MEASURING TINY SOLDER DEPOSITS WITH ACCURACY AND REPEATABILITY

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ABSTRACT:

Miniaturization is an unrelenting force in the electronics industry. Components continue to get smaller and smaller, requiring even tinier solder paste deposits for assembly. This is a challenge for solder paste printing processes and material selections, and now we are reaching sizes that require further capabilities for analysis. A crucial step to assembling reliable PCBs is inline paste inspection. As deposits become tiny, it is much more difficult to accurately measure their volume. Different inspection technologies are proving to have very different results for small deposits because of how each technology calculates small volumes.

This study will look at improvements in how tiny deposits are measured, and the theory behind accurately (and repeatably) measuring them. The challenge of measuring tiny deposits is that a less-than-brick-shaped solder deposit occurs due to incomplete release from the stencil, resulting in a need to measure in closer proximity to the substrate because the deposits are not as thick. Also, the smaller the deposit, the more a computational inaccuracy will impact the results. Therefore, it is critical to understand the capabilities of inspection and define some best practices for measurement to prepare for further miniaturization of PCB assemblies.

Keywords: stencil printing, solder paste inspection, SPI, miniaturization

INTRODUCTION:

Miniaturization drives many of the requirements for the electronics industry. As devices for many applications get smaller, components and solder connections are pushed to the limits of reliable assembly using traditional methods. Reduced aperture sizes to accommodate smaller components, at some point (aperture ratio limit), drastically affect the ability of the solder paste to release from the apertures, leading to decreased print transfer efficiency.

Depending on the solder paste and the size of the aperture, smaller solder deposits that don't release well result in deposits which vary in shape and end up being shorter than the solder paste inspection measurement plane. Solder paste inspection algorithms had been developed with the goal of accurately measuring larger deposits (>10 mils). Smaller deposits that are often not as tall challenge the accuracy of current measurement algorithms. To accommodate the ability to measure tiny apertures, improvements have been made and tested that more accurately characterize the topography of the board and allow users to set a measurement threshold closer to the board.

This study focuses on the impact of these improved measurement protocols in measuring paste deposits from tiny apertures.

BACKGROUND:

Notes on transfer efficiency

In this study, transfer efficiency is the primary data collected. Transfer efficiency is defined as the measured deposit volume divided by the geometric, calculated volume of the stencil aperture. Although the bulk of the paste is transferred to the pad, some of the paste sticks to the walls of the aperture, resulting in less than 100% transfer efficiency, or insufficiency.

The interaction between the paste and the walls of the aperture vs. the pad is characterized as "area ratio." Area ratio is calculated by dividing the area of an aperture by the surface area of the walls of the aperture. Equations for this will include length and width of the aperture as well as stencil thickness. Aperture ratios for a 4 mil stencil are presented in Figure 1. Green fields denote aperture sizes with area ratios favorable to transfer. A rule of thumb is that most pastes will release for area ratios down to 0.66. However, this limit has been extended with improved printing processes to allow consistent printing of aperture ratios down to 0.5. The area ratios between these limits are denoted in yellow, while area ratios of concern are shown in red.

Aperture Ratio Chart (mils)

Aperture Size (mils)	11	12	13	14	15	16
Aperture Size (µm)	279.40	304.80	330.20	355.60	381.00	406.40
Stencil Thickness 4 mil	0.69	0.75	0.81	0.88	0.94	1.00
Aperture Size (mils)	6	7	8	9	10	
Aperture Size (µm)	152.40	177.80	203.20	228.60	254.00	
Stencil Thickness 4 mil	0.38	0.44	0.50	0.56	0.63	

Green: Typically within process window
Yellow: Marginal or attainable with newer generation products
Red: Not typically within the

Figure 1. Aperture ratio chart, showing area ratios for each aperture size, color-coded for ease of printing.

Notes on how deposits are measured

Solder paste inspection instruments vary significantly regarding their technology for measuring apertures, as well as the software algorithms used to program them. The basic premise for all instruments is that light will shine on the programmed areas of the board, focused on a point some distance above the surface of the board, where a solder paste deposit should be waiting for measurement. A typical measurement might occur at 35 microns above the surface of the board. To figure out the volume for the whole deposit (the part measured and the part below the plane of measurement), some extrapolation is calculated. As illustrated in Figure 2, this model works well when measuring deposits that are uniform below this plane and are well characterized in the measured area. However, as deposits are smaller and shorter, the measurement only catches part of the deposit, and the extrapolation omits significant portions of the deposit volume. Smaller deposits that are shorter and fall below the measurement plane will show zero transfer efficiency. The smallest deposit in the illustration would measure zero volume because the top of the cylinder is not intersecting the paste deposit.

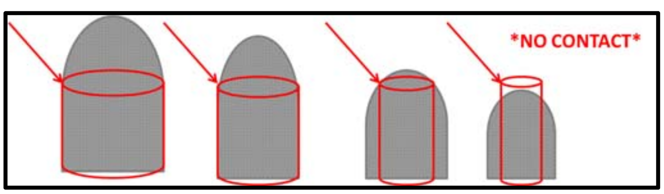


Figure 2. Illustration of solder paste inspection measurements. The arrow shows the level of the measurement plane. The paste above this arrow will be scanned and measured. The red cylinder represents the portion of the deposit that is extrapolated from the area of the deposit at its intersection with the measurement plane. A cylinder was chosen here for ease of illustration, but it should be noted that some software versions allow the shape of this extrapolation to be set for even more accurate measurement.

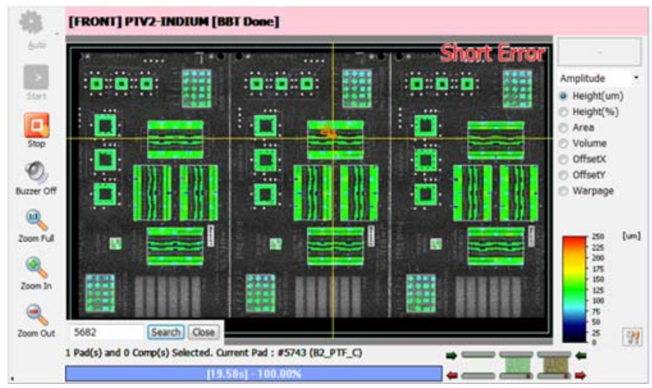
EXPERIMENTAL PROCEDURE:

The goal of this study is to show how transfer efficiency data varies with improved methods for measuring solder deposit volumes. Results were first observed for a typical solder paste designed for best-in-class printing performance with type 4 powder. In order to produce better deposits on the smallest aperture sizes, the same results were collected with a fine powder of non-standard "type 5.5".

Test Board Design:

Test boards were provided by Parmi USA. The main focus was on the twelve sections of the board with varying sizes of square and circle apertures down to 3 mils, as shown in Figure 3b.

3a.



3b.

Figures 3a and 3b. (a) Board overview. (b) Design detail for sections considered in this study.

During set-up, many of these boards were measured for topography in order for the software to produce a standardized topography for the test board. In Figure 3a, slight variations in pad height are shown. When the threshold of 10 microns is introduced into the software, the measurement algorithm takes into account the average measure of the pad heights for this board.

Test Parameters:

Boards were printed at 150mm/s with 8kg of squeegee pressure. The paste used was Indium8.9HFA, selected because of its high quality printing performance, with SAC305 powder sizes T4 and "T5.5".

Six boards were printed and then a stencil wipe was performed. Typically there was an hour pause and then another six boards were printed. The results from the second set of boards did not show significant differences and, therefore, are not presented in this study.

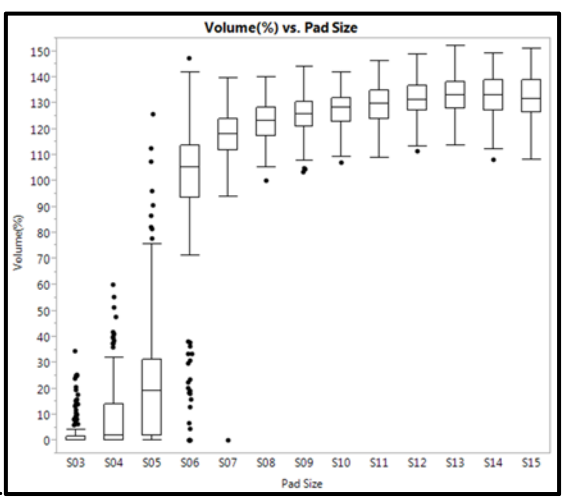
Solder paste deposits on each board were measured with no threshold, similar to how they would be using previous measurement algorithms. Images of the deposits in specific areas of the board were collected to compare with the measured shape of the smallest deposits. The same boards were then measured with a threshold of 10 microns away from the surface of the pad.

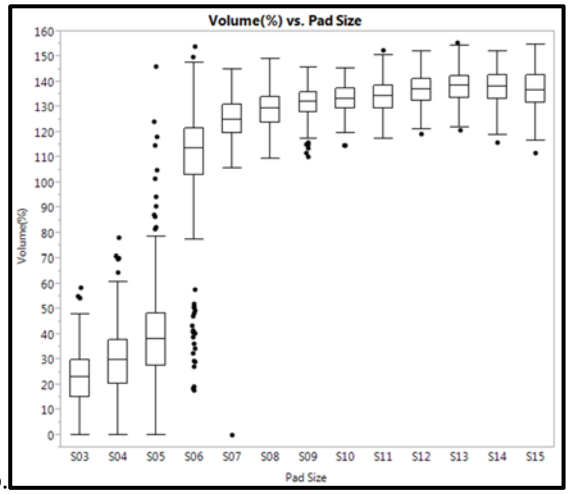
In order to maximize the transfer efficiency for this study, a few best practices for stencil printing were established: use a high quality stencil with even, smooth apertures, consider results for solder mask defined pads, optimize print speed based on solder paste formulation, apply only minimal squeegee pressure for a clean stroke, and optimized snap-off speed to encourage release.

EXPERIMENTAL RESULTS:

The most common powder size used for PCB assembly solder paste, especially for miniaturized applications, is type 4. Typically, pastes with type 4 powder are capable of consistent transfer efficiencies for apertures with area ratios higher than 0.6. For a 4 mil stencil, as used in this study, this equates to a 9 mil aperture as being the largest of the challenging apertures.

Figures 4a and 4b show box plots for all of the square apertures on one board. The boxes show the size of the scatter on the mean data, while the bars show the standard deviation of the data. Black dots outside of these box plots indicate individual outliers.

4a.


4b.


Figures 4a and 4b. (a) Boxplot results for square apertures on the fourth board, printed with T4 paste and using no threshold. (b) Boxplot for the same board analyzed using a threshold of 10 microns.

Looking at the box plots in Figure 4a, it seems clear that, regardless of the threshold, deposits larger than 8 mils are consistent, and consistently measured. Most of the differences are observed on the 3, 4, and 5 mil squares, which show low transfer efficiencies and lots of outliers. When the deposits are measured with a lowered threshold, the transfer efficiencies are considerably higher, with considerably fewer zero measurements. In looking at the 7 mil apertures, it is interesting to note that the measured transfer efficiency with a threshold is a little bit higher, but the one outlier (a pad with a clogged aperture) is accurately measured because it is repeatable for both thresholds. This missing deposit is documented in Figure 5.

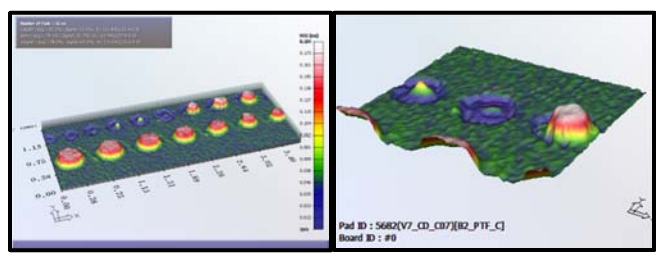
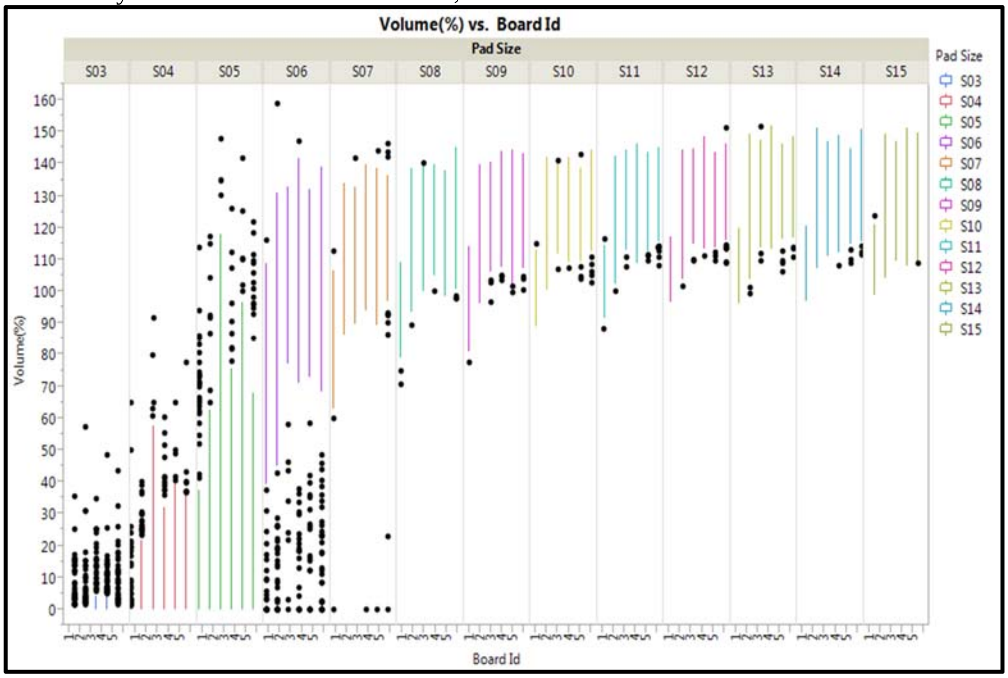


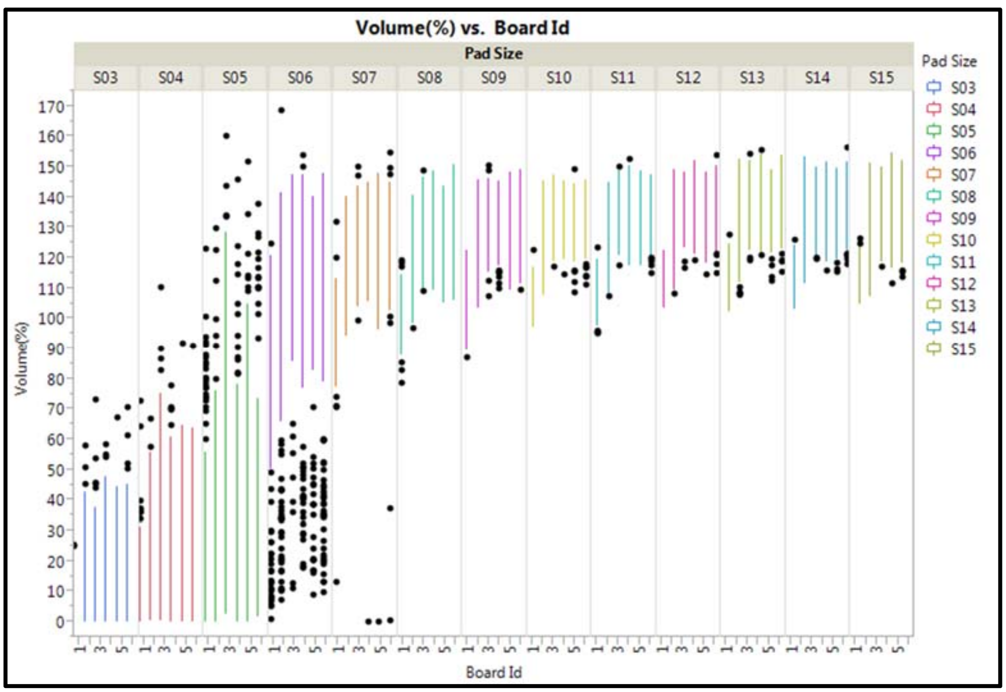
Figure 5. Shows detailed topography images of a missing deposit. The smaller deposits in the image on the left are 3-10 mils from left to right. In the zoomed image on the right, 6, 7, and 8 mil deposits are shown.

Instead of looking at box plots for every board printed (many different graphs for comparison), the following graphs combine results for all 6 boards. In the space provided for each aperture size, the results are shown consecutively for each of the six boards printed. Each colored line essentially shows the scatter for the deposits of that size on that board. The black dots indicate outliers.

The results for type 4 paste are shown in Figure 6. The trends seen in the box plot graphs are mirrored when looking at the complete data set. Deposits smaller than 8 mils show greater variability and low transfer efficiencies, especially in the data collected without a threshold.



6a.

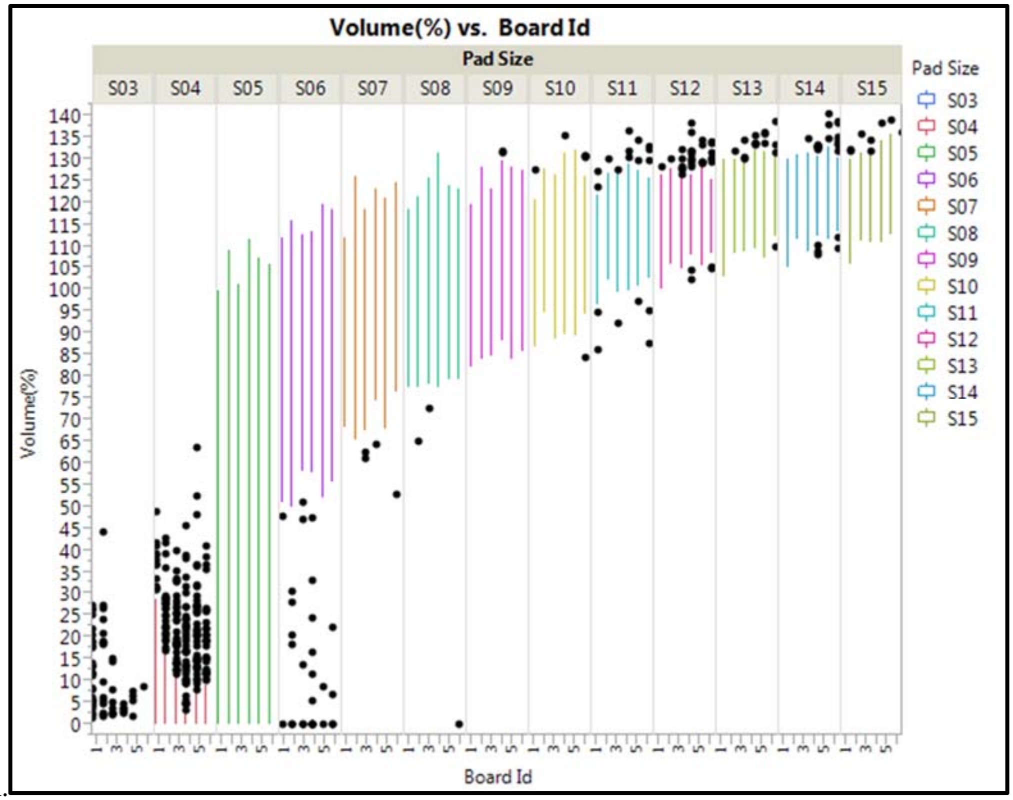


6b.

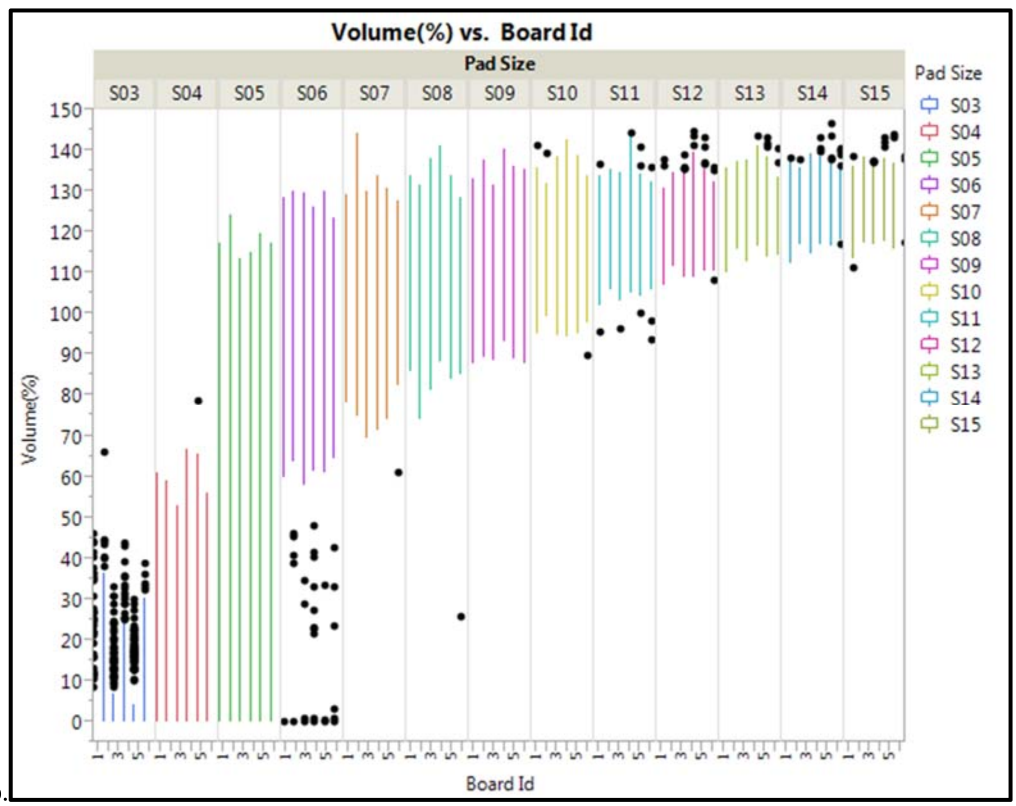
Figure 6a and 6b. (a) Results for T4 paste on square apertures, showing transfer efficiencies for six boards, grouped by pad size without a threshold. (b) Results for the same boards measured with a threshold of 10 microns.

Figure 6b also clearly shows that for small deposits of less than 6 mils, there really is very little transfer with paste containing type 4 powder. In order to improve the ability of these apertures to release, a finer powder size is analyzed. This powder is referred to as “type 5.5”, which is just a trimmed down distribution of powder within the type 5 range.

The results for the type 5.5 paste are shown in Figure 7. Because the paste releases more easily from the apertures, the shapes of the deposits are more consistent. The difference between the two powders can be seen most prominently for 5 and 6 mil apertures. The two smallest apertures do not release well in either case, but it is clear that the threshold value adjustment allows for a more accurate measurement of paste volume.



7a.



7b.

Figure 7a and 7b. (a) Results for “T5.5” paste on square apertures, grouped by pad size, without a threshold shows transfer efficiencies for six boards. (b) Results for the same boards measured with a threshold of 10 microns.

DISCUSSION:

Test results clearly show a difference in the volumes measured for printed solder deposits, especially on apertures with area ratios less than 0.6. Higher transfer efficiencies are seen because more of the deposit top is being measured. Additionally, the extrapolation reflects more representative data. Generally, having the data show numbers closer to the full 100% transfer is beneficial, but it is far more important to accurately characterize the small deposits. Perhaps these results also show that there is paste transferred through these small apertures, and indicate that lower pass/fail criteria could be used even without changing the algorithms for measurement.

CONCLUSION:

On the smallest apertures, the improvements made (setting the threshold for the measurement plane and specifying the shape extrapolated for small deposits) clearly show more measured volume and higher transfer efficiencies. Because there was little variation in the results for larger deposits, current measurement techniques are sufficient for deposits larger than 8 mils. For deposits as small as 3 or 4 mils, using the improved measurement techniques allows for characterization of the paste transferred. In these cases, because of the extremely low area ratios, it is not expected that paste would transfer to form a brick-shaped aperture, but for assembly of components with solder balls or other additional solder, a small amount of transfer can be enough. Since these small deposits are now measured, it is possible to set pass/fail criteria (different from the usual >50%, for example), and accurately characterize the transfer of these tiny deposits.