Hand Soldering with Lead-Free Alloys

Introduction

As companies start to implement lead free soldering processes, hand soldering and associated techniques have been identified as key functions in the manufacturing process requiring additional research and development.
Hand soldering tends to occur at the end of the process line where the circuit board has a high intrinsic value and so correct process control will have a significant effect on manufacturing costs and productivity.
This paper discusses the fundamental aspects of the hand soldering process and discusses process adaptation requirements for successful lead free implementation.

The Process

Many manufacturing organizations control and define their hand soldering process by specifying the soldering iron tip temperature. With the implementation of lead-free alloys, with higher melting points than traditional tin/lead alloys, a more comprehensive set of process parameters needs to be defined.
The IPC defines the hand soldering process with a "rule of thumb" that talks in terms of reaching an optimum connection temperature for a fixed period. This places more emphasis on heat transfer efficiency rather than absolute tip temperature. Factors such as tip shape, tip condition, power output of the soldering iron and time on the joint will all impact on heat transfer efficiency and should therefore be taken into account when monitoring, controlling and defining the process.

The hand soldering process can therefore be defined by the following steps:

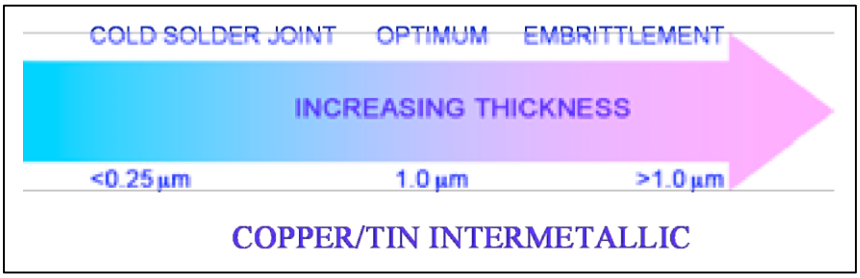
(a) The tip should be clean, well tinned and of the correct shape to maximize the contact area with the lead/pad. The solder wire and the heated tip are applied to the lead and pad.
(b) The connection is brought to 40C above the melting point of solder for 2 to 5 seconds, during which time the flux starts to activate, and the solder starts to flow.
(c) The solder flows. It moves across the surface, wicks up the lead and fills the through-hole/covers the pad.
(d) The heated tip is removed and the solder solidifies.

Connection Temperature

As with any other soldering process, reaching the correct connection temperature during hand soldering is vitally important for the formation of good quality solder joints. Examination of the thickness and morphology of the intermetallic layer in the joint can give a clear indication if the correct amount of thermal energy has been applied to the joint.

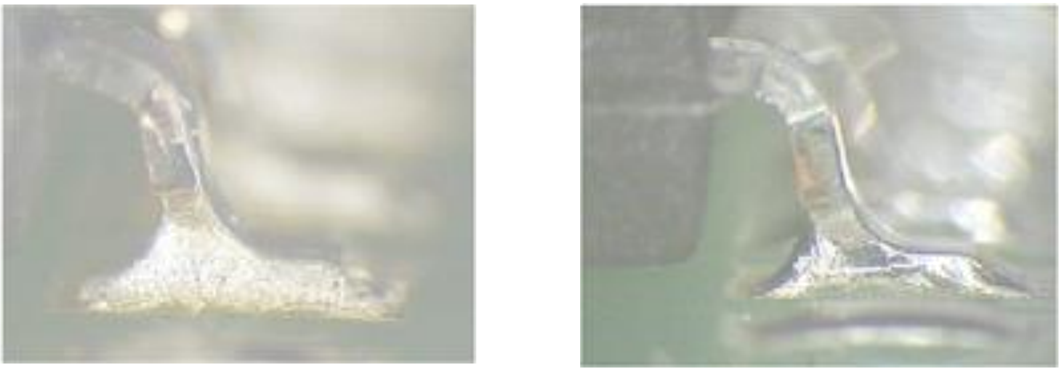
The presence of an intermetallic layer is a good indication that there has been a metallurgical reaction between the solder and the termination and the solder and pad/land.

Controlling the thickness of the intermetallic (rate of reaction) is critical in the formation of a mechanically strong joint. The growth rate of the intermetallic layer is temperature and time dependent. Too much thermal energy will produce increased volumes of intermetallic, which are brittle. Too little intermetallic is an indication of insufficient thermal energy, resulting in a dry joint during the soldering process.



Intermetallic layer thickness can be an indication of joint quality.

The overall shape and surface finish of the solder joint fillet has traditionally been an indicator to solder joint quality. Unfortunately, the surface finish and shape of lead free solder joints are significantly different to those observed with tin/lead alloys.



Pictures Courtesy of Cobar

Lead free joints have a dull surface and higher wetting angles.

Flux Considerations

The application of the correct amount of thermal energy will also affect flux performance.

The typical constituents of electronics grade fluxes are shown below with their corresponding boiling points.

Acids. (Adipic, Glutaric)	200C-260C B.Pt
Alcohols. (Ethanol, Propanol)	78C-180C B.Pt
Water	100C B.Pt

The boiling points of the alcohols and some of the acids are well below standard hand soldering temperatures. It is important, therefore, not to apply too much heat too quickly during the hand soldering process, as this will cause the flux to evaporate before it has time to activate and promote the wetting of the solder.

Flux selection is also important for a good soldering process. With the higher process temperatures, resulting in higher oxidation rates, and the weaker wetting forces that lead free alloys have, “stronger” fluxes may need to be used. There is also likely to be an increase in the percentage volume of flux in solder wire, from about 1.0% typically used now to amounts in excess of 2%.

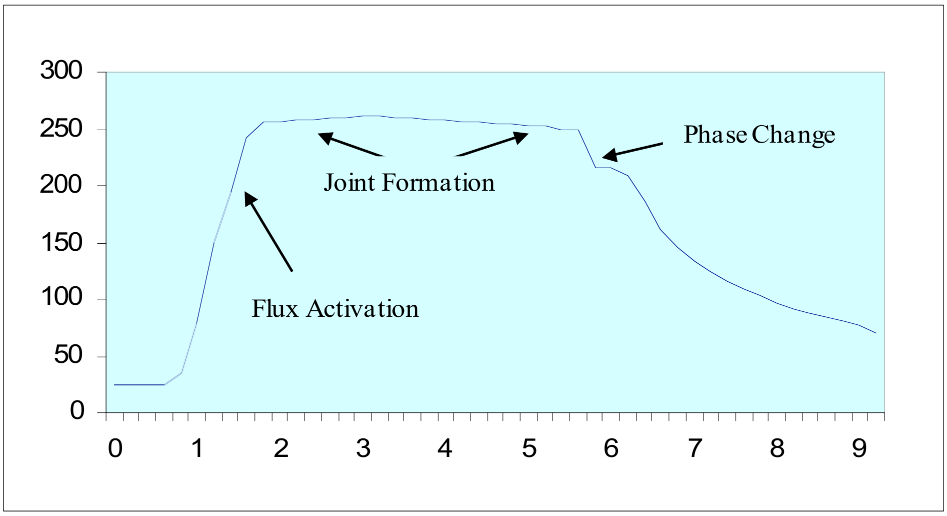
Stronger more aggressive fluxes in greater volumes may require some form of cleaning from the PCB after the soldering process. This adds an additional process, as most electronics manufacturers are no-clean, and cleaning materials can pose their own environmental problems.

The stronger the flux, the more aggressive the flux residues

Thermal Profile

For a good hand soldering process, we need to apply sufficient thermal energy, equivalent to bringing the connection temperature to 40C above the melting point of the solder alloy for 2 to 5 seconds. Most companies that are switching over to lead free manufacturing processes seem to be opting for the SAC alloys based around the Tin/3.8 Silver/0.7 Copper eutectic. This has a melting point of 217C, giving us a target connection temperature of 257C.This means that when using SAC alloys the connection temperature needs to be brought up to about 260 C.

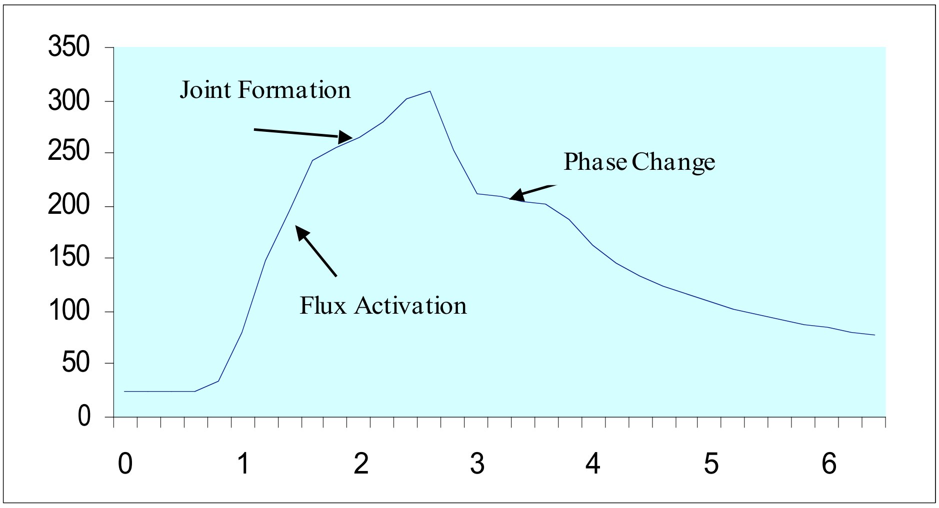
If we were to map out a theoretical profile, taking into account the IPC "rule of thumb" we would get this:



Theoretical Profile

Initially as the tip and solder wire are brought into contact with the joint we see a rapid increase in temperature, during which the flux activates. As the temperature rises above the melting point of the alloy the solder flows and starts to form the solder. The temperature is then maintained for about 4 seconds, the soldering iron is then removed and the joint cools.
Note that a trough is observed in the curve as the solder changes phase from liquid to solid during the solidification part of the process.

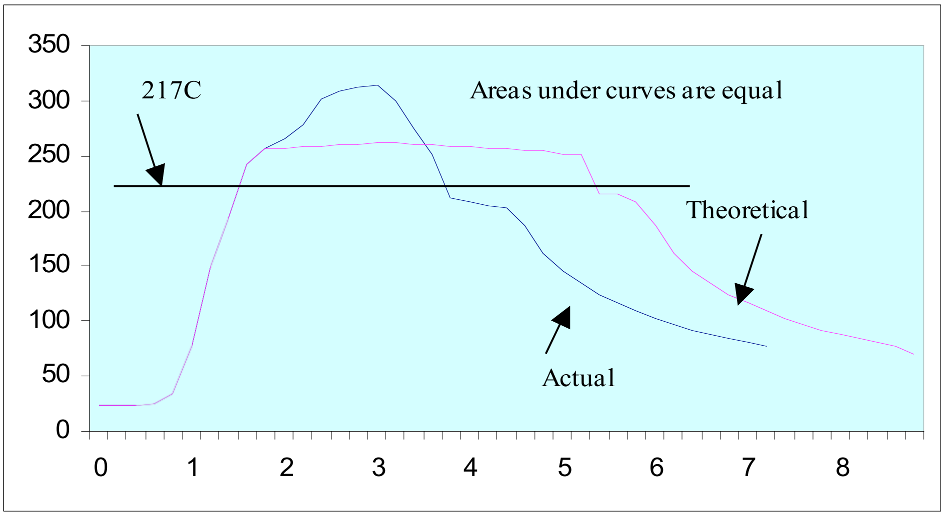
It is very rare for an operator to leave the soldering iron on the joint for more than about two seconds and so actual profiles tend to show much more of a thermal spike for a shorter period of time.



Actual Profile

Comparing theoretical profiles with actual profiles shows that in general the joint temperatures reach a higher level than the recommended 40 C above the melting point for the alloy, but for a much shorter time period. However, the thermal energy used in each case is very similar as this is temperature AND time dependent.

The thermal energy can be calculated as the area under the profile curves, above the melting point line. It can be seen from this graph that the areas are equal.



Profile Comparison

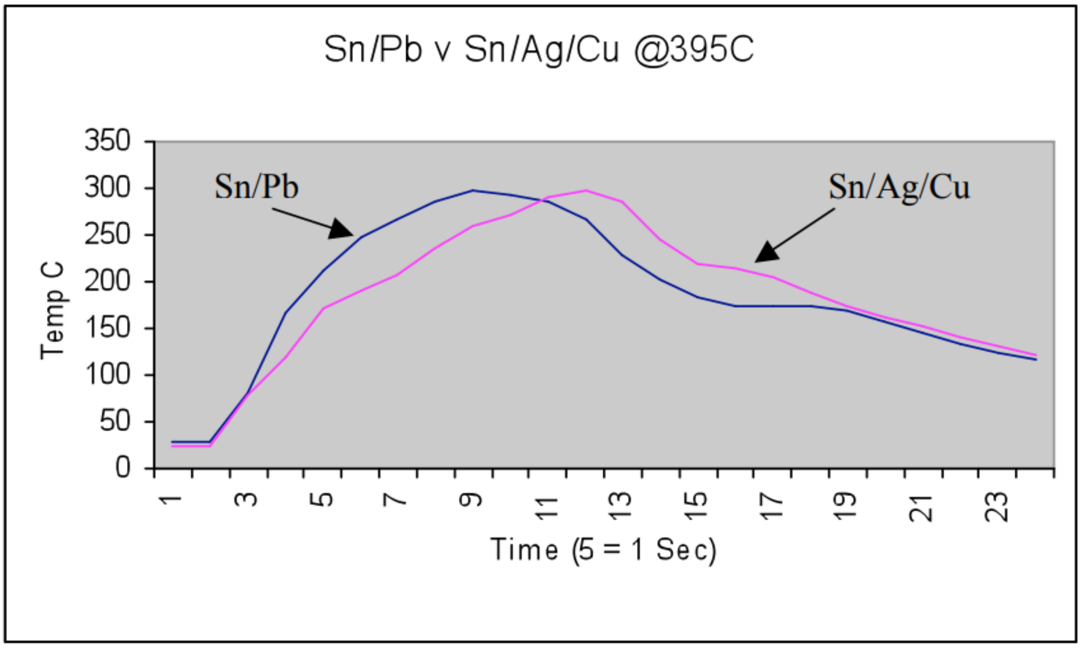
A series of thermal profiles were taken from plated through holes from a four-layer PCB. Connector holes were chosen as these represent the most “odd form” hand soldering applications, and as discussed earlier it is likely that this type of hand soldering will increase, initially, when lead free alloys are introduced. A k-type thermocouple was placed inside the plated through hole, the connector was then inserted, and the hand soldering operation was completed.

The same 4 holes were soldered during the study to give true comparisons.

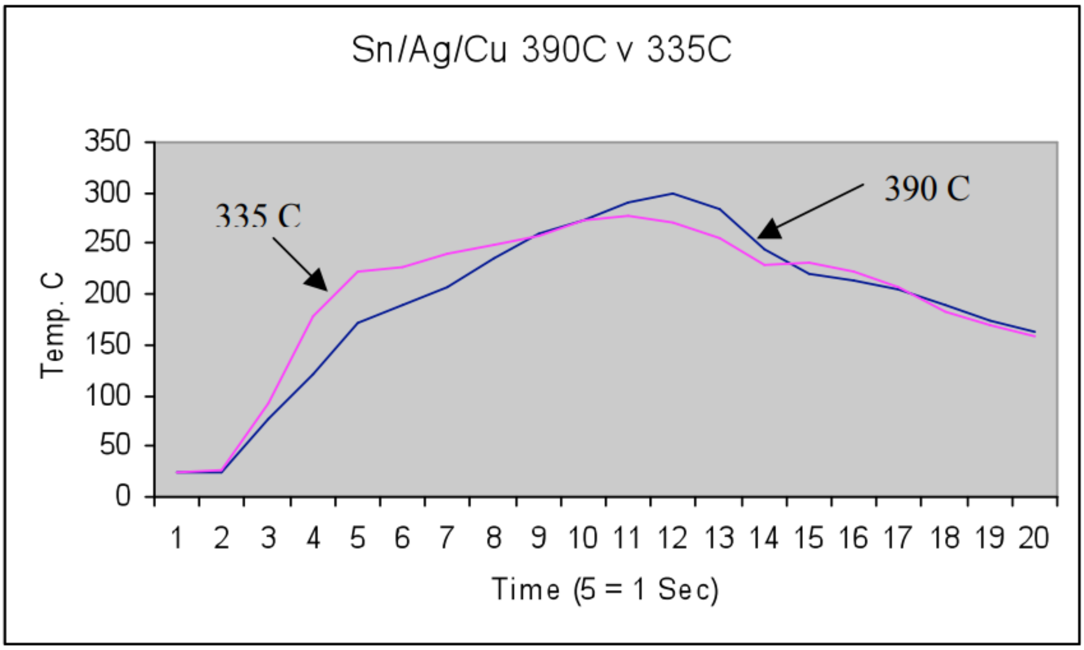
Profiles were developed and average profiles generated using a standard chisel tip with a measured tip temperature of 395C using 60/40 Sn/Pb alloy and then repeated using Sn/Ag/Cu alloy.

Another set of profiles were developed, and average profiles generated with Sn/Ag/Cu at two different tip temperatures of 395C and 335C.

Comparing the first sets of average profiles it can be seen that the peak temperatures are very similar, and the rate of temperature rise during the flux activation phase are also very similar. There was a marginal increase in time for the solder flow/joint formation phase, typically 0.25 – 0.5 seconds This is probably due to the lower wetting forces of Sn/Ag/Cu alloys compared with Sn/Pb alloys.



The second set of profiles compare the two different soldering temperatures. At lower tip temperatures the solder flow/joint formation phase is longer. The maximum joint temperature reached is also lower, although the temperature difference appears to be quite small. Interestingly the rate of temperature rise during flux activation is greater at the lower tip temperature and the overall soldering time similar.



The general conclusions that can be made from this study are that ;

1. A slight increase in process time is observed during the solder flow/joint formation phase of the profile with Sn/Ag/Cu alloys due to the inferior wetting properties of these alloys, (alloy effect)
2. Flux activation and maximum joint temperature appear to be unaffected by the change in alloy composition.
3. Maximum joint temperature can be affected by soldering iron tip temperature, but this affect can be minimized by good thermal transfer at the beginning of the process, (soldering iron and joint size effect)

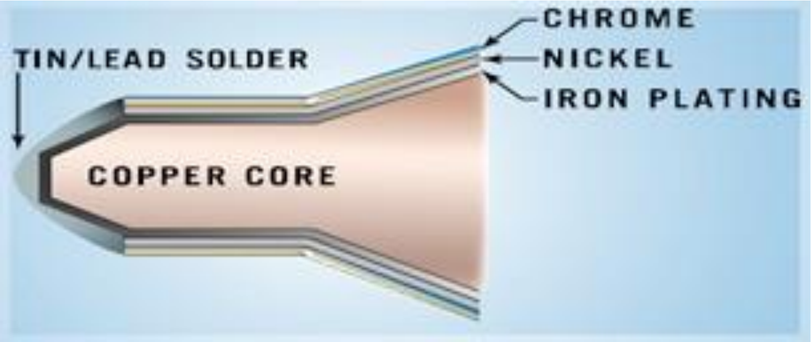
The correct balance between process time, process consumable cost and correct joint quality must be achieved.
Increasing tip temperature may improve the wetting characteristics of lead-free alloys and make the overall process time quicker, but this is likely to affect flux activation rate and risk damage to the circuit board and components.

The other option is to increase and maintain high levels of heat transfer efficiency.

This is by far the most desirable option both with respect to reducing the possibility of thermal damage and also to keeping the cost of the process as low as possible.

Optimizing Heat Transfer

These are the materials used in any standard soldering iron tip.



Tips are now available with lead free solder coating

Copper is used because of its high thermal conductivity, iron (Fe) plating is used as this helps to maintain the shape of the soft copper core material and prevents copper dissolution. The solder coating (which must be lead free !) keeps the iron plating wetted and acts as a thermal bridge. The maintenance of this solder/tinned layer is crucial for optimizing heat transfer.

(Chrome and nickel are used to prevent solder wicking up and away from the area of the tip used for the soldering operation)

The other important factor in improving thermal transfer efficiency is correct tip selection. The correct tip should have similar dimensions to the object being soldered. Flat tips produce a bigger contact area with a termination than do round tips and therefore tend to transfer heat more efficiently.

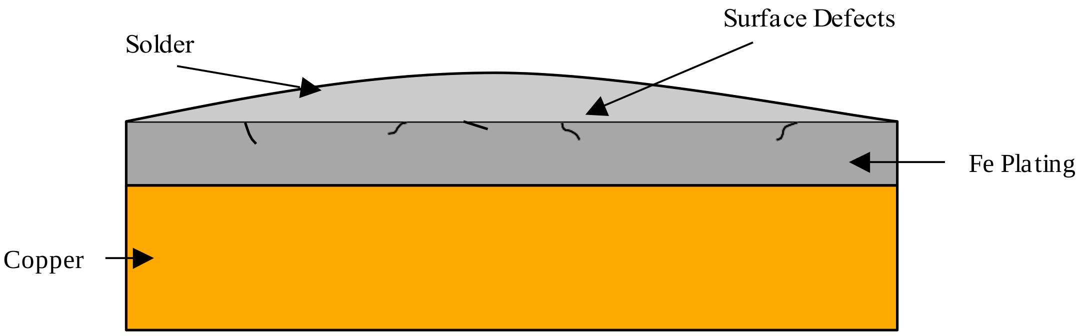
The tip should have a similar width to the object being soldered.

Tip Life

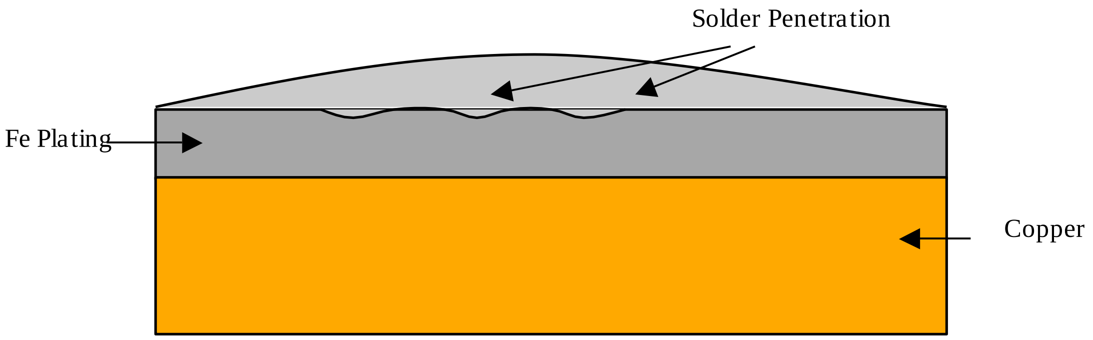
Generally speaking, all tips from all suppliers will have a reduced tip life when using lead free alloys. This is due to:

1. The higher tin content of the alloy. Tin readily erodes iron plating.
2. The higher melting point of lead-free alloys. The rate of erosion is temperature dependent.
3. Higher oxidation rates of the iron plating
4. More aggressive fluxes

The failure mechanism cannot be avoided and is a “natural” failure mode. Basically, all forms of plating have minute surface defects. These take the form of small surface cracks, inclusions or stress regions.

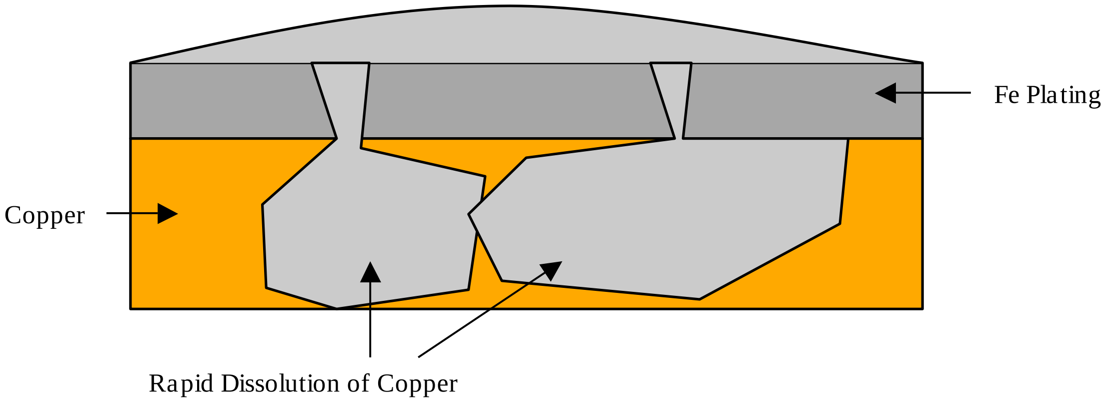


The molten solder starts to penetrate these surface defects. This is called the defect initiation phase and represents the largest portion of the time to failure



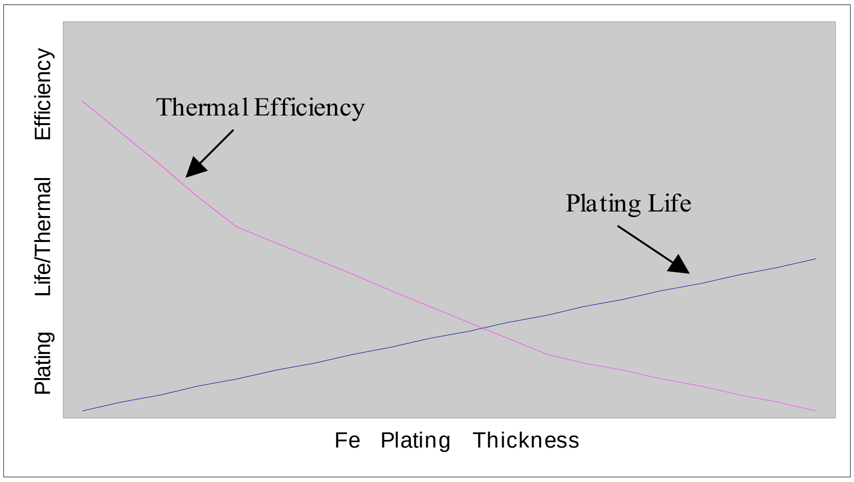
Initiation Phase takes 90% of Total Time to Failure

Once the molten solder has penetrated through the iron plating, rapid dissolution of the copper core takes place, and the tip finally fails.
This is called the defect propagation phase and represents approximately 10% of the total time to failure.



Propagation Phase

Increasing the thickness of the iron plating will increase the life of the tip however iron has a relatively poor thermal conductivity and so the overall thermal transfer efficiency of the tip will be significantly reduced.



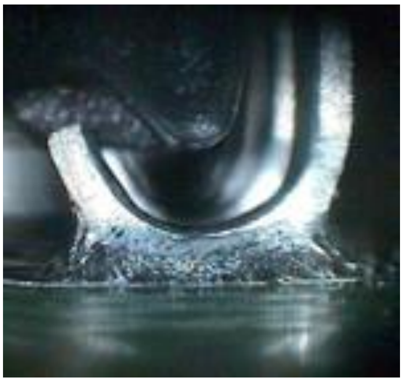
Good quality plating and good tip care techniques will have a significant improvement on plating life and heat transfer efficiency.

Solder Joint Appearance

Lead free joints look completely different to tin/ lead joints.

Organizations like IPC are beginning to produce standards on joint appearance, but many companies are generating their own. It will be important for manufacturing companies to implement new inspection training programs, otherwise operators and quality inspectors may well start to reject perfectly good solder joints, and this may result in un-necessary rework.

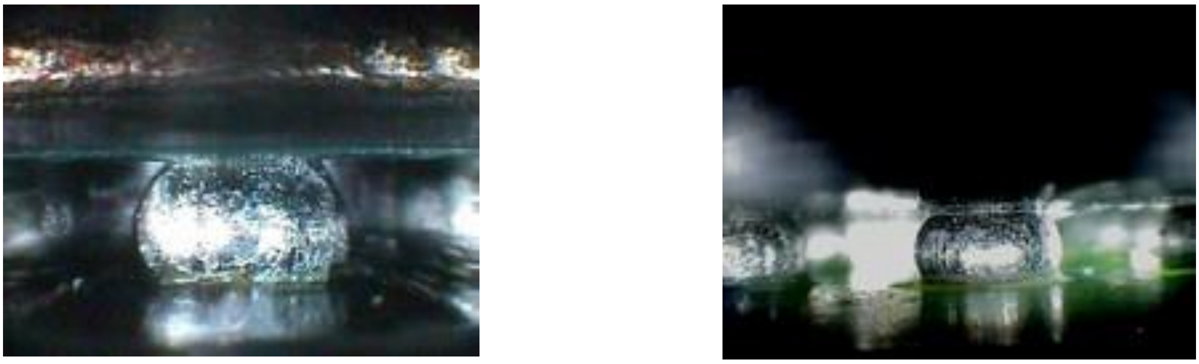
Below are some typical examples of lead-free solder joints.



High Contact Angle on PLCC

Dull Surface Finish on Thru-Hole

Poor Wetting Characteristics



Difference in Ball shape, surface finish, and standoff height between lead free and traditional tin/lead alloys

General Conclusions

If excessive process temperatures, and subsequent thermal damage to assemblies, are to be avoided in the hand soldering process the following aspects must be considered.

1. Tip shape and condition. Using a tip of the correct size maximizes the contact area the tip makes with the joint and improves heat transfer efficiency.
2. Flux content of solder wire and activation rate. Flux contents, by volume, are likely to increase which will help heat transfer, but may have post solder cleaning implications. Activating the flux at the correct rate is vital
3. Thermal performance of the soldering iron. The ability of the soldering iron to input the correct rate of temperature rise to the solder joint is important, both with respect to flux activation and also final solder joint temperature
4. Tip Temperature. Existing tip temperatures can be used in most applications providing the correct tip shape is implemented as well as good housekeeping techniques. Higher tip temperatures may be needed for very thermally demanding applications

The implementation of lead-free alloys will place more emphasis on process control than ever before. The hand soldering process will need to be more fully defined and should include specification of tip shape, power output and thermal transfer efficiency as well as absolute tip temperature.