Achieving Sn/Pb Void Performance Utilizing Lead Free Solder Pastes

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Abstract
One of the reported problems in moving to lead free has been increased solder voiding. Current research indicates that paste formulation, reflow profile and board finish, when selected carefully, can produce equivalent void performance to eutectic tin/lead systems. A method of simulating solder void conditions under a chip using copper performs is described. These methods, when combined with traditional BGA porosity testing, are used to study the influences of board finish, paste formulation, reflow profile and atmosphere on the solder voiding phenomena. All of this work is done with the popular SAC305 and SAC405 lead free alloys. Finally, there are solutions to lead free solder void formation and one less trade-off in the global effort to replace lead bearing materials in electronic assembly.

Introduction

The origins of solder voiding have been reported to come from many different sources within the solder paste formulation, board finishes and the reflow process. Adding to the complexity of solder voiding is a lack of quantitative measurement tools in the industry with few exceptions. BGA void analysis software is one of these exceptions. This software uses gray level pixel analysis to determine the perimeter of the solder sphere and the internal perimeters of the voids. Once the perimeters are established the areas within these structures can be measured and an overall percent voiding can be calculated. This type of measurement works well if the voids are large or found on the outer edges of the sphere but if the void is small and centrally located where the sphere density is the greatest then the void may be invisible due to its relatively similar gray level to the surrounding material. Increasing the X-ray power will reveal the small void but also shrink the measured area of the sphere and yield an inaccurate and inflated percent voiding. This problem is even more complicated in a chip or a leaded component solder joint. When X-raying a completed assembly, internal traces, vias and even components on the backside of the board that intersect the image of the solder joint confound the software algorithms ability to accurately determine the perimeter of the solder joint. In simple terms the X-ray image is two-dimensional and the ideal structure must be symmetrical about the Z-axis such as a box or a cylinder.

To better quantify voiding, a novel method needed to be developed.[1] In a project to simulate porosity under a high Pb column on a ceramic column grid array structure CCGA, very thin (0.005") high Pb performs were placed over printed solder paste and reflowed. This in effect created a "see though" column and permitted the quantitative porosity analysis using standard BGA porosity analysis tools. This also created a symmetrical structure about the Z-axis as can be seen in Figure 1. By simply replacing the high Pb performs with OFHC copper performs with the same dimensions and using 1mm pitch BGA pads on standard FR4 board construction, this method could be used to study porosity on conventional SMT material and process sets.

The move to lead free alloys has historically increased solder voiding as can be seen from a compilation of benchmark data from 2002 (Figure 2) in the early stages of lead free formulation. Figure 3 illustrates the wide porosity distribution typical of early lead free formulations compared to Sn/Pb offerings. This data is from testing done on the leading lead free offerings at the time from all of the major solder paste suppliers using the copper perform method described. The "points" described in this paper are unit-less and are designed to summarize the frequency distribution in a simple number between -100 and +100. These points (100 is best) are calculated as follows: **Points = (≤4% - ≥6%)** or "points equal the percent of structures with 4% total voiding or less minus the percent of structures with 6% total voiding or more".

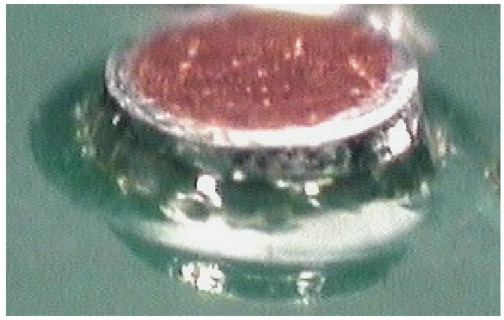

Figure 1 - Soldered Copper Preform

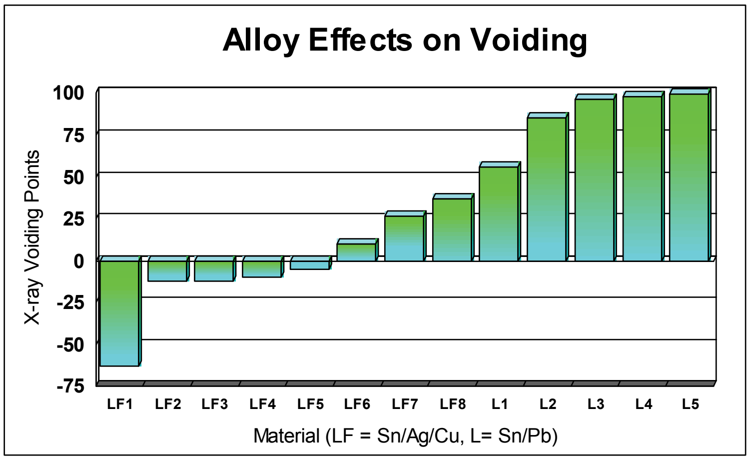

Figure 2 - Historical Lead Free Porosity

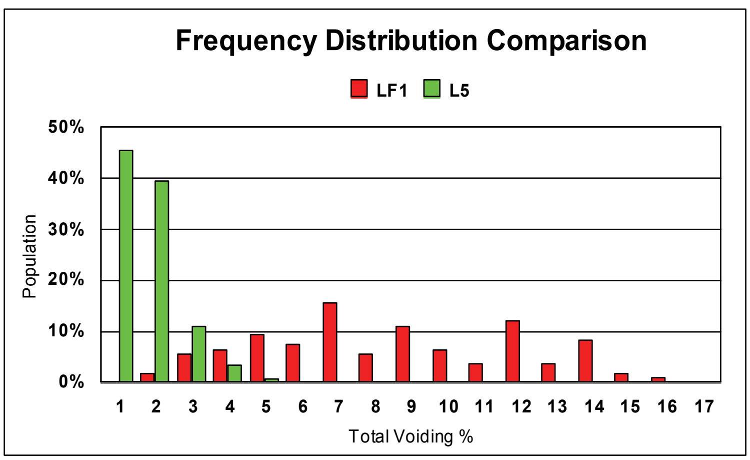

Figure 3 - Sn/Ag/Cu Vs Sn/Pb

Second Generation Lead Free

The material designated "LF1" in Figure 2 was the first generation formulation, born out of a robust Sn/Pb no clean flux system to help compensate for wetting deficiencies typical of lead free. Although wetting was better than most first generation materials on the market at the time, voiding was not. A completely new formulation "LF8" demonstrated equivalent wetting but with much less voiding, verifying that flux formulation for lead free alloys requires new chemistries and knowledge that may not originate from the known world of Sn/Pb.

A comprehensive study[2] of this second generation lead free (F620) revealed a sensitivity to profile but provided a process for best overall performance that included minimal voiding as can be seen in Figures 4, 5, 6 and 7. The following table details the main profile attributes of the 4 profile variants used in this study to identify the best overall profile for F620Cu0.5 89M3 which is a Class L rated no clean with the SAC alloy (95.5Sn/4Ag/0.5Cu). As can be seen in the table, the key attributes varied were liquidus time and preheat style. Profile number 2 with a longer liquidus time and ramp-to-spike preheat format yielded the best overall results and is shown in Figure 8. From previous studies it is quite common for the best profile to have both the strongest wetting and lowest voiding.

The study was expanded to explore the effects of board finish and reflow atmosphere. The wetting tests, solder defect tests and solder voiding tests were repeated with the addition of gauging BGA voiding on the following *Benchmarker II* finishes:

- ENIG (Gold)
- Entek (Copper OSP)
- Immersion Tin
- Immersion Silver

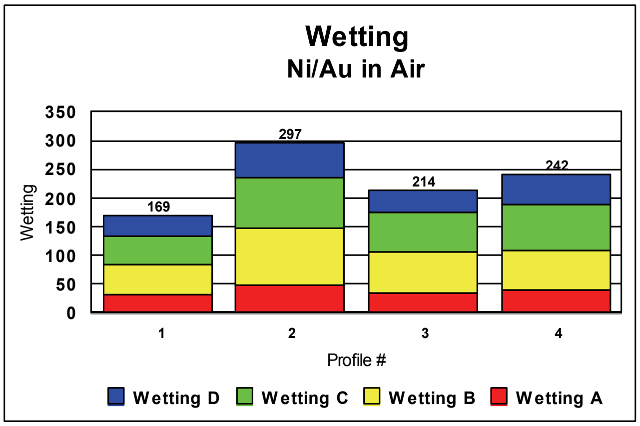

Figure 4 - Wetting Points

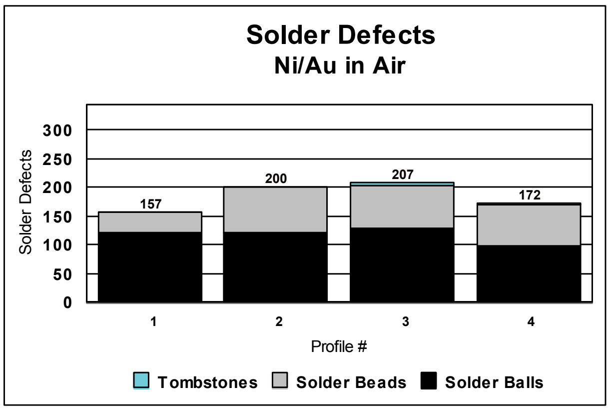

Figure 5 - Reflow Related Defects

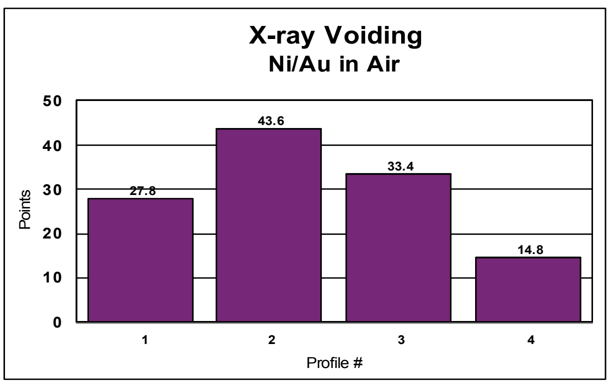

Figure 6 - Copper Perform Voiding

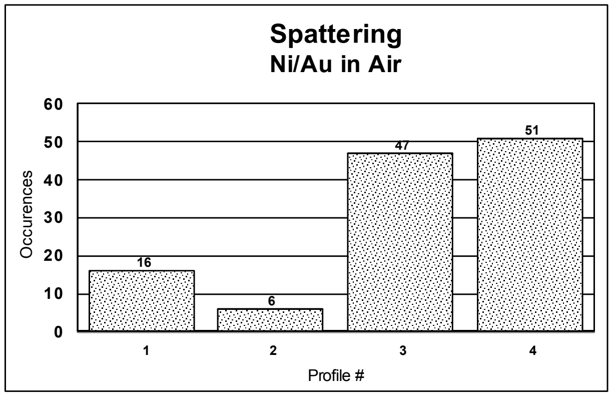

Figure 7 - Profile Related Solder Splashes

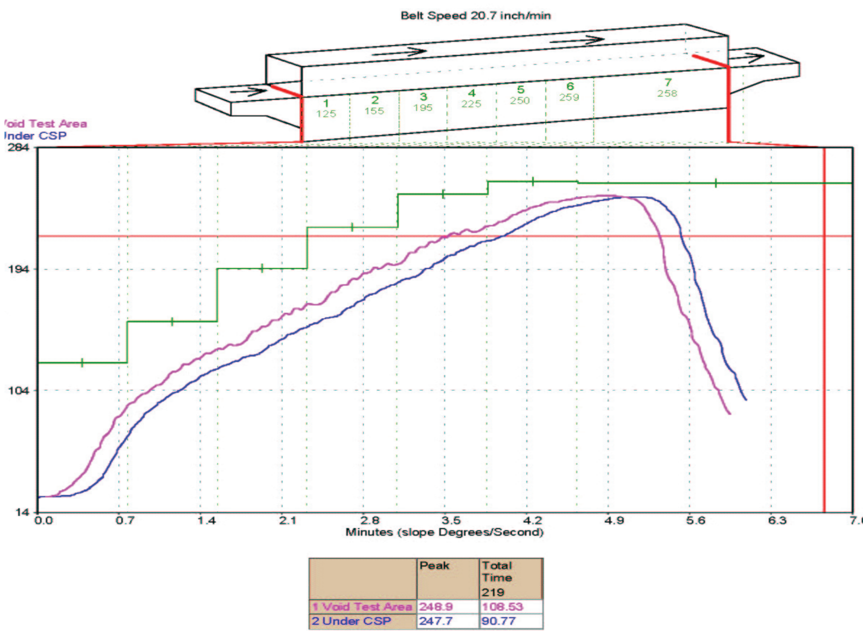

Figure 8 - Profile 2 with Longer Liquidus Time

Profile	Peak	Liquidus	Preheat
1	250	52s	Ramp
2	249	108s	Ramp
3	250	55s	Soak
4	248	90s	Soak

Reflow atmosphere was also varied. The BTU FCB 7 zone oven was purchased with an O2 doping feature. This feature bleeds into the central portion of the oven metered amounts of air during nitrogen reflow. Oxygen content was measured in Zone 7 (Reflow) and adjusted from the pure nitrogen O2 level of 25ppm to the following levels, in addition to testing in straight compressed air (≈ 200,000ppm):

- 50ppm
- 100ppm
- 200ppm
- 400ppm
- 800ppm

It was expected that the ENIG finish would have the lowest voiding from numerous internal studies. The high voiding (negative points) of the immersion silver, however, was a discovery. When the data was compiled, plotted and initially looked at it was theorized that the copper preforms and the silver pad finish combined with the acids in the flux system to form some sort of battery during the preheat that resulted in a byproduct that expanded into visible voids during reflow. Visual examination of the x-rays, however, revealed that the solder pads that had no copper preforms also had significant voiding and that the presence of the preforms simply amplified the voiding (Figure 10). Additionally, the relatively abundant large BGA void formations were found over the tin finish. There were no trends to indicate that reflow atmosphere affected copper preform or BGA voiding.

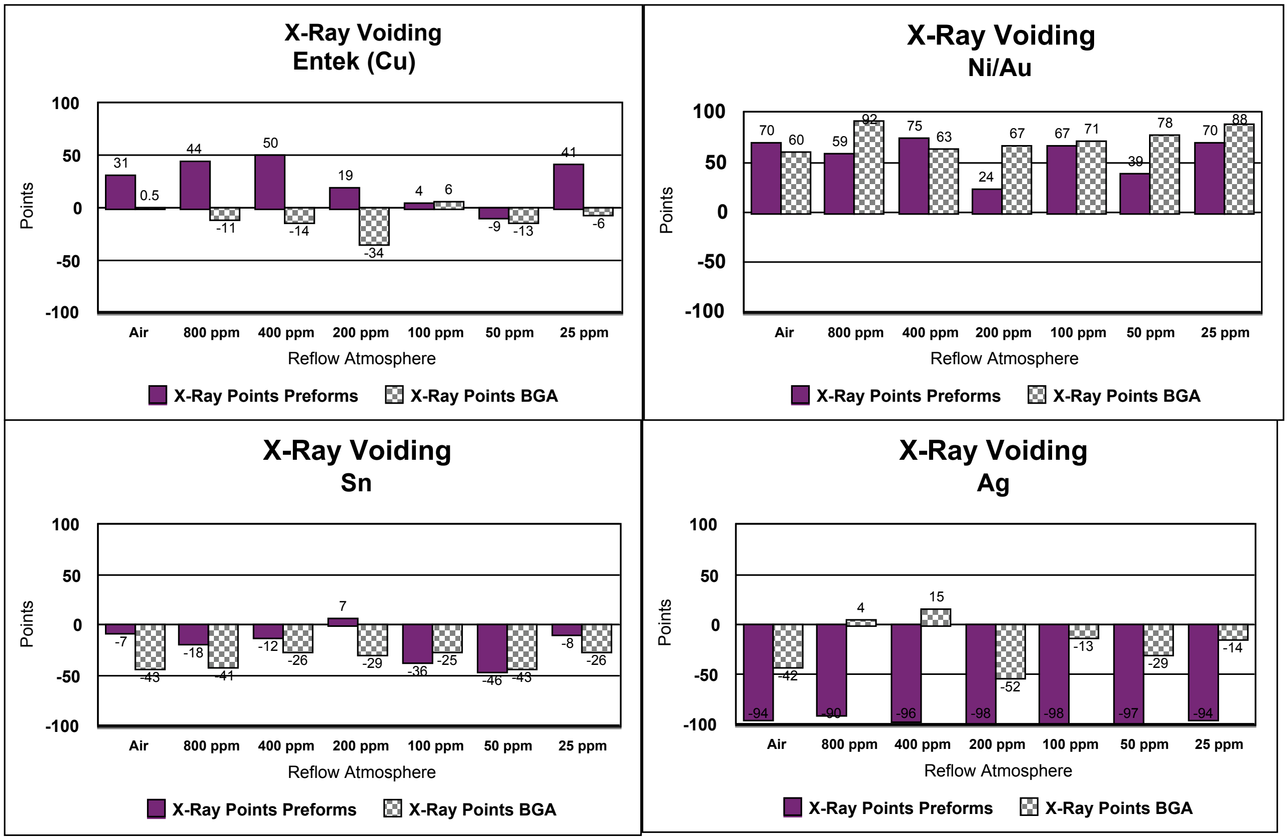

Figure 9 - Board Finish/Atmosphere Effects on Voiding

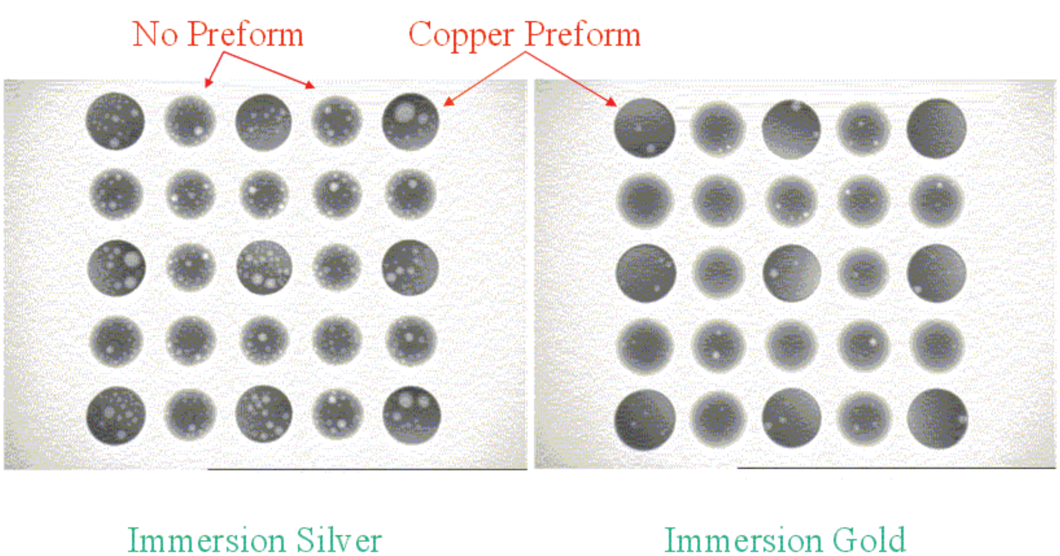

Figure 10 - Severe Voiding over Immersion Silver in 25ppm O2

Third Generation Lead Free

A third generation lead free formulation (F640) with a completely new flux system has been developed to specifically target voiding and wetting which have been the two largest paste performance tradeoffs in the move to lead free. As can be seen in Figures 11 (SAC305) and Figure 12 (SAC405) the low voiding is independent of powder source or combinations (A-F). The SAC405 average performance was less than 3 points better than the average SAC305 performance indicating relatively equal performance in this new flux system for these two popular SAC alloys.[3]

Field experience supports the lower voiding of the newest lead free formulation as can be seen in the captive internal flat leads of the devices in Figure 13.

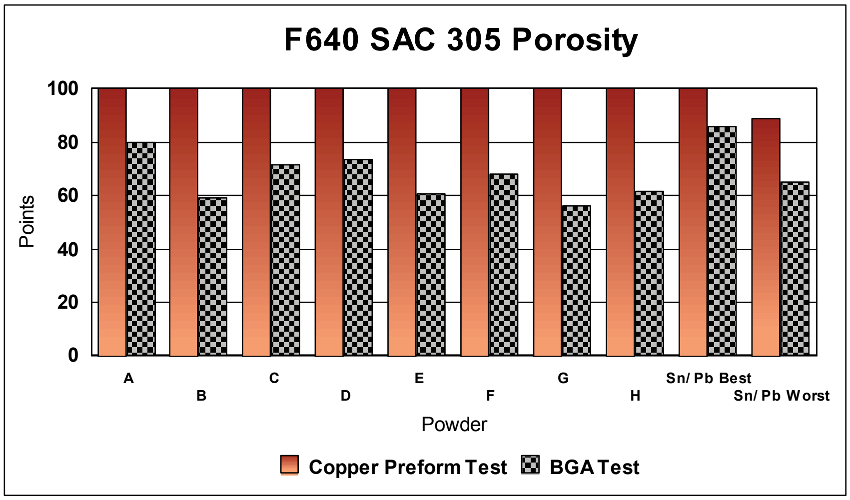

Figure 11 - Comparative Voiding Performance for 3% Ag SAC Alloy

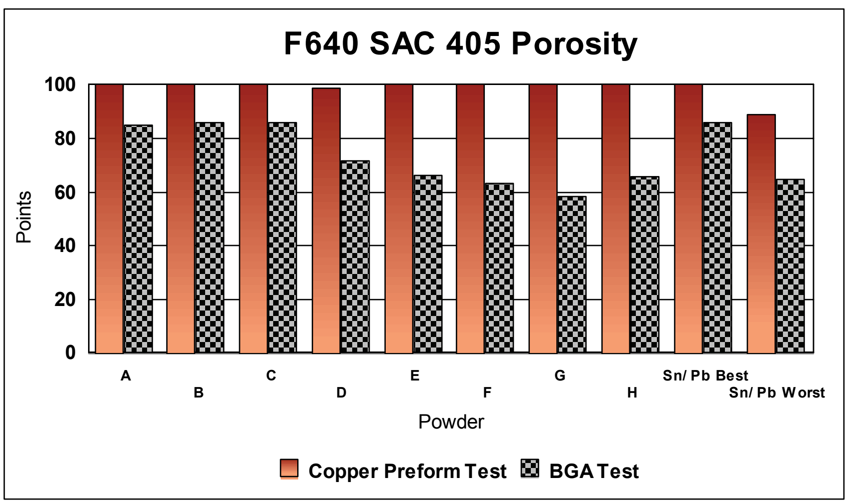

Figure 12 - Comparative Voiding Performance for 4% Ag SAC Alloy

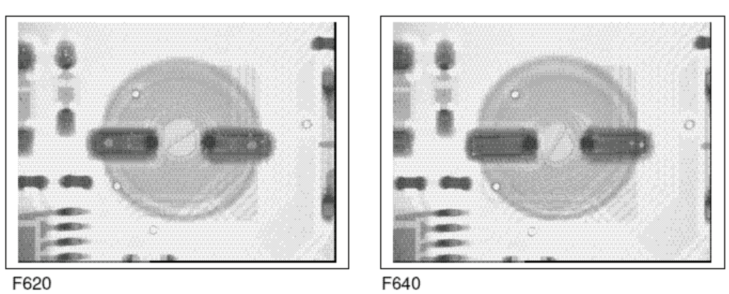

Figure 13 - Field Experience (Red Arrows Point to Voids)

With this new formulation the immersion silver voiding was revisited with basically the same results. Competitive lead free pastes were also tested with similar severe voiding. The board supplier suggested that the age of the boards were the root cause. A new lot of boards were received, tested with minimal voiding measured[4] as can be seen in Figures 14, 15 and 16. Upon obtaining these two very different results, the source of the immersion silver chemistry was consulted to help explain this phenomenon. Both blank and populated boards were sent to MacDermid's analytical labs in Waterbury Connecticut. The cross-section in Figure 17[5] shows the concentration of voiding of the old lot of boards at the surface of the solder pad as was suspected. Detailed quantitative analysis revealed that the root cause was that the Ag thickness of the old lot was out of specification (6µ-18µ) with readings of 22.8µ to 39.1µ. The new lot was well within specification with readings of 7.9µ to 12.1µ. Future orders of immersion Ag will include a thickness specification.

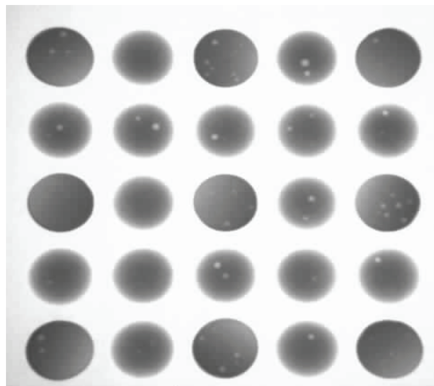

Figure 14 - Formulation with New Lot

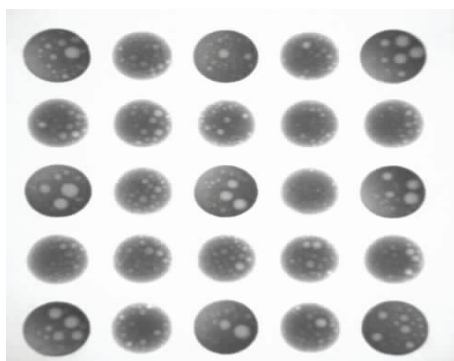

Figure 15 - Formulation with Old Lot

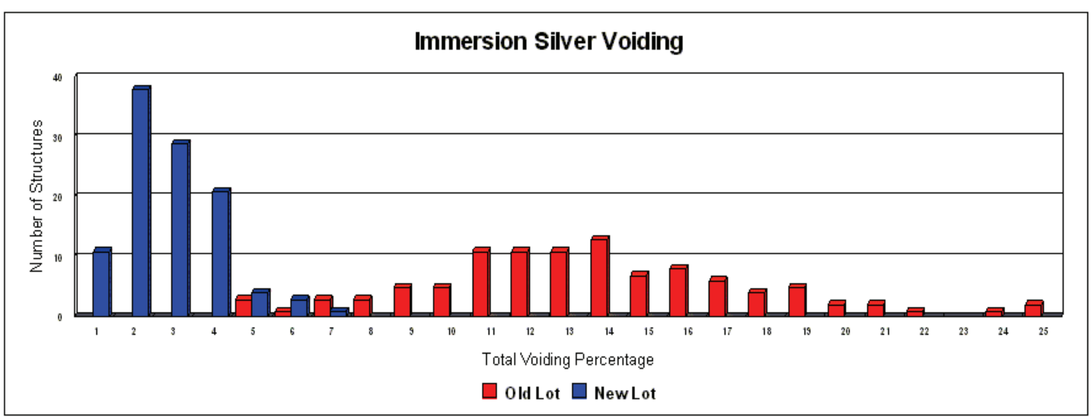

Figure 16 - Voiding Caused by Ag Finish Thickness

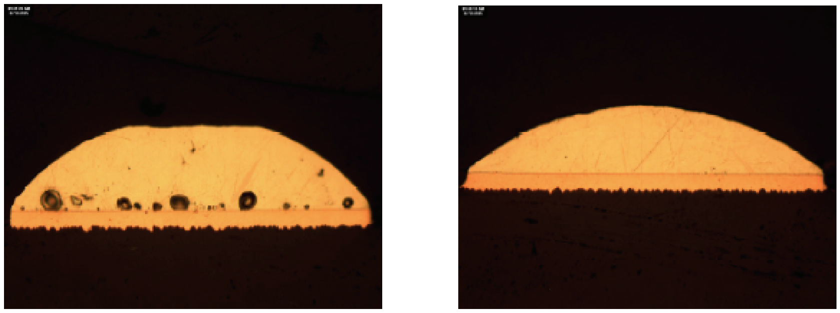

Figure 17 - Immersion Ag Voiding

Conclusions

From these studies it is clear that to achieve porosity levels equivalent to Sn/Pb, the entire system must be engineered. This should first begin with a well developed lead free flux formulation that has demonstrated low porosity performance. The reflow process should also be studied to determine the optimal profile window for minimal porosity. Our extensive study with our second generation material indicated little or no effect on joint porosity due to reflow atmosphere, although wetting can be enhanced with inerted atmospheres. Another key element of the system is the board finish. ENIG proved to be the best overall finish for porosity but with careful attention to coating thickness, immersion silver can also be considered. Lastly from our third generation powder source/alloy study, SAC305 and SAC405 alloys can produce fairly equivalent Sn/Pb porosity performance assuming the optimal flux is used.

References

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2. Richard R. Lathrop, *Maximizing Lead Free Wetting,* Apex 2005 Proceedings, Anaheim CA, 3/2005.
3. Heraeus internal technical report S200504-16, *F640 Voiding Study*, 4/29/2005.
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