Evaluation of Lead Free Solder Paste Materials for PCBA

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This paper was presented at IPC APEX 2011.

Abstract

Most of electronic components on a printed circuit board assembly (PCBA) are surface mount components assembled using solder paste material. Having a good solder paste material is very critical for having a high yield and reliable product. There is a strong correlation between the SMT defects to solder paste quality[1], but there is limited published information on the evaluation procedure and requirements for a good solder paste material.

This paper discusses the strategy and methodology for selecting a good lead-free solder paste material for volume manufacturing uses. A statistical and methodological evaluation approach will be addressed in details. It shows how to screen the solder paste candidates for quality using printability tests, slump test, solder ball test and wetting tests and how to select a robust solder paste material using a design of experiment. The performance of lead-free no clean solder paste, lead-free water soluble solder paste, halogen containing solder paste and halogen free solder paste will be compared. Characteristics and requirements of a good lead free solder paste material are also outlined.

Keywords: solder paste, lead-free, no clean solder paste, water soluble solder paste, halogen free solder paste, halogen containing solder paste, evaluation methodology.

Introduction

There are many solder paste suppliers in the industry. Each of them has a variety of lead-free solder paste materials based on powder size (such as type 3 or type 4) and the flux chemistry (clean versus water soluble, halogen-containing versus halogen-free). How to select the best solder paste for manufacturing uses can be a challenge, expensive and time consuming. Traditionally, many evaluations focus on the printing quality of the solder paste material. However, there are many other characteristics that determine a good solder paste. In this paper we present a complete methodology for the solder paste evaluation. This methodology can be used for evaluating any solder paste type and alloy, but we focus on lead-free solder paste evaluation in the discussion. The selection is based on data and statistical approach to avoid operation and human bias. The performance of lead-free no clean solder paste and lead-free water soluble solder paste (halogen containing and halogen free) will be discussed.

Test Vehicle

Flextronics lead-free 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), leaded components (SOIC, QFN100, QFN208, etc.), chip

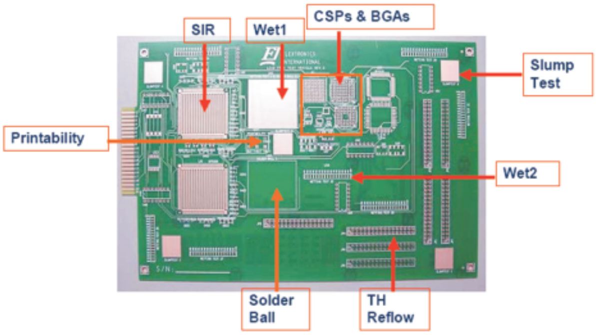

Figure 1 - Flextronics lead-free test vehicle.

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, etc...

Screening Tests

Printability tests, slump test, solder ball test and wettability tests are used in the evaluation for screening.

Printability Tests

Printability is a very important characteristic for any solder paste material. Each solder paste has its own printing process window. Optimized printing parameters should be used for each paste in the screening phase. A design of experiment (DOE) is usually used for printing optimization based on the print speed, squeegee pressure, snap-off speed and separation distance. Methodology for optimization of solder paste parameters using DOE can be found in the literature[2] and will not be mentioned in this paper.

For printability tests, the solder paste is printed using the optimized printing parameters on the Flextronics Lead-Free Test Vehicle at 0 hour and 4 hour stencil life. Solder paste volume and its standard deviation are then recorded and analyzed. Besides the solder paste volume and standard deviation, we also consider 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 are used for the missing solder evaluation (Figure 2). The insufficient or missing prints are analyzed. The missing solder is defined as less than five solder particles on a pad. Most lead-free solder pastes print well at aperture opening ≧ 10 mils. Good solder paste can be distinguished by having fewer missing prints at aperture opening < 10 mils. Example of missing prints is shown in Figure 3.

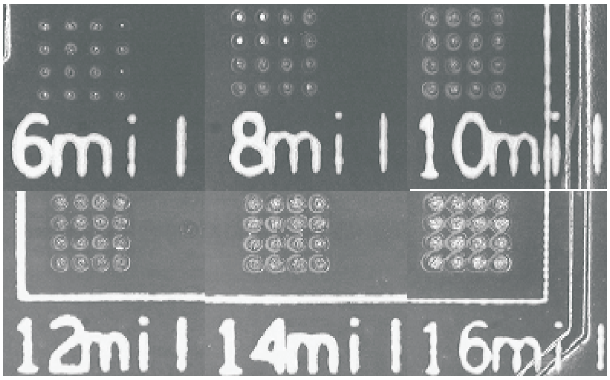

Figure 2 - Printability Area for Missing Print

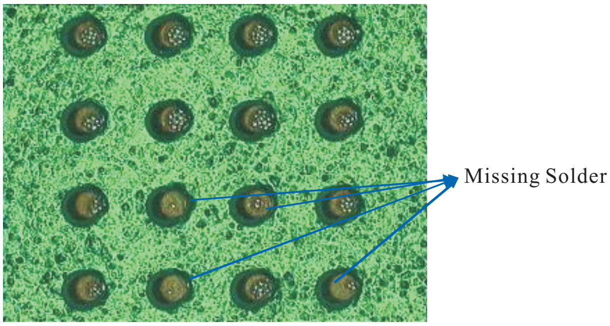

Figure 3 - Example of Missing Solder Using 6 mil Aperture Opening

Slump Test

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

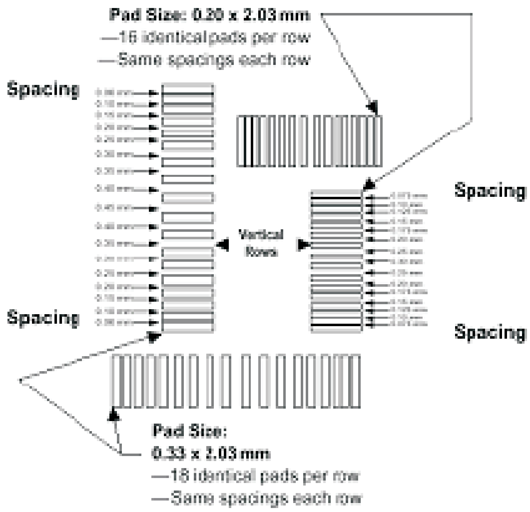

Figure 4 - IPC-A-20 Stencil Pattern

Hot slump typically has more solder bridges than cold slump (Figure 5). In our evaluation, some materials performed well in the cold slump test, but had many bridges in the hot slump test. A good solder paste material should perform well on both cold slump and hot slump tests.

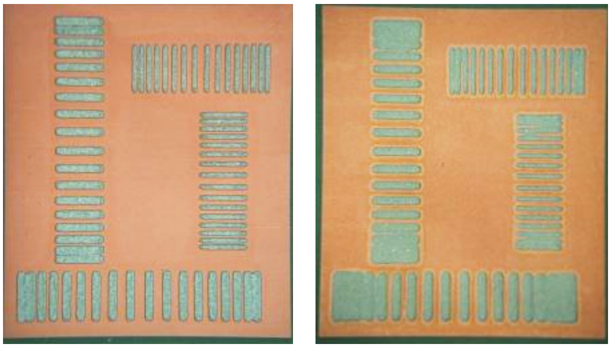

Figure 5 - Slump Test a) Cold Slump b) Hot Slump

Solder Ball Test

Solder paste is printed on solder mask and reflowed (Figure 6). The solder ball appearance and flux residues are analyzed. Most of the latest lead-free solder pastes perform well in this test. A quantified test for solder balling can be done by counting the number of solder balls at a designed location. This solder ball test is usually done in the next phase with the presence of the components.

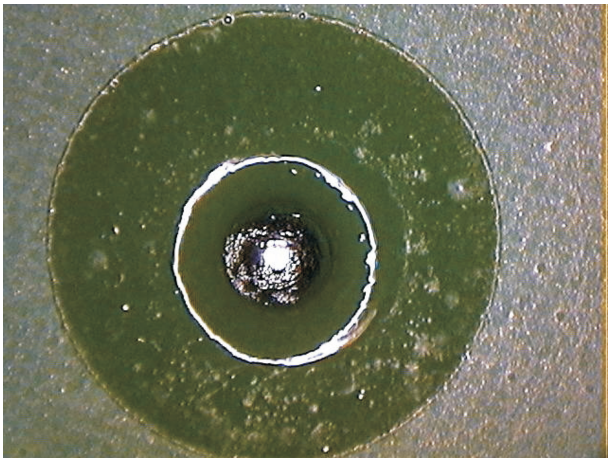

Figure 6 - Solder Ball Test

Wetting Tests

Solder wetting test is done by reflowing the solder paste printed at time zero and at 4hr of stencil waiting time. Two wetting tests are used in our evaluation. In Wetting Test 1, the solder spreading

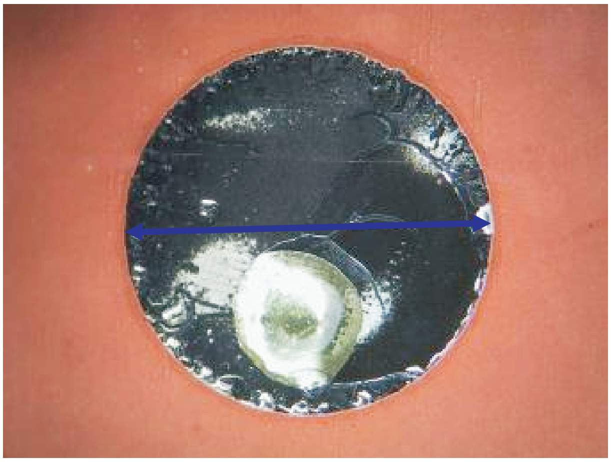

Figure 7 - Wetting Test 1

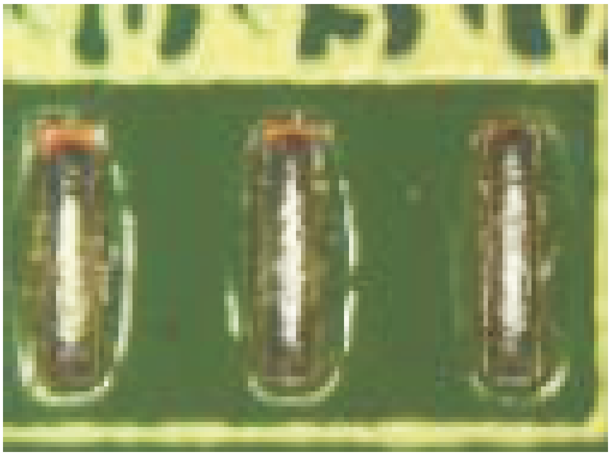

Figure 8 - Wetting Test 2

(diameter) is measured and compared (Figure 7). In Wetting Test 2, the solder paste is 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 will be observed and analyzed.

Reflow and Process Robustness Tests

To verify the process robustness of the solder paste materials, further tests are performed on the top performing solder pastes from the screening tests. Real components are used to simulate the production environment. A DOE should be designed with different reflow profiles and reflow atmosphere. An example of the DOE matrix is shown in Table 1.

Solder Paste	Reflow Profile	Reflow Atmosphere
Paste A	Low	Air
Paste A	Low	Nitrogen
Paste A	Medium	Air
Paste A	Medium	Nitrogen
Paste A	Hot	Air
Paste A	Hot	Nitrogen
Paste B	Low	Air
Paste B	Low	Nitrogen
Paste B	Medium	Air
Paste B	Medium	Nitrogen
Paste B	Hot	Air
Paste B	Hot	Nitrogen
Paste C	Low	Air
Paste C	Low	Nitrogen
Paste C	Medium	Air
Paste C	Medium	Nitrogen
Paste C	Hot	Air
Paste C	Hot	Nitrogen
Paste D	Low	Air
Paste D	Low	Nitrogen
Paste D	Medium	Air
Paste D	Medium	Nitrogen
Paste D	Hot	Air
Paste D	Hot	Nitrogen

Table 1 - DOE Matrix for Reflow Robustness

Print quality (volume and standard deviation), solder balls, wetting, voiding, flux residues and appearance are then evaluated. A good solder paste should have good performance across all the tests. A robust lead-free solder paste should perform well in both air and nitrogen, and its quality should be consistent within a wide process window.

As more component warpage and head in pillow (HIP) defects are seen with lead-free soldering in the industry, the occurrence of HIP is also part of the evaluation.

Overall Observations and Summary

In one of our evaluations, 21 lead-free solder paste materials were evaluated, including eight lead-free no clean halogen free, eight lead-free no clean halogen containing and five lead-free water soluble solder pastes. In general, there was insignificant difference in printability and solderability for the top performing solder pastes. Similar solder paste volumes were obtained for lead-free no clean and lead-free water soluble solder pastes and for no clean halogen containing and no clean halogen free solder pates (Figure 9). The best no clean halogen containing paste could have better wetting than halogen free solder pastes or water soluble solder pastes; however, the difference was not significant (Figure 10). There was no significant difference in voiding for no clean halogen containing solder pastes and no clean halogen free solder pastes (Figure 11). However, more voids were observed for lead-free water soluble solder pastes as compared to lead-free no clean solder pastes (Figure 11).

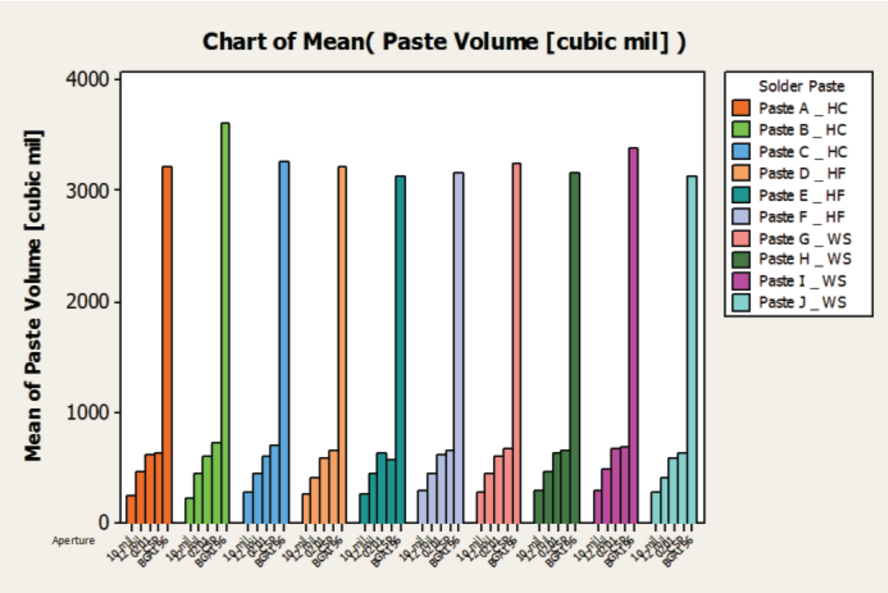

Figure 9 - Lead-Free Solder Paste Comparison _ Printability

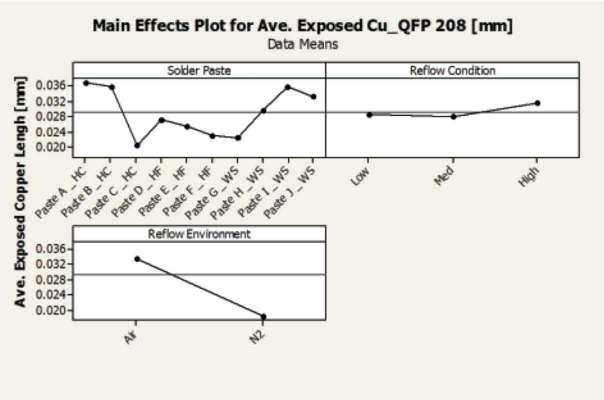

Figure 10 - Lead-Free Solder Paste Comparison _ Solderability

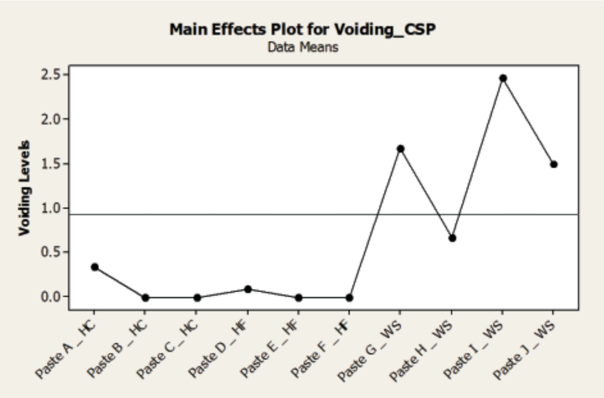

Figure 11 - Lead-Free Solder Paste Comparison _ Voiding

In general, at the present time, lead-free no-clean solder pastes are more robust and perform better than lead-free water soluble pastes, and lead-free no clean halogen containing solder paste typically performed better than lead-free no clean halogen free solder paste in the paste. This is most likely a reflection of the amount of efforts that the solder paste suppliers have spent on optimizing the formulation and performance of the various types of solder paste materials. It is noticed that the performance of lead-free no clean halogen free solder paste has been significantly improved most recently; certain halogen free solder pastes can have equivalent (or even better) performance as many lead-free no clean halogen containing solder pastes. In the future, lead-free no clean halogen free solder paste will become more popular, and solder paste which helps mitigate HIP will also be in high demand.

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