The effects of Pb-free solder paste formulation on voiding in reflowed assemblies

Brian Toleno PhD, Application Engineering Team Leader, The Electronics Group of Henkel, Irvine, CA

It's generally accepted that voids in solder joints are more common in Pb-free assemblies. While a very low amount of voiding may have little detrimental effect, a limit on the acceptable level of voids has never been established, thus the safest course of action is to strive for their elimination.

To do this, one must first consider the factors that influence void formation. Compared to Sn-Pb solders, Pb-free solder alloys exhibit higher alloy surface tension, reduced speed of wetting, and higher alloy solidification temperatures, requiring correspondingly higher reflow temperatures. When a Pb-free alloy powder is blended with other chemical components to form solder paste, additional variables are introduced that may also have an effect on void formation. To judge the influence that solder paste formulation has on voiding, factors to be considered are solder paste flux content, the solvent concentration in the flux, the boiling temperature of the solvent in the flux and the activator concentration in the flux. It is wise to also consider one of the process factors that is subject to considerable variation – the shape of the reflow profile.

Experimental outline

To determine the effects of these factors on a commercial Pb-free solder paste, it was decided to produce a series of Pb-free solder pastes having various flux/solvent/activator formulations and reflow them with Sn-Pb components, using two different reflow profiles. To ensure a suitably scientific study, an experiment incorporating these formulation and process variables was planned using design of experiment (DOE) techniques to devise 28 procedures based on the following:

- *Primary materials factors:* flux concentration, solvent concentration, solvent boiling temperature and activator concentration.
- *Secondary materials factors:* viscosity, hot slump, flux volatile content and rate of flux volatilisation at alloy solidification.
- *Responses:* number of joints with voids, percentage area of voiding, and size distribution of voids.

To carry out each experiment, SAC387 Pb-free solder paste was printed on copper pads at 0.5mm pitch, using a 0.12mm (5 mil) thickness stencil, and a BGA component with Sn-Pb balls was placed – this was the combination expected to give the highest rate of voiding. The reflow profiles employed were a linear profile of 1 minute 48 seconds duration and a soak profile of 3 minutes 10 seconds, the soak occurring at around 160°C. Both profiles peaked at 236°C. Similar experiments were carried out with SOICs for comparison.

Analysing the data

With the experimental procedures completed, the gathered data were analysed to:

- seek out solder paste properties that were affected by the primary parameters
- look for correlation between the physical properties of the solder pastes with the voiding response
- observe the influence of the primary parameters on the voiding responses.

Using an x-ray system offering feature recognition down to 1µm, it was possible to count the number of BGA balls showing voids, the number of voids and to measure their projected area. Similarly, for SOIC joints, the number of joints with voids and the number of voids were counted.

Half-normal probability charts were plotted to determine the parameters that had the greatest effect on paste viscosity, hot slump, BGA voiding and SOIC voiding.

Results – Parameters having the greatest effect on paste properties (in descending order)

Viscosity:

1. Solvent concentration in the flux
2. Solvent choice

Hot slump:

1. Solvent choice
2. Activator concentration in the flux

Voiding – for BGAs:

1. Reflow profile alone
2. Choice and quantity of solvent and activator
3. Quantity of flux, plus choice and quantity of solvent
4. Choice of solvent, plus activator level, plus reflow profile

Voiding – for SOICs:

1. Solvent choice
2. Flux quantity in solder paste
3. Solvent quantity in flux
4. Quantity of solvent in flux and solder paste, plus reflow profile

The worst case for voids in the study occurred when soldering BGAs with a highly volatile flux and a linear profile.

Results – Parameters having the greatest effect on volatilisation (in descending order)

Flux weight loss:

1. Concentration of solvent in the flux
2. Concentration of activator in the flux

Rate of flux weight loss:

1. Solvent type
2. Reflow profile

These results hold true for both the linear and the soak profile; comparing the percentage weight loss and the rate of weight loss at the alloy freezing temperature, there was no consistent difference between the profiles.

It was noted that the average number of voids increased with increasing rate of volatilisation for both BGAs and SOICs, although the voiding response to flux volatility was much more pronounced for the latter type of component.

Interpretation of results

From this experimental work, the main factors controlling void formation appear to be reflow profile and flux volatility. Although altering the flux formulation affects other physical properties of the solder paste, these do not seem to be strongly related to voiding. Void formation in BGA and SOIC joints seem to be controlled by different mechanisms, the rate of flux volatilisation as the alloy freezes having a greater effect on voiding around SOIC joints.

In search of a voiding-resistant solder paste formulation

With this information in hand, a low-voiding solder paste formulation was devised and trialled on the production line of a contract manufacturer in China. The SAC387-based solder paste was used to solder both lead-free and Sn-Pb PBGA 256 components; the Pb-free type was bumped with SAC405 and the other with Sn63.

Eight different profiles were run for the Pb-free, and four for the Sn-Pb, and the results compared to those achieved with other commercially available solder pastes. Two distinct differences were noted between the profiles that gave good results and those that gave the worst results: extended preheat times and reduced time above liquidus were preferable (see Table 1).

Table 1: Effect of profile on voiding results

Setting	Profile 1	Profile 2	Profile 3	Profile 4
Preheat time 130-165°C, s	101	80	107	35
Time to peak, s	261	333	260	289
Ramp time 165-217°C, s	39	100	32	72
Time above liquidus, s	33	68	44	96
Voiding result	✔	✔	✔	✘

Conclusions

Studies are still ongoing, but it is apparent that a better understanding of the solder paste factors that influence voiding can contribute to the design of a solder paste that reduces the incidence of this defect. Also worth bearing in mind is the effect of the reflow profile – paying close attention to preheat time and time above liquidus can reduce voiding.