Six Sigma® Techniques for Solder Paste Selection

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ABSTRACT

Numerous studies have shown that greater than 60%[i] of end of line defects in SMT assembly can be traced to solder paste and the printing process. Reflowing adds another 15% or so. In light of this fact, it is surprising that no simplified procedure for solder paste evaluation has been documented. This paper is about such a procedure.

By using designed experiments and the measurement of critical solder paste-related process metrics, we were able to develop a solder paste evaluation procedure that maximizes information about the solder paste and its processability while minimizing experimentation. While using only 12 stencil printed PWBs, we were able to generate statistically significant results that enabled us to rank solder pastes according to their performance. Response metrics that were investigated were print volume and definition before and after pause, squeegee hang up, slump, tack, release from aperture, and solder joint quality.

In addition, we found such variation in solder paste volume repeatability that this criterion alone can be used as a screening procedure.

SIX SIGMA® INTRODUCTION

The heat of modern Six Sigma® Techniques is DMAIC. DMAIC refers to a data-driven strategy for improving processes, and should be an integral part of any company's Six Sigma Initiative. DMAIC is an acronym for five interconnected phases: Define, Measure, Analyze, Improve, and Control.

Each step in the cyclical DMAIC Process is required to ensure the best possible results. The process steps:

1. Define the Customer, their Critical to Quality (CTQ) issues, and the Core Business Process involved.
    a. Define who customers are, what their requirements are for products and services, and what their expectations are
    b. Define project boundaries - the stop and start of the process
    c. Define the process to be improved by mapping the process flow
2. Measure the performance of the Core Business Process involved.
    a. Develop a data collection plan for the process
    b. Collect data from many sources to determine types of defects and metrics
    c. Compare to customer survey results to determine shortfall
3. Analyze the data collected and process map to determine root causes of defects and opportunities for improvement.
4. Identify gaps between current performance and goal performance
    a. Prioritize opportunities to improve
    b. Identify sources of variation
5. Improve the target process by designing creative solutions to fix and prevent problems.
    a. Create innovate solutions using technology and discipline
    b. Develop and deploy implementation plan
6. Control the improvements to keep the process on the new course.
    a. Prevent reverting back to the "old way"
    b. Require the development, documentation and implementation of an ongoing monitoring plan
    c. Institutionalize the improvements through the modification of systems and structures (staffing, training, incentives)

From *GE's DMAIC Approach*

Although a full Six Sigma® program goes beyond our needs for selecting solder pastes, the fundamentals of DMAIC are vital to a successful program to systematically determine a superior material in any process. Hence, we used DMAIC concepts in the following work.

INTRODUCTION

Solder paste expense represents only 0.05%[ii] of the value of the finished electronics, yet no single entity affects the resulting product more. Given the importance of solder paste to the final assembled product, it is vital to evaluate solder paste performance in a systematic way. Printability, tack, reflow characteristics, surface insulation resistance (SIR), solder balling, and wetting, form a minimum of solder paste performance metrics that one should consider. Testability and cleanability may also be metrics to assess in certain assembly processes.

Printability

A well shaped printed “brick” with good volume consistency, is likely the best predictor of high end of line yields. See Figure 1.

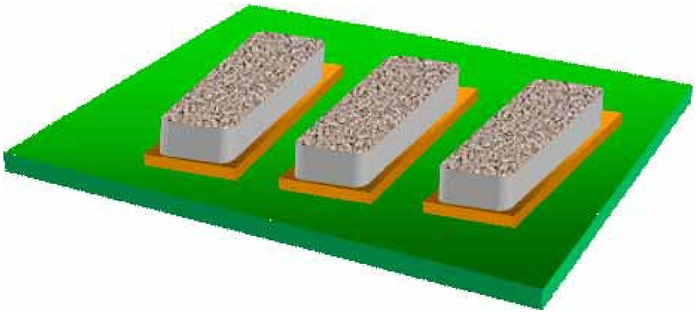

Figure 1. A well shaped printed “brick” with consistent volume is probably the most important predictor of good end of line yields

Too much solder paste in the printed brick could result in shorts, whereas too little may cause opens as shown in Figure 2. Setting solder paste volume specifications and monitoring the printing process for conformance to these specifications can have a positive effect on yields.

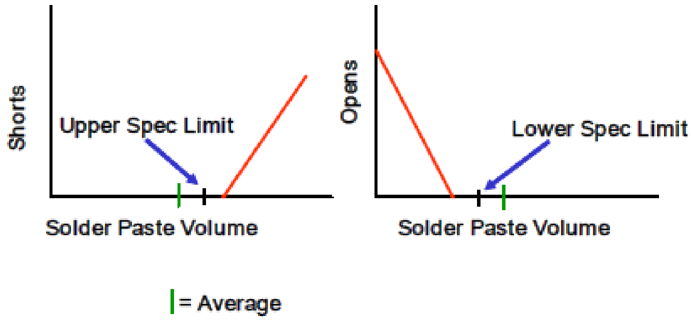

Figure 2. Too much solder paste can cause shorts or too little may result in opens. Setting solder paste volume specifications and monitoring the printing process for conformance can have a positive effect on yields.

An effective way to accomplish such control is a statistical process control (SPC) program[iii]. Such a program assures that the control limits of the printed brick volume are within the upper and lower specification limits, as shown in Figure 3.

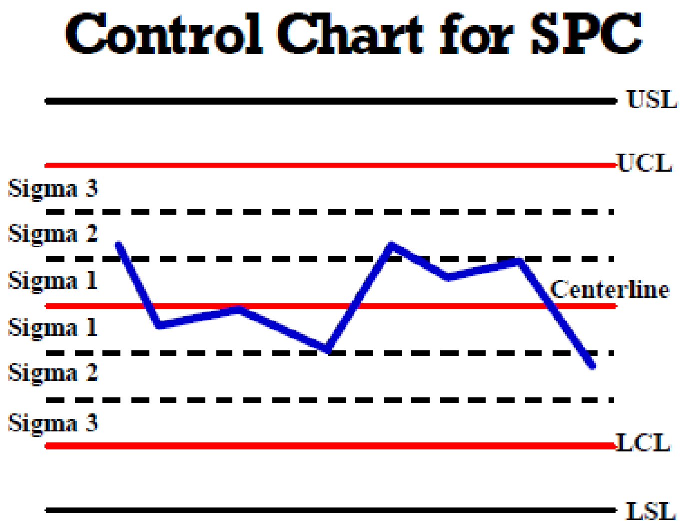

Figure 3. The upper and lower control limits of an effective SPC program are comfortably within the upper and lower specification limits.

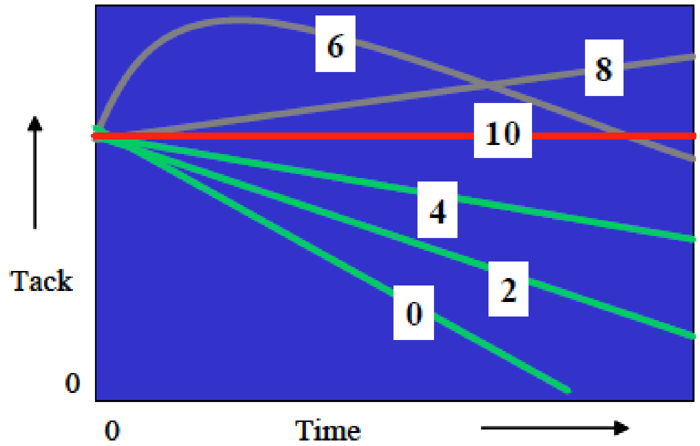

Figure 4. The ideal tack does not change over time. The figure shows a rating scale proposed by Lee, 10 is the best, 0 the worst.

The importance of printed volume consistency on end of line yields suggests that its determination is probably the most critical in solder paste evaluation.

Tack

Tack is the ability to hold the component on the PWB after it has been placed. Optimum tack will hold the component with an acceptable amount of strength that does not vary with time. Unfortunately, tack will typically vary with time, as shown in Figure 4. Lee[v] has proposed a rating scheme for tack, as shown in Figure 4.

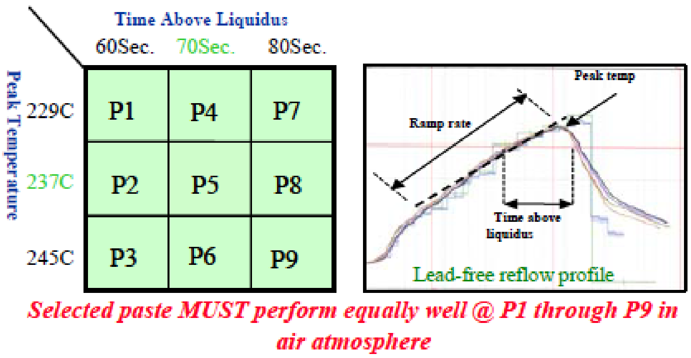

Figure 5. It is beneficial to have a large process window when using lead-free solder paste. Few pastes will reflow well from P1 to P9. Figure courtesy of Motorola.

Due to the concern for components surviving the higher reflow temperatures related to lead-free assembly, much more discipline is needed to assure successful reflow at minimum temperatures. Figure 5 shows nine profiles for Sn3.8Ag0.7Cu solder paste ($T_m = 217^0$C). In Goudarzi's work, only one solder paste was able to reflow with good wetting and coalescence with all nine profiles.

Reflow Characteristics

Most modern Pb-bearing solder pastes reflow relatively well. Reflow performance does not vary as much as printing performance. With Pb-free solder pastes however, reflow performance can very much more. Goudarzi[iv] has proposed, that for lead-free pastes, two reflow criteria are important:

- The paste reflows in a large "temperature and time above liquidus" window
- Post reflow, the solder shows good coalescence (See Figure 6.)

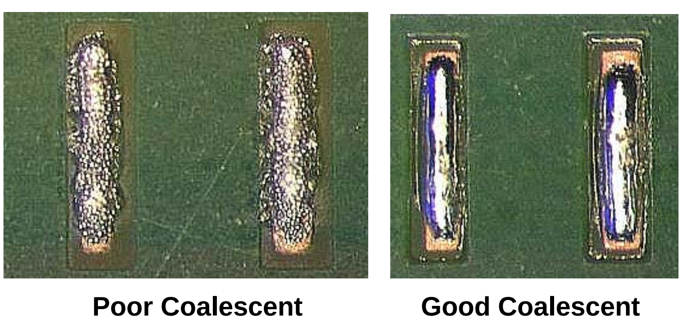

Figure 6. Lead-free solder pastes often do not coalesce well. This figure shows the difference between good and bad coalescing paste. Figure courtesy of Motorola.

SIR, Solder Balling, Slump, Wetting and Electromigration

J-STD-004 and J-STD-005 (IPC-TM-650) cover a wide variety of tests related to surface insulation, solder balling, slump, wetting, and electromigration. It is not our intent to minimize the importance of these tests, however, our experience is that most solder paste companies perform these tests with reasonable integrity and the data that the solder paste data sheets provide can be used in a screening process for assessing the pastes. However, after selecting the final candidates in any evaluation process, it may be wise to perform some of these tests yourself on the final candidates.

A PROPOSED SCREENING TEST FOR SOLDER PASTE

Considering the importance of stencil printing and the fact that most paste vendors faithfully test and report the results of their pastes for J-STD-004 and J-STD-005 (IPC-TM-650), a screening test for printed volume consistency, with visual analysis of print characteristics such as slump, bridging, etc., can quickly separate the top paste candidates from the also-rans.

Herber et al.[vi] had proposed such an approach, but it did not include measuring printed brick volume. It also required printing 27 boards. We propose an evaluation process that requires printing only 12 boards and has printed volume consistency as its foundation. See Figure 7.

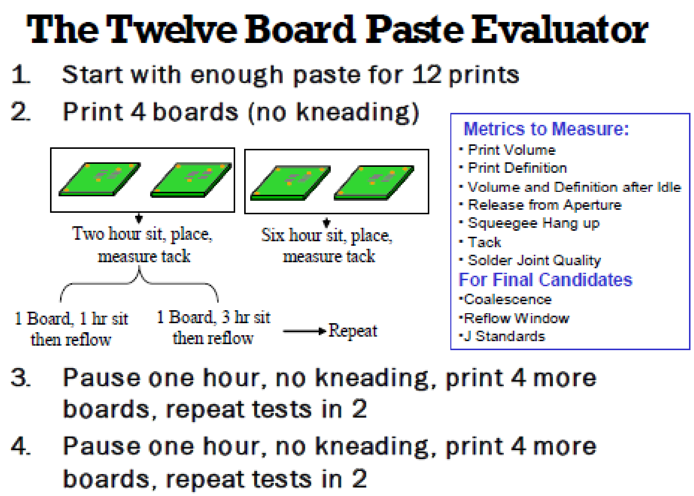

Figure 7. The 12-board paste evaluator.

To follow the 12-board paste evaluator process, start with enough paste for 12 prints. No kneading is done to the paste before printing. Four boards are then printed in Step 1 as shown in Figure 7. No stencil wiping is done during the prints. Print volume, print definition, release from aperture and squeegee hang up are measured. Two of the four boards sit for 2 hours and two of the four boards sit for 6 hours and then components are placed. Tack is then measured. One of the first two sets of boards sits for one hour and one for 3 hours prior to reflow. The same procedure is performed on the second set of two boards.

In Step 2 of Figure 7, the paste is left idle for one hour and the process in the previous paragraph is repeated. In Step

3, the paste is left idle for another hour and the process is repeated again. For initial screening, the process may stop at measuring printed volume consistency and definition. This approach may be reasonable as it minimizes work and poor printed volume consistence or print definition may eliminate a paste candidate.

For paste candidates that do well in printed volume consistency, tack, coalescence, reflow window size (larger preferred), solder joint quality, and the J-STD-004 and J-STD-005 standard tests may want to be verified.

An Example

We performed an analysis of three no-clean pastes to see how they performed with the 12-board paste evaluator. We printed through a 6 mil stencil using apertures for a 208 0.5mm QFP. Twenty (20) apertures were used for measuring the print deposits and the average volume of the apertures was 7,968mil^3. The printed volume consistency yielded quite striking results as seen in Figure 8. Each data point represents (for each print number), the average paste volumes of the aforementioned 20 aperture sites.

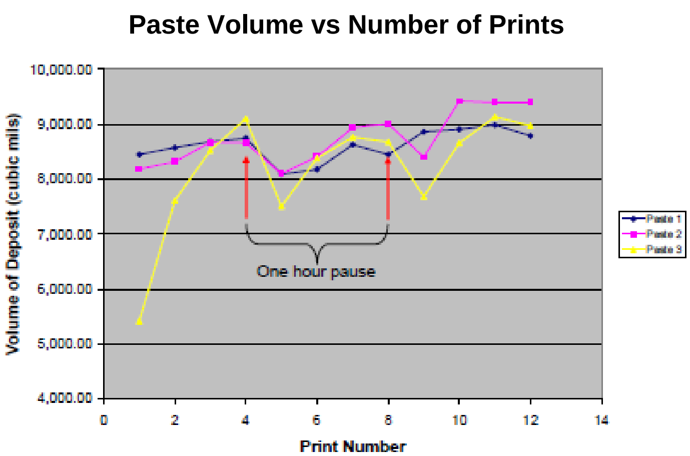

Figure 8. Printed volume versus print number in the 12-board paste evaluator. Note that we could eliminate Paste 3 after just this test as it has an unacceptable response to pause and poor printed volume consistency.

As we see from Figure 8, the printed volume consistency of Paste 3 is poor. It varies from about 5400 to 9050 cubic mils. It also shows an unacceptable response to pause, the first printed volume decreasing significantly after each one hour pause. The average of this paste was 8206 cubic mils (or an average transer efficiency (TE) of 1.03) and the standard deviation 1047 cubic mils. Paste 1 was, by far, the most consistent with an average of 8616 cubic mils (average TE of 1.08) but with a relatively low standard deviation of 279 cubic mils. Paste 2 finished second with an average printed volume of 8745 cubic mils (average TE of 1.10) and a standard deviation of 485 cubic mils.

Most SPC programs set control limits to +/- 3 standard deviations. Using these criteria, the best performer, Paste 1 would have control limits of 8616 +/- 837 cubic mils or less than +/- 10%. Typically, solder paste volume control of +/- 20-30% is needed. With these criteria, Paste 2 would still be a candidate at 8745 +/- 1455 or +/- 16.6%.[i] From a screening perspective, we have eliminated one paste and can now devote our resources to evaluating the other parameters for just Pastes 1 and 2.

In addition to printed volume consistency being the most important solder paste metric, our experience suggests it is the most variable among solder pastes. Hence, using it as the first criteria can save much time in screening pastes.

CONCLUSION

A 12-board solder paste evaluator is proposed. Although the solder paste evaluator includes all-important solder paste evaluation criteria, solder paste volume consistency is the first one evaluated. Due to the fact that solder paste printed volume consistency is the most important criteria for high end of line yields, this first part of the 12-board evaluator can be used as a screening test.

ACKNOWLEDGMENT

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