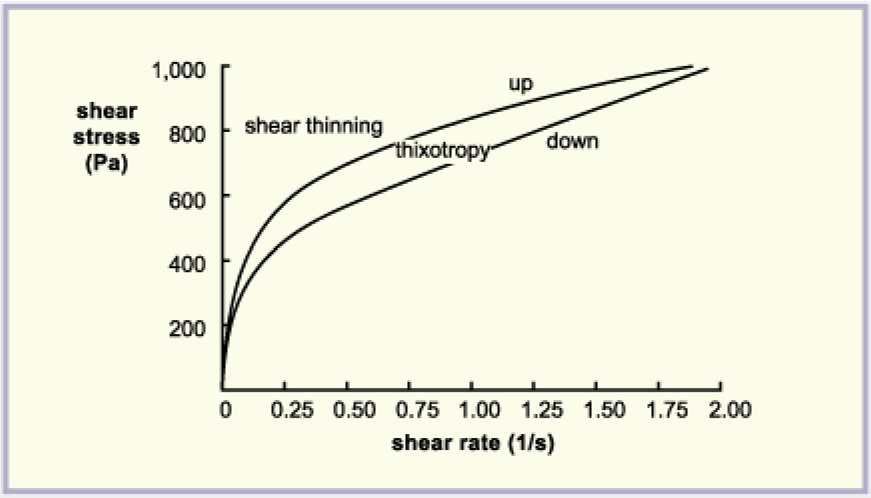
Characteristics of Solder Paste

Flow

Solder paste is a viscous non-Newtonian fluid, whose resistance to flow is not constant, and which exhibits shear thinning. This is an essential requirement for printing, as the paste must flow in and out of the stencil apertures during the print stroke, but afterwards remain in position without slumping.

Most solder pastes are also thixotropic, and their viscosity depends not just on the shear rate but also on the shear *history* of the paste. After stirring, or movement over the stencil, the paste becomes less viscous.

Figure 1: Relationship between viscosity and shear rate: data sheet for a 62S alloy paste with 89% metal content

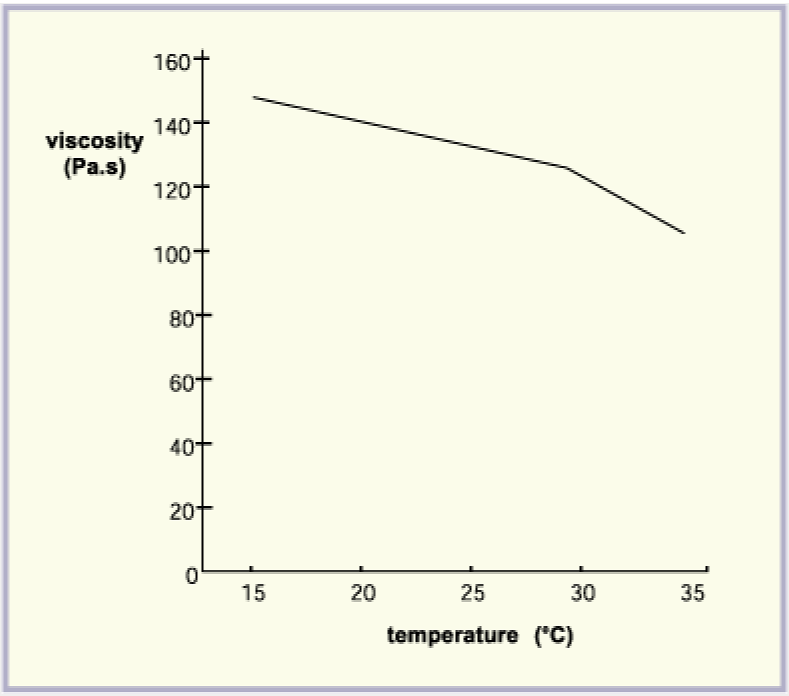


after Bloomfield, 1991

Figure 1 reproduces an actual data sheet which shows the relationship between viscosity and shear rate. This flow curve or ‘rheogram’ plots shear stress against shear rate, measured continuously as the shear stress first increases and then decreases. In this case there is only a very small amount of thixotropic hysteresis.

Being thixotropic, solder pastes also have a yield point, a minimum shear stress below which the cream does not move. This ensures that the material will not slump during use or separate during transport and storage. If a paste is too thick, because it does not shear thin, or has too high a yield point, it will be difficult to print.Unfortunately, in the same way that viscosity depends on history, it also depends on temperature. Figure 2 shows how the viscosity of a typical solder paste changes with temperature. Notice how, for this particular paste, the viscosity falls off at an increasing rate at higher temperatures – this corresponds to a change of state of one of the materials in the composition. Whilst this behaviour varies between paste types, invariably solder pastes become less viscous as they warm up. This has obvious implications for equipment practice.

Figure 2: Temperature-viscosity relationship for a typical paste



Rheology

Rheology is a term used broadly to represent the flow and deformation of solder paste under a given set of conditions (such as temperature or force). This flow and deformation behaviour directly affects the way in which paste is deposited, and therefore:

- control of paste rheology in manufacture is crucial to the control of print quality
- the paste characteristics have to be matched to the application.

In paste, the solder particles are homogeneously distributed in an organic carrier phase (or ‘matrix) with or without the aid of dispersion agents. There are many coating materials, such as non?drip paints, which exhibit shear thinning and thixotropy, and which contain an organic carrier phase and dispersed filler particles.

However, in these the carrier usually has a yield value high enough to counteract the gravitational force on the particles and keep them suspended, whereas in solder pastes, there are a number of factors which make attaining the desired paste rheology more of a challenge.

- There is a major (order-of-magnitude) difference in density between the organic matrix and the metallic particles
- The suspended particles are metallic rather than oxides, and have a different surface finish and chemical reactivity
- The particles are relatively large and spherical
- There is a very high load of particles.

Slump

After the solder paste has been printed or dispensed, it tends to slump and spread, because it is a fluid. This spreading may cause solder bridging between the pads and inadequate solder joint stand-off height. The degree of ‘cold slump’ depends on:

- the viscosity of the paste – slump is most common with pastes with a low metal loading
- the volatility of the binders, which governs the speed with which the paste begins to dry
- the height of the paste deposit
- the temperature.

Some cold slump may also be seen with dried pastes which are left for an extended period, in the form of ‘crumbling’ at the edges, caused by loss of solvent.

A second type of slump – ‘hot slump’ – is also generally recognised. This occurs during the preheat part of the reflow cycle, where the flux vehicle is more mobile and may be less able to keep the heavy solder particles in suspension, so the paste tends to spread or slump due to the effect of gravity.

Tackiness

One of the merits of solder paste is its ‘glue’ characteristic, which enables components to be held in position before the solder joints are made, in order to accommodate the delay between paste deposition on the board and reflow. Fresh paste generally possesses adequate tackiness to serve this function; however, this ‘tackability’ tends to decline after the paste has been exposed to the atmosphere for a time, primarily due to solvent evaporation.

The tack in paste is produced by components in the flux vehicle, and the natural ‘stickiness’ of rosin is a frequent contributor. Pastes with high metal loadings, with reduced flux vehicle content, are more difficult to formulate with high tack qualities. On the other hand, they are more resistant to slump, and the retention of tackiness must be a compromise with the limit of slump specified.

Solder paste is designed to have a proper holding force over the time required by the application, which will vary between assemblers. This ability to hold the component can be expressed in tack force and tack time.

Solder balling

Solder balling results when small spherical particles with various diameters are formed away from the main solder pool during reflow, and do not coalesce with the solder pool. Solder balling has been a long-time concern in solder paste reflow; the densely populated components, and the small clearance between SMT components and the board, make near freedom from solder balls one of the performance requirements for solder paste.

Solder balling appears to be a simple phenomenon, yet its mechanism can be complex and its origins different, although the results appear the same. Six likely sources are:

1. inefficient flux (as regards wetting of powder and/or board), resulting in particles which do not coalesce – due either to paste formulation or subsequent degradation
2. a preheating schedule which is incompatible with the paste, degrading the fluxing activity
3. paste spattering due to heating wet paste too fast
4. solder paste contaminated with moisture or other ‘high energy’ chemicals or aggregates that promote spattering
5. interaction between solder paste and the solder mask
6. solder paste containing small particles of solder (known as ‘fines’).

Metal content

The usual aim is for as high a metal content as possible, in order to increase the process margin, particularly with fine-line devices, where the printed track widths are low. After reflow this produces a fuller solder fillet, with a greater component stand-off from the board. A high metal content gives a number of advantages.

- The higher the component is off the board, the easier it is to clean away flux residues from beneath it
- Increasing the fillet height improves the joint fatigue strength by allowing a degree of flexibility
- The more solder there is in the joint, the less detrimental is the effect on the joint of impurities leached from the solderable surfaces of the component and the board

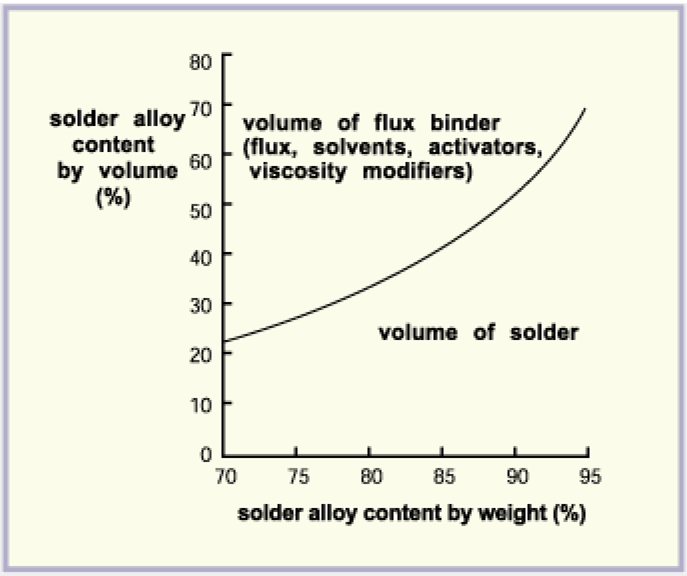
- The increase in paste viscosity reduces paste slump, minimising bridging problems
- Less flux can reduce the emission and entrapment of volatiles, leading to a reduced number of voids.

One of the key parameters of the solder paste is therefore its metal content, and often this will appear within the product code. Values between 85% and 92% are most generally used for stencil printing, but there is a very real danger that we will take this to mean that almost the whole volume of solder paste is metal.

This is very far from the truth. In fact, a 90% metal loading is approximately what results when equal volumes of flux vehicle and solder pad are mixed together. The 90% figure is the percentage by weight, and is distorted by the fact that solder balls are between eight and ten times denser than the flux vehicle in which they are suspended. 85–92 weight % of metal corresponds to approximately 50–55 volume %, depending on the solder alloy and flux vehicle employed.

Figure 3 shows the relationship between weight percentage and volume percentage for a eutectic alloy, calculated from an alloy density of 8.4g/cm^3, and a typical flux vehicle density of 0.9g/cm^3.

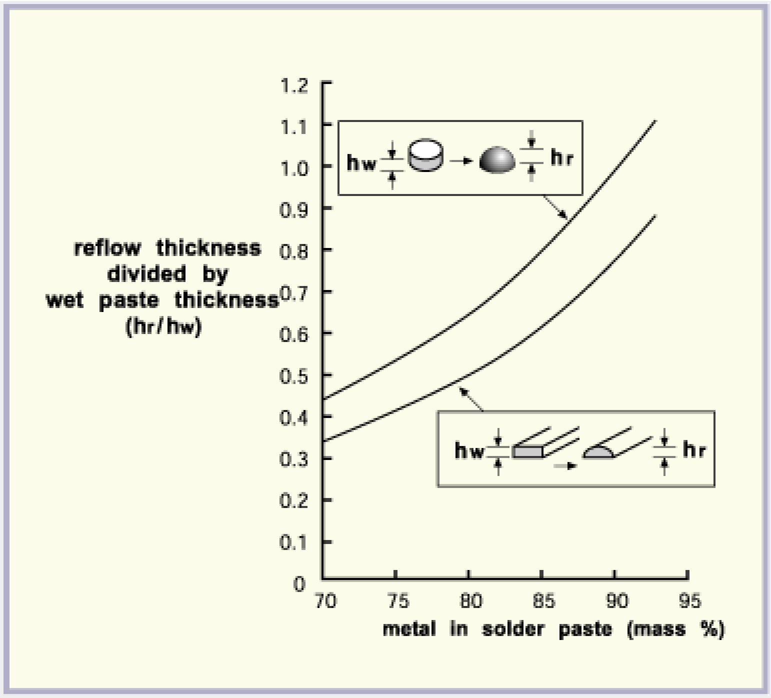
Figure 3: Relationship between solids content measured by mass and volume



The consequence is that, while the stencil may be 150µm thick, the solder volume produced corresponds only to a 75µm layer of the same size as the stencil aperture. This is masked to some extent by the way in which the forces of surface tension contract the solder mass into a convex shape, but the amount of solder is always less than you might expect, and the situation becomes more difficult with fine-pitch prints, where one solution to the definition problem is to use a thinner stencil.

Figure 4 gives a guide to the relationship between the reflowed solder thickness and the applied print thickness for a range of solids contents, both for the simplified case of a circular pad and for a track of solder paste.

Figure 4: Calculated relationship between wet paste and dried paste thickness



after Lea 1988

The print thickness can be measured either immediately after printing or after drying, as the difference between the screened wet layer and same print dried is not large. Note that during melting and reflow there is a substantial change in the shape and size of the deposit; although there is always a volume reduction on reflow, in some instances the maximum height of the reflowed deposit can be greater than the printed thickness.

If you have ever mixed mortar or plaster, you will know that the fluidity of the mix changes quite rapidly with fluid content, and that with only a small amount of extra dry matter the material reaches an unworkable consistency. The same is true with solder paste; flux vehicles have a limit to how much metal powder they will absorb whilst maintaining a workable rheology. As the metal content is increased, the viscosity increases very rapidly, quickly reaching the point at which the paste can no longer be printed. The metal loading percentage at which this occurs depends on the size of the particles and on the properties of the flux vehicle, but it is very difficult to achieve metal loadings higher than 94 weight %. The upper limit of metal loading currently being researched is of the order of 60 volume %.

If the paste is too stiff, it becomes impossible to print. Also, increasing metal loading inevitably has the effect of reducing the volume of flux vehicle. In the absence of changes to the flux composition, this will result in lower tack and shorter tack time.

Source : http://www.ami.ac.uk/courses/topics/0246_spc/index.html