As originally published in the IPC APEX EXPO Conference Proceedings.

Assembly Process Feasibility of Low/No Silver Alloy Solder Paste Materials

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Abstract
Sn3.0Ag0.5Cu (SAC305) is the most popular near eutectic lead-free alloy used in the manufacturing processes. Over the last several years, the price of silver has dramatically increased driving a desire for lower silver alloy alternatives.

As the results, there is a significant increase in the number of alternative low/no silver lead-free solder alloys available in the industry recently. In this paper, we'll present the performance and process capability of various low/no silver alloy solder pastes. Data from printability, wetting test, slump test, solder ball test, voiding, etc… will be discussed and compared with the control SAC305 solder paste. Benefits and concerns of using low/no silver alloy solder paste materials will also be addressed.

Keywords: lead-free, SAC305 solder paste, low silver alloy solder paste, alternative lead-free solder paste.

Introduction
Sn3.0Ag0.5 solder paste is currently common alloy for lead-free solder paste in the industry. However, the price of silver has kept increasing over the last several years. The silver price chart within the last 5 years is shown in Figure 1. This drives the desire for alternative low/no silver alloy materials and leads to the development of many alternative alloys. Today, many alternative low/no silver alloy solder pastes are available in the market. There are publications on the alternative lead-free alloys [1-3]. However, most of the studies focuses on the alternative alloys of the BGA's solder balls and their reliability. There is very limited publication on the performance of low/no silver alloy solder pastes. In this paper, we will discuss the process feasibility and challenges of low/no silver alloy solder pastes.

Figure 1 – 5 Year Silver History Chart

Alternative Low/No Silver Alloy Solder Pastes
In the study, we evaluated eleven different alternatives alloys and compared their performance with the control SAC305 solder paste (Table 1). Type 3 was used in the evaluation. Sn3.0Ag0.5Cu alloy typically melts at ~217ºC. Alternative low/no alloys have about 10 ºC higher melting temperature than SAC305 solder paste. Its liquidus temperature ranges from 225ºC to 228 ºC.

Table 1 – Alternative Low/No Silver Alloy Solder Pastes

Item #	Alternative Material	Alloy Composition	Liquidus Temp. (ºC)	Type
1	Material A	SAC0307	227	3
2	Material B	SACX0307	228	3
3	Material C	SAC0307	227	3
4	Material D	Sn99.2/Bi3/Cu0.5/Co	228	3
5	Material E	SAC0307	227	3
6	Material F	Sn0.1Ag0.7Cu0.03Co	227	3
7	Material G	Sn100C	227	3
8	Material H	SAC0307	227	3
9	Material I	Sn-0.3Ag-0.7Cu-Bi,In	225	3
10	Material J (Control)	SAC305	217	3
11	Material K	SN100C	227	3
12	Material L	Sn100C	227	3

Test Vehicle

Flextronics Multi-Function Test Vehicle is used in the evaluations (Figure 1). The board dimension is 225mm x 150mm x 1.67mm. The board surface finish is OSP. The test vehicle has many different SMD component types such as BGAs (0.8mm and 1.0 mm pitch), CSP (0.5mm pitch, 0.4mm, 0.3mm), QFN component (0.5mm pitch and 0.4mm pitch), leaded components (SOIC, QFN100, QFN208, etc.), chip components (0201,0402, 0603, 0805), through hole components, etc… In addition, the test vehicle has different areas designed for printability test, slump test, wettability test, solder ball test, pin testability, etc…The picture of Flextronics Multi-Function Test Vehicle is shown in Figure 2.

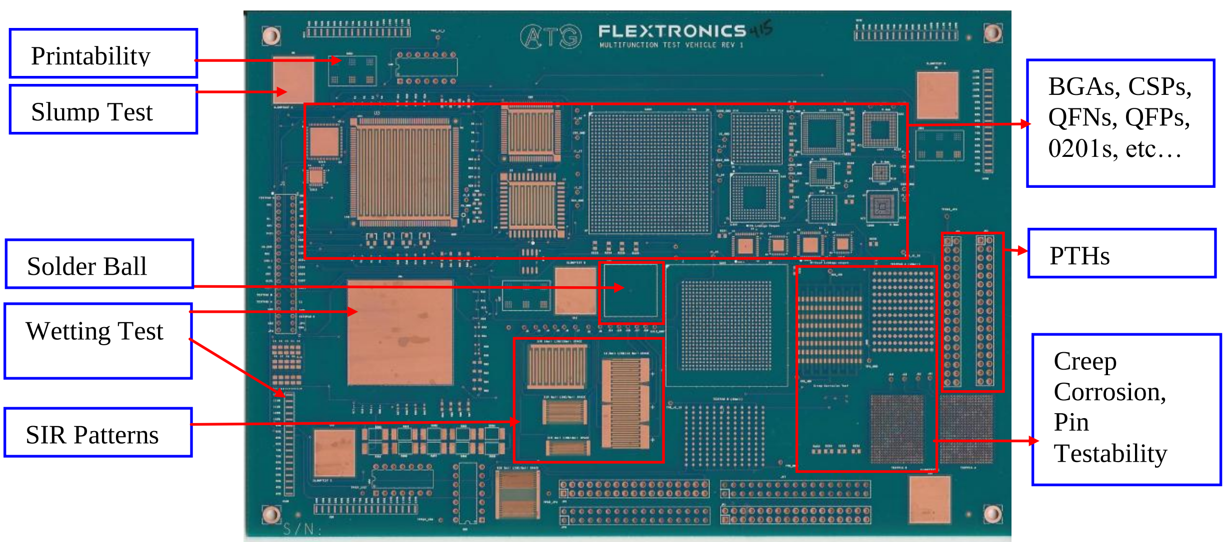


Figure 2 - Flextronics Multi-Function Test Vehicle, Rev 1.0

Evaluation Methodology and Procedure

Printability Tests

For printability tests, the solder pastes were printed using the optimized printing parameters at 0 hour and 4 hour stencil life. Solder paste volume and its standard deviation were then recorded and analyzed. Besides the solder paste volume and standard deviation, we also considered other aspects of printability such as printing speed and missing solder. Typically, a slower printing speed tends to provide a better paste volume and small standard deviation. For volume manufacturing a good solder paste material should perform well not only at slow printing speeds but also at high printing speeds. While the printing speed varies based on the complexity of the product, a good solder paste should be able to print well at a speed of 50-70mm/s or higher.

Different area ratios ranging from 0.3 to 0.8 were used for the missing solder evaluation (Figure 3). The insufficient or missing prints were analyzed. The missing solder was defined as less than five solder particles on a pad.

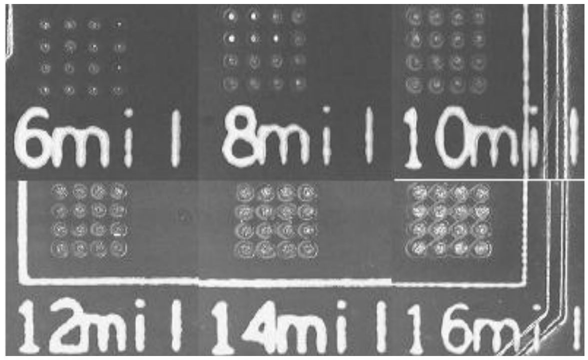


Figure 3 - Printability Area for Missing Print

Slump Test

Cold and hot slump tests were performed at 0 hour and 4 hour using the IPC-A-20 stencil pattern (Figure 4). The number of solder bridges at different spacings was analyzed. For the cold slump test, the solder bridges were counted at the room temperature. For the hot slump test, the test vehicles were baked at 125-150degC for about 20 minutes. The solder bridges were then recorded and compared.

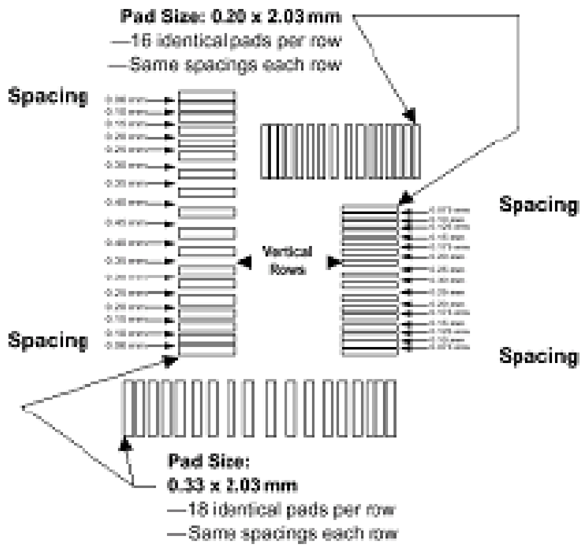


Figure 4 – IPC-A-20 Stencil Pattern

Solder Ball Test

Solder paste was printed on solder mask and reflowed (Figure 5). The solder balls, its appearance and flux residues were analyzed. A quantified test for solder balling can be done by counting the number of solder balls at a designed location.

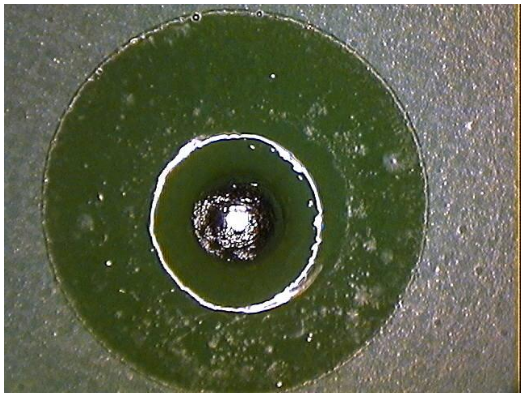


Figure 5 - Solder Ball Test

Wetting Tests

Solder wetting test was done by reflowing the solder paste printed at time zero and at 4hr of stencil waiting time. Two wetting tests were used in the initial evaluation. In Wetting Test 1, the solder spreading (diameter) was measured and compared (Figure 6). In Wetting Test 2, the solder paste was printed at different aperture openings and reflowed. Lead-free solder paste usually does not wet as well as tin lead and thus requires an over pad print to achieve full pad coverage. For Wetting Test 2, the minimum print area to achieve 100% solder coverage of the pad was observed and analyzed (Figure 7).

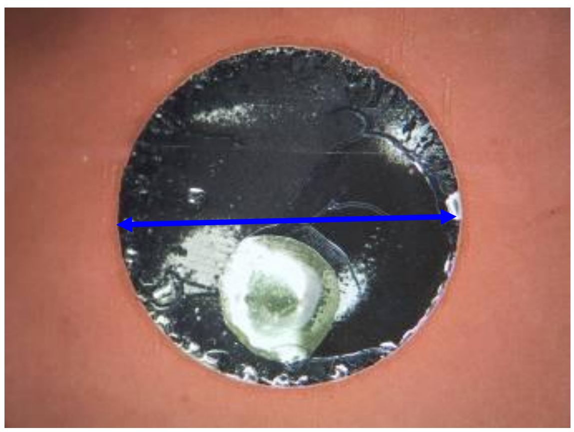


Figure 6 - Wetting Test 1

Figure 7 – Wetting Test 2

Reflow and Process Robustness Tests

To verify the process robustness of the solder paste materials, further tests were performed on the top performing solder pastes from the screening tests. Real components were used to simulate the production environment. Three different reflow profiles (low, medium, hot) were used in the low/no silver solder paste evaluation. Table 2 summarizes the difference between the profiles. All the boards were reflowed in air environment. Print quality (volume and standard deviation), solder balls, wetting, voiding, flux residues and appearance were then evaluated. A good solder paste should have good performance across all the tests, and its quality should be consistent within a wide process window.

Table 2 - Reflow Profiles Summary

Profile Name	Peak Temperature (ºC)	Reflow Time (s) (>217ºC)	Soak Time (s)
Low	231-240	52-69	75-82
Medium	240-245	57-77	102-110
Hot	250-255	79-89	100-110

Results and Discussions

Printability

Alternative low/no silver alloy solder pastes can print as well as SAC305 solder paste at t=0 (Figure 8). However, some low/no silver alloy solder paste materials (such as A, D, E, F, K) didn't perform well after 4 hour waiting time as compared to SAC305 solder paste. It is believed that the flux chemistry in the solder paste played an important role in the material printing performance.

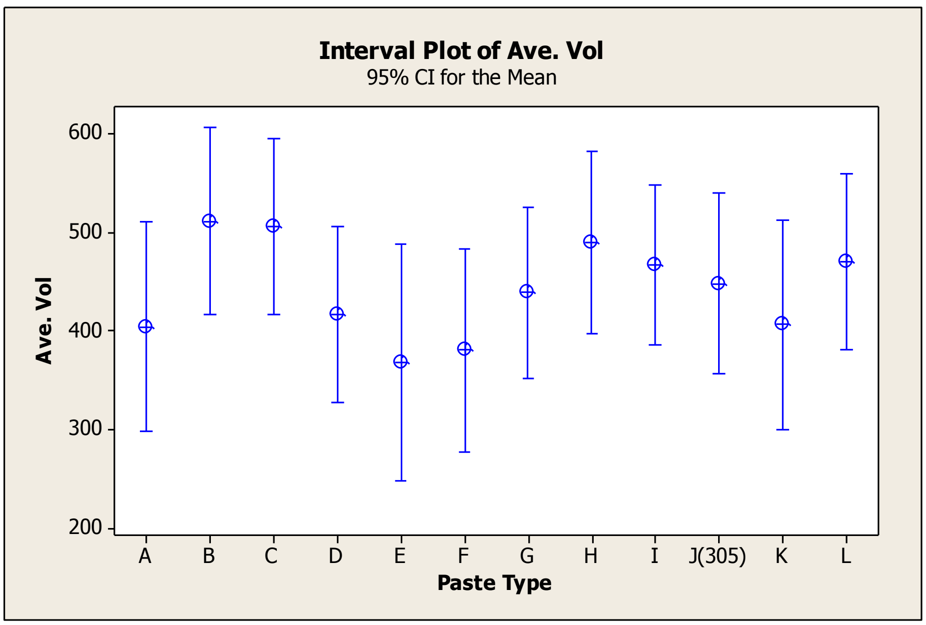
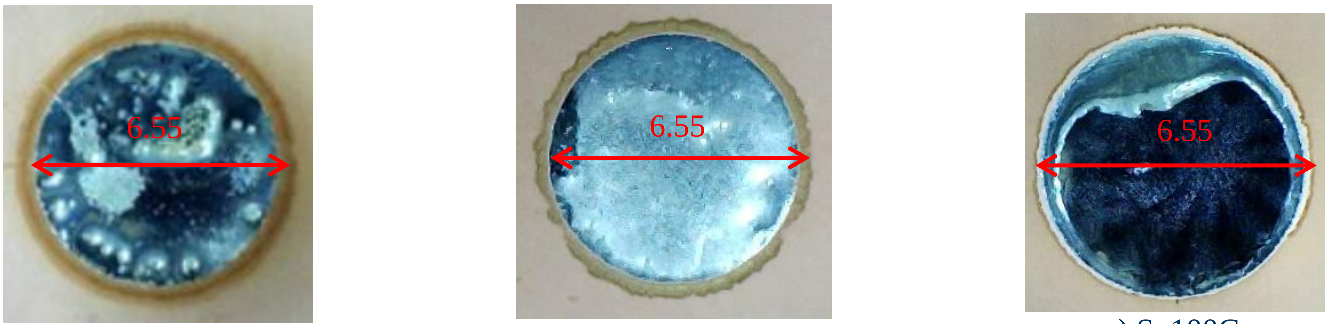


Figure 8 – Printability of low/no silver alloy solder pastes at t=0

Wettability

In term of wettability, many low/no silver alloy solder performed well in this category. Figure 9 shows the images of Wetting Test 1 for a SAC305, SAC0307 and SN100C alloy solder paste. These 3 solder pastes averagely had a similar spreading diameter. Again, flux chemistry has a greater impact on the material performance than the alloy composition.

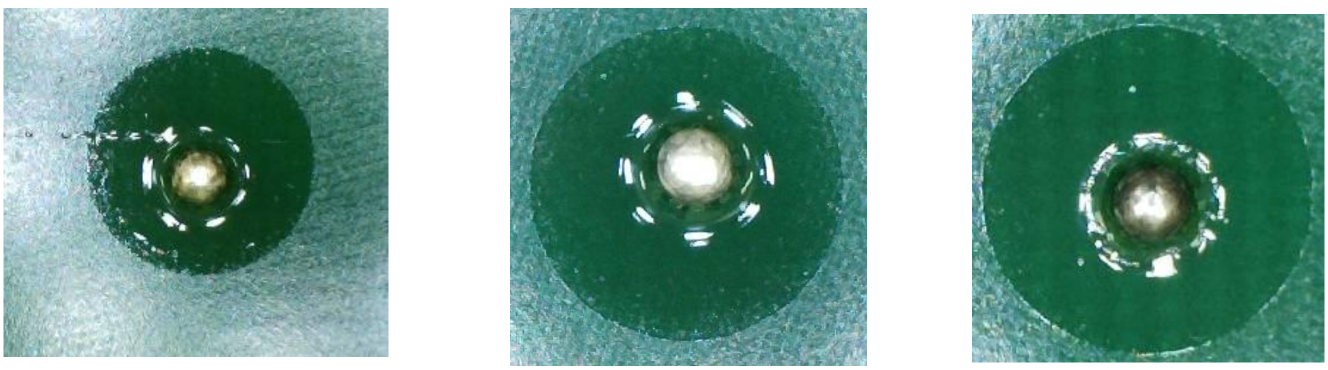


a) SAC305 b) SAC0307 c) Sn100C

Figure 9 – Wetting Test Results of Various Lead-Free Alloy Solder Pastes.

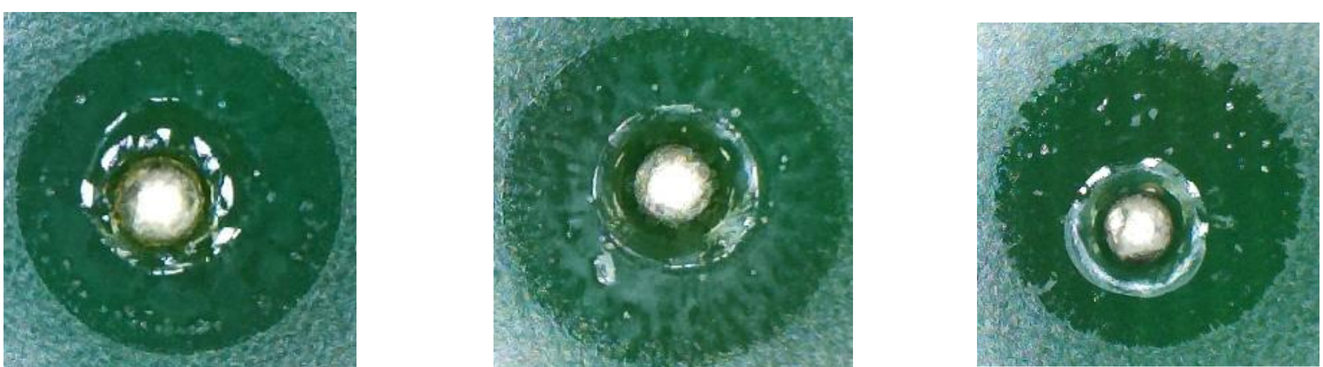
Solder Balling Test

Some alternative alloy solder pastes performed good in the solder balling test (Figure 10). However, many alternative low/no silver alloy solder pastes had excessive solder balls (Figure 11). During the previous lead free (SAC305) solder pate evaluations, almost all materials performed well in this solder balling test, and excessive solder balls weren't seen.



a)SAC305 **b) SAC0307**_A **c)** Sn100C_K

Figure 10 –Solder Ball Test Results – Good Solder Paste Materials



SAC0307_E **SAC0307+_I** **Sn100C_G**

Figure 11 – Solder Ball Test Results_ Many Alternative Alloy Solder Pastes Resulted in Excessive Solder Balls

Voiding

The x-ray image of BGA solder joints reflowed with SAC305 solder paste is shown in Figure 12. The x-ray images of BGA solder joints reflowed with SAC0307 and SN100C solder paste are shown in Figure 13 and Figure 14, respectively. In general, many alternative low/no silver alloy solder pastes resulted in more voiding than SAC305 solder paste. Some alternative alloy solder pastes had similar voiding level as SAC305 solder paste for the BGA solder joint (Figure 13a and

14a). For the QFN components, the voiding level was significantly increased for the samples reflowed with low/no silver solder pastes, as shown in Figure 15.

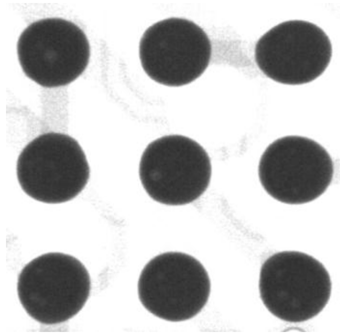
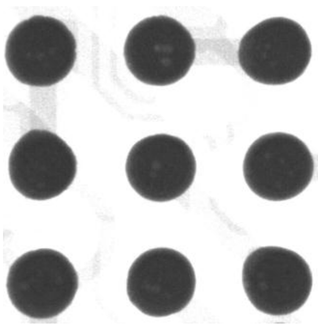
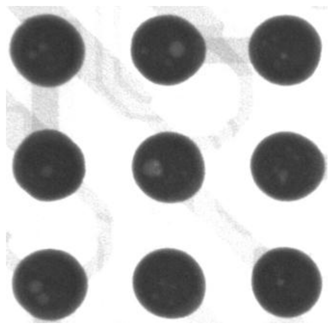


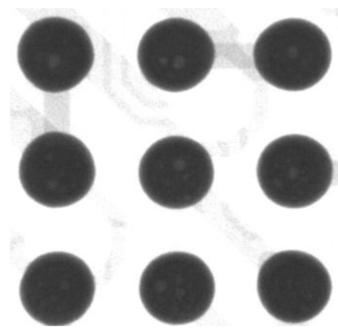
Figure 12 – X-Ray image of BGA solder joint reflowed with SAC305 solder paste. Little voids were seen



a)SAC0307 _ C

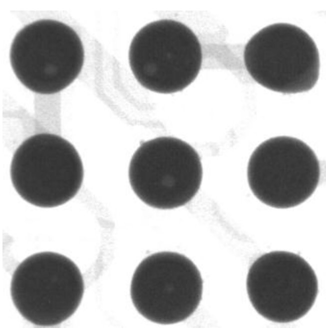


b)SAC0307_ E

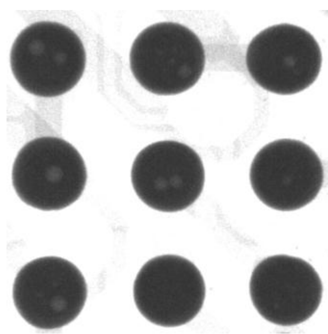


c)SAC0307_ H

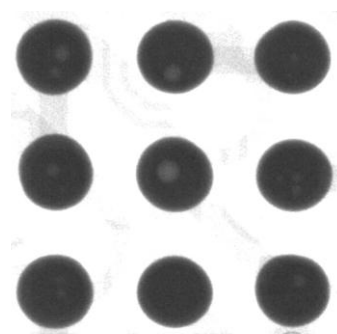
Figure 13 - X-Ray images of BGA solder joints reflowed with SAC0307 solder pastes. Good SAC0307 solder paste (13a) had similar voiding level as SAC305 solder paste. Many evaluated SAC0307 solder pastes (13b,c) had slightly more voids than the control SAC305 solder paste.



a)SN100C_ L

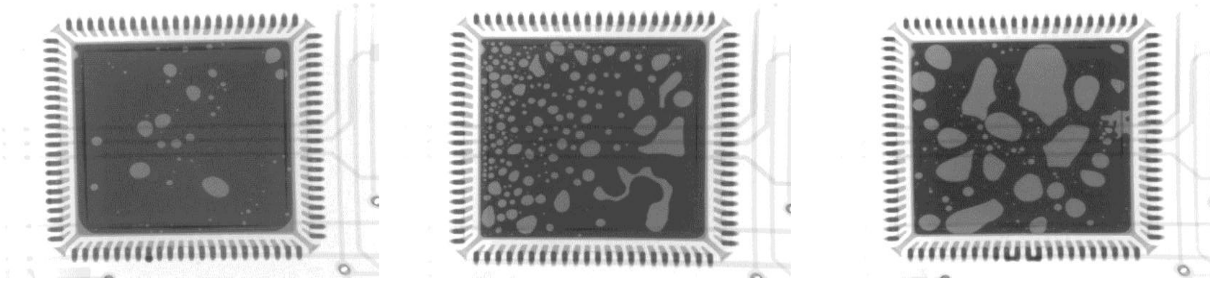


b)SN100C_ G



c)SN100C_ K

Figure 14 - X-Ray images of BGA solder joints reflowed with Sn100C solder pastes. Good SN100C solder paste had similar voiding level as SAC305 solder paste (Figure 14a). Many evaluated SN100C solder pastes had slightly more voids than the control SAC305 solder paste (Figure 14b and Figure 14c).

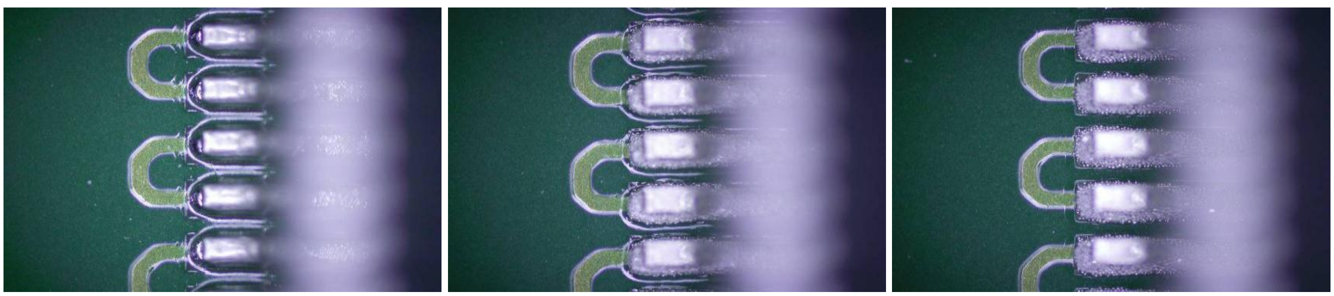


a)SAC305 b) SAC0307 c)Sn100C

Figure 15 – X Ray images of QFN88 components assembled with different lead-free alloy solder pastes. Low/no silver alloy solder pastes resulted in more voids and larger voids than SAC305 solder paste.

Process Window

Alternative low/no silver alloy solder pastes had a narrower process window than SAC305 solder paste. Many alternative alloys hadn't completely reflowed at the low lead-free profile [Figure 16]. Medium or hot profile may be needed when alternative low/no silver alloy solder paste is used. This raises the concern about the profile temperature impact on the component's process temperature limitation.



a) SAC 305 – Low Profile b)SAC0307- Low Profile c) Sn100C- Low Profile

Figure 16 – Visual images of solder joints reflowed with different lead-free alloys using low lead-free profile. 16a) Solder paste was melted for SAC305 alloy. 15b and 15c) Cold Solder was observed for SAC0307 and SN100C using a low lead-free profile.

Conclusions

There are many alternative low/no silver solder pastes in the market today. In general, alternative low/no silver solder pastes have higher liquidus temperature and require a higher reflow profile than SAC305 solder pastes. Thus, the process window of low/no silver solder paste is much narrower than the process window of SAC305 solder. Many alternative lead-free solder paste materials have good printing and wetting performance. However, low/no silver alloy solder pastes may result in more defects such as solder balling, voiding (especially on QFN components) and solder bridging. Flux chemistry and supplier play a critical role in the performance of alternative lead-free solder paste materials. A good selected low/no silver solder can have similar performance as SAC305 solder pastes in many aspects when the process conditions are optimized. The higher reflow profile associated with alternative low/no silver alloy solder paste creates some concerns about the component's process temperature and its limitation. When alternative low/no silver solder paste is used, it is recommended to review the component's temperature limitation to make sure that they can survive the reflow profile. Further work on the reliability of lead-free solder joints assembled with alternative low/no silver solder paste is recommended.

References

1. J. Smetana, R. Coyle, P. Read, T. Koshmeider, D. Love, M. Kolenik and J. Nguyen, " Thermal Cycling Reliability Screening of Multiple Pb-Free Solder Ball Alloys," *Proceeding of APEX conference*, 2010.
2. G. Henshall, et al., "INEMI Pb-Free Alloy Characterization Project Report: Part I-Program Goals, Experimental Structure, Alloy Characterization and Test Protocols for Accelerated Thermal Cycling," *Proceeding of SMTAi*, 2012.
3. K. Sweatman, et al., "iNEMI Pb-Free Alloy Characterization Project Report: Part III – Thermal Fatigue Results for Low Ag Alloys" *Proceeding of SMTAi*, 2012.
4. Jennifer Nguyen, David Geiger and Dongkai Shangguan, "Evaluation of Lead-Free Solder Paste Materials for PCBA," *Proceeding of APEX conference*, 2011.