Lead-free Rework Experiences Using SAC and Sn-Cu Based Alloys

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Abstract
As companies transition over to lead-free assembly a certain amount of hand-soldering and rework will be performed. An article from Tech Search International last year did state that in Asia where lead-free soldering is much more common, hand-soldering was more of a production problem than lead-free SMT or wave soldering or other soldering processes.

In fact most user problem calls and requests for training these days are related to lead-free hand-soldering and rework. In many cases the assemblers are using materials from various solder suppliers with similar issues occurring in all cases. Often the problems are more than just material issues.

Switching to lead-free without proper preparation is not recommended. Although this seems easily understood some assemblers have attempted to transition without adequate training; resulting in line stoppages occurring only a few hours into lead-free hand-soldering. Operator complaints, loss of reliability and poor joint quality were experienced. This could be a production engineer's nightmare but it need not be this way if the basic concepts of hand-soldering are revisited, some experience gained prior to the transition and adequate training of operators is performed before and after the switchover.

This paper is a compilation of questions often asked by assemblers in reference to hand-soldering with lead-free. These questions are in fact some of the issues addressed during lead-free hand-soldering on-site audits or training at assemblers using lead-free solders at their facilities. It offers practical answers as to
enable the reliable implementation of lead-free.

Which alloys and fluxes are compatible with lead-free hand-soldering?
The limiting factor with lead-free solders is probably its availability in wire form; some alloys are not easily drawn into wire, as is the case with tin-bismuth solders.

At this time the most popular alloys used to make wire are tin-silver-copper and tin-copper based solders. This compliments the industry well at this time where 68% of SMT assemblers and 50% of wave assemblers have chosen tin-silver-copper (SAC) solders. In wave soldering 20% have chosen tin-copper (SnCu) based solders due to the cost of lead-free solder bar. Wire solders for hand-assembly are therefore readily available in these two alloys.

The main differences between SAC and SnCu solders are the melting points; the melting temperatures are approximately 217ºC and 227ºC respectively. From a soldering performance perspective, SAC wets more readily than SnCu based solders, so flow with SAC solders, everything else being equivalent, will be better.

Both SAC and SnCu solders are available in no-clean, water washable and rosin based flux formulas. No-clean accounts for over 85% of the total wire usage while water washable is less than 15% and rosin based fewer than 5%. These numbers apply to North America. In other parts of the world no-clean is dominant.

What are the high melting temperature options with lead-free solders?
Lead-free higher melting temperatures are very limited; Sn-Sb and SnAu are alloy options but the cost of these are high and are not good choices for the replacement of less expensive high lead solders normally used today. Higher temperature, high lead solders with lead above 85% are exempt in current RoHs legislations because of this. Tin-Antimony can be an option in some limited cases but its availability in wire form due to brittle fracture during the drawing process makes it difficult to obtain.

What are the key variables in choosing lead-free solder wire for hand-soldering or rework?
The flux content or flux percentage by weight in the wire will be a critical factor in determining soldering performance and wetting speed. Lead-free solders such as SAC, SnCu and the higher temperature option tin-antimony SnSb wet a little slower than 63/37 when compared using similar conditions in wetting balance tests.

Lead-free solder wires should contain at least 2% flux by weight. Leaded solders are available with lower flux percentages as low as 1% wt/wt; this low flux volume will not work well with lead-free. Three percent flux content enables better wetting than the 2 % especially with no-clean type fluxes.

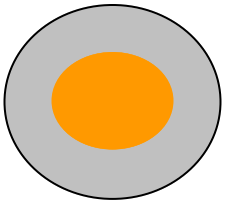


Figure 1

Typical flux distribution in a solder wire, the density of the flux is close to 1 g/cc; therefore the volume is more obvious in the cross-section. Multiple cores are used at times but the percent is usually 2 or 3 % for lead-free. Less flux results in difficulties during the soldering operations. Usually the lower the activity of the flux, the higher the percentage should be.

If wetting is sluggish 3% flux in the wire may be tried but this will give higher residues, not always cosmetically appealing in no-clean applications. The addition of flux using a squeeze bottle is normally not acceptable due to over application issues. This is not acceptable for no-clean applications and less additional flux can be applied using a higher flux content or using a felt applicator, flux pen.

Another important point is to insure the flux is designed for lead-free applications and therefore it should be able to withstand higher soldering tip temperatures without charring, spattering and decomposition. Some fluxes may smoke more when using hotter tip temperatures. Revisiting flux fume extraction systems may be required.

When choosing a solder wire make sure to observe the flux IPC classification. Many no-cleans meet the ROL0 classification meaning they are rosin based, low activity and halide free. These are the most reliable and meet the SIR and corrosiveness tests in the IPC specification. With lead-free there is a tendency to use higher activity to compensate for the reduced wetting; this is not always a good idea.

Water washable fluxes are more active classed often as ORH1 and do better with lead-free soldering. However insure the residues are still completely removable in hot water; doing ionic contamination testing is recommended. If ionic contaminants still remain after water washing, a clean process change may be warranted such as increasing the cycle time, water temperature or a change of the cleaning chemistry.

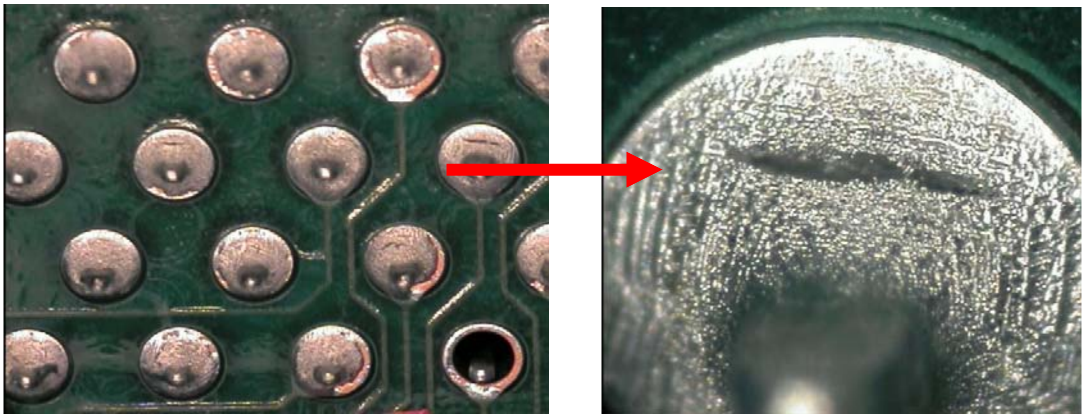
In comparative studies done with SAC and SnCu wetting balance tests indicate that using the same flux types that SAC out-performs SnCu solders in the time required to reach maximum wetting. This applies also to SnCu solders with dopants of nickel, cobalt or other additives.

In choosing an alloy it is important to determine the overall solderability of the parts to be assembled. If the parts are older, more oxidized, manually handled, SAC solder may be a better choice.

What are the main changes associated with lead-free hand assembly cosmetics?
Lead-free solders flow a little slower than 63/37 using the same activation levels for the fluxes. The contact angles are slightly larger and feathering out of the solder is therefore less pronounced. The solder joints tend to be less reflective than 63/37 solder. Some re-training is required prior to a full transition to lead-free is done.

In some cases certain shrinkage effects as described in Section 5 of the IPC-STD-610D occur. The IPC-610 classifies these as soldering anomalies and not necessarily defects.

As mentioned on page 5-22 of the above document, it is not a defect for Class 1, 2 and 3 if the tear bottom is visible and the shrink hole does not contact the lead, land or barrel wall. See the photos below for examples taken from laboratory tests.

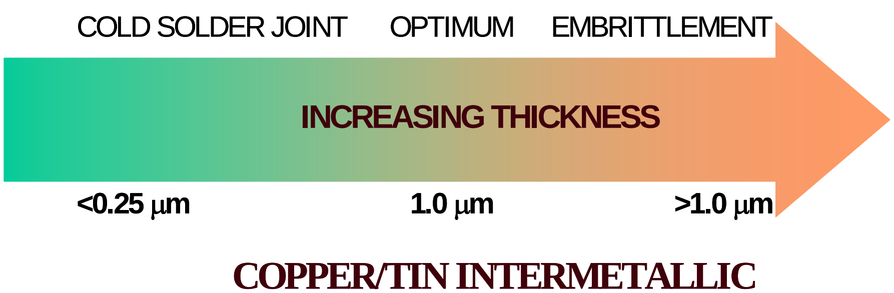


Figures 2 - Typical shrinkage effects with SAC solder   Figure 3 – Close-up of SAC shrinkage tear

The issue with shrinkage effects is that the bottom of the tear is difficult to assess. The only way to determine the structure and depth of the tear is with the use of X-ray or cross-sectional testing. Sn-Cu solders with additives have reduced shrinkage and therefore there is no concern. Thermal cycling can aggravate the tear and this may lead to reliability concerns.

What is the best soldering tip temperature for lead-free SAC and SnCu?
The temperature of the tip or contact temperature is very important to ease the lead-free hand-soldering operation. When using 63/37 solders temperatures as low as 650ºF have been used but with lead-free 700-800ºF is best. The higher temperature does compensate for the slower wetting exhibited with these lead-free alloys.

Above 800ºF issues of board and component damage may arise; at lower temperatures cold solder joints and flagging are the normal complaints.



Higher temperatures and longer contacts with the parts to be soldered may also increase the intermetallic bond layer. So avoiding prolonged contact and repeated rework is not recommended. The above diagram shows what happens as the bond layer increases in thickness a higher risk of embrittlement occurs.

The risk of de-wetting also increases with higher temperatures and increased contact times. If de-wetting occurs it is very difficult to solder to the de-wetted metallization and often a more active flux must be used.
The higher leaching potential of high tin solders is directly increases with high temperature and contact times with the molten metal, using the lowest soldering tip temperature is therefore recommended. This will also reduce tip maintenance, flux fumes and flux charring.

How about soldering tips for lead-free soldering?
Lead-free tips are required however just as important is the choice of tip design. Lead-free is less forgiving and the right tip for the job will go a long way in prevent defects.

Choosing a tip with enough heat delivering capacity is critical to solder spread and wicking. Fine point tips cannot be used in all applications and in some cases a tip such as a chisel type is best suited to deliver sufficient heat to the parts to be soldered. Many soldering station manufacturers have redesigned their tips for lead-free applications. See the diagram below for examples of correct tip selection criteria.

Figure 4 - Choose the tip with the correct configuration with lead-free

How about tip life with lead-free solders?
Tip life will be reduced with lead-free solders and it is important to choose tips really designed for lead-free soldering. Many tips are only tinned with lead-free solder and the iron plating is no different than traditional soldering tips. High tin solders like to dissolve iron and this reduces tip life. Some assemblers have reported important reductions in tip-life; for example a manufacturer reported that with 63/37 the tips lasted 3 months with lead-free the tip-life was only 3 weeks.

Not all soldering tips are equal when comparing dissolution rates so choosing tips carefully and asking for more compatibility information is a good practice.

Figure 5 - Lead-free tip failure after 3 weeks

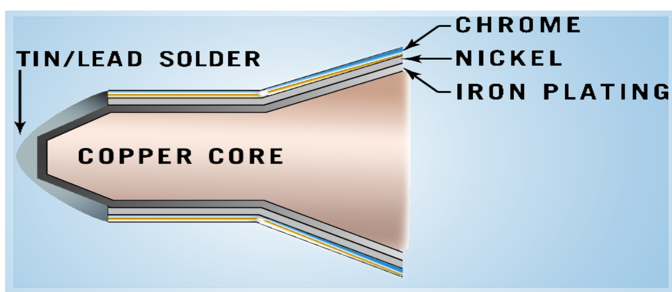


Figure 6 - Tip cross-section, with lead-free the solder is lead-free

There are several ways to increase tip life and these are listed below:

- Avoid abrasive cleaning practices
- Avoid the use of acidic fluxes
- Use lower temperatures
- Use less contact times
- Turn off iron after use
- Do not apply force to tip
- Avoid the use of excess flux
- Choose tip brands carefully

My soldering iron tips are charring, turning black and de-wetting when I use lead-free solder wire, what can be done?

Not all fluxes are created equal and some are thermally incapable of sustaining the higher soldering temperatures used with lead-free solder. A recent video clip from OK International demonstrates this well when two solder wires are compared side by side. Called the “black tip syndrome”, less thermally stable resins turn the tip black and makes re-tinning of the tip more difficult.

Once “black tip syndrome” occurs the reduction in heat transfer makes lead-free hand soldering difficult, tip life is reduced, tip costs and operator frustration goes up and reliability goes down.

Proper flux selection, using lead-free tips and lead-free hand solder process training for operators will offset these costs. The important points to help avoid these problems are listed below.

- Use lead-free solder wires with lead-free designed fluxes
- Avoid using high temperatures
- Use wires with a lower flux percent
- Reduce the use of additional flux using flux pens or squeeze bottles
- If tip-tinner is used, wipe excess tinning material on a clean sponge
- Use the right tip geometry
- Use the correct wire diameters
- Train all operators

Which defects or issues can appear and how can they be prevented?
Common issues reported with lead-free hand-soldering and rework operations are listed below.

- Grainy joints
- Cold solder joints
- De-wetting
- Flagging
- Poor wetting and wicking
- Flux charring; darkened residues
- Difficulty cleaning residues
- Copper dissolution

Grainy joints can be due to too high a tip temperature and the dissolution of the metals to be joined. Increased contact times will also promote this.

Cold solder joints can be due to several process parameters such as too low a tip temperature, too weak a flux or insufficient flux in the wire.

De-wetting can be caused by prolonged tip contact and the dissolution of the plated metals, exposing a less solderable surface. Too high temperatures can also cause this.

Flagging can be caused with the use of too high soldering tip temperatures or the use of solder wires with low volumes of flux. Flux activity may be low also and prolonged contact with the iron is de-activating it.
Too long a contact time will also result in flagging.

Flux charring with no-cleans and water washable flux wires can be due to soldering temperatures being too high or the flux is not properly designed for the higher temperatures required for lead-free. Avoiding prolonged contact and using lower soldering temperatures can help with this situation. The addition of flux external to the flux in the wire will also create flux charring on soldering tips. Avoiding improper use of liquid fluxes will reduce this problem.

Flux charring or flux decomposition may also render the flux residues less removable. This is particularly a problem with water washable fluxes due to the corrosive nature of these chemistries. Tip life is further reduced with these products; higher temperatures and longer contact times accelerate this problem.

Poor wetting leading to inadequate joint formation, excessive contact angles and poor wicking of solder can be a solderability issue but also relates to the flux activity as well as the temperature used in the process. Poor wetting can be alleviated by using the right flux classification for the metals to be joined and using the right temperature to achieve good thermal transfer without decomposing the flux needlessly.

Copper dissolution is a problem that can be encountered in rework fountain operations where the contact times are longer. The high tin in lead-free alloys tends to dissolve copper from boards and components more readily than 63/37. Choosing alloys designed with less copper dissolving potential can be way to reduce this. SnCu with additives has demonstrated less dissolution than SAC solders. Using lower solder temperatures can also help reduce this problem.

When compared, how do SAC and SnCu based solders differ in hand-soldering and rework?
The main difference between these alloys is wetting speed and cosmetics. SAC wets more readily than SnCu based solders and additions to SnCu tend to give brighter joints free of shrinkage effects. Both can work well in hand-soldering, if the points already mentioned are applied.

In rework fountain processes SnCu based solders with additives may behave better with their lower dissolution of copper. Less dissolution results in less copper being striped off the board at the solder joint area; this can create better reliability. However less dissolution also means the solder contaminates more slowly, requires less analysis and less dross is created, reducing the overall maintenance process and cost.

How can a good lead-free hand-soldering process be had, which will therefore ease the lead-free soldering operation and maintain reliability?
The reason lead-free hand-soldering and rework is found to be more challenging is that they are processes which are operator dependant when compared to reflow and wave soldering. The surface tension in lead-free solders is slightly higher; wetting, spread and wicking are also slower when compared to 63/37.

To reduce operator issues and reduced wetting proper optimization of the soldering process is important. To avoid issues use a flux content of 2-3% by weight in the solder wire, use a solder tip temperature of 700-800º F. Also Tin-Silver-Copper (SAC) solder will flow more readily than Tin-Copper (SnCu) solder.

The main issues encountered with lead-free hand-soldering can be avoided if the following procedures are used. A step-by step process transition would be as follows:

- Insure the tips are designed for lead-free
- Insure the temperature is set between 700-800 ºF
- Insure the flux content in the wire is 2 or 3% wt/wt
- Use Lead-free tips with the longest life
- Use the correct geometry tip for the job
- Insure the parts are easily solderable with the chosen flux
- Avoid prolonged contact times
- Avoid needless reworking of the joint
- Avoid the use of additional liquid flux
- Turn off the temperature after use
- Avoid lead cross contamination
- Train personnel on the issues and expectations

In reference to cross contamination, identifying lead-free work areas and soldering stations as to be lead-free is important.

Conclusion:
These are some of the questions asked by lead-free users which come regularly. A little training goes a long way in avoiding costly issues with the hand-soldering process and rework. Proper techniques will need to take in account the differing properties of lead-free alloy. Understanding cosmetic differences will prevent touch-ups and aggravating the process further.

Although the process is more operator dependant using the points mentioned above can make hand-soldering less frustrating for the operator and engineers. Maintaining the same levels of reliability they are accustomed to with leaded soldering is therefore achievable.

Lead-free defects need not increase over 63/37 operations as long as lead-free soldering practices are used. These practices may differ from 63/37 because of the higher melting temperatures of these alloys but also their wetting behaviors.

Both SAC and SnCu based solders can be used and both are popular options. As long as the reduced wetting behavior is compensated for by the use of higher flux percentage and higher soldering tip temperature SnCu solders especially those with minor additives will do comparable to SAC solders.

When setting up lead-free work areas proper identification is necessary to avoid lead contamination and this should be a topic in the training of existing and new personnel.

References

1. OK International, joint customer training modules, 2004, 2005.
2. Kester training audits at numerous customer sites from 2004-2007
3. Discussions with soldering station manufacturers globally
4. Problem solving technical questions initiated by lead-free end-users from 2004-2007

Lead-free Rework Experiences Using SAC and Sn-Cu Based Alloys

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On a lighter note. Soldering …did it change?









TechSearch International

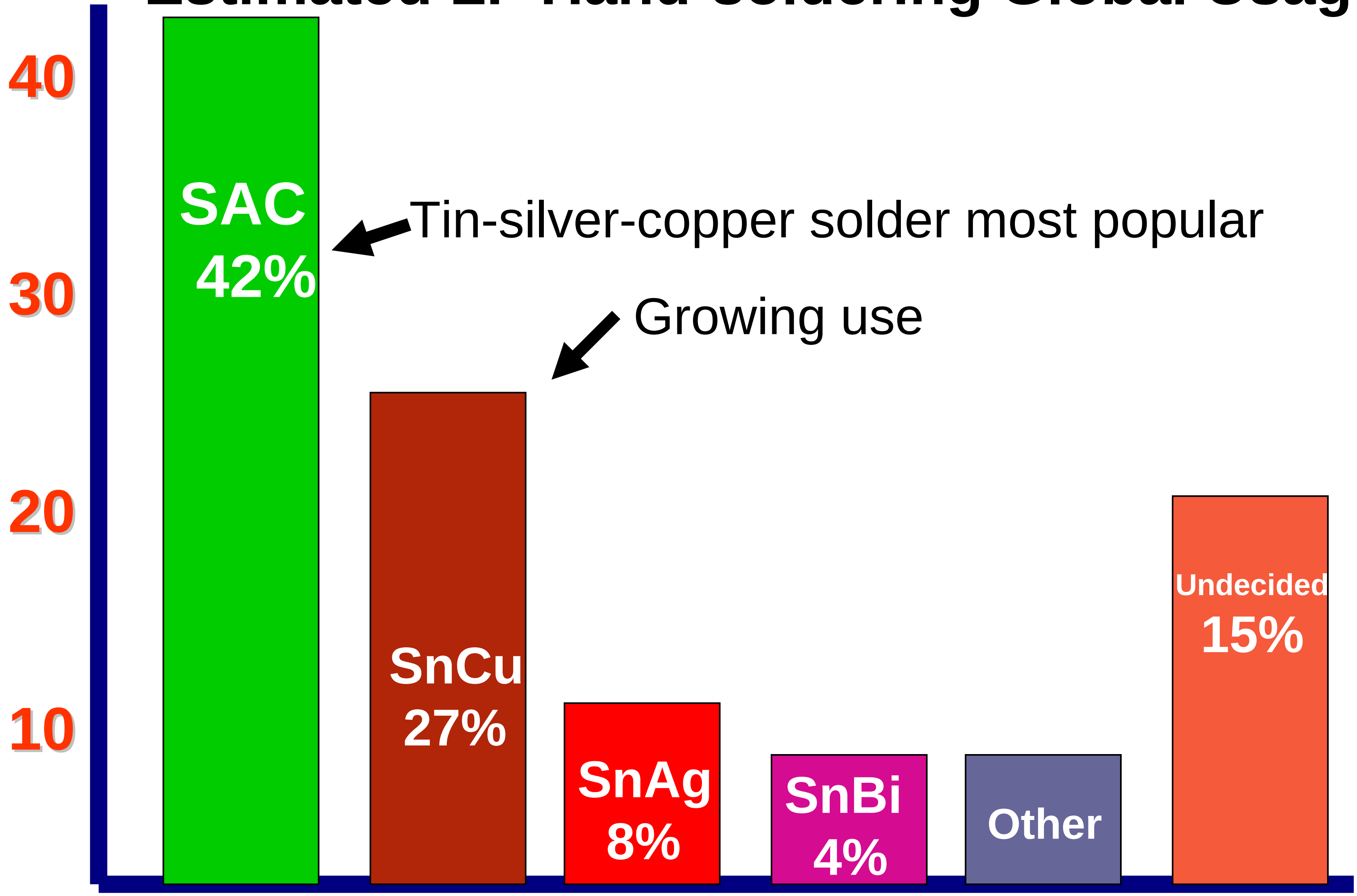
as per Lead-free Update Service Bulletin

"The main issue found in Asia with lead-free is not wave or SMT but hand-soldering".

Hand-soldering Process Variables

- Alloy melting temperature
- Solder wetting speeds, spread, wicking behavior
- Soldering temperature requirements
- Flux selection - no clean, rosin, rosin free, water soluble
- Flux activation level
- Flux percentage 1, 2 or 3%
- Flux volatility, decomposition and flux spatter
- Cleanability of residues and cosmetics
- Soldering equipment, tip geometries, tip-life

Estimated LF Hand-soldering Global Usage



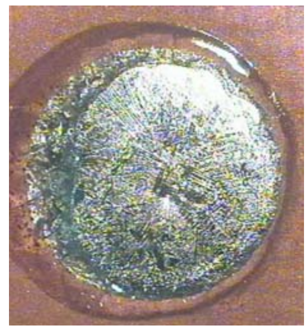
Melting Points

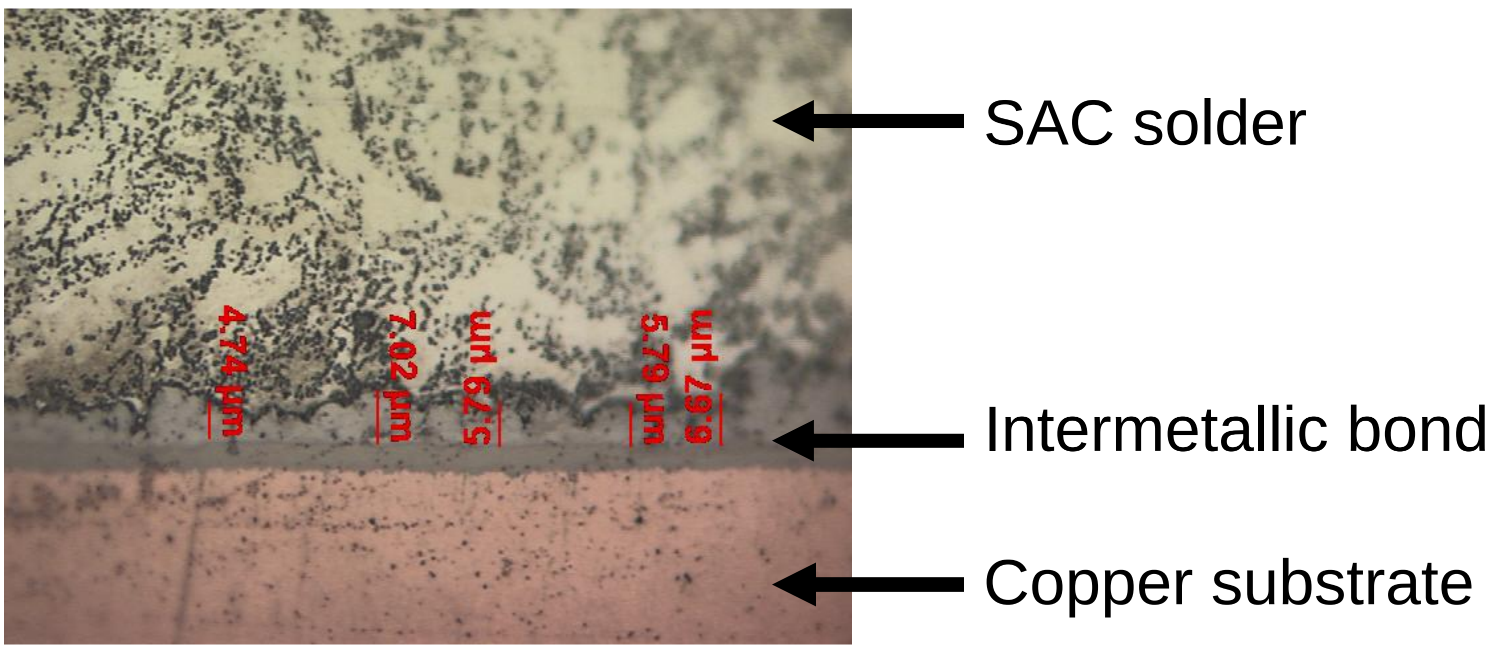
Both are used

Alloy System	Composition	Melting Range
Sn-Pb	60Sn-40Pb	183-188 (361F)
Sn-Cu	**Sn-0.7Cu**	**227 (441F)**
Sn-Ag-Bi	Sn-3.5Ag-3Bi	206-213 (408F)
Sn-Ag-Cu	**Sn-3.8Ag-0.7Cu**	**217 (423F)**
Sn-Ag	Sn-3.5Ag	221 (430F)

Solder Wetting with Lead-free Alloys

- Wetting is the process of the flux cleaning the surface allowing the solder to bond.
- Proper wetting requires:
  - Solder … Slower wetting
  - Flux … Thermal stability
  - Heat … Higher temperatures





What is flux in reference to lead-free?

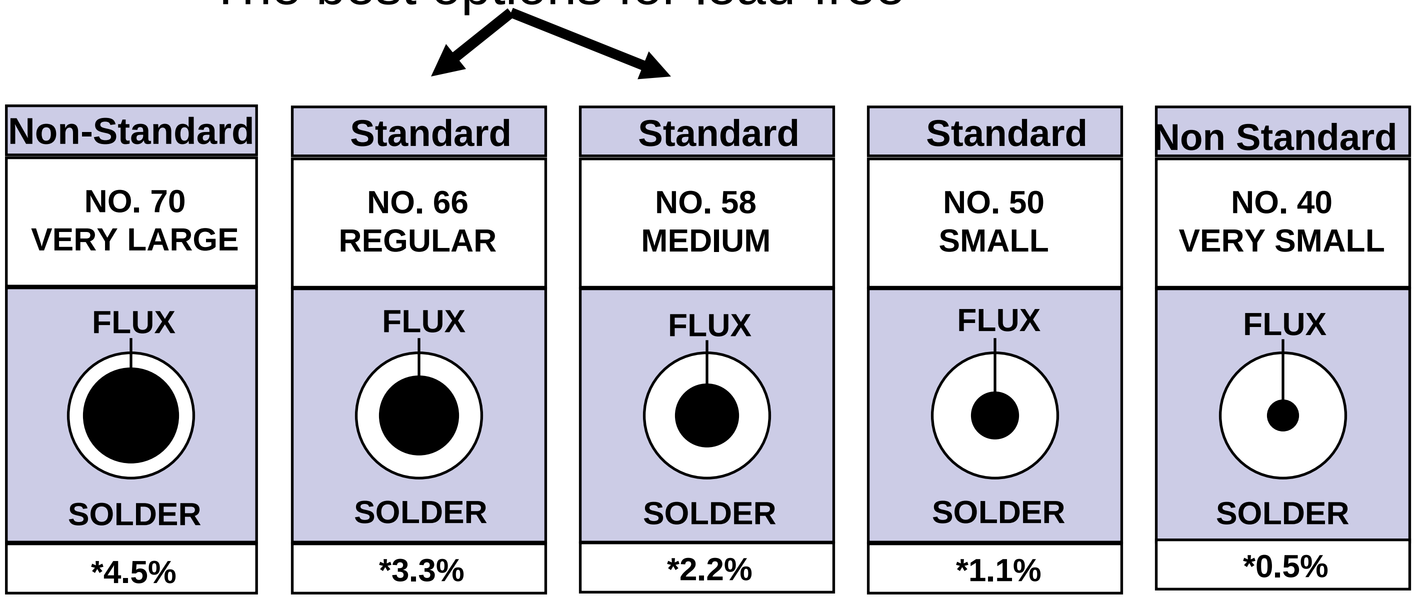
- Flux is a chemical that is used to remove oxidation from the metal surfaces that are to be joined; protect from further oxidation; reduce surface tension.
- The are 3 major flux types:
  - No-clean
  - Organic Acid (Water Soluble)
  - Rosin based

New fluxes for lead-free due to higher soldering temperatures, higher surface tensions, slower wetting, higher oxidation potentials and lead-free finishes.

- New activators
- Thermally stable resins
- Higher activity but still meeting IPC requirements
- Better surface active agents
- Anti-oxidant additives
- Clean-ability
- Residue cosmetics
- Low impact on equipment
- Low spatter and decomposition

Standard Core Sizes

The best options for lead-free



*Average weight percentage for Sn60Pb40 alloy but also lead-free. The average weight percentage will vary slightly depending on the density of the alloy.

Lead-free Connection Temperature

- High enough to melt solder & form inter-metallic.
- High enough to activate flux & cause wetting.
- Low enough to avoid damage to components/PCBs

INCREASING TEMPERATURE

Too Low → **Too high**

▪Cold solder joints	▪Good wetting	▪Component damage
▪Poor wetting	▪Good contact angles	▪Board damage
▪Little intermetallic	▪Thin intermetallic layer	▪Thick intermetallic
▪Large contact angles	▪Less oxidation	▪Dewetting
▪No reliability	▪Reliable joints	▪Reduced reliability

700-800°F

Standard Wire Diameters, using the correct diameter

Lead-free requires the proper diameter because of its slower wetting, higher soldering temperatures and to reduce flux decomposition and defects.

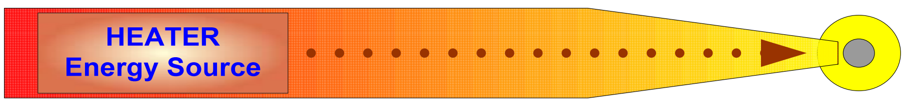
The wrong wire diameter results in:

- Increased defects and re-touches
- Use of additional flux
- Excessive decomposition of flux
- Reduced tip-life

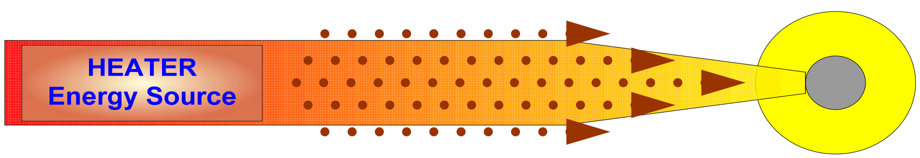
COMMONLY SPECIFIED DIAMETERS		
INCH	ENGLISH WIRE GAUGE EQUIVALENT	APPROXIMATE MM EQUIVALENT
0.125	11	3.17
0.093	13	2.36
0.062	16	1.57
0.050	18	1.26
0.040	19	1.02
0.031	21	0.78
0.025	23	0.63
0.020	25	0.50
0.015	28	0.40
0.010	31	0.25

Tip Geometric Design
(Conductivity Factor)

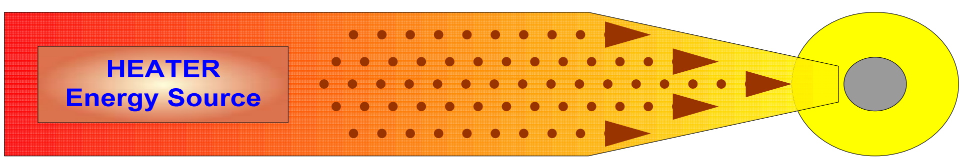
The Tip Geometry is the Thermal Energy "Highway"



Small Pad Demand is Satisfied With Low Conductivity Factor Tip



Large Pad Demand is Not Satisfied with Low Conductivity Factor Tip

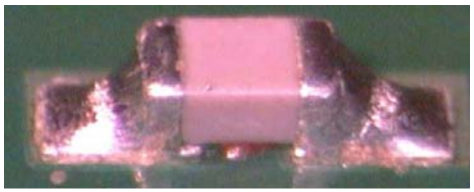


Large Pad Demand Requires High Conductivity Factor Tip

Use the correct tip geometry

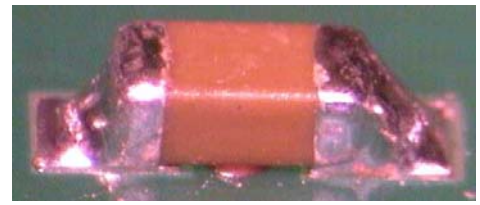
Contact angles, cosmetics will differ from 63/37

Good example

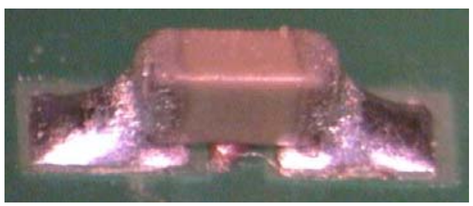


0603-Sn (cap)

0805-Sn (res)



1206-Sn (cap)

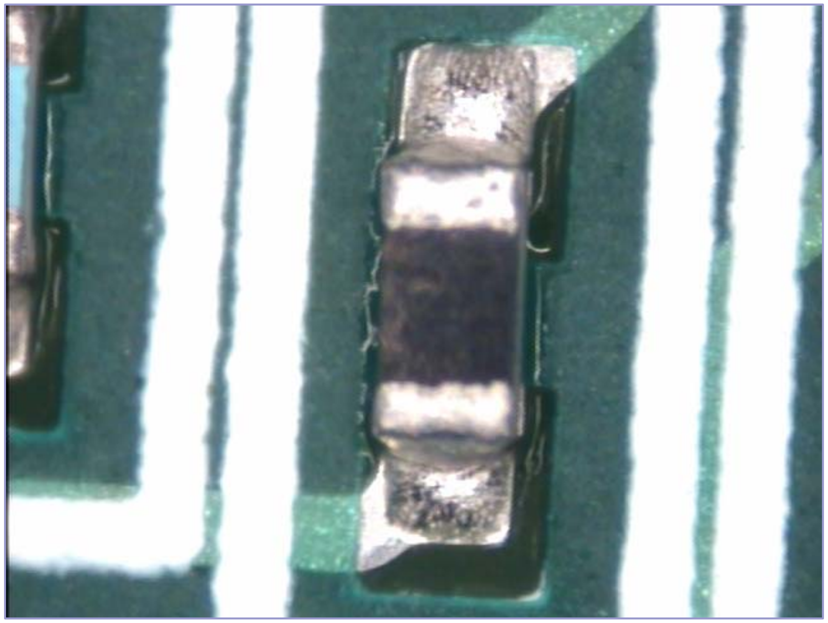


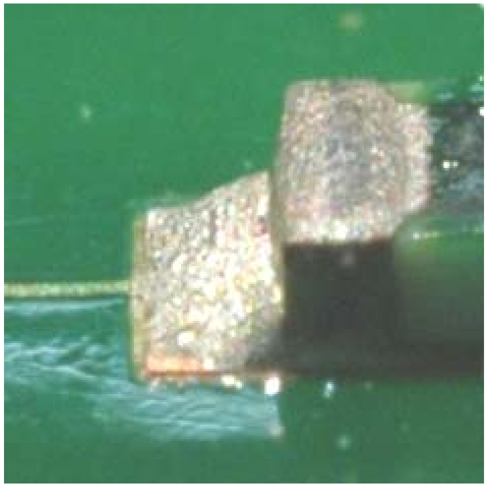
0603-AgPd (cap)

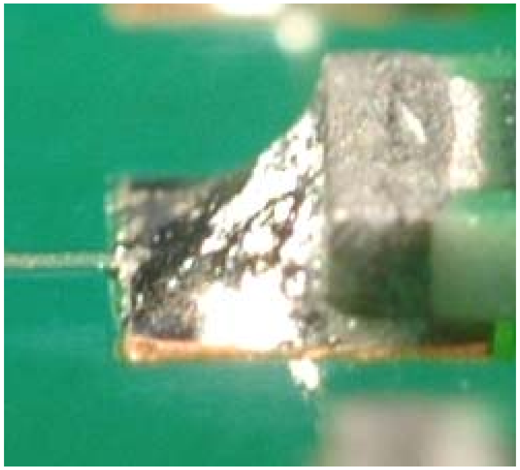
0805-SnPb (res)

NiAu FR4, Flux type No-clean ROL0

SAC Alloy

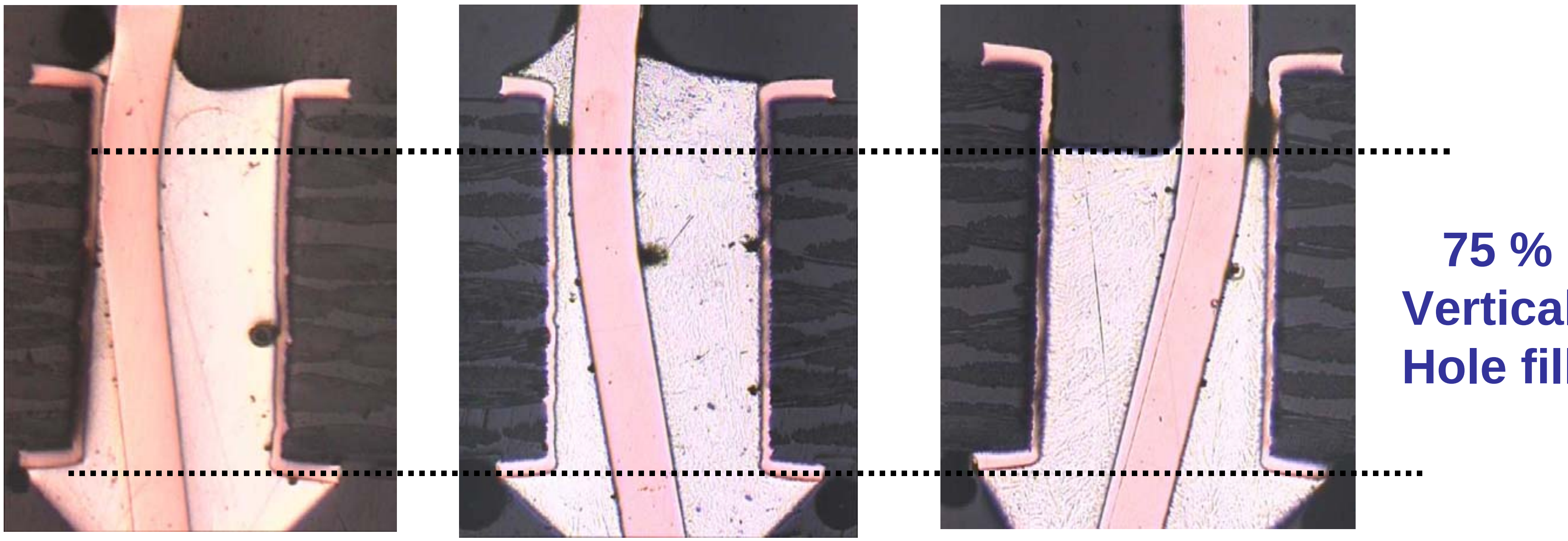






Large contact angles
Reduced wicking

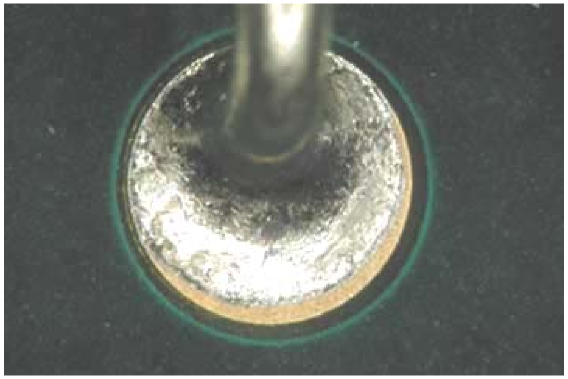
Hole Fill and Board Finish

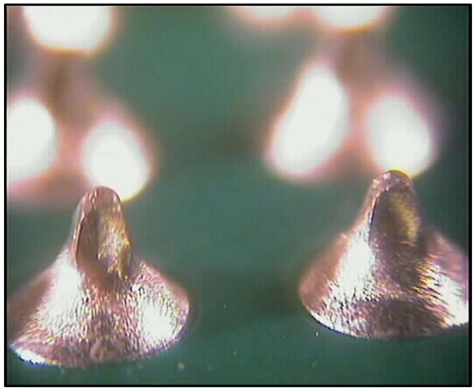


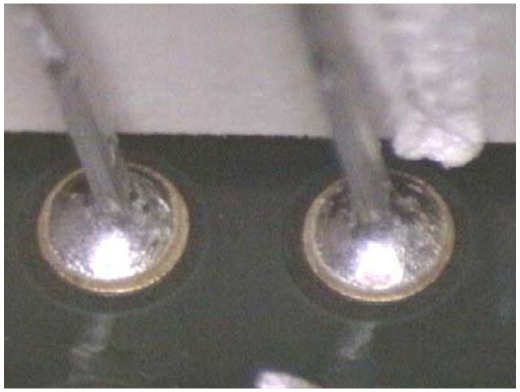
Ni/Au | **Ag Immersion** | **Copper OSP**

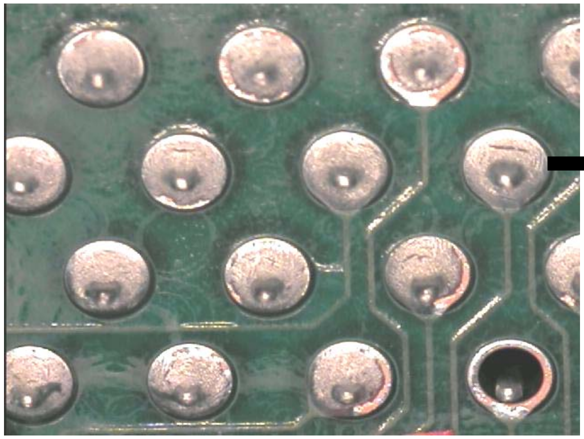
Board finish, component finish and their solderability will impact the process

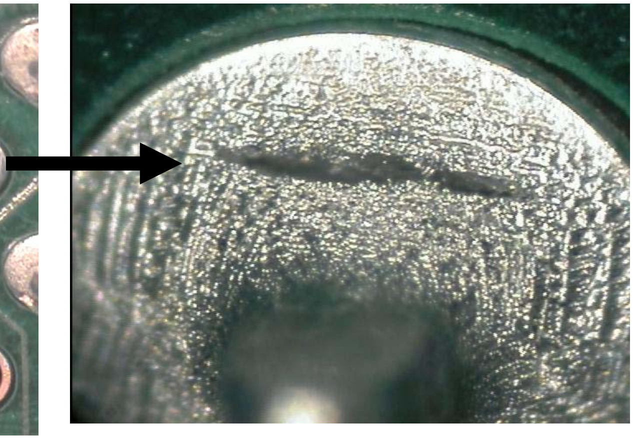
SAC305 Solder Joints







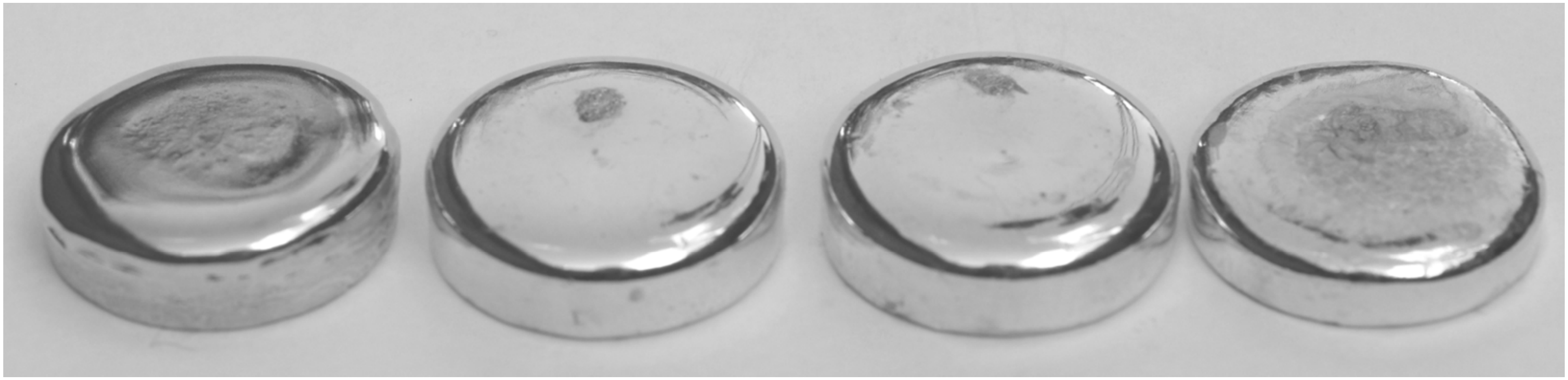




Shrinkage or hot tear with SAC.
Some concerns.

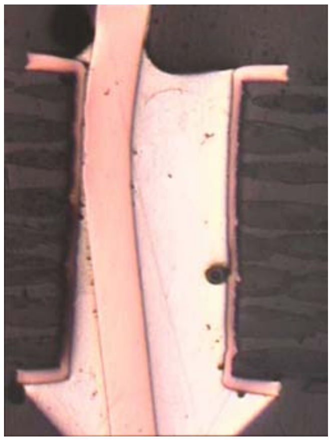
iNemi Wave Soldering Project 2006.

Not seen in Tin-Copper based solder with certain additives

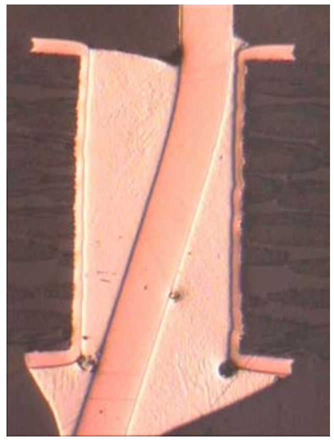


Sn63 Pb37 SnCu+Ni SnCuNi+Bi SAC305

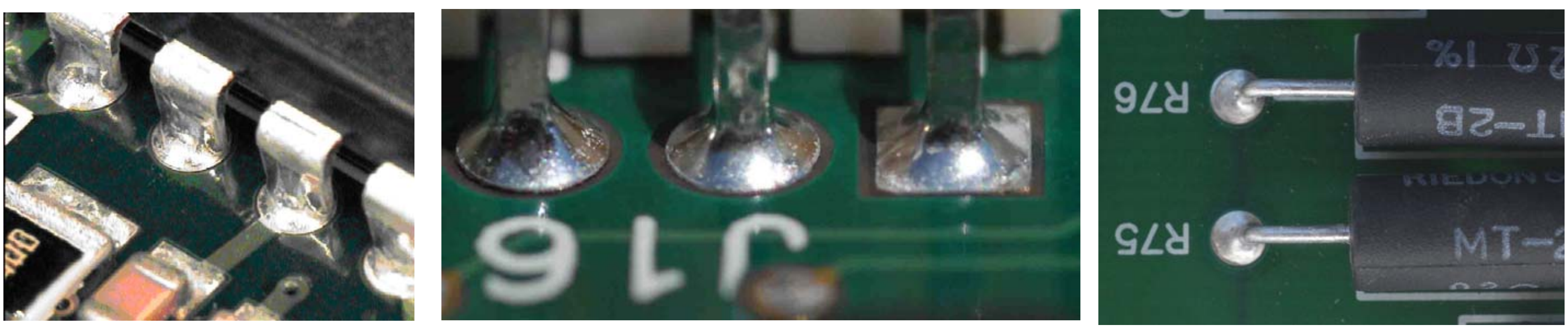
Good lead-free joints, either way



SnCu

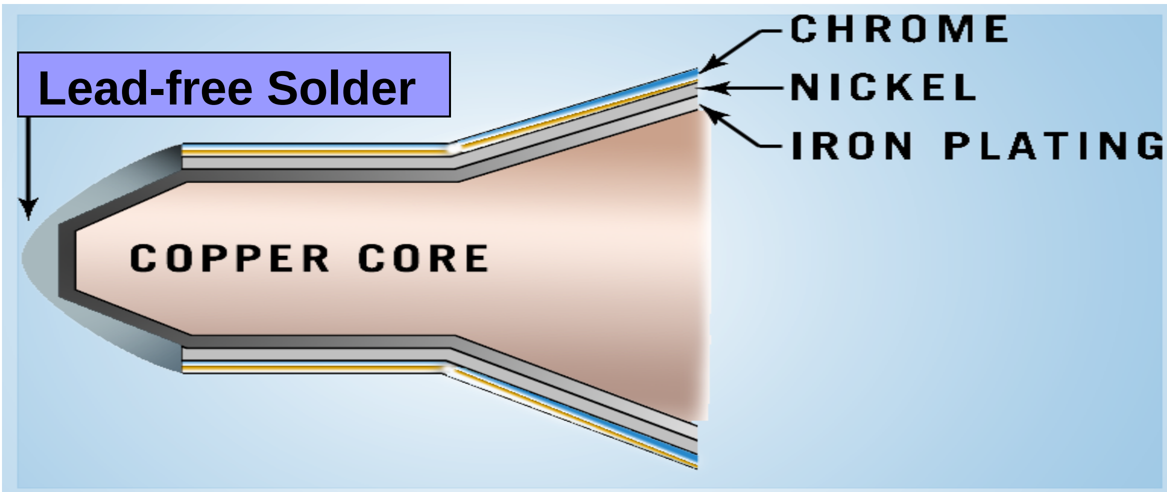


SnAgCu



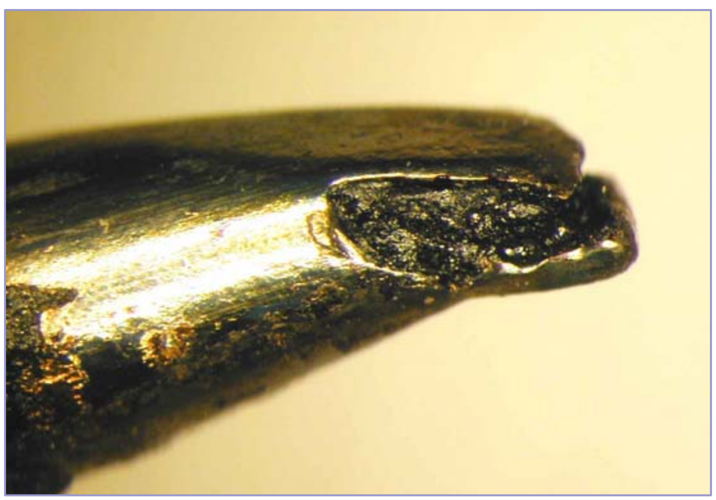
SnCu+Ni solder joints with tip temperature of 750°F

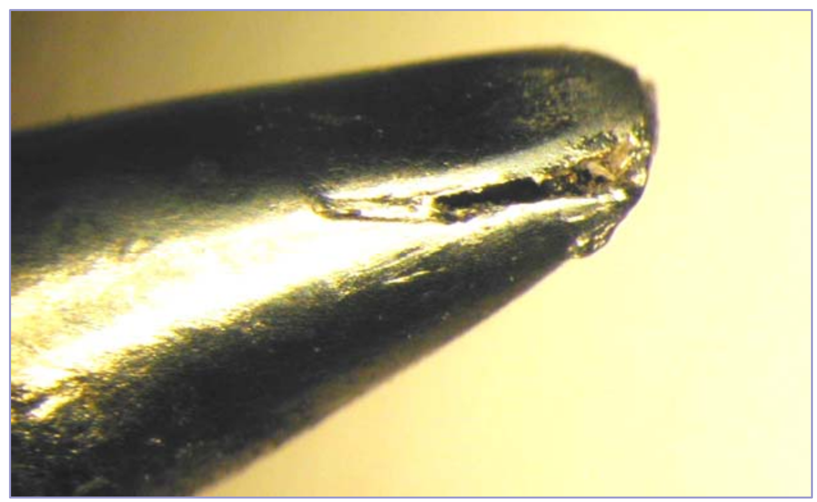
Major complaint – Tip Life



Example, below from end-user.

With leaded tips lasted 3 months now with SAC only 2 weeks.

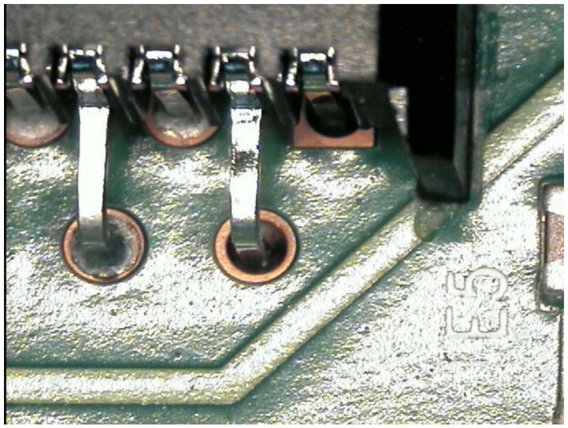


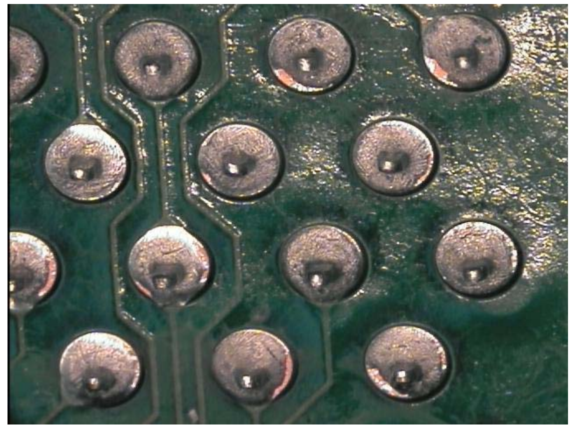


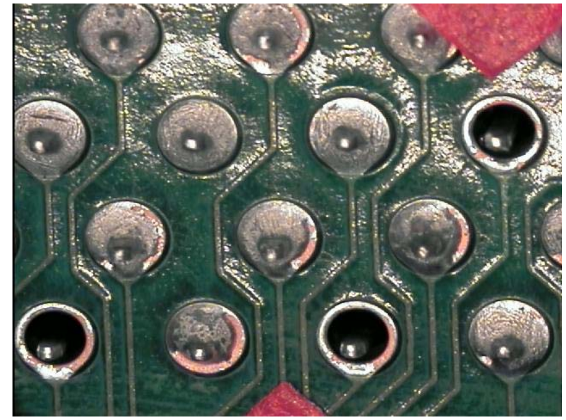
What causes tip failures summary

FAILURE	CAUSE	EFFECTS	PREVENTION
Stress/Crack	Unnecessary Force Applied to Tip Mishandling	Iron Plating Cracks Solder Dissolves Exposed Solder Core	Select Proper Tip Use Tip as Designed
Abrasion **Normal Wear**	Scrubbing Tip with High Abrasives Normal Use	Premature Wearing Away of Tip Plating Solder Dissolves Exposed Solder Core	Use De-Ionized Water Follow Proper Cleaning Procedures Use Clean,Sulfur-Free Sponges
Corrosion	Tip Tinners Used incorrectly Solder & Flux Interaction **LEAD-FREE** **MORE AGRESSIVE**	Iron Platting Stripped Away **ISSUE** **FLUX REQUIREMENT**	Use Lower Activity (RMA) Fluxes (Opposite w/LF) Use Standard Solders for Tip Tinning Use Clean,Sulfur-Free Sponges
De-Wetting	Oxidation of Iron Plating	Solder Doesn't Adhere to Tip Reduced Heat Transfer	Clean & Tin Regularly Solder @ Lower Temps

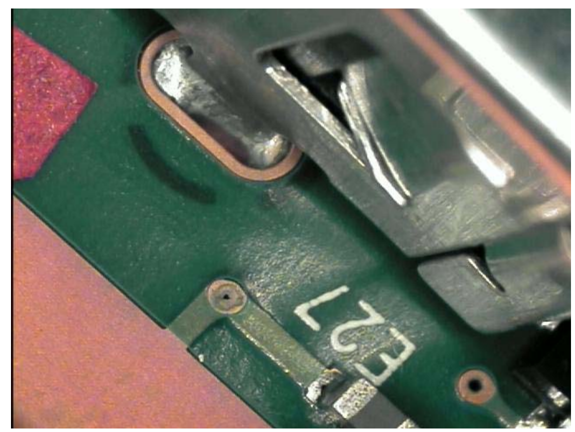
Non-wetting, insufficients





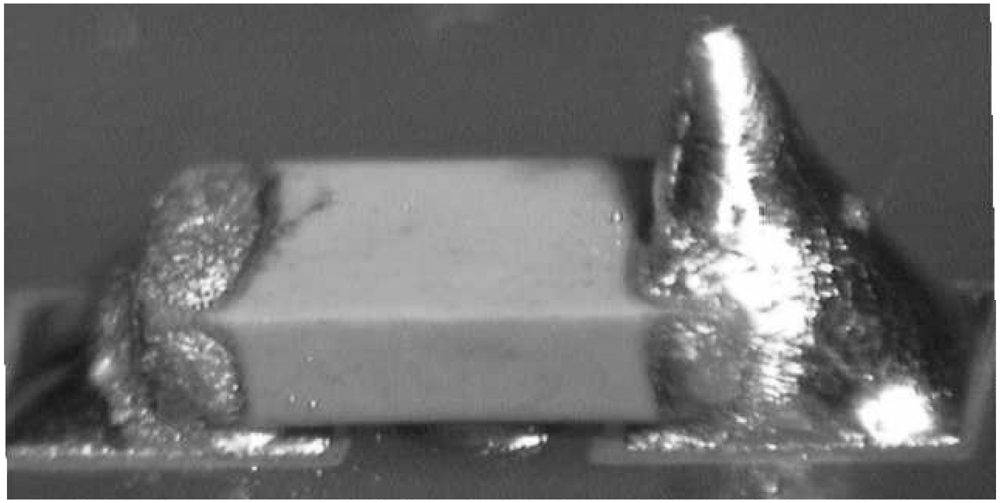


- Solderability issue
- Flux too weak
- Too long contact time
- Too low tip temperature
- Too high tip temperature
- Not enough flux in wire
- Wrong tip or wire diameter



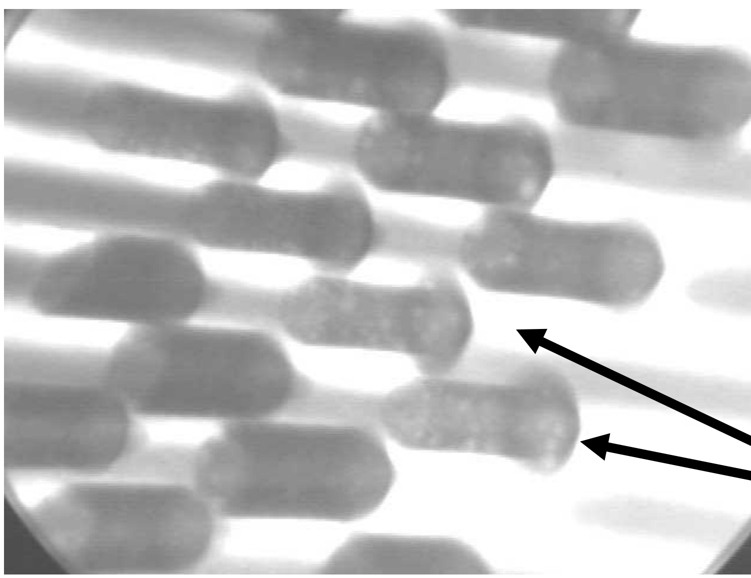
Icicling Cases

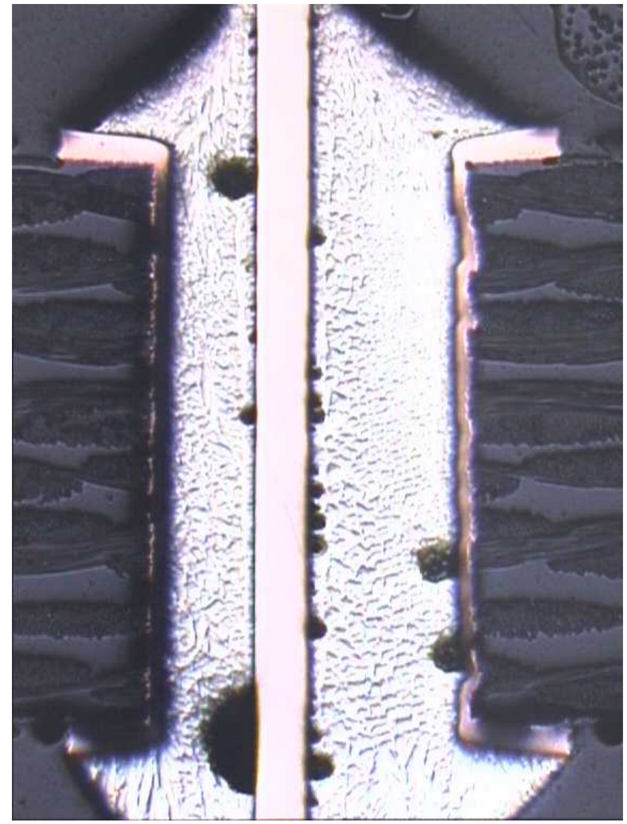
- ❑ Too long contact time
- ❑ Excess tip temperature
- ❑ Flux too weak
- ❑ Improper tip
- ❑ Wire diameter



Voids with Lead-Free alloys

- Higher surface tension impact
- Flux dependent
- Solder temperature dependent
- Contact time dependent
- Finish dependent, copper worst





White spots are voids in X-Ray test

Higher temperatures equals higher rate of dissolution

SAC Lead-free Solder and Copper Based Lead-free

Hand-Soldering Conclusions

- Process Control is Critical
- More Thermal Energy Required
- Choose the Right Tip
- Choose the Right Flux and Percentage
- Slightly Slower Wetting Process, modify technique
- Tip-Care re-training is important
- Preserve solderability of parts