldering and hand-assembly. It was found important to select a SnCu alloy with the required additives to offer consistent wetting results and good cosmetics. The solder’s properties must be carefully studied and the process parameters such as conveyor speed and contact time have to be set to compensate for the slower wetting speed normally found with SnCu solders. This applies also to the hand-soldering operations.

It was found that SAC305 solder paste printing characteristics did not differ from traditional 63/37 pastes. Setting up a thermal profile to reflect what heat the parts see especially more difficult parts, will reduce the incidence of non-wetting or wicking.

After the validation process all 120,000 boards were run successfully and no soldering defects were reported. The SnCu based solder used in wave solder also demonstrated a slight reduction in dross creation. This was due to a combination of proper working practices and the property of the alloy.

If an assembler chooses equipment needs carefully, monitors its lead-free capable parts, sets up a lead-free process, validates it and then controls it, reliable lead-free builds in high volume are possible. Adequate training is also a requirement for those involved in all lead-free operations.

References

1. SMT Dynamics, Anaheim, California, Lead-free Process Validation Reports
2. CE Analytics Laboratory Report
3. SMT Dynamics Production Data
4. ITW Kester Visual Assessment Reports