Soldering

Introduction

One trainer in this subject makes the very valid point that an assembly house doesn't make circuits or assemblies, because it buys in components and PCBs; all that an assembler 'makes' is solder joints! Solder joints are therefore crucially important, because the integrity of the whole assembly rests on the quality of these connections.

Inevitably, because other units have dealt at some length with solder, the focus now will turn to fluxes and the importance of correct wetting.

What is soldering?

Soldering has been defined as a 'thermic process for the permanent joining and coating of materials, whereby a liquid phase is introduced either by means of melting a solder (melting soldering) or by means of diffusion on the surface (diffusion soldering)'.

Printed circuit assembly processes are melting soldering and fall into three categories.

1. Applying molten solder to the surfaces to be soldered (as in hand soldering or 'wave soldering'). The form of the joint is determined by mechanical and process conditions, and is not limited by the amount of solder available, which is essentially infinite.

2. Melting solder contained in a paste in contact with the surfaces to be soldered (called 'reflow soldering'). There is a constraint on the shape and volume of such a joint, because the only solder available is that contained in the paste which was deposited.

3. Remelting pre-tinned (pre-soldered) parts in contact with each other. This process is relatively rare, though it has some utility for hand soldering, where it is relatively easy to hold parts in contact.
   Of these processes, the second is currently the most important, reflow soldering having displaced wave soldering for many applications, particularly with high density assemblies.

The function of soldering

In **pin-through-hole** technology, the surfaces to be soldered are held together mechanically before soldering by a method such as 'clinching' the leads. Applying solder forms an electrical joint, although it also strengthens the mechanical attachment.

In **surface mount** technology, the mechanical interconnection is actually made by the solder: unless chip-attach adhesive ('glue') has also been used, the solder forms the only permanent joint between component and board.

Partly because the through-hole component already has some mechanical attachment, but mostly because the solder joints are substantially more robust in design, with contact made to the leads throughout the depth of the hole, through-hole connections are substantially stronger than they need to be. Some sources would claim that they are x10 over-designed. The surface mount solder joint, by contrast, has a much smaller margin of safety. As we will find when studying *Failure mechanisms*, the reliability of a joint depends on the volume of the solder available to absorb the inevitable strains. Insufficient solder equates to insufficient long-term strength, and increases the potential for failure.

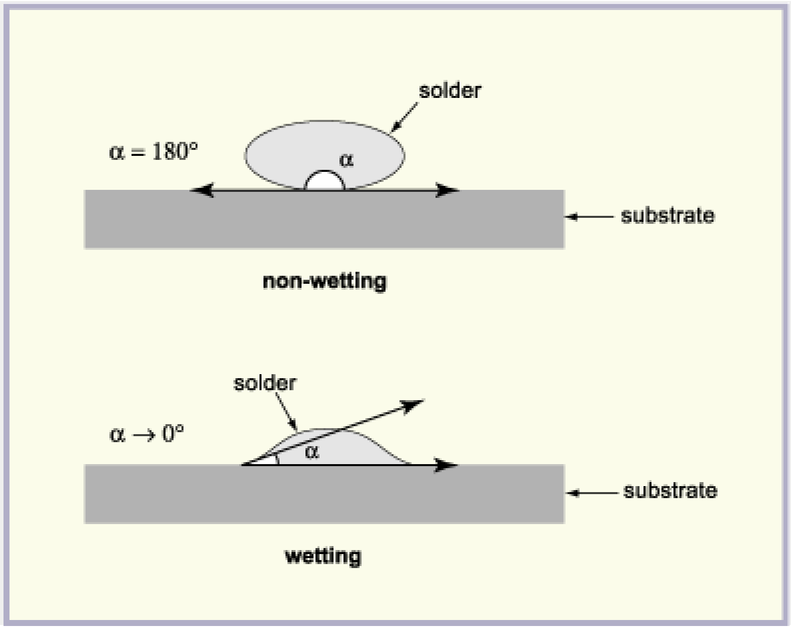
Soldering standards

What is a good joint? Visual standards of quality are notoriously difficult to define, although practised inspectors have an intuitive feel for what is a 'good soldered joint', that is one which will perform both its mechanical and electrical functions without failure. However, it is generally agreed that, *irrespective* of the way in which the joints are made:

- there should be a visual appearance of **good wetting**, with the **correct amount** of solder and a **sound and smooth surface**;
- all soldered joints on an assembly should give a **uniform** impression independent of their location on the board.

Solder should flow evenly over the surfaces to be soldered and run out thinly towards the edges of the joint, with a contact angle a <<30° (Figure 1), unless the solder fillet is small and the contact angle constrained by the closeness of the edge of the solder land, as may be the case with small SM components.

Figure 1: Wetting and the contact angle



The solder should ideally wet the entire periphery of the termination to be soldered, and the thickness of the joint should increase evenly from the pad boundary to the termination: this presence of a 'fillet' helps confirm that the solder volume has been determined by joint geometry and surface tension and not constrained by undesirable factors.

There is a wide range in acceptable solder volumes, depending to a great extent on whether a SM joint has been reflowed or wave-soldered. However, a balance must be sought between sufficiency and excess!

Generally accepted criteria for solder adequacy are that:

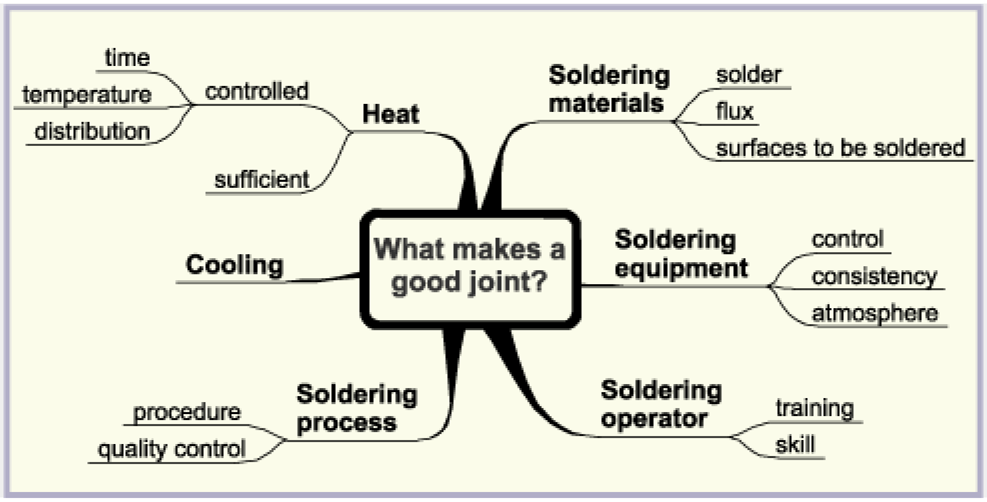
- for a chip component, the joint should extend up the component termination for a minimum of one-third of the component height, or 0.4 mm, whichever is less;
- for an SO-package lead, the height of the solder at the sides should be at least half the height of the foot (although there need be no more than a meniscus at the cut end).
- for gull-wing packages, the foot of the lead should be wetted over three-quarters of its length and to a height of at least half the lead thickness.

Apart from minor irregularities, the surface of the solder should be uninterrupted and smooth, and near-eutectic tin-lead solders are generally uniformly shiny in appearance. However, where components have metallisation which dissolves in solder (such as some capacitors) small irregularities in surface finish are acceptable.

IPC-A-610 *Acceptability of Electronic Assemblies* has been developed to reflect what is generally regarded as good practice for a very wide range of electronic assemblies. This standard often forms the basis of in-house specifications.

'What makes a good joint?' is an even harder question to answer than 'What is a good joint?'. Our ideas about this have been condensed into Figure 2, and we shall be considering some of these issues later in the module.

Figure 2: What makes a good joint?



The ‘liquid phase’

In order to understand the ‘melting soldering’ process, we have to consider:

- the nature of the ‘liquid phase’ being introduced
- how it cools to form a permanent joint
- how solder ‘wets’ the surfaces to be joined, and how flux encourages this
- the role played by the atmosphere in which solder is melted.

In *Metal basics* we showed the stages in metal solidification, and introduced the idea of the phase diagram for the tin-lead alloys which are the main solders currently in use. Then in *Solder materials*we revisited the phase diagram for tin-lead, and looked at the structure of a solidified solder joint.

However, whilst *Solder paste basics* makes reference to the flux vehicle, there is very little explanation about the process of wetting or the use of fluxes. In the sections which follow, we will be attempting to explain the process of solder wetting, and discussing the various types of flux used. We will be doing this in a more practical context than in *Viscosity and flow*, but if you don’t recall the discussion on the spreading of droplets, capillary action and contact angles, now would be a good time to re-read that section.

The process of wetting

As the temperature rises, the flux melts and begins to interact with the metal surface, removing or displacing oxides, and preparing a ‘clean’ metal surface for the solder. As this is happening, the solder particles in the paste begin to melt at the hottest spots, replacing the flux and wetting the clean surfaces. This wetting action results in the wicking of the solder onto the hottest and cleanest metal surfaces.

The speed of the action depends on:

- the fluxing action
- the local temperature
- the metal alloys of component termination, solder paste, and substrate.

Under most conditions, temperature non-uniformity is the major factor dictating the wetting time for the assembly as a whole. It is normally recommended that the heat source should be 25–40°C above the liquidus temperature to assure complete melting of the solder and good bond formation.

After all the solder particles have melted, a liquid solder ‘volume’ forms. The surface tension acting to minimise surface area then prevents further wicking action, helps hold the solder in place, and bridges gaps between lead and substrate, forming a fillet upon cool-down. The resultant fillet shape and joint strength depend on how much solder was available, the materials being soldered, and the geometry of the solderable surfaces.

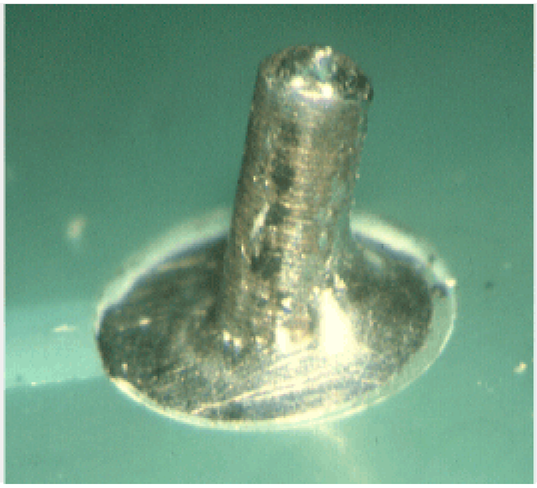
Degrees of wetting

Several terms are used to refer to the state of the solid surface after a solder operation, when molten solder has covered the surface and is then drained off.

Non-wetting

The surface becomes uncovered again, without any visible interaction with the solder. Non-wetting occurs if the oxide film on the basis material is too thick to be removed by the flux applied, within the available time (Figure 3).

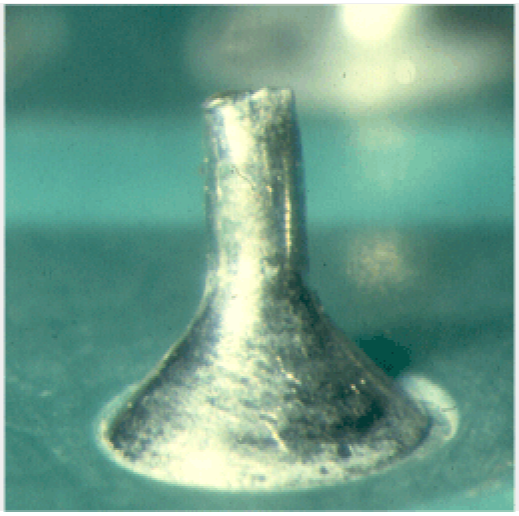
Figure 3: Non-wetting



Wetting

A layer of solder is retained, proving that metallic interaction has taken place. Perfect wetting shows a uniform smooth, unbroken and adherent layer of solder to the basis material(Figure 4).

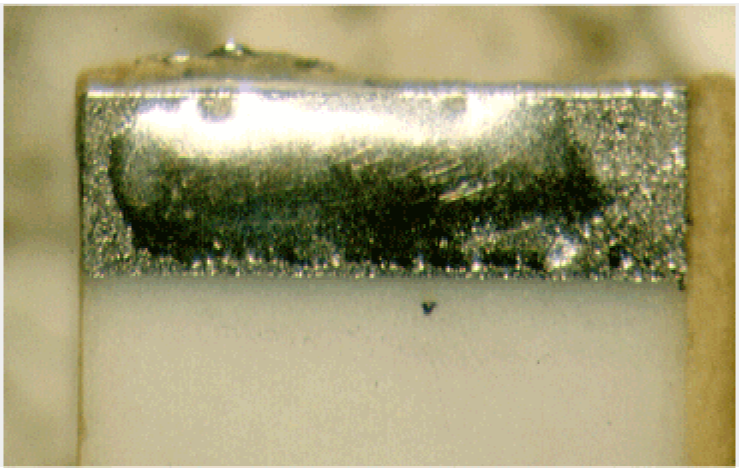
Figure 4: Wetting



Partial wetting

The surface has some regions showing wetting and other regions showing non-wetting. This should not be confused with cases in which part of the solder remains fixed simply because it did not flow off sufficiently, but can in most cases be peeled off. The contact angle provides evidence of real wetting at the boundaries of the wetted regions (Figure 5).

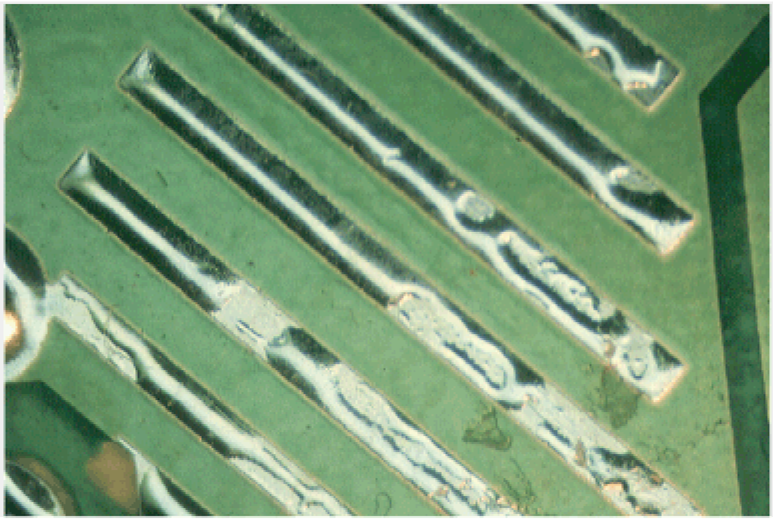
Figure 5: Partial wetting



Dewetting

The surface is initially wetted, but the solder then withdraws from part of the surface, typically resulting in a combination of dewetted regions and irregularly shaped solder droplets. Quantitative assessment is difficult, because the boundaries between wetted and dewetted regions are not sharply defined and the dewetting is often unevenly distributed over the surface (Figure 6).

Figure 6: De-wetting



Note that a copper surface retains its colour, but one that has been wetted by solder will never become a clean copper surface again, because a diffusion layer has been formed.

Dewetting is a real problem encountered in soldering. It can affect the quality of soldered joints by reducing the size of the solder fillets on printed boards. In other cases, the component terminations can exhibit dewetting which will also result in poor joints.

Changing factors

Some parameters are not constant.

1. The surface tension of the solder may alter, because elements of the base metal dissolve in the liquid solder, thus changing its composition.
2. During soldering, flux performs the cleaning action by which the surfaces (and the prevailing surface tensions) change. If the flux becomes exhausted or flows away, re-oxidation takes place, again changing the wetting conditions.
3. In practical soldering operations, considerable temperature gradients exist. An extreme case of change of conditions is provided by the phenomenon of dewetting: the conditions at first favour complete wetting, but after time they change, rendering the solder coating unstable.

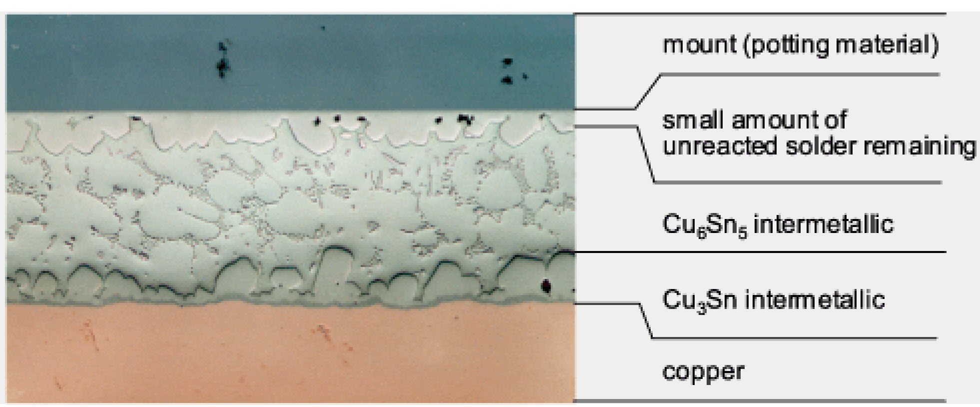
Intermetallics

When a solution solidifies, alloys of metals which have a limited mutual solubility may form new phases at certain ratios. These new phases possess crystal structures different from either component and are called intermetallic compounds. The properties of intermetallics generally differ from those of the component metals, often being less metallic, with reduced density, ductility, and conductivity.

Soldering depends on intermetallic formation because, if intermetallics are formed at the interface, the interfacial energy will be relatively low and wetting will be promoted.

Pure lead does not form intermetallics, but the addition of even a few per cent of tin is enough to form intermetallic compounds and promote wetting on copper. The interface has a Cu_3Sn phase next to the copper, followed by a Cu_6Sn_5 phase, as shown in Figure 7. Tin is depleted by the formation of intermetallics, so there will be a resultant lead-rich region in the solder.

Figure 7: Intermetallic formation between copper and tin



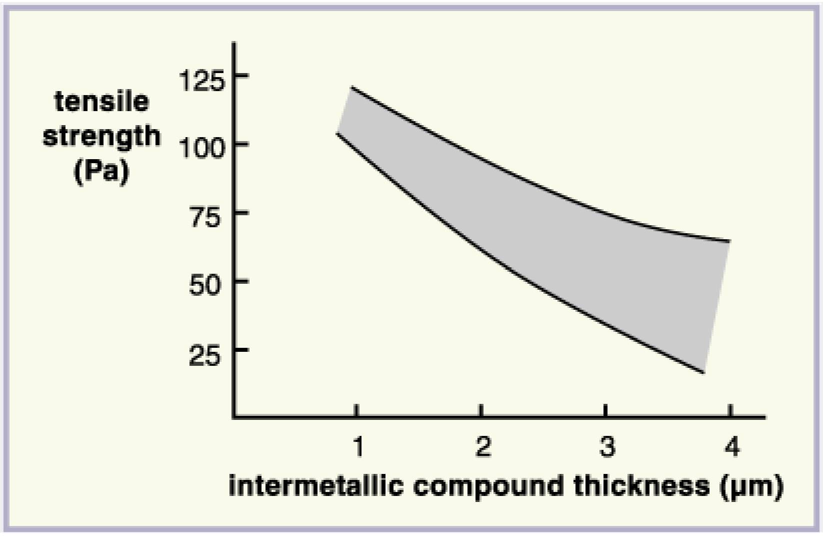
Similarly with nickel-plated surfaces, the contact is between the tin and the nickel, rather than to the base copper foil, and is enhanced by a very thin tin-nickel intermetallic layer. However, this has lower strength than copper-tin intermetallics.

When solder remains in contact with a substrate for long enough at a sufficiently high temperature, there is the potential for intermetallic compounds to continue to form. Although a thin intermetallic layer is necessary to produce wetting, thicker intermetallic layers may alter the appearance of the joint and have an adverse effect on its integrity. Some of the reasons are:

- the frequently brittle nature of intermetallics
- differences in the coefficient of thermal expansion between intermetallic and bulk solder which can contribute to internal stress
- depletion of one element of the surface, which may impair solderability, for example tin depletion from the tin-lead coating on copper leads, resulting in poor solderability of the leads.

A reduction in the fatigue life of solder also occurs as the joint ages, because of the continuing growth of intermetallic compounds at the joint interfaces (Figure 8).

Figure 8: Thickness and strength of the intermetallic layer



Source: Klein Wassink, 1994

Source : http://www.ami.ac.uk/courses/topics/0127_hjm/index.html