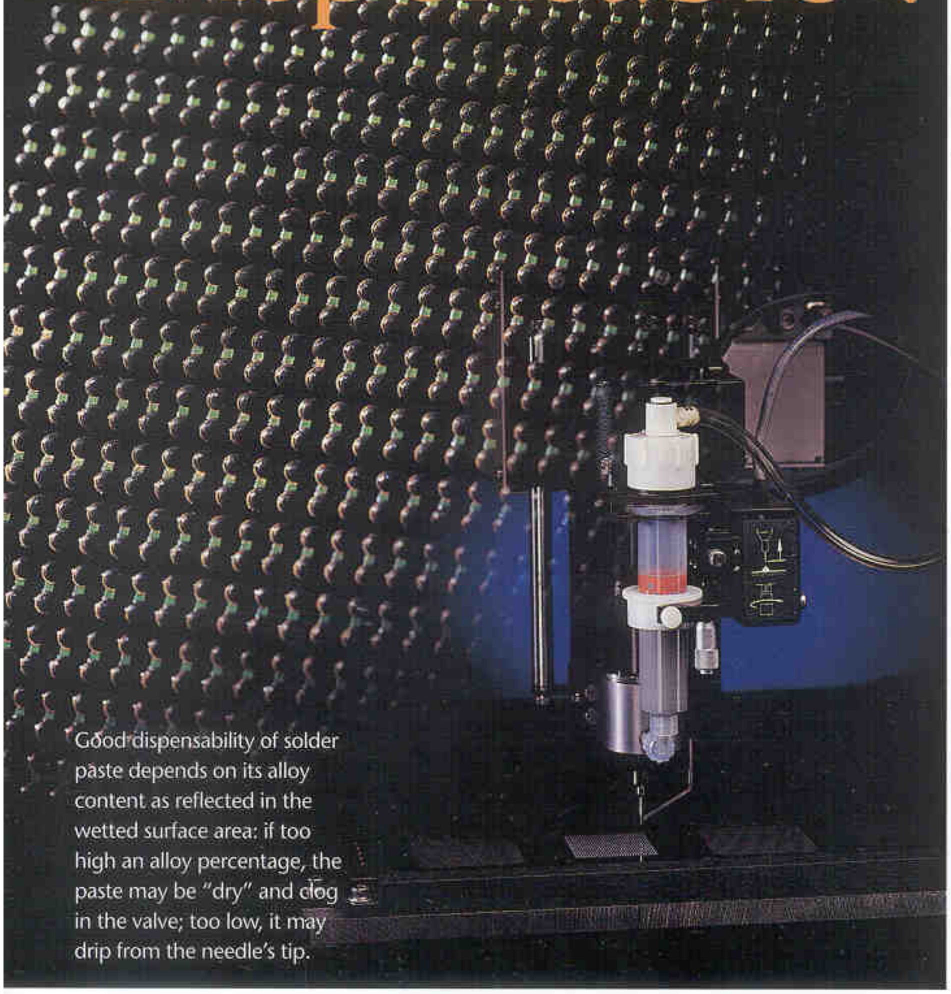
THE FACTORS THAT SHOULD INFLUENCE SELECTION ARE, IN FACT, CRUCIAL FOR HIGH-YIELD CIRCUIT BOARD ASSEMBLY.

By Eric L. Austin and Alan R. Lewis

Is Your Solder Paste "Dispensable"?



Good dispensability of solder paste depends on its alloy content as reflected in the wetted surface area: if too high an alloy percentage, the paste may be "dry" and clog in the valve; too low, it may drip from the needle's tip.

The first step in specifying a solder paste is to choose an alloy and flux type. Alloy selection is typically based on metal's compatibility, temperature requirements, environmental considerations and desired joint strength. Flux selection is usually determined by surface- and post-reflow-cleaning requirements. (For specific recommendations on alloy and flux choice, an appropriate source is consulted.[1])

Solder alloy and flux densities together with the weight-percent-alloy determine the first important factor for dispensability: volume-percent-alloy. Why? The wetted surface area of the solder sphere is directly proportional to the volume-fraction-of-alloy in the paste. If too high (the wetted surface area is low), the paste tends to be too "dry" for dispensing and may clog the valve or needle. Conversely, pastes with a low alloy-volume-fraction may slump sufficiently to cause solder bridging. Such pastes may even drip or "weep" from the dispense tip while the valve is off.

A few simple calculations, however, will yield the volume-percent-alloy and how the alloy, flux and weight-percent-alloy affect the dispensing characteristics of the paste.

From simple physical properties, three equations can be written for any solder paste based on material properties:

1) $\rho_\alpha \upsilon_\alpha + \rho_f \rho_f = \rho_\rho \upsilon_\rho$

2) $\upsilon_\alpha + \upsilon_f = \upsilon_\rho$

3) $\dfrac{\rho_\alpha \upsilon_\alpha}{\rho_\rho \upsilon_\rho} = \alpha$

where ρ_α = alloy density; υ_α = alloy volume; ρ_f = flux density; υ_f = flux volume; ρ_ρ = paste density; υ_ρ = paste volume and α = weight-fraction-metals (alloy).

Using an equation for solder paste density as a function of weight-percent-alloy, alloy and flux densities can be derived:

4) $$\rho_\rho = \frac{\rho_f \rho_\alpha}{\rho_f \alpha + \rho_\alpha^{(1-\alpha)}}$$

From this simple relation, the density of any solder paste can be calculated given the alloy density, flux density and weight-percent-alloy; Table 1 displays some common solder alloy densities.

As an example, to calculate the density of a paste consisting of 10 Sn/88Pb/2Ag (10.4 g/cc) mixed at 88 percent metals with RMA flux (1 g/cc), from equation 4, the density is about 4.9 g/cc.

From this, the volume-fraction-of-the-alloy can be calculated:

First, equations 1 and 2 can be rewritten:

5) $$\frac{\rho_\alpha \upsilon_\alpha}{\upsilon_\rho} + \frac{\rho_f \upsilon_f}{\upsilon_\rho} = \rho_\rho$$

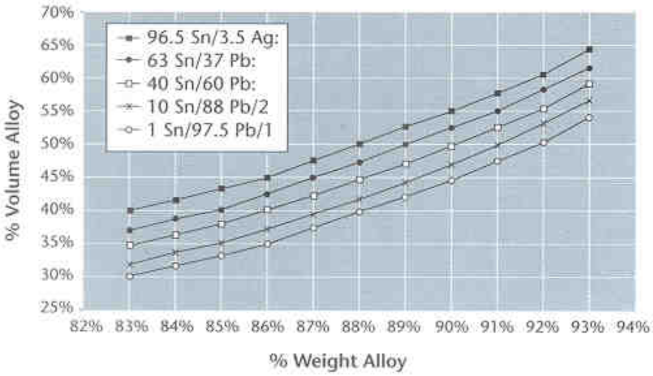


Figure 1. Percent-volume-alloy vs. percent-weight-alloy for selected solders (flux density = 1 g/cc). Pastes with an alloy volume fraction higher than 40 percent tend to be too dry for dispensing.

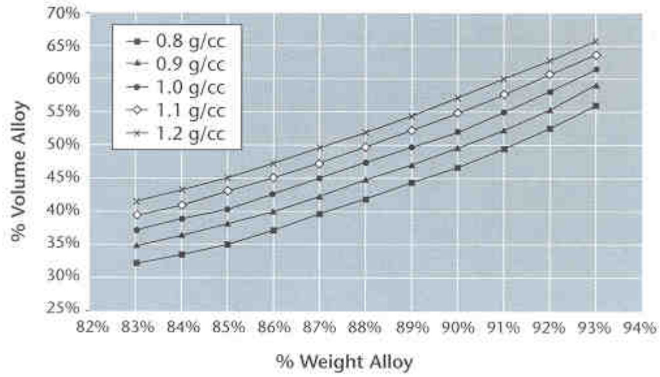


Figure 2. Percent-volume-alloy vs. percent-weight-alloy for common flux densities (solder alloy density = 8.3 g/cc), showing how flux density can be altered to achieve 40 percent alloy by volume.

6) $$\frac{\upsilon_\alpha}{\upsilon_\rho}+\frac{\upsilon_f}{\upsilon_\rho}=1$$

Then, substituting and solving for the volume-fraction-of-alloy:

7) $$\frac{\upsilon_\alpha}{\upsilon_\rho}=\frac{\upsilon_f-\rho_f}{\rho_\alpha-\rho_f}$$

Equation 7 shows that the volume fraction of alloy is a function of the densities of paste, alloy and flux. Equation 4 shows that paste density is a function of the weight-percent-alloy and alloy and flux densities. Therefore, volume-fraction-of-alloy is simply a function of the weight-percent-alloy and the alloy and flux densities and, vs. the weight-percent-alloy for a variety of alloys and fluxes, it may be plotted to determine the most dispensable paste.

The "Magic Number"

Figure 1 shows volume-percent-alloy plotted against weight-percent-alloy for selected solder alloys covering a typical range of alloy densities. The flux density for all curves is 1 g/cc, which is a good approximation for RMA type fluxes.

The "magic number" for dispensing is about 40 percent alloy by volume. Pastes with a higher alloy-volume-fraction tend to be too "dry" for dispensing, leading to clogging. Pastes with a lower alloy-volume-fraction may slump, causing a number of reliability problems. (Note that the common 63Sn/37Pb alloy is 40 percent alloy by volume when the paste is about 85 percent alloy by weight. This is why solder paste is often specified at 85 percent alloy by weight for dispensing.)

Also note that the curves are increasing in solder alloy density from left to right. As density increases and solder volume remains constant, the wetted surface area remains the same while the alloy-weight-percent increases. Thus, with a very dense alloy (e.g., 1Sn/97.5Pb/1.5Ag @ 11.3 g/cc) and with alloy weight as high as 88 percent, the paste still can be dispensed successfully. Conversely, lighter alloys (e.g., 96.5Sn/3.5Ag @ 7.4 g/cc) must be around 83 percent alloy by weight for proper dispensing. Here, 85 percent alloy by weight will result in a "dry" paste (see sidebar).

Figure 2 shows volume-percent-alloy vs. weight-percent-alloy for a range of flux densities. All curves are for 63Sn/37Pb, with a density of 8.3 g/cc. This graph simply illustrates that flux density can be altered to achieve 40 percent alloy by volume.

Summarizing, one of two courses can be followed: 1) after selecting a solder alloy and flux type, the alloy-weight-percent can be specified so that the paste will be dispensable at 40 percent alloy by volume; or 2) given a complete solder paste formulation (solder alloy, flux type *and* weight-percent-alloy), dispensability can be checked. Of course, the composition of the flux can significantly affect the rheological properties of the paste as can solder particle size.

TABLE 1

Common Solder Alloy Densities

Composition	Alloy Density (g/cm³)
100Sn	7.3
95Sn/5Pb	7.3
48Sn/52In	7.3
96.5Sn/3.5Ag	7.4
70Sn/18Pb/12In	7.9
60Sn/40Pb	8.5
40Pb/60In	8.5
50Sn/50Pb	8.9
20Sn/80Pb	10.0
10Sn/88Pb/2Ag	10.4
100Pb	11.3
1Sn/97.5Pb/1.5Ag	11.3

Paste Characteristics

Alloy particle size. As a rule, finer mesh pastes, though more expensive, exhibit better dispensing characteristics, especially for fine-pitch applications. For the latter (0.020" pitch or less), -400/+500 mesh is required; for coarser pitches, -325/+500 mesh works well. For large shot sizes where larger needles (21 gauge or less) will be used, -200/+325 mesh is sufficient. Table 2 summarizes mesh recommendations together with suitable needle sizes for standard and fine-pitch applications.

Viscosity. As a general guideline, dispensable solder paste should have a viscosity of 300 to 450 Kcps. Screen-printable pastes usually have higher viscosities (450 to 650 Kcps), while those intended for stenciling typically range from 650 to 1,200 Kcps.

Packaging. When selecting an appropriate package for dispensable solder paste, the following issues should be considered:

- Solder paste for dispensing is typically packaged in 3,5,10 and 30 cc syringes. For optimum performance, paste should be packaged in 10 cc syringes or smaller. This reduces the likelihood of paste separation in the syringe. Prolonged agitation via high acceleration of automated fluid-dispensing equipment can cause separation of the solder particles from the flux. Larger syringes are subject to agitation for longer periods and are thus more susceptible to

TABLE 2

Paste Mesh Recommendations

Mesh Designation	Particle Size (in.)	Needle Size (gauge)	Pitch
-200/+325	0.0017 - 0.0029	21 or less	0.050" standard pitch
-325/+500	0.0014 - 0.0017	23 or less	0.025" fine-pitch
-400/+500	0.0014 - 0.0015	25 or less	0.016 - 0.020" fine-pitch

High-Temperature BGA Solder Bump Attach: A Case Study

To solder high-temperature BGA solder bumps to copper pads on a substrate using low-temperature 63Sn/37Pb eutectic solder in paste form (with RMA flux) and an automated dispensing system, the intention is not actually to form the solder bumps. Rather, it is desired that only enough paste be deposited to solder the bumps to the pads. Thus, using the equations in the text and other ideas discussed, answers to the following questions are pertinent:

How will the solder joint appear?

What paste formulation should be specified for high-quality dispensing?

How much paste should be dispensed per pad for a "good" solder joint after reflow?

How can equipment operation be verified? And, working with paste currently applied with a screen printer, how can the material be made compatible for dispensing?

First, to determine the desired solder joint size based on pad size and high-temperature solder-bump size, assume that a 0.035" solder bump is to be attached to a 0.025" pad. Calculate the volume between the solder bump and the pad:

- The fillet is calculated by computing the volume of a cylinder 0.0053" high using the basic equation for a circle (see drawing). Then, the volume of the intersecting sphere

$$V = 1/3\pi h^2 (3R - h)$$

is subtracted from the cylinder, resulting in a solder alloy volume of 1,213 mil^3.

- As stated, a solder paste of 40 percent metals by volume is desirable for dispensability. Referring to Figure 1, a 63Sn/37Pb, RMA flux solder paste is about 40 percent metals by volume when mixed to 85 percent metals by weight. Calculate the total volume of paste necessary to produce 1,213 mil^3 of solder alloy after reflow:

$$V_{total} = \frac{1,213}{0.40} = 3,033 \text{ mil}^3$$

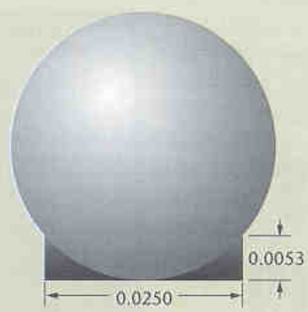
Thus, about 3,000 mil^3 (or 0.2 mg using equation 4) of solder paste must be dispensed on each pad.

The dispensing machine can be easily configured to dispense these dots. After depositing a number, the machine's built-in vision system measures the dot diameters and the parameters are adjusted accordingly until the desired dot size is reached.

Finally, assume that a 63Sn/37Pb paste is currently applied with a screen printer. Screen printing pastes are typically formulated at about 50 percent alloy by volume (too dry) and are *not* interchangeable with dispensing pastes. However, if the amount of paste being applied to the pads via the screen printing process is known, one can determine the proper amount to dispense to obtain the same amount of solder alloy after reflow. For example, for 0.050"-pitch BGA pads, the paste applied by a printer is usually about 0.007 or 0.008" thick with 100 percent pad coverage. A 0.007" cylinder of paste 0.025" in diameter is equal to about 3,436 mil^3 (50 percent alloy by volume, or 1,718 mil^3). To achieve this alloy volume after reflow with a dispensing paste, 4,300 mil^3 (from equation 6) should be dispensed.

In summary, to translate from volume of screen-printable paste to volume of dispensable paste, this simple relation is used:

$$V_{dispense} = \frac{\text{Volume\%Alloy (Screen Print Paste)}}{\text{Volume\%Alloy (Dispense Paste)}} \bullet V_{screenprint}$$



The fillet can be calculated by computing the volume of a cylinder, in this case 0.0053" high, using the basic equation for a circle. Then the volume of the intersecting sphere is subtracted from the cylinder, resulting in a particular solder alloy volume.

flux separation than smaller syringes.

- The correct follower or piston, used properly, can improve dispensing quality. The "no-draft flat wall" type follower is desirable for two reasons: First, with the more common "no-drip" type followers, air can easily become trapped between the piston and the fluid. As the syringe is pressurized, air is compressed; when released, the air expands, forcing extra fluid to be dispensed. Second, the no-draft type follower's diameter is slightly smaller than the syringe's inner diameter, permitting air to escape.
- The syringe taper design may also affect dispensing consistency. The taper is the transition from the larger diameter fluid reservoir to the smaller diameter fluid exit port. Two typical designs feature a cone-like transition and a rounded, semi-spherical transition. Syringe manufacturers generally are adopting the latter design. Also, a height sensor can assist in dispensing consistent dot sizes (Figure 3).
- Air entrapment in the fluid can cause failures in solder-paste dispensing. Most paste formulators have devised syringe-filling methods that greatly reduce entrapped air. However, new syringes of paste should always be inspected for air bubbles or voids, which can lead to missed dots.

Conclusion

The ultimate test of dispensability is actually performing the step using a paste sample. However, by using these physical principles as a guide, a better understanding of solder paste formulations and their characteristics can only improve process reliability by minimizing downtime due to dispensing problems. The proper specification of solder alloy, flux, weight-percent-metals, particle sizes, viscosity and packaging will place the engineer on the path to successful dispensing. SMT

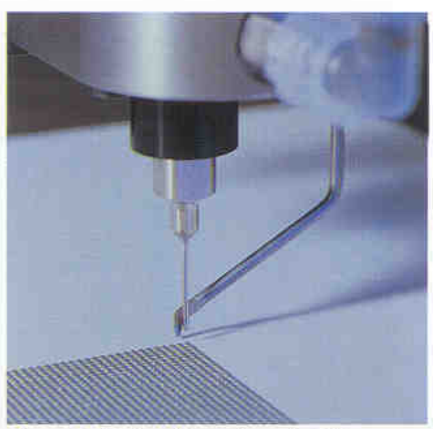


Figure 3. During dispensing, a height sensor can ensure even dot sizes by compensating for vairations in substrate surfaces.

WORKS CONSULTED

[1] J.S. Hwang, *Solder Paste in Electronics Packaging*, Van Nostrand Reinhold, New York, 1989.

[2] J.H. Lau, *Ball Grid Array Technology*, McGraw-Hill, 1995.

[3] A.J. Babiarz, "Solder Paste Dispensing Test — Part III," *Surface Mount Technology*, July 1990.

[4] A.R. Lewis and E.L. Austin, "Test Standard: Choice of Sample Size for Experiments," (draft), January 1996.

[5] P.E. Waitkus and K.W. Gaugler, "Fine-Pitch Solder Paste Dispensing," *Circuits Assembly*, November 1994.

ERIC L. AUSTIN and ALAN R. LEWIS may be contacted at Asymtek, Inc., 2762 Loker Avenue West, Carlsbad, Calif. 92008-6603; (619) 431-1919.