Solder Materials

Introduction

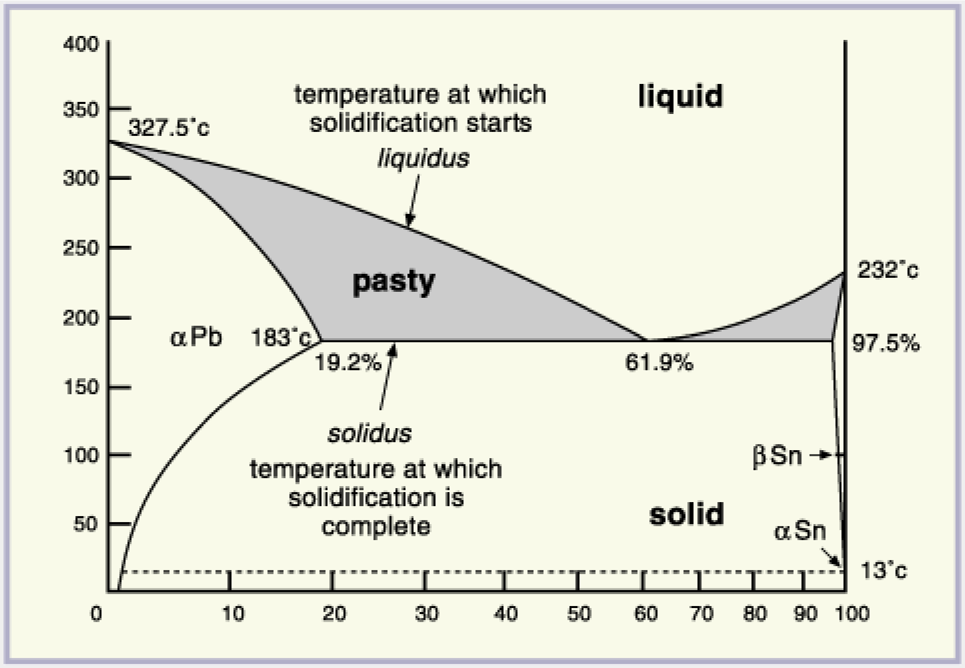
Most assemblies currently use solder in order to create connections between components and the printed circuit board. There was an indication in *Polymer applications within electronics* that conductive adhesives can be pressed into service for this application, but solder remains far and away the most widespread joining medium. Familiarity, low cost, high reliability and ease of use mean that solder will continue to be a main player. The only question, in the light of pressures to remove lead from electronics, is which solder will replace the tin-lead alloys which have been the mainstay of electronics for the last century.

In this module, we are confining our attention to tin-lead alloys as solder. If you have a good grasp of how and why these solders work, you will be in a good position to understand the implication of changes to the materials, a topic to which we will return in the environmental units of *Design for eXcellence*.

Solder

In *Metal basics* we showed how cooling curves are used to produce a composite thermal equilibrium (or 'phase') diagram. Figure 1 shows the effect the relative proportions of the constituents have upon the temperature at which solidification starts and at which it is complete.

Figure 1: Phase diagram for tin-lead alloy



Eutectic composition

Most tin-lead alloys have a melting, or pasty range, between the temperatures at which the alloy is properly solid (solidus) and completely liquid (liquidus). While wide pasty ranges are ideal for plumbers, who may need to ‘dress’ joints, they are not satisfactory for electronic applications. At the eutectic composition of 61.9% tin: 38.1% lead:

- the temperature at which melting occurs is a minimum
- the solidus and liquidus lines meet, and the solid to liquid transition takes place at a true melting point (183ºC).

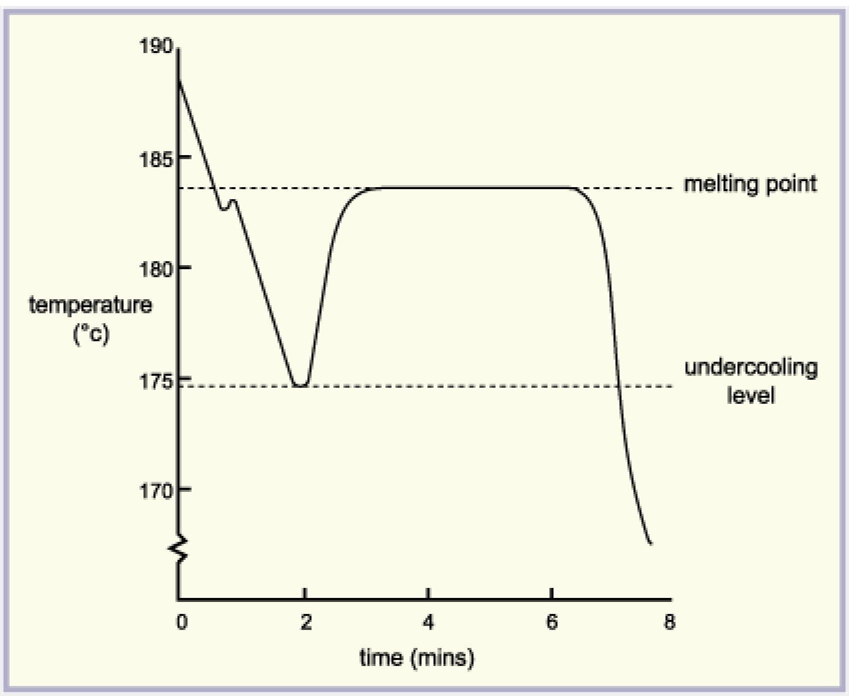
The situation is more complex on cooling, as is shown in the following sections. Remember that, during cooling, although the phase transition takes place at the solidus temperature, the alloy will remain only partially solid until the whole latent heat of fusion has been dissipated (or, during melting, only partially liquid until the whole latent heat of fusion has been supplied). Even eutectic alloys have a pasty *time*!

Undercooling

As cooling solder reaches the solidus temperature (183ºC for the eutectic) the precipitation of crystals is not spontaneous, but requires some activation energy. This is usually supplied thermally, by the solder temperature falling below the solidus temperature. This undercooling can be as much as 8ºC.

The phenomenon can be seen in the cooling curve of Figure 2, where the temperature has been monitored as a mass of molten solder loses heat at constant rate. Note also that, as the solder solidifies, the latent heat of fusion is liberated, causing cooling to stop until the whole of the solder mass has solidified.

Figure 2: A partial cooling curve for 60:40 tin-lead solder, showing the undercooling required to nucleate the primary crystals



Source: Lea 1988

Structure and strength

The solidified structure consists of alternate lamellae of tin and lead phases with the lamellar spacing X being related to the freezing rate R by:

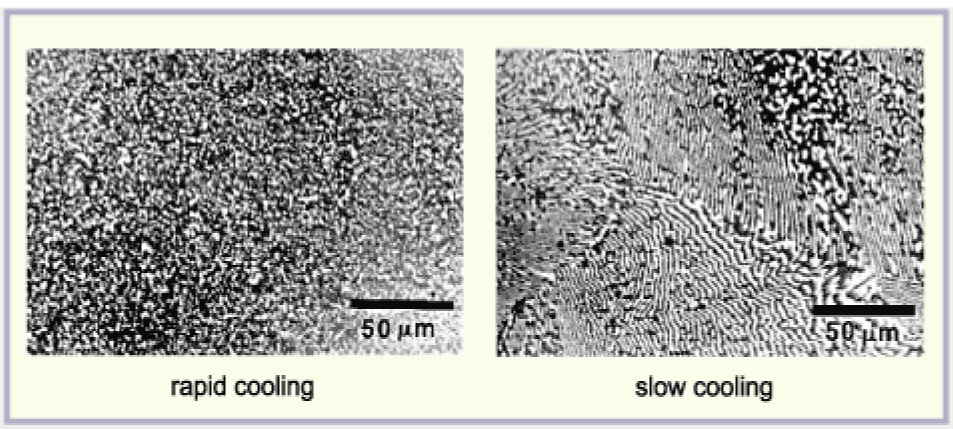
$X^2 \times R = \text{constant}$

With slower cooling rates, the inter-lamellar spacing increases, and the size of colonies (regions where lamellae are orientated in the same direction) increases.

As the cooling rate increases, the number of colony nuclei formed is enhanced; at sufficiently fast cooling rates, the lamellar character is lost.

Figure 3 shows microsections of eutectic tin-lead solder both slow-cooled and fast-cooled. Differences in the microstructure have implications for the mechanical properties of the joint: slow-cooled joints are more ductile; fast-cooled joints, with a fine grain structure and closer grain boundaries, are more brittle.

Figure 3: The effect of cooling rate on microstructure



Source: Frear 1991

Solid state diffusion processes continue to alter the microstructure of the cooled solder and this process is accelerated both by plastic deformation and by increasing temperature. Solder alloys operate at 70–80% of their melting point, so metallurgical changes occur in the joint over relatively short time-scales, even though diffusion happens at rates very much less than with molten solder.

The general tendency is for the microstructure to coarsen. As this happens, the interfacial area between the two phases and the free energy are reduced, and the joint becomes less brittle. A consequence is that joints do not reach their full strength until 24 hours after initial cooling.

Solder joint strength

Through-hole interconnects are ‘over-designed’: Manko has calculated that even on single-sided boards the solder joint is stronger than the average board, and the strength of the joints on PTH (plated through-hole) boards is 8–13 times greater than is necessary. Termination problems have not been a major reliability issue!

In SM (surface mount) assemblies, however, joints are considerably weaker, because the joint area and the amount of solder used are both much smaller. Manko’s calculations and tests showed that fillets should exhibit 80% of design strength or better.

Is solder a structural material?

In *Metal basics* we graphed the relationship of the strength and rigidity of a metal with temperature. This follows a similar pattern for all metals , reducing to zero at the melting point, and reducing markedly as that temperature is approached. Unfortunately, solder is used at a temperature close to its melting point, and bulk material is not very strong.

Fortunately, the mechanical properties of a joint don't merely reflect the strength of the bulk solder. They depend on its metallurgical microstructure, which is influenced both by the materials being connected (due to alloying or intermetallic compound formation) and by the soldering process. They also depend on the joint's shape and size, and in particular on its thickness. It has been found for tin-lead solders that:

- 0.1mm–0.15mm joint clearances give the highest strength
- Thicker joints demonstrate bulk performance
- Joints thinner than 0.1mm may be weak because of poor solder penetration and flux inclusion.

Solder materials

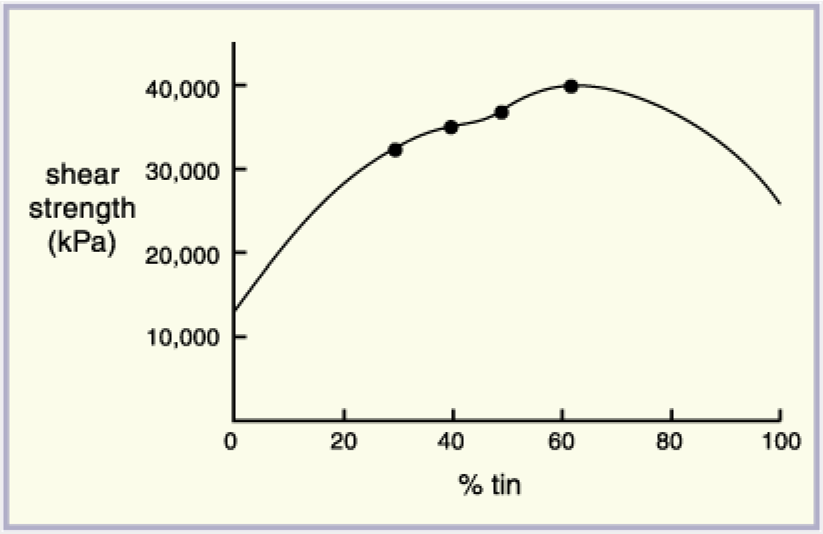
Recent moves towards a world-wide ban on lead (to be explained in the *Design for eXcellence* module) have resulted in the development of a wide variety of solder alloys. For the moment, however, we shall continue to focus on solders made of tin and lead, primarily in eutectic and near-eutectic ratios, because these have been by far the most common materials used for over 50 years. They are readily available at modest cost, and have favourable strengths, melting points and wetting characteristics.

There have been a number of reasons for concentrating attention on eutectic alloys:

- The temperature at which melting occurs is a minimum, reducing the stress on components
- The liquid to solid transition takes place at a single temperature, with no pasty range, and minimum solidification time

- Near-eutectic tin-lead alloys have optimum strength, as shown in Figure 4.

Figure 4: Strength vs composition for tin-lead solder



Source: Rahn 1993

Another popular solder is also a eutectic tin-lead alloy, but contains a small amount of silver, with the composition 62% tin : 36% lead : 2% silver.

This addition has the effect of:

- reducing leaching from silver-containing surfaces on components such as capacitors (the original reason for its inclusion) (Figure 5)
- reducing the melting point to 179ºC
- strengthening the joint – silver is a grain boundary pinner and gives increased strength and resistance to thermal fatigue.
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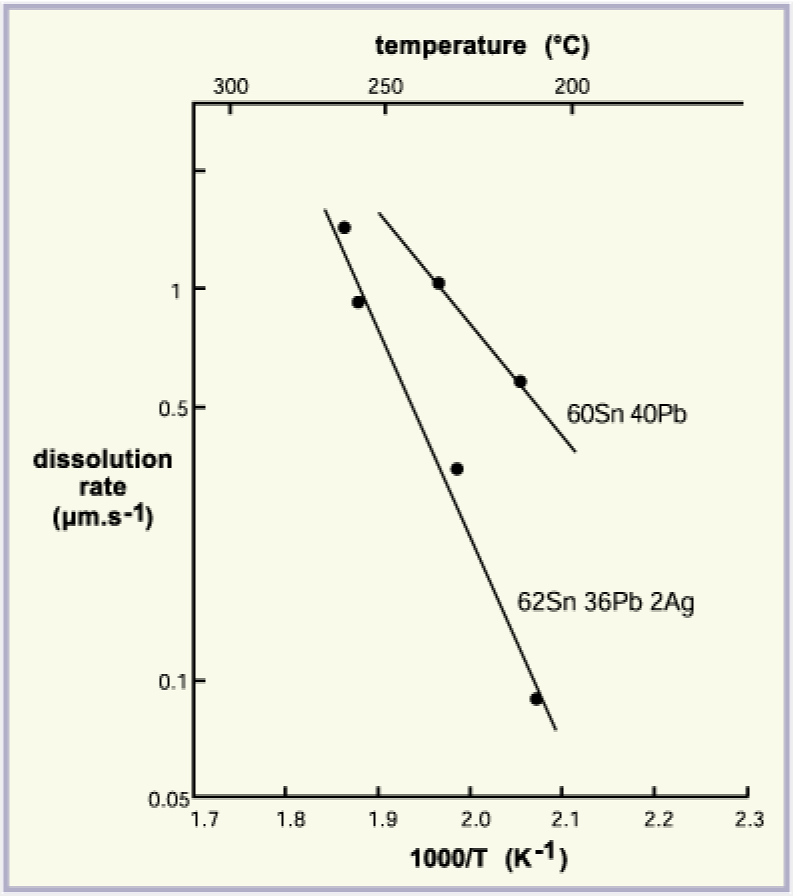
Figure 5: Dissolution of silver into solders of different compositions plotted as a function of temperature



Source: Lea 1988

Near-eutectic tin-lead solders are not the only possibilities, and a much wider range of solders is in use, depending on the melting temperature and mechanical characteristics desired. Table 1 lists some of the more frequently-used materials.

Table 1: Some common electronic solder alloys and their designations						
Tin	**Lead**	**Silver**	**Melting point °C**	**ANSI/J-STD-006**	**QQ-S-571E**	**Application**
62%	36%^{Sb}	2%	179	Pb36A	Sn62	Surface mount device assemblies and hybrid microcircuits
63%	37%^{Sb}		183	Pb37A	Sn63	
60%	40%^{Sb}		183–191	Pb40A	Sn60	
96.3%		3.7%	221	Sn96A	Sn96	High melting point lead-free
10%	90%		275–302	Sn10A		Ball Grid Arrays
3%	97%		314–320	Sn03A		C4 flip-chip
5%	93.5%	1.5%	296–301	Pb94B		Thermocouple attachmentHigh temperature component manufacture

For materials marked Sb in the lead column, the percentage shown includes 0.2–0.5% of antimony, added to improve low temperature performance. Equivalents without antimony are also available.

Where only a single melting point is shown, this indicates a eutectic material.

As explained in *Practical Solder Paste Issues*, designations given are the ‘short names' from ANSI/J-STD-006. QQ-S-571E has been superseded by ANSI/J-STD-006, but references to it may still be found.

Most of the alternative solders:

- contain at least a small percentage of tin or indium, both of which readily form intermetallic bonds with a wide range of surfaces
- are eutectic, or have a restricted pasty range
- are mechanically weaker and less conductive than tin-lead
- are substantially more expensive than tin-lead.

Source : http://www.ami.ac.uk/courses/topics/0128_sm/index.html