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Lead-free Reliability - Building it right the First Time

By Peter Biocca, Kester, Des Plaines, IL, U.S.A.

As lead-free and RoHS compliancy fast approaches, it is more important than ever to build it right the first time. Lead-free assembly and RoHS will bring about numerous changes and the number of variables with which to contend is increasing, creating increased risk of defects and reduced product reliability. However, understanding what the variables are and their impact on the assembly can great increase product reliability.

Below is a summary of some of the changes that may occur during the transition to lead-free soldering. All aspects of the assembly process will be affected by the transition to RoHS compliant manufacturing.

- Solder alloy
- Component termination
- Board finish
- Board and component thermal limits
- Component moisture sensitivity levels (MSD)
- Flux Chemistry
- Thermal profile requirements
- Possible equipment changes
- Cleaning process changes
- Inspection processes

Due to the reduced wetting speeds of lead-free solders such as the most popular choices such as SnAgCu (SAC) and SnCu, optimizing the production process will be critical to the final reliability of the product. The alloy choice in wave soldering will directly impact hole-fill and a carefully chosen flux system designed for performance with the particular alloy is best. Optimization to maximize hole-fill without voids will then be necessary. In reflow soldering, SAC alloys are predominantly used and the wetting may be reduced if the profile is not optimized to the manufacturer's recommended parameters.

Those experiencing the least issues with lead-free builds at this time are those assemblers using more active water-washable flux systems. Higher activity flux systems will improve hole-fill in wave soldering and wicking and spread properties in reflow soldering. Such fluxes are often classified ORH1 per J-STD-004. Users of these active fluxes account for about 20% of the North American market and less than 5% elsewhere in the world. The added activity does offer better joints, which can be more reliable due to the increased wetting behavior. The challenge with these flux systems becomes complete residue removal as incomplete residue removal can cause corrosion and serious reliability risks in the field. Residue removal is further complicated by using hotter thermal profiles in reflow soldering and increased contact times in the wave; resulting in situations where complete residue removal is more difficult.

No-clean fluxes and solder pastes tend to be of the mostly of the ROL0 classification per J-STD-004 and their activity has to be carefully designed for lead-free assembly to sustain higher reflow profiles and possibly longer contact times during wave soldering.

Typical Joint Reliability Issues

In wave soldering the main defects which are encountered which can impact reliability are:

- Lack of Hole-fill
- De-wetting of leads
- Voids in the barrel
- Bridges

The cause for lack of hole-fill could be lack of flux activity and is also dependent on the solder alloy. If flux activity is depleted prior to entry into the solder wave, poor hole-fill will be likely. De-wetting can be caused by prolonged contact time with the molten solder or the solder temperature being too high. Voids can be caused by the properties of the solder; lead-free solders have higher surface tensions than Sn63Pb37. The flux and board finish can also affect void volume. Bridging can occur when a flux is not sufficiently active, insufficient flux is applied or excessive contact time at the wave solder.

For lead-free reflow soldering the main defects, which appear to impact reliability are:

- Poor wetting
- De-wetting
- Solder balls
- Bridges
- Tombstoning
- Voids

Insufficient wetting during reflow can be caused by an improper thermal profile for the particular paste, insufficient activity of the paste flux or board and component solderability. De-wetting is seen with excessive times above liquidus. Bridges and solder balls can be solder paste related if a paste has poor hot slump characteristics but also the chosen thermal profile can be a contributor. Excessive preheating can overly oxidize the paste, board and component and would therefore deplete wetting ability. Voids are another problem reported and the cause can be flux chemistry, an incorrect profile, or termination geometries. The higher surface tension of lead-free solders tends to increase void volume and careful solder paste selection and thermal profiling is therefore essential.

In hand-soldering the main defects associated with the reduction of reliability are:

- Poor wetting
- De-wetting
- Cold solder
- Component damage
- Board damage

The greatest number of complaints received during the transition to lead-free is from hand-soldering operators as per a recent survey published in TechSearch International December 2004 issue of the Lead-free Update. In hand-soldering poor wetting and cold solder joints occur when the flux contained in solder wire is too low, the activity insufficient, or too low temperatures are used. De-wetting often occurs if excessive solder tip temperature is used.
The correct tip with adequate but not excessive heat transfer will go a long way in creating reliable solder joints.

Design of Experiments for Lead-free

Defects are indicative of a lead-free process that requires further optimization. This includes the flux selection, the soldertability of the parts to be joined, and the equipment process parameters. Before undergoing mass build of lead-free assemblies a Design Of Experiment should be conducted to insure the process is defined to give solder joints compliant with IPC-610D. Below is an example of a DOE performed on a lead-free wave process.

Trial Number	Conveyor Speed (m/min)	Preheat Temp. (˚C)	Soldering Temp. (˚C)
1	1.0	105	260
2	1.0	105	255
3	**1.0**	**115**	**260**
4	1.0	115	255
5	1.2	105	260
6	1.2	105	255
7	1.2	115	260
8	1.2	115	255

Typical DOE Wave Process with No-clean flux, ENIG boards, Lead-free finishes

In the above trials it was found that Trial 3 gave the best hole-fill and wetting of bottom side SMD's. The slighter higher preheat temperature gave better results at a conveyor speed of 1.0 meter per minute. These parameters also gave reduced icicling with the chosen flux activity level ROL0.

A DOE prior to any reflow, wave, and hand-soldering process change to lead-free will essentially increase the reliability of the solder joints and product assembly. After the DOE soldering experiments proper inspection will be required to confirm which settings give the best wetting and least defects. Checking for voids is also important. This is especially true with reflowed assemblies and wave solder boards.

A DOE for the reflow profile process may include the following variables: board thermal mass, complexity of components, peak temperature, soak time, component metallization, board finish, and time above liquidus temperature.

With hand-soldering a simple DOE can go a long way in reduces the common cold solder, poor wetting issue associated with lead-free. Here varying tip temperature after a 2-3 % flux content solder wire and correct tip design is chosen will make the process operator friendly and avoid non-reproducibility or variance from one operator to an other.

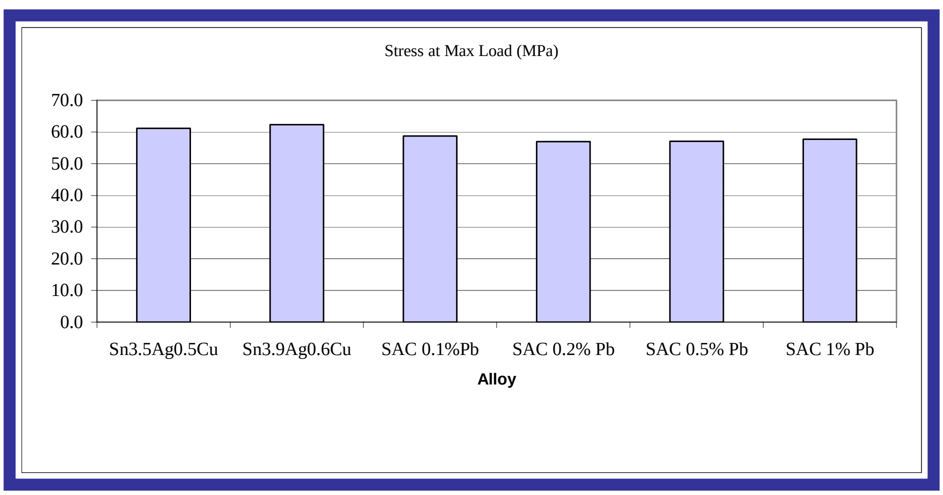
A well-formatted DOE will be the first step in insuring reliability. Too often extensive testing is engaged such as thermal cycling, vibration tests, pull and shear tests with questionable solder joints. This results in assumptions that lead-free is less reliable than Sn63Pb37.

Solder Joint Reliability

A common concern that can impact solder joint long-term reliability is the introduction of lead in lead-free solders. In wave soldering processes, lead-bearing terminations may rapidly increase the lead content beyond the allowable limits imposed by RoHS (0.1%). The use of lead-bearing terminations can also increase the risk of fillet lifting. Although fillet lifting is documented in IPC-610D as a soldering anomaly its long-term effect on joint reliability is not fully understood at this time.

In reflow soldering some have reported little difference joint performance however more work is required before this statement can be applied to high reliable products.

Below is some data obtained from the Gintic Consortium report, which indicates little to no change in pull testing results.



Lead in SAC alloy joints versus Load data, obtained from Gintic Consortia Tests

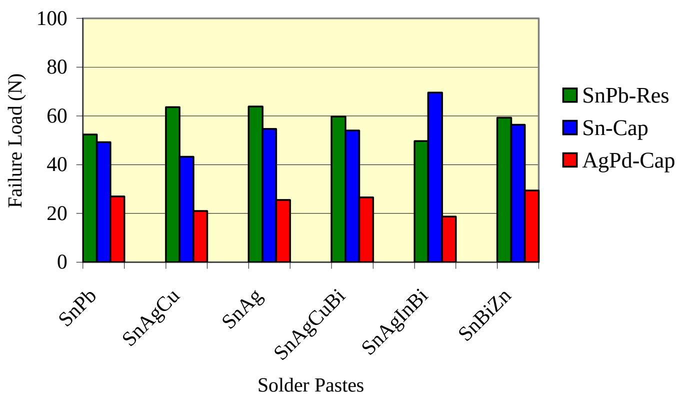
Additions of 0.1 to 1% lead were added to SAC alloys in this test but no difference was noted.

Other studies were also done within the Gintic Consortium, which compared the reliability of leaded Sn63Pb37 and lead-free solder joints under varying conditions. After extensive process optimization it was shown that SAC solders both in wave and reflow can produce reliable solder joints comparable to Sn63Pb37. The consortia members spent a considerable amount of time optimizing the process parameters before reaching this important conclusion.

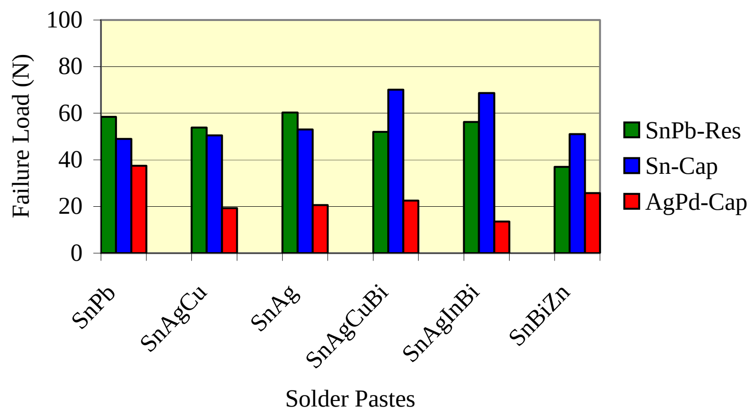
Differences were noticed when ENIG and copper OSP boards were tested. Variations in test results were also noted with component termination finishes. Several component types were tested and shear and pull forces were applied to several lead-free solder joints as indicated in the diagrams below. The component terminations tested were tin-lead, pure tin and silver-palladium.

Schematic diagram indicating force application to SMD components

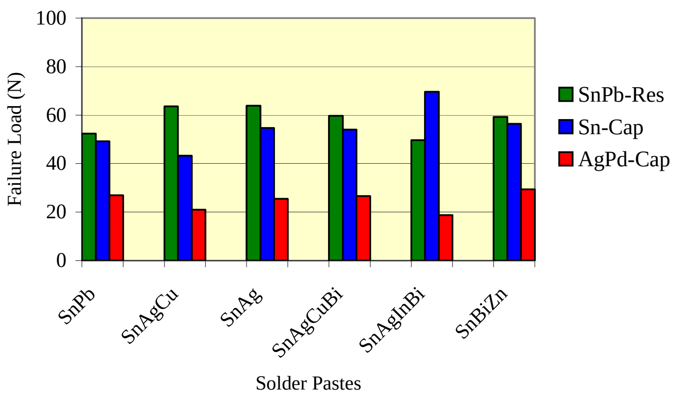
For the sake of this article only the comparable data between leaded and SAC is of interest. Some of the data extracted from this experiment is shown below.



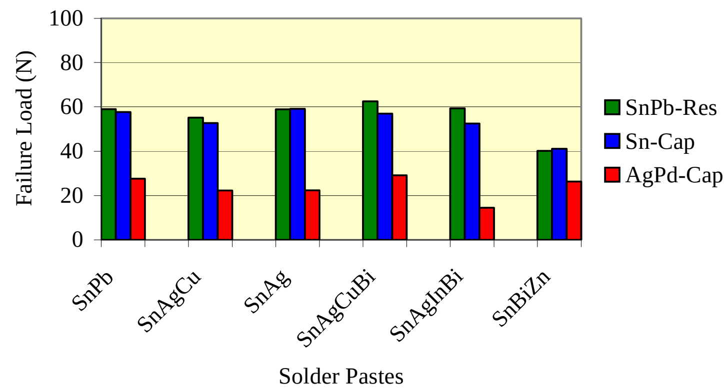
ENIG boards Time Zero.



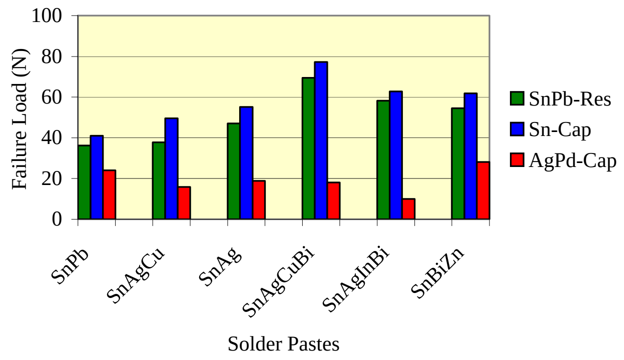
ENIG boards after 1000 hours storage at 150 °C.



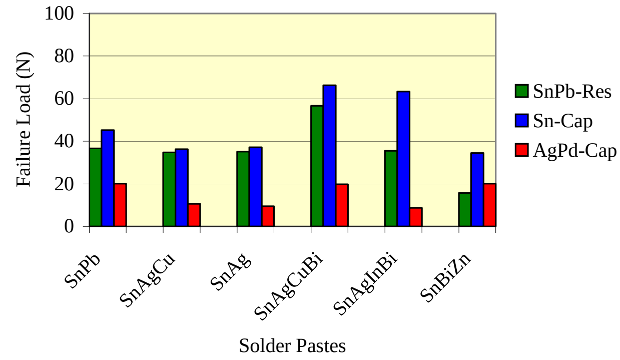
Copper OSP boards Time Zero.



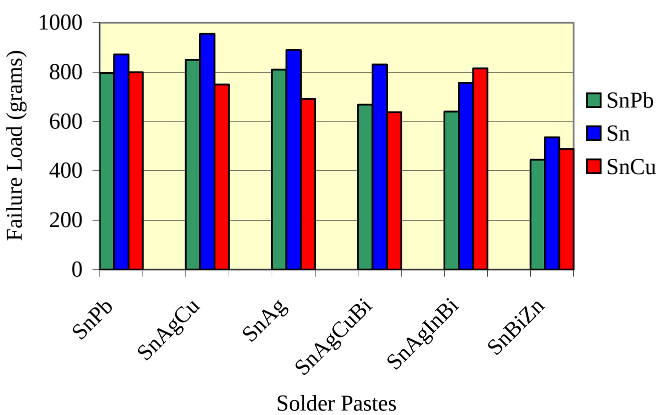
Copper OSP boards after 1000 hours storage at 150°C.



Push strengths for chip component on Cu OSP board after 1000 cycles at –40 to 125°C

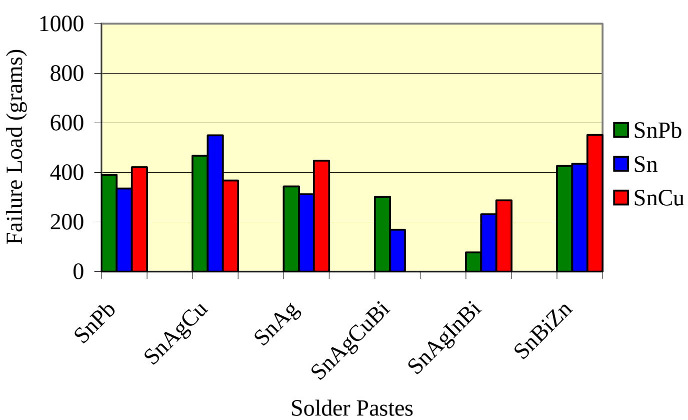


Push strengths for chip component on NiAu after 1000 cycles at –40 to 125°C.

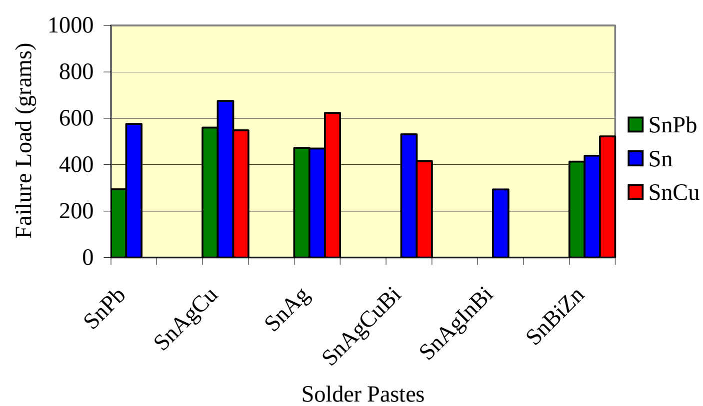


Pull strength data on chip component NiAu board. at Time Zero.

Pull strength data on chip component Cu OSP board at Time Zero.



Pull strength data chip component NiAu board. after 1000 cycles –40 to 125ºC.



Pull strength data chip component Cu OSP after 1000 cycles –40 to 125ºC.

Some of the conclusions drawn from the above are that SAC can be as reliable as Sn63Pb37 solder joints in most cases. A small amount of lead originating from the component finish does not seem to negatively impact pull and push strength values. The above data applies to SMD parts and not through-hole. The data also showed reduced values for AgPd terminations where pull and shear strengths showed a reduction after thermal cycling, so some added consideration is required here.

Reliability with lead-free soldering can only be achieved if all the variables are carefully considered and this begins with components and boards, followed by alloy and flux selection and finally the thermal optimization of the soldering processes.

Even if a manufacturer is not transitioning to lead-free at this time, the changes in component finishes will require careful review to avoid incompatible lead-free finishes in a leaded process. This will insure reliability in exiting assemblies.
Before building lead-free assemblies it may be warranted to do some limited reliability testing on specific products. The more reliable a build must be, the longer the life of the product is and the greater the liability if failure occurs the more this becomes necessary.

Lead-free is proving to be very feasible and reliable but the whole process optimization cannot be underestimated in its contribution to solder joint robustness.

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.

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For further information please contact Peter Biocca at pbiocca@kester.com