Developing a Reliable Lead-free SMT Assembly Process

Author: Peter Biocca, Senior Development Engineer, Kester, Des Plaines, Illinois
Telephone 972.390.1197; email pbiocca@kester.com

Developing a Reliable Lead-free SMT Assembly Process

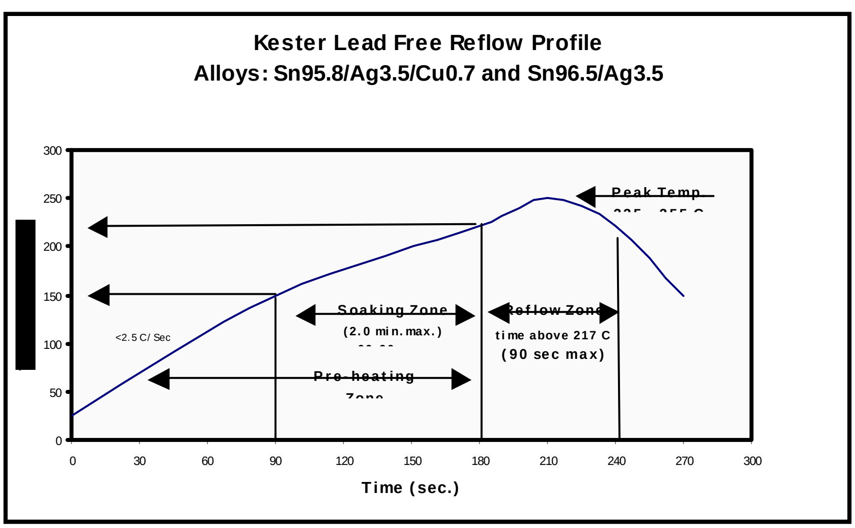
What are the key process requirements to achieve reliable lead-free SMT assembly?

Lead-free SMT can be achieved reliably if several process requirements are implemented carefully. Some of the variables to account for are listed below. The most common alloys used in lead-free SMT are tin-silver-copper alloys; these alloys all have a meting range between 217-220°C. These alloys all melt at higher temperatures than traditional leaded solders such as the 63/37which has a melting point of 183 °C.

Summary of Key Variables in SMT

- **Melting temperature of alloy**
- **Flux chemistry - activation, temperature effects**
- **Wetting and surface tension properties of the alloy**
- **Solder balling and bridging potential increases**
- **Component / board reliability**
- **Compatible rework / repair**
- **Compatible wave, selective soldering processes**
- **Quality inspection criteria modifications**
- **Cosmetic effects of flux at higher reflow temperatures**
- **Nitrogen versus air reflow**
- **Pin-testability of flux residues**
- **Solder voids impact**
- **Residue cleaning / removal process changes**
- **Conformal coating and under fill compatibility**
- **Oven maintenance, flux decomposition volumes**

Because the melting point of these alloys is higher the thermal profile will also require optimization to avoid excessive temperatures on components and boards. Typically the peak temperature range for tin-silver copper alloys will be between 235and 245°C but if the boards have small thermal masses and the oven has sufficient heating zones peak temperatures as low as 229°C have been used.



Typical reflow profile used with lead-free SAC and SnAg alloys

With hotter preheats and higher peak temperatures, the classification of non-hermetic solid-state SMD components may change. Moisture pick-up can further aggravate component reliability with lead-free reflow soldering. Internal delamination, cracks, bond lifting, die lifting and in extreme cases pop-corning effects can occur.

The IPC/JEDEC J-STD-020C specifies the new reflow requirements for small to very large bodied components.

It is summarized in the following table.

Lead-free Temperature Profile for MSL Classification

Thermal Profile Features	Small devices	Large Devices	Very Large Devices
PREHEAT			
Ramp-up rate to 150 °C	Minimum 3 K/Sec Average value over 10 sec.		
Time From 190-200 °C	Minimum 110 seconds		
PEAK			
Ramp-up rate From 200° C to Peak temp.	0.5 K/sec, average value over 10 seconds		
Time above Liquidus 217 °C	Minimum 90 seconds		
Peak Temperature	260 °C	250° C	245° C
Time above Peak temp.	Minimum 40 seconds	Minimum 30 seconds	Minimum 30 seconds
COOLING			
Ramp down from Solidus Temp. 217 °C	Minimum 6 K/seconds, average over 10 seconds		
General info			
Time 25°C TO Peak	Minimum 300 seconds		

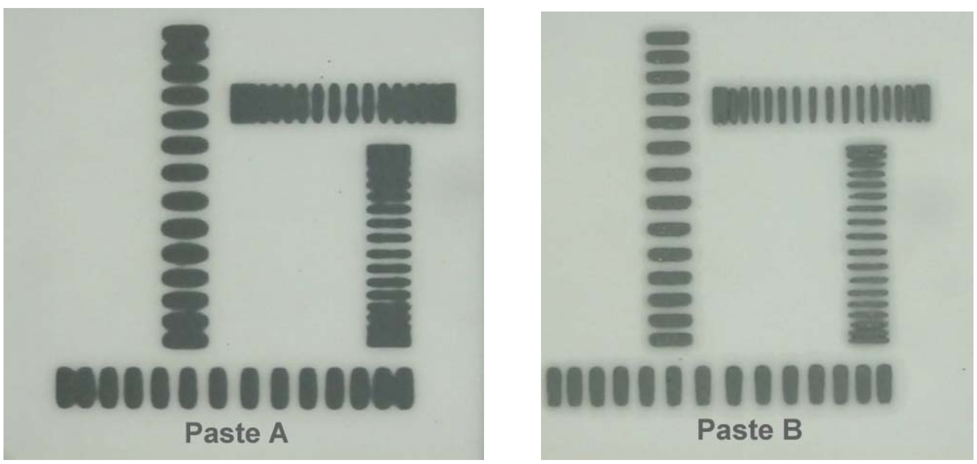
Thickness/volume: Small components 350 mm^3 or less, large 350-2000, very large 2000 mm^3 or more.

The flux chemistry used in lead-free pastes is designed to minimize several of the issues associated with higher reflow temperatures. Higher temperature issues can range from increased paste slump to charring of the residues. Solder paste manufacturers are using resins and gelling agents, which offer good hot slump resistance and good activators which are stable at higher preheats and higher peak reflow temperatures.

Some of these newer chemicals used in lead-free pastes are detailed below.

- **New activator packages, higher activation temperatures**
- **New resins, low decomposition**
- **New thermally stable gelling agents**
- **Better surfactants**
- **Additives to prevent oxidation**
- **Alloy specific fluxes**

Below are photographs of two lead-free solder pastes after hot slump testing at 185° C. Paste A has gelling agents incorporated within its flux system that do not prevent slumping. Paste B contains gelling agents, which prevent slumping at higher preheat temperatures; this paste will reduce the incidence of bridging, solder balls and mid-chip balling. Paste B has better hot slump behavior.

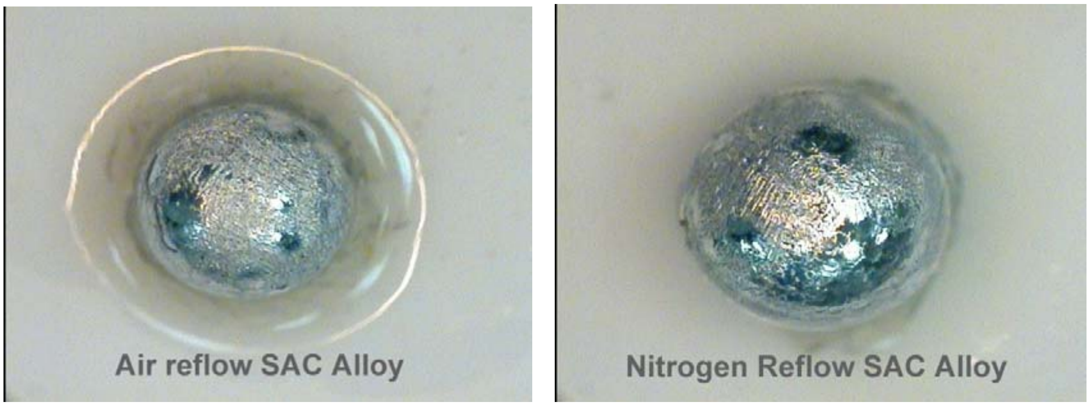


Solder pastes printed on inert ceramic and preheated at 185°C in air

Due to the lower wetting speeds associated with alternative lead-free solders, flux activation will be a critical factor in paste performance. No-clean and water washable solder pastes are being designed to not require nitrogen reflow and can produce reliable solder connections with good wetting in air. Water washable solder pastes with their higher concentration of activators will solder most metal finishes adequately. No-clean solder pastes will require careful selection of finishes to be soldered but also careful selection of a paste's attributes. Some lead-free no-clean pastes are designed to solder adequately a variety of metal finishes; others have difficulty with second pass bare copper boards due to their lower activity. Some no-clean pastes require lower peak temperatures and others can withstand higher temperatures without charring or polymerization of the resins.

Nitrogen will impact solder joint cosmetics as seen in the photographs below. Solder paste reflow in nitrogen will offer brighter and more uniform solder joint surfaces. Nitrogen reflow also will enhance wetting with lead-free solders, especially on bare copper OSP surfaces. It must be noted that the vast majority of assemblers seek a solder paste that can be reflowed in air; so many lead-free paste chemistries are being developed with this in mind.

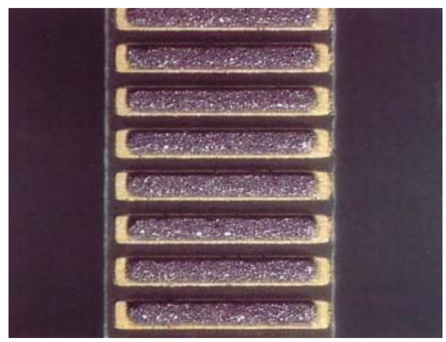
The test below was achieved by printing lead-free solder paste on a white ceramic substrate then reflowing one in air the other in nitrogen. Although the surfaces look different, this is only a surface reaction.



Impact of nitrogen on Tin-Silver-Copper Solders

Selecting the best lead-free solder paste for the SMT process will be a critical variable and the following can be used as a guide in the selection process. It is important for the process engineer to determine which attribute is most critical in the process.

- **Print speed**
- **Abandon time**
- **Stencil life**
- **Tack life**
- **Solder ball potential**
- **Slump, cold and hot**
- **Spread on various metallization**
- **Solderability on various finishes**
- **Reflow window**
- **Voiding potential**
- **Double reflow window capability**
- **Clean-ability, if water washable paste**
- **Pin-testability, if no clean paste**



Solder paste with good gel system

It is not necessary to repeat the above tests in-house, good solder paste manufacturers will make the information available to the user. It is important to ask yourself several important questions in reference to your process requirements. These questions will help you define the solder paste best suited for your process.

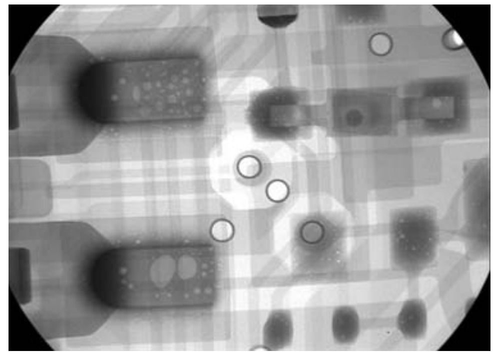
Some of the questions, to better define the lead-free solder paste are:

- **Which solder alloy and powder diameter will be specified?**
- **Are you going to need water washable or no-clean solder paste chemistry?**
- **What are the finishes you are soldering?**
- **Are you going to use nitrogen reflow or air reflow?**
- **Are you doing double-sided SMT?**
- **If a no-clean paste will be used, which IPC classification?**
- **If you use water washable pastes, how cleanable is the flux residue?**
- **Do you need high speed printing pastes?**
- **Do you need a paste with a wide print process window, tack life, stencil life?**

If the paste is selected carefully and the SMT process optimized to suit the chosen chemistry, the lead-free transition will be achievable without jeopardizing reliability and product yields. Sometimes a solder paste is selected which does not fit the process, high speed printing may not be a necessity, a paste which will perform at lower peak temperatures not required. Solder paste formulation is all about creating certain attributes at the expense of others.

Common defects associated with lead-free are:

- **Off-pad solder balling**
- **Mid-chip solder balling**
- **Tomb-stoning**
- **Bridging (shorts) on fine pitch QFP leads**
- **Open joints**
- **Non-Wetting**
- **De-Wetting**
- **Cold solder joints**
- **Voids**
- **Excessive dullness or surface cracks**

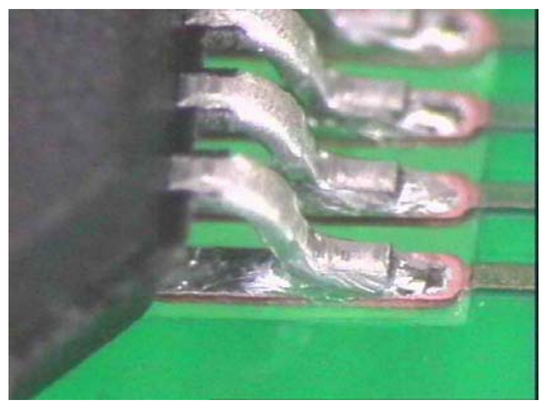


Voids, flux by-products trapped within joints

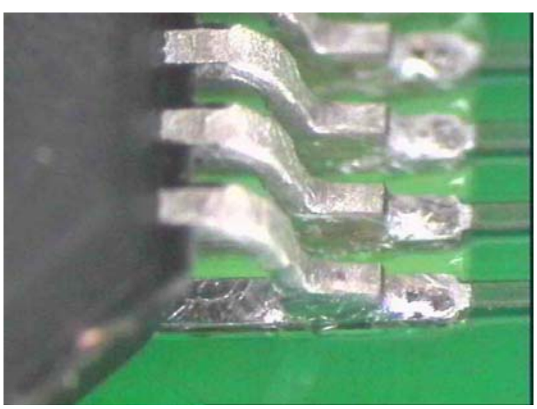
These defects can be avoided in a properly optimized process with a lead-free solder paste designed to give adequate wetting, low slumping, and low voiding with lead-free alloys. Good activity at higher reflow temperatures will be had by choosing solder pastes with activator packages, which do not decompose before at 217 °C.

Lead-free solders due to their reduced wetting speeds will at times not completely solder the pads. This will be impacted by the flux activity, thermal profile used, board finish and the reflow atmosphere.

However some assemblers are modifying the stencil to have less aperture reduction. This requires a solder paste with excellent hot slump properties to avoid bridging, solder balls and mid-chip balling. Other assemblers are seeking modifications to pad design. In most cases this is not considered an issue.



Exposed copper, OSP Board, SAC Alloy in air

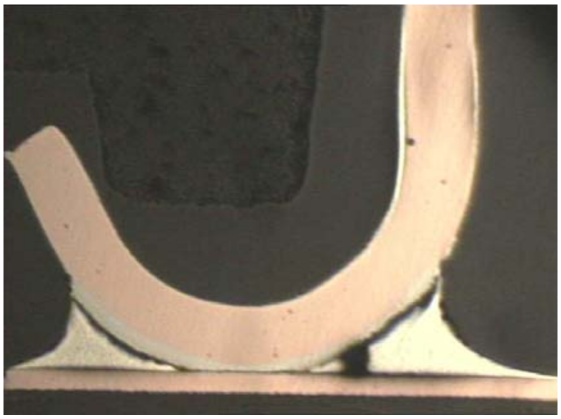


Silver Immersion Board and SAC solder

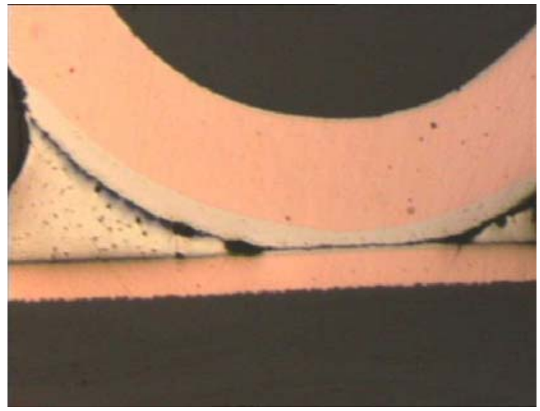
In reference to solderability, SAC alloys will wet the metallization at substantially reduced rates when compared to 63/37. Solderability is impacted at both the speed of wetting and the degree of spread.

Pure tin finishes are the easiest to solder with SAC alloys. While bare copper OSP usually gives the poorest results especially on assemblies that have seen a previous thermal process. Silver Imm. and NiAu finishes give values between tin and copper, and are popular lead -free choices.

In reference to component finish compatibility and the use of leaded component terminations with lead-free solders, studies are still ongoing. Some OEM'S have found little impact to their products reliability when leaded terminations are soldered with SAC alloys. The Gintic Consortium, recent work on lead-free wave assembly, did report that the best results were obtained with lead-free components such as pure tin and copper tin. These finishes had fewer failures during flex testing using various thermal profiles and resulted in less solder cracks.



Bismuth containing paste and SnPb lead



Close-up of fracture after 1000 hours at 150°C

Solder joints containing bismuth such as using SnAgBiCu lead-free paste to solder lead bearing terminations is not recommended. High temperature storage at 1000 hours at 150°C resulted in more solder joint cracks. Typical failures are noticeable in the above micro-sectional photos of a gull-wing component.

As lead-free is slowly implemented in an organization, both leaded and lead-free solders will be used. It is important to maintain good traceability of components, boards and solder products. To assist the industry, component suppliers have started to adopt the new standard, JESD97, "Marking, Symbols, and Labels for the Identification of Lead-free Assemblies, Components and Devices".

Lead-free Packaging

To avoid confusion with solder products, some manufacturers have adopted different colours and shapes for the packaging of lead-free soldering materials.

Training of all personnel will be required not only at the final inspection level but also at incoming inspection, inventory control and at BOM levels. Good traceability of all components and boards, including solder materials will be required.

Other processes requiring attention are the hand soldering and rework processes. Although the lead-free solder spools may be packaged with different colours, the soldering irons used to solder lead-free parts must also be identified as to avoid cross contamination with leaded solder, which may also be used in close proximity. A simple way to do this is to label the soldering iron with a label stating "lead-free" and also applying fluorescent green tap on the handle.

Conclusion:

Developing a lead-free SMT process requires good planning and a close working relationship with all suppliers. Understanding the components and board compatibility issues with the use of higher temperatures is essential. Also important is the avoidance of certain elements such as bismuth and lead, which may impact solder joint reliability.

Solder paste alloy must be selected and then a compatible flux system to meet the solderability requirements of the finishes to be soldered is needed. The reflow process will need optimization to warrant good intermetallic bonding, while avoiding temperature excesses, as to prevent board delamination, component damage, excessive intermetallic growth, solder surface and flux residue effects.

Rigorous material controls will be essential. A team approach and proper training will be required for lead-free integration, especially where dual systems, leaded and lead-free are present.

About the author:

Peter Biocca is Senior Market Development Engineer with Kester in DesPlaines, Illinois. He is a chemist with 24 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 7 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.

For further information please contact Peter Biocca at Kester, telephone 972.390.1197 or via email at pbiocca@kester.com