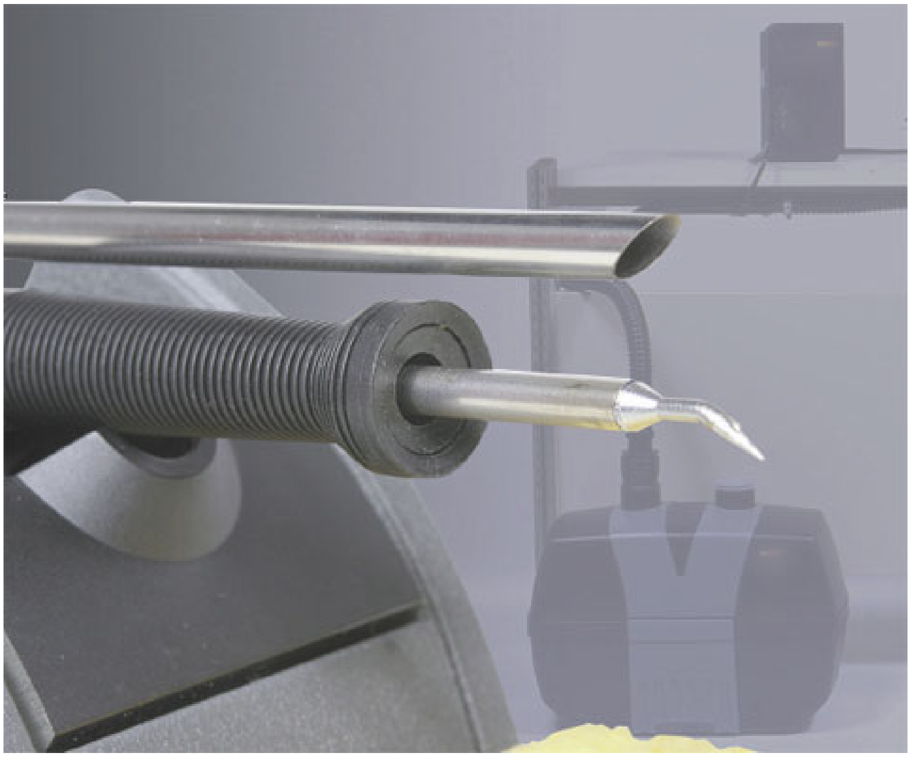
Hand Soldering with Lead-free Alloys

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 affect on manufacturing costs and productivity.

by Craig Brown, OK International



Many manufacturing organisations 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.

IPC defines the hand soldering process 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.

controlling and defining the process. The hand soldering process can therefore be defined by the following steps:

1. 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.
2. The connection is brought to 40°C 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.
3. The solder flows. It moves across the surface, wicks up the lead and fills the through-hole/covers the pad.

4. 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 dependant. 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 (Figure 1).

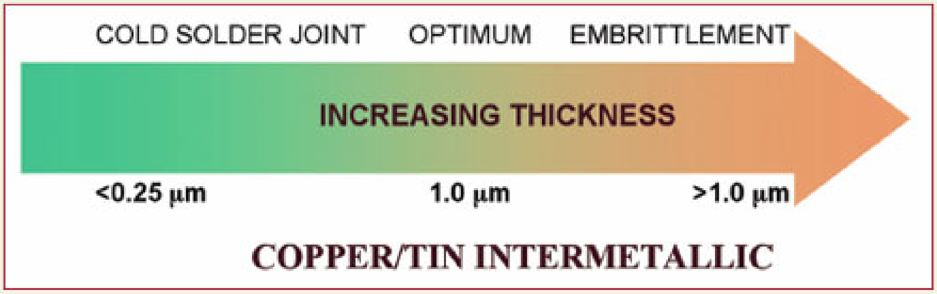


Figure 1: Intermetallic layer thickness can be an indication of joint quality

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 from those observed with tin/lead alloys **(Figure 2)**.

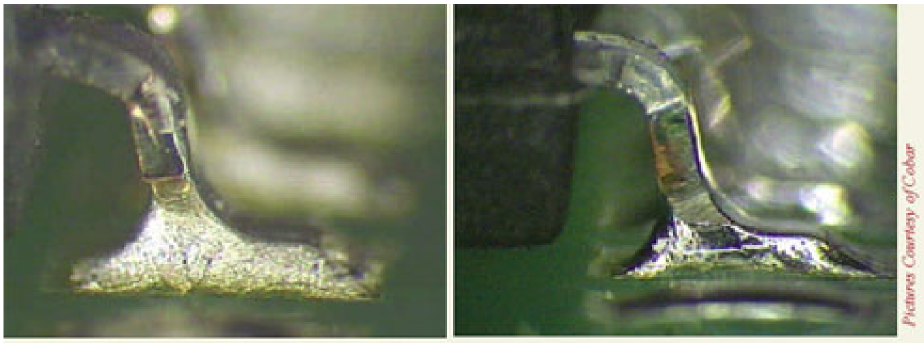

Pictures Courtesy of Cobar

Figure 2: 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)200°C-260°C
Alcohols (Ethanol, Propanol)78°C-180°C
Water 100°C

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 percent typically used now to amounts in excess of 2.0 percent.

Stronger, more aggressive fluxes, in greater volumes may require some form of cleaning from the PCB after the soldering process (Figure 3). This adds an additional process, as most electronics manufacturers are no-clean, and cleaning materials can pose their own environmental problems.

Figure 3: The stronger the flux, the more aggressive the flux residues

Fluxes affect tip life and the power to the joint, and the use of tip tinners can affect performance if not used correctly. The type of flux used is often the cause of tips degrading at high temperatures faster than previously encountered in tin lead soldering.

So, the lower the temperature, with a more active flux, the better the life of the tip compared to a high tip temperature with high active flux. Operators will sometimes use both and this will destroy the tip plating very quickly.

As an example, when an operator selects a high tip temperature with a water wash flux which contains active acid, and does not clean the acid from the tip after use, the tip has a very short life, sometimes as low as just a few hours.

Acid will be even more detrimental to tip life if the tip plating is cracked due to misuse. Misuse can fall into several categories:

1. A small tip pressed hard into a joint to try to get thermal transfer will crack the plating.
2. Aggressive cleaning with an abrasive material many times an hour, to overcome oxidization build up of the tip due to burned flux, will abrade the plating off the tip very quickly.
3. A high temperature with a small tip geometry provides the worst case. A better solution for lead free would be to consider a smaller length tip, with the same geometry using a lower or the same temperature.
4. If tip tinners are used to clean the tip, this can also be detrimental to tip life if not used correctly. Tip tinners contain active flux because they have to overcome heavy oxides on the tip to function correctly. If the tip tinner is used and the tip is just put back in

the stand un-tinned, then the acid will eat the tip away very quickly.

If these tools have to be used, the correct method is to first clean the tip in tip tinner as this removes the oxide in some cases. Then clean the tip in sponge to remove any acid from the tip. Sponges must be wet using deionised water, not tap water. Tap water can blacken the tip from contamination in the water, that then burns onto the tip creating black spots. You then need to tin tip to coat the tip with solder as this will exclude air from the tip and stop reoxidisation.

Thermal profiles

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 217°C, giving us a target connection temperature of 257°C. This means that when using SAC alloys the connection temperature needs to be brought up to about 260°C.

Mapping out a theoretical profile, taking into account the IPC “rule of thumb,” would get the results shown in **figure 4.**

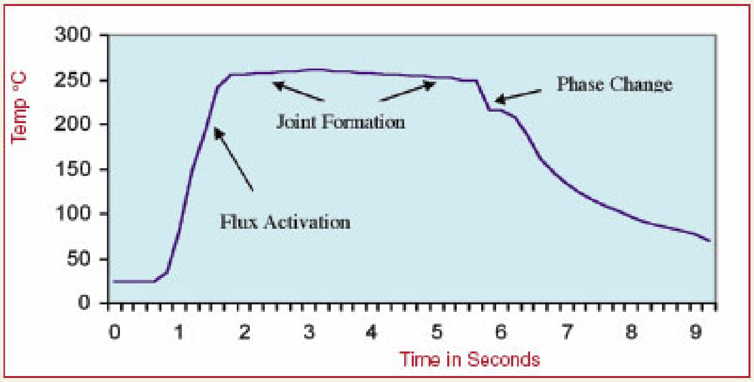


Figure 4: Theoretical profile

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.

In reality 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 **(Figure 5)**.

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 dependant. 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 **(Figure 6)**.

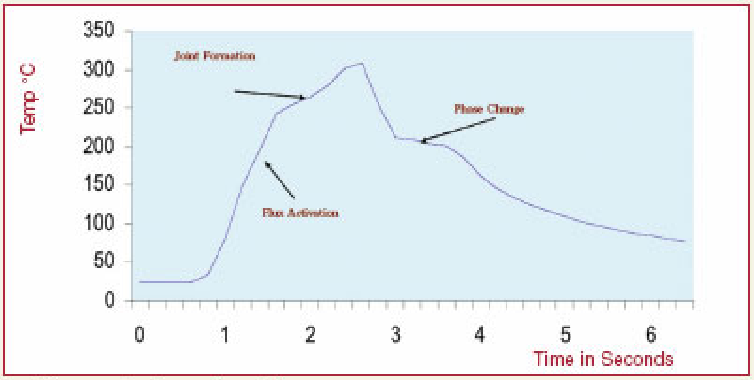


Figure 5: Actual profile

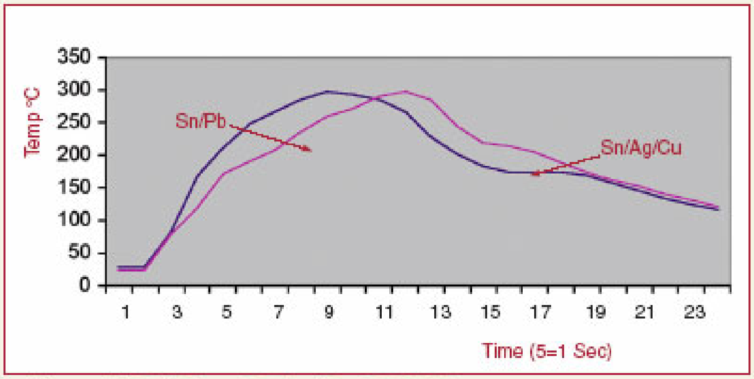


Figure 7: Sn/Pb vs Sn/Ag/Cu @ 395C

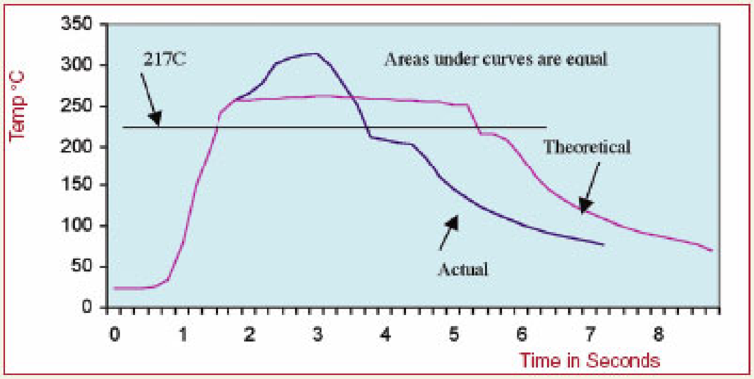


Figure 6: Profile comparison

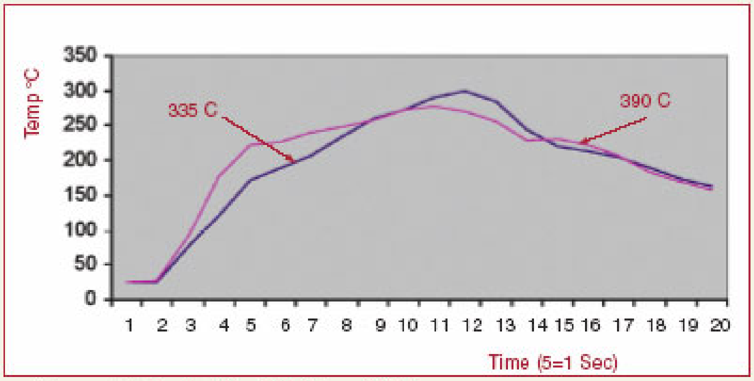


Figure 8: Sn/Ag/Cu 390C vs 335C

A series of thermal profiles were taken from plated through holes from a four layer PCB. Connector holes were chosen as these represent most “odd form” hand soldering applications, and 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 395°C 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 395°C and 335°C.

Comparing the first sets of average profiles **(figure 7)**, 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 compares the two different soldering temperatures **(Figure 8)**.

It can be seen that 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.

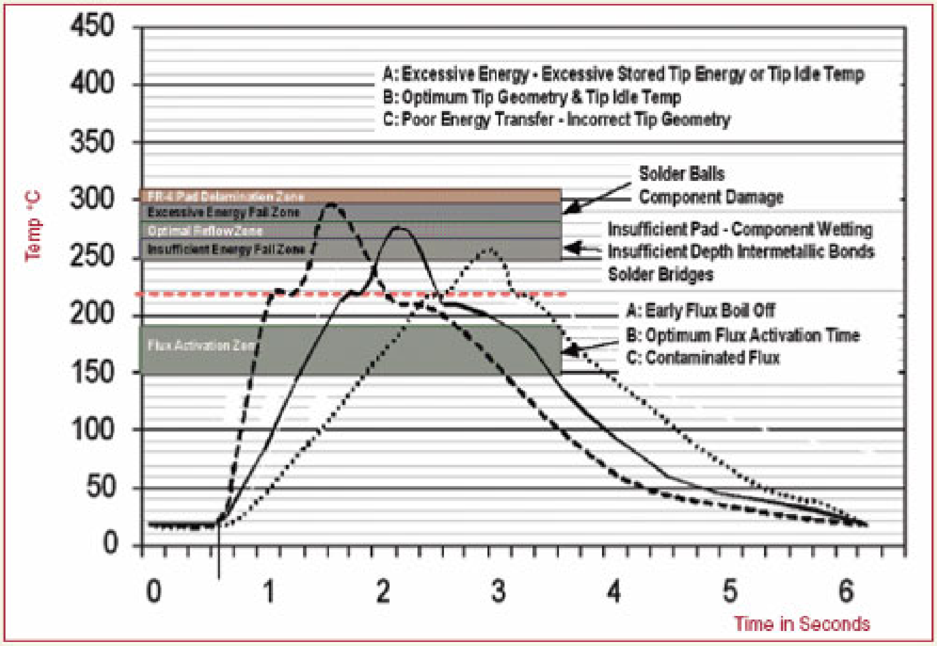


Figure 9: Optimised thermal profile

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 minimised 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.

Optimising heat transfer

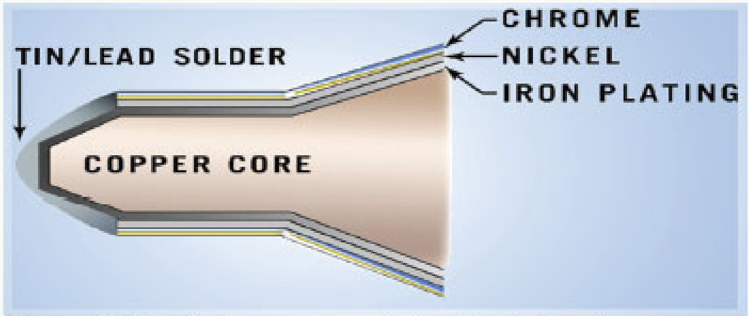


Figure 10: Materials used in standard soldering iron tips.

Figure 11: The tip should have a similar width to the object being soldered

As shown in **figure 10**, 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. Maintenance of this solder/tinned layer is crucial for optimising 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 **(Figure 11)**. 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.

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 (Fe) plating.

2. The higher melting point of lead free alloys. The rate of erosion is temperature dependant.

3. Higher oxidation rates of the iron plating.

4. More aggressive fluxes.

Conclusions

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

1. Tip shape and condition. Using a tip of the correct size maximises 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.

References

IPC standard IPC-610 Compiled in conjunction with OK International's Simon Hawkins, Paul Wood, Craig Brown, Joe Curcio