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CHARACTERIZING THE RELATIONSHIPS BETWEEN A SOLDER PASTE'S INGREDIENTS AND ITS PERFORMANCE ON THE ASSEMBLY LINE: HEAD-IN-PILLOW TESTING

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ABSTRACT

With the majority of the circuit assembly industry focused on Lead-free soldering, Tin-Lead has been overlooked for a long time. So when paste formulators set out to create a brand new Tin-Lead platform, they wanted to use the most modern materials and methods available. Synthetic or highly purified raw materials have displaced many of their naturally occurring predecessors as primary ingredients due to their superior stability, and the old trial and error experimental strategies that were used to develop past generations of solder pastes have been replaced with sophisticated Design For Six Sigma tools. The result is a better understanding of the relationships between a paste's composition and its behavior in print and reflow processes.

This paper provides a brief overview of the new solder paste development and benchmarking processes, and introduces a new method for assessing a solder paste's robustness against Head-In-Pillow defects[1].

Key words: Solder Paste, Benchmarking, BGA Head-In-Pillow, Design For Six Sigma

BACKGROUND

Material Differences and Mixture Experiments

Variation is normal and expected in both nature and in manufacturing processes. The rosins and resins used in solder pastes are subject to natural variations, and those variations can impact paste performance. Measured by volume, solder paste is approximately 40% rosin or resin. Minor changes in properties of this key ingredient have the potential to create major changes in the performance of the final product.

Rosins are produced by trees, and their properties can vary widely based on their growing conditions and other climatic factors. Resins are either produced synthetically or are highly refined natural products that show far less variation than the materials from which they were derived, but because they are commercially produced, their availability can be subject to variation in the supply chain.

Some of the solder paste performance factors that can be affected by changes in the raw materials include:

- Print characteristics
- Coalescence/solder balls
- Voiding
- Wetting to different finishes
- Residue acceptability
- Stencil life
- Shelf life
- Thermal sustainability in long, hot processes

In order to maintain consistent performance in a solder paste formulation, the natural variation of the rosins and resins must be managed effectively. One method of managing variation is to use a blend of resins that work together to complement each other and compensate for individual deviations. To optimize the blend, mixture experiments are required.

Mixture experiments are relatively sophisticated designed experiments that are applied to blended materials. The independent factors are all proportions of different components in the blend and must add to 100%. There are different types of mixture designs that are used regularly; the method that has been refined for solder paste formulation is known as the Augmented Lattice design. This design is now used on a regular basis for raw material characterization and product development.

DESIGNED EXPERIMENT OVERVIEW

The DOE requires each raw material to be used singularly and in predetermined combinations with each other. Details of individual resin traits and combination percentages are considered proprietary.

After solder paste batches are blended and allowed to stabilize for at least 48 hours, they are tested for 26 performance criteria, which include:

- 4 wetting pattern tests
- Tombstoning
- Solder balls
- Solder beads
- Pull back from solder mask
- Voiding
- Tack*

These tests are all performed at time zero and after two hours of conditioning at 25^{o}C and 65% RH (*tack is tested after 4 hours). Additional tests include:

- Hot slump
- Finest printable pitch
- Spread
- Maximum print speed

- Minimum squeegee pressure
- Pin Testability
- Intrusive reflow capability
- BGA Head-In-Pillow prevention

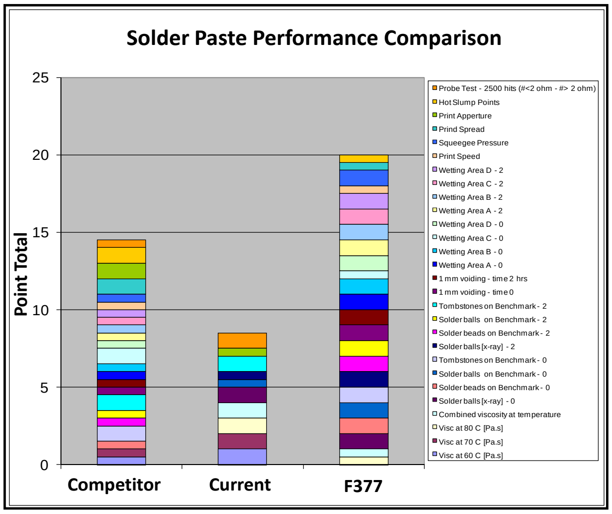

Figure 1. Stacked bar chart summarizes solder paste characterization process

Each criterion is scored individually, and the individual scores are then normalized to a point system. All the points are added up, and top performing paste candidates are the ones that have the highest total point scores *and* meet minimum performance requirements in each individual category. Figure 1 shows an example of the analysis in the form of a stacked bar chart.

Testing paste formulations for 26 different properties can be time consuming and expensive. Screening tests have been developed to speed the evaluation process. Many of them have been adapted from industry standard practices to yield results quickly, and have been reviewed in previous publications.[2] In cases where industry standard tests do not apply or exist, such as with Head-In-Pillow (HIP) formation, new tests are developed. Robustness against HIP defects is the most recently developed test, and the latest addition to the Design For Six Sigma solder paste development program.

EXPERIMENTAL METHOD

Ball Grid Array Head-In-Pillow

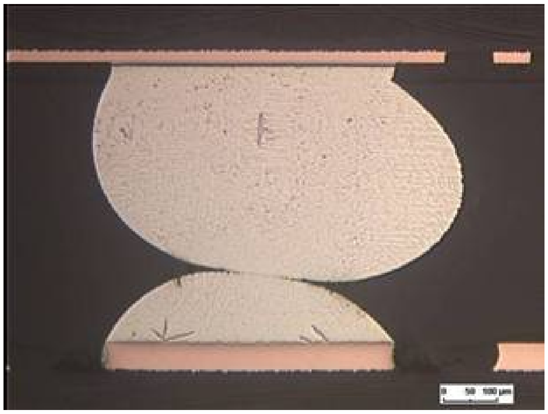

Figure 2. Head-In-Pillow Defect

Head-In-Pillow (HIP) defects occur when both the BGA ball and the solder paste melt during the reflow process, but do not fuse together properly, as shown in figure 2. The fusion is prevented by an oxide layer that forms on the surfaces of the liquid metals. The oxide film is formed when the bottom surface of the ball and the top surface of the paste deposit, which usually make contact with each other, become separated by package body warpage and get exposed to the hot, moving air of the reflow oven. As the reflow process begins cooling, the package flattens out and the solder masses meet, but the oxide layer is often too tenacious to break, resulting in a solder joint that may make electrical contact, but is mechanically unreliable.

Flux chemistry plays a large role in HIP formation. One of a flux's primary functions is to reduce existing oxides and prevent additional ones from forming. Longer, hotter thermal profiles often challenge a flux's ability to continue working – it eventually gets spent and can no longer keep oxide formation in check.

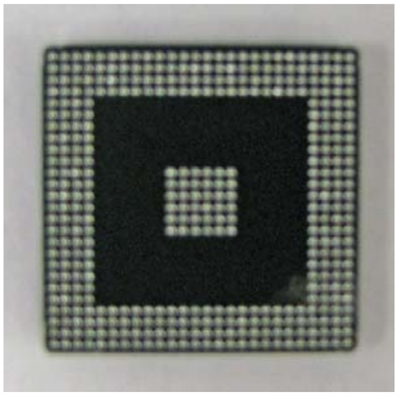

Figure 3. BGA388 used for HIP testing

There are no industry standard tests for HIP propensity, so one needed to be developed. A 1.27mm pitch Plastic BGA-388 with a 35mm body (figure 3) was selected as a test component. Preliminary investigations into the relationship between initial coplanarity and HIP incidence showed no correlation between the two, indicating non-repeatable package distortion at reflow temperatures.

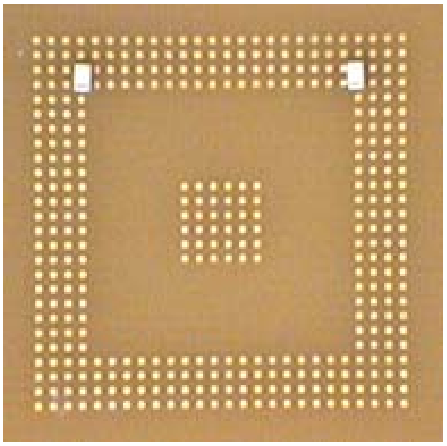

Figure 4. Placement locations of 1206 devices under BGA-338s. (Shown during placement verification without solder paste)

To effectively predict which solder pastes ingredients would be more robust against HIP defects, the effect of ball and paste exposure due to package warpage needed to be accelerated. To amplify the exposure of the balls and paste, the packages were propped up with 1206 components placed near the interior corners of the peripheral array, as shown in figure 4.

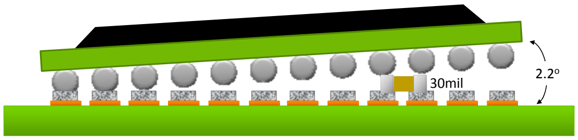

Figure 5. Cross-sectional view of propped up BGA device before reflow.

Figure 6. Cross-sectional view of propped up BGA after reflow

The 1206 components are about .75mm (30mil) tall, roughly the standoff of the BGA device. After placement, they act as shims that lift the device at approximately a 2° angle, as shown in figure 5. Most of the balls are lifted from the paste for the first 3.5 minutes of the reflow cycle until they reach liquidus temperatures, when the balls that are propped up by the 1206 collapse and allow the remaining balls to make contact with the (now molten) solder that was printed on the pads, as shown in figure 6. At this stage, the remaining balls may or may not make contact immediately, as the package warpage now becomes a factor in solder contact.

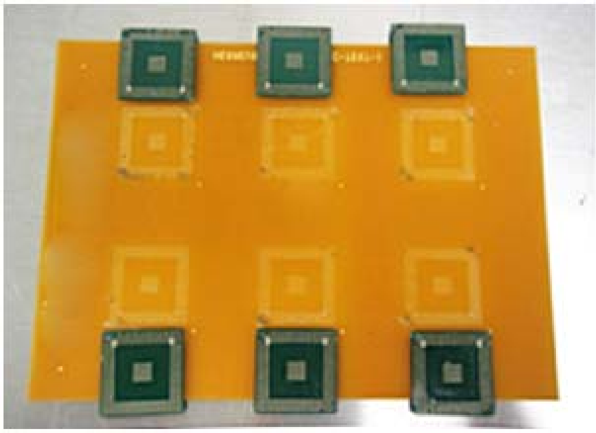

Figure 7. Test vehicle

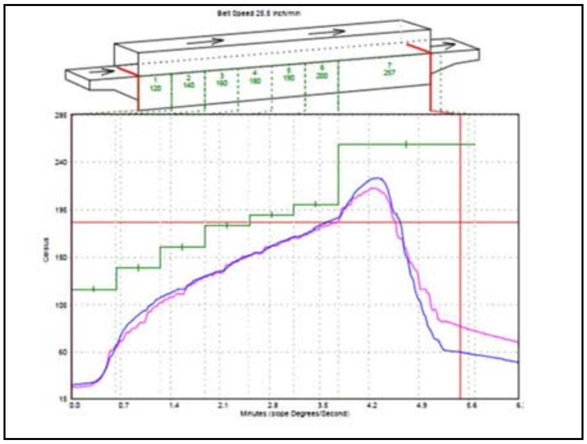

Figure 8. Reflow profile

The HIP test vehicle shown in figure 7 contains six BGA components. Solder pastes are printed with 23mil (0.58mm) apertures in a 6mil (150um) foil on a DEK 265 stencil printer. The components are placed with a Quad System IVc MK2 and reflowed in a BTU FCB98 7-zone reflow oven, using the profile shown in figure 8.

Four pads on each BGA were obscured by the 1206 components, resulting in 384 solder joints per test component. Preliminary tests showed consistent results on all six devices per paste/board combination. It was determined that single-device tests would be adequate to screen for HIP vulnerability in developmental solder paste formulations.

After reflow, the components are manually pried from the PWB using a specially designed hand tool and visually observed.

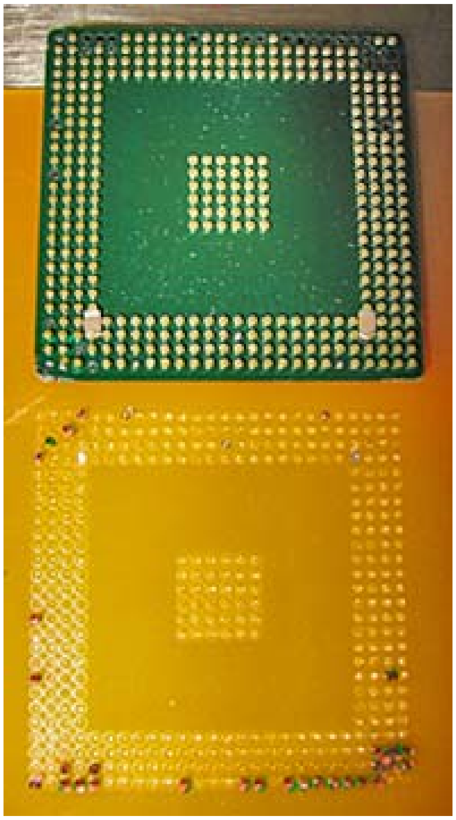

Figure 9. Failures of BGA joints after device removal

RESULTS

Three failure modes are typically observed. The most common mode is the lifting of pads from the PWB, which constitutes roughly 90% of the failures. About 10% of the failures are pads lifted from the devices. Figure 9 shows a typical failure pattern, with most of the balls remaining on the package.

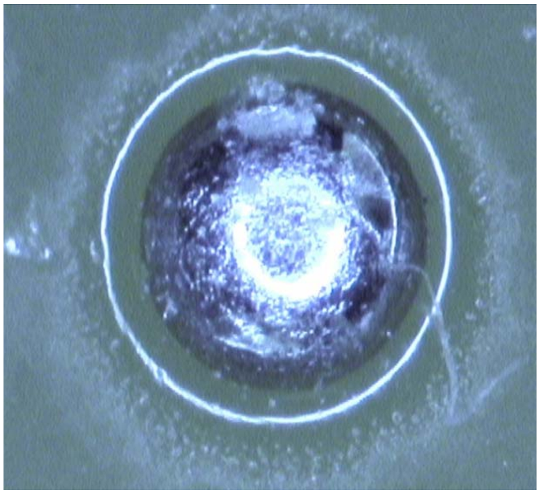

Figure 10. HIP Solder failure (PWB side shown)

Failures of interest, however, are those that fail in the bulk of the solder and leave the pads intact on both the PWB and the device. Those failures were indications of HIP defects. Approximately 0.5% of the devices exhibited this failure mode, shown in figure 10.

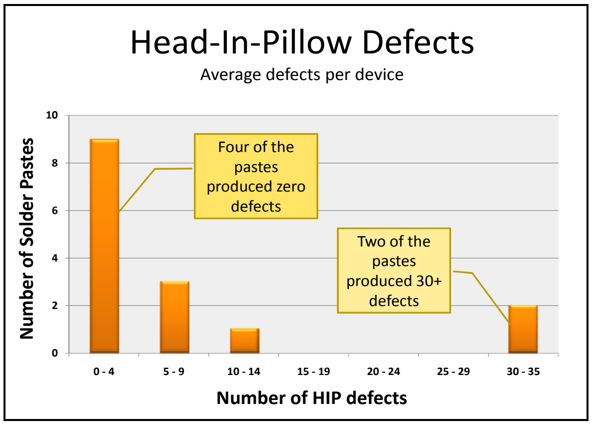

Figure 11. Histogram of HIP defects

A total of 107 solder failure defects were observed in 21,120 opportunities among the 15 solder pastes that have been tested with this method. Although the average defect per device is 7.14, only three devices of the 55 processed had more than 7 defects. About half the pastes produced zero or one defect, while 2 of the pastes produced 30 and 33 defects each. The full distribution of defects is shown in figure 11.

The bimodal distribution of the data indicates that certain paste formulations perform considerably better than others, and the performance differences have been correlated to specific raw material systems.

CONCLUSIONS

The Design For Six Sigma process has produced a reliable, data-driven method of characterizing the influence of raw materials on multiple aspects of solder paste performance. The latest test developed under the DFSS program assesses a paste's robustness against Head-In-Pillow defects.

The new test method increases the opportunity for oxidation on the surfaces of both the balls and the paste deposits. In addition to the atmospheric exposure due to package warpage during reflow, the test exposes the surfaces throughout the entire pre-liquidus phase of the the soldering cycle by propping up the device on its own solder balls.

The test has consistently shown clear results, and has proven to be very successful in predicting which raw materials help or hinder HIP prevention. It has become an integral part of solder paste evaluations.

REFERENCES

[1] Moyer, D., et al, "A Novel Six Sigma SnPb Solder Paste," Circuits Assembly Magazine, July, 2009

[2] Latrhop, R., "Defining Solder Paste Performance via Novel Quantitative Methods," Proceedings of SMTA International, 2003.