Dispensing Solder Paste Micro-Deposits to 0.2mm – A Process Solution

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Abstract
Solder paste dispensing is not a new process. However, today's microelectronics present a daunting array of technical challenges to meet deposit size requirements. The need for better paste formulations, more precise equipment, and more tightly controlled processes is driving paste suppliers and equipment suppliers to develop new methods and materials. The most challenging solder paste deposits are those smaller than 0.25mm in diameter and today's electronics demand such deposits. This paper addresses the process requirements for solder paste micro-deposits in terms of material, equipment and process variable control required for success in producing 0.25mm and smaller deposits.

Concept of Scale
Under ordinary circumstances, fluid pressure, auger pitch, auger rotation rate, tip design, and tip to substrate gap are the variables that must be controlled to ensure successful solder paste dispensing. When the goal is deposits of 0.25mm and smaller, some of these variables take on secondary roles and the process is dominated by other variables.

The microdot process becomes easier to understand if put into perspective. A typical process specification for a dispensing operation is to produce a particular deposit size +/- 10% at 3σ of the target diameter or mass. To apply a concept of scale, consider that an individual 0.25mm deposit is 40% the size of just the 10% error value for a 0.50mm deposit. That means a 0.5mm deposit can vary by four (4) times the amount a 0.25mm deposit can and still meet a +/- 10% variation limit. In getting yet smaller, an individual 0.10mm deposit is roughly 60% the size of a similar +/- 10% error when making a 0.25mm deposit. This means that deposit size control needs to be on the order of six (6) times better for a 0.1mm deposit than a 0.25m deposit.

Each time an auger valve actuates, it applies a force cycle on the solder paste. This force causes a small amount of separation both within the auger channel itself and beyond the auger within the dispense tip. As deposit size decreases, the number of force cycles paste is exposed to increases.

Among the tips tested, the dispense tip that contained the least material, from the bottom of the auger to the tip exit (Ref: Figure 1), was found to contain roughly 1600 0.50mm diameter deposits worth of solder paste. When making 0.25mm deposits, the quantity of cycles the material within the tip had to survive increased to 6,400. Just 0.05mm smaller at 0.20mm (Ref: Figure 2) the number of cycles is 10,000. In shrinking to a diameter of 0.10mm the number of cycles inflates all the way to around 40,000 and that is just for the material beyond the auger, not considering the material within the auger channel or in the syringe.

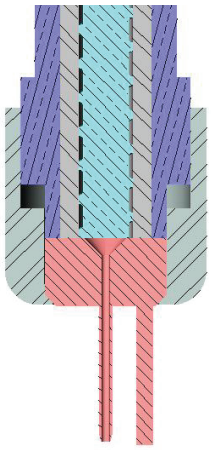

Figure 1 - Auger and Tip Assembly Illustration

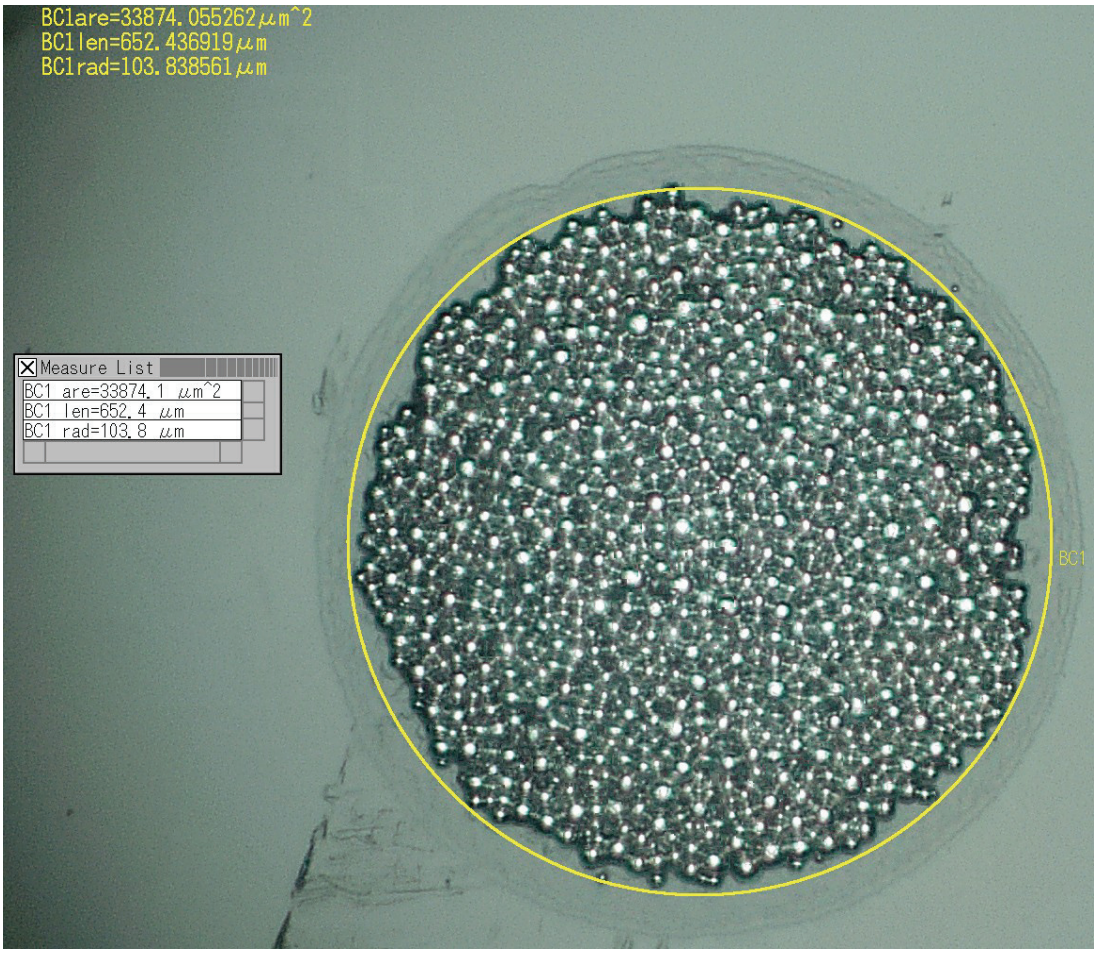

Figure 2 - 0.207mm Solder Paste Deposit

Scope of Microdot Dispensing Study

The goal of the complete study is to identify the degree to which each process variable influences the process and the range over which each needs to be controlled to ensure a successful process.

In the first stage of the study, reported on last year, the first step was identification of a solder paste product capable of surviving the rigors of microdot dispensing. Using that solder paste as a vehicle, a list of variables influencing the dispense process was identified and tabulated. The variables of valve type, tip design, and the relationship of Z-gap to deposit diameter (the distance between the tip and substrate) were explored for their impact on deposit consistency. Over the course of testing, two variables, Z-gap and temperature, were identified as having a significantly larger impact on deposit consistency than with larger deposits.

The second stage in the study focuses on controlling the variables of Z-gap and temperature so they can be evaluated individually. The scope of this report is the presentation of data and conclusions drawn in stage two. It begins to address the practical requirements for success in making solder paste deposits 0.25mm in diameter and smaller.

Experimental Method

The variables that were chosen to remain constants in the study were valve type, auger screw design, tip design, Z-gap and solder paste. The valve elements and tip design were chosen to remain constants as they are functionally hard tooling with predictable variability. The paste was chosen as a constant because only a single vendor's product proved capable of surviving the rigors of microdot dispensing conditions.

The variables remaining for study were system temperature, visual dot diameter vs. volume, valve control parameters, and dispense gap. Of these, results of testing for all but valve control parameters are presented in this paper.

One point of note is that with a static Z-gap, standard deviation for deposit size was not a meaningful measure of success as the range of deposits studied included both those larger and smaller than optimal for the Z-gap chosen. In all cases, data averages were used as those did accurately reflect material flow rate over a large population of deposits.

Experiment 1: Temperature vs. Deposit size
Method: Data was collected over the temperature range of 15°C to 29°C in 2°C increments with all other variables being kept equal. Dispense process temperature was maintained at a measured +/- 0.1°C. Measurements of dot diameter and mass were taken for each set and compared to identify the impact of temperature change.

Experiment 2: Diameter vs. Volume
Method: Dot diameter and dot mass data were collected over a range of dot diameters with the Z-gap kept the same. Dispense process temperature was maintained at a measured +/- 0.1°C within each dot set. Dot set diameter measurements and mass measurements [which directly correlate to volume] were compared to see if there was a predictable relationship between diameter and mass with all other variables being equal.

Experiment 3: Dispense Gap vs. Process Control
Method: Data was collected where the only variable allowed to change was Z-gap. Dot to dot Z-gap was varied by specific values. Pairs of dots, with different but specific Z-gaps, were measured for diameter over a range of Z-gaps. For purposes of evaluation, the sensitivity of the process was tested at two levels. The arbitrary thresholds constituting "failure" of the process were defined as the Z-gap difference at which the difference in average dot diameter for all the paired dots in a set was different by 5% and 10%, respectively. Figure 3 illustrates extreme examples of the classic behavior of too small, optimal and too large Z-gaps.

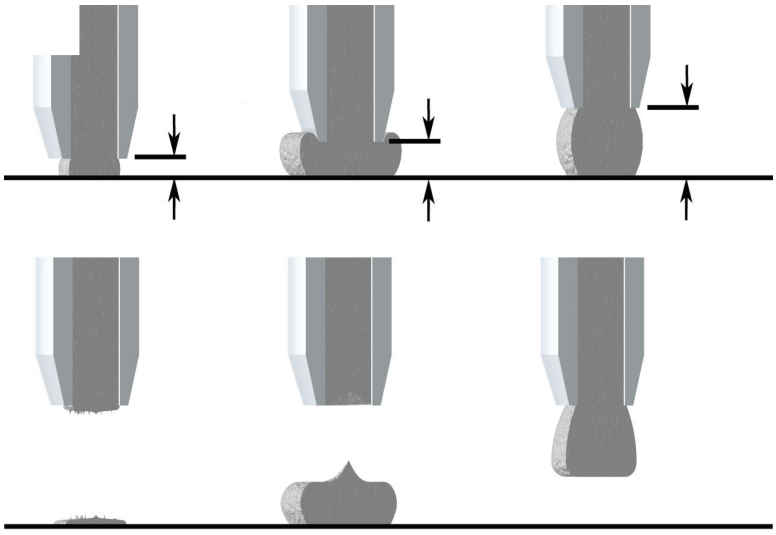

Figure 3 - Z-gap Impact on Deposit Formation Illustration

Experiment Results and Observations
Experiment 1: Temperature vs. Deposit size
Results: Series of deposit diameter measurements were averaged for each temperature tested at. The summary of this deposit diameter data is graphically displayed in Figure 4. Series of deposit mass data were averaged at each temperature. The summary of this deposit mass data is graphically displayed in Figure 5. Best fit polynomial linear regression formulae and R^2 values are included on the Figures.

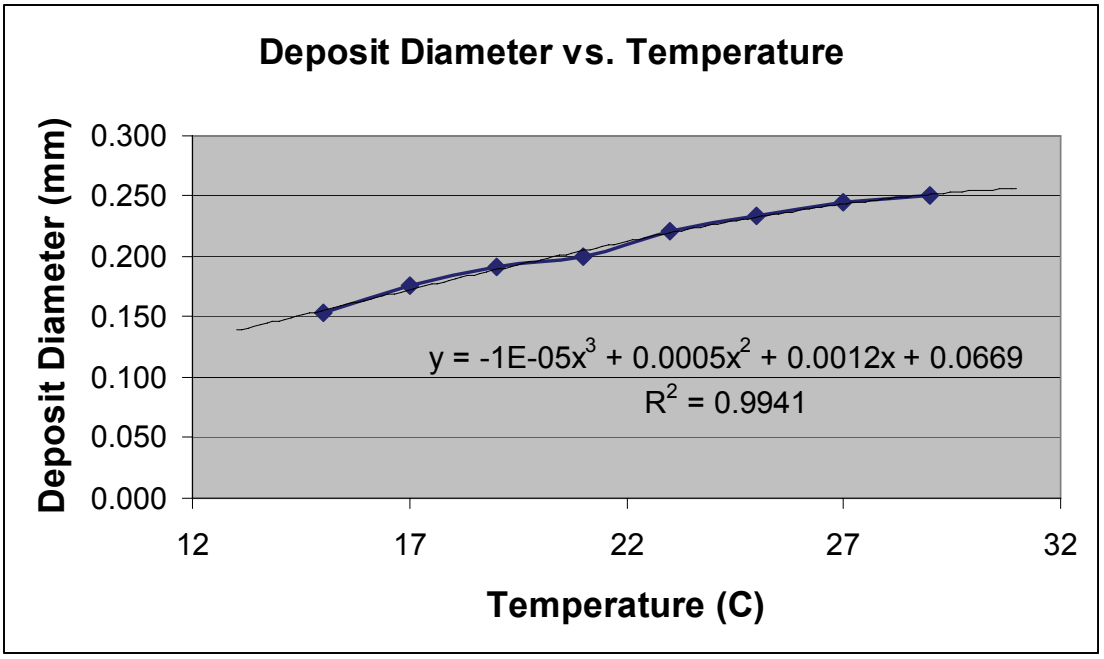

Figure 4 - Deposit Diameter vs. Temperature Graph

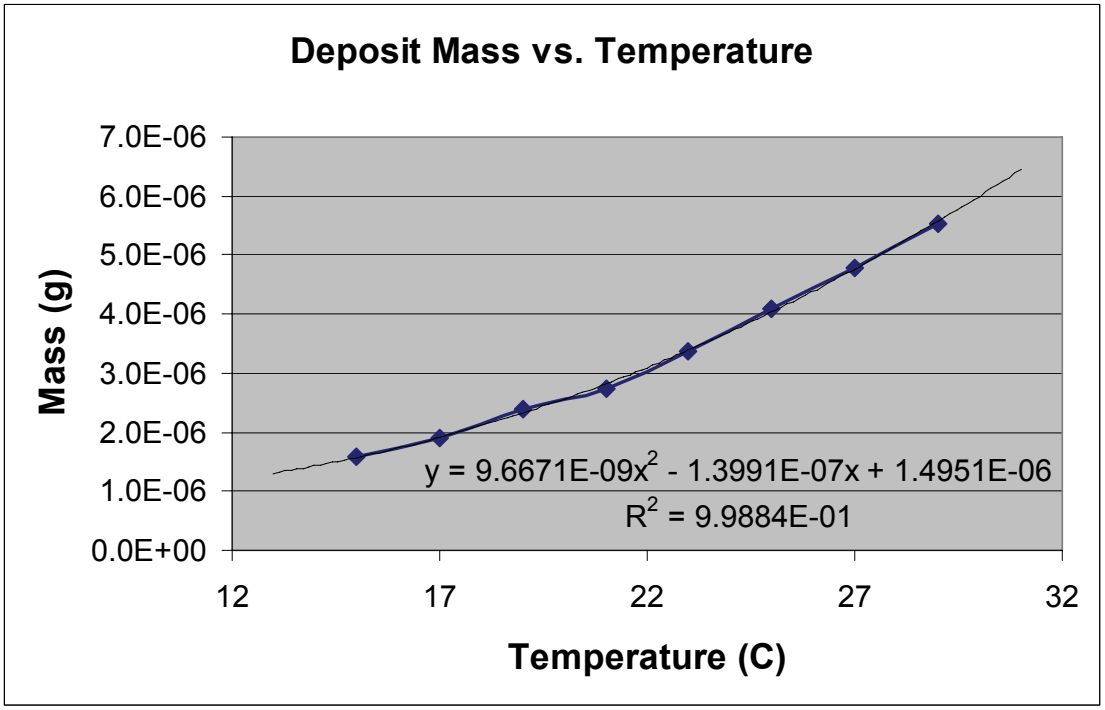

Figure 5 - Deposit Mass vs. Temperature Graph

Observations: With the exception of the 15°C deposit set, the first few deposits of each set had to be discarded. This was due to their being oversized as a side effect of paste flow under constant pressure since the pressure setting was not adjusted down as paste viscosity dropped. In a production environment, this "oversized first dot" phenomena would manifest itself as yield loss due to dot size variation. Material viscosity must remain constant for a particular pressure setting to remain appropriate when using an auger valve dispensing process.

Both data sets followed a remarkably regular polynomial curve and the high R^2 values suggest good predictability within a fairly wide range of temperatures. For the deposit mass results, it was necessary to use a second order polynomial as opposed to a linear relationship. It is suspected that this occurs because the pressure setting began having an effect on

deposit size as temperature increased due to declining viscosity. This phenomena will be investigated further in future elements of the study.

If the deposit mass values are compared from temperature to temperature in order of increasing temperature, the average mass increase is 9.8% per °C over the 15°C to 29°C temperature range.

Experiment 2: Diameter vs. Volume
Results: Series of deposit diameter and mass measurements were averaged over a range of deposit sizes. The summary of relative diameter and mass values is graphically depicted in Figure 6.

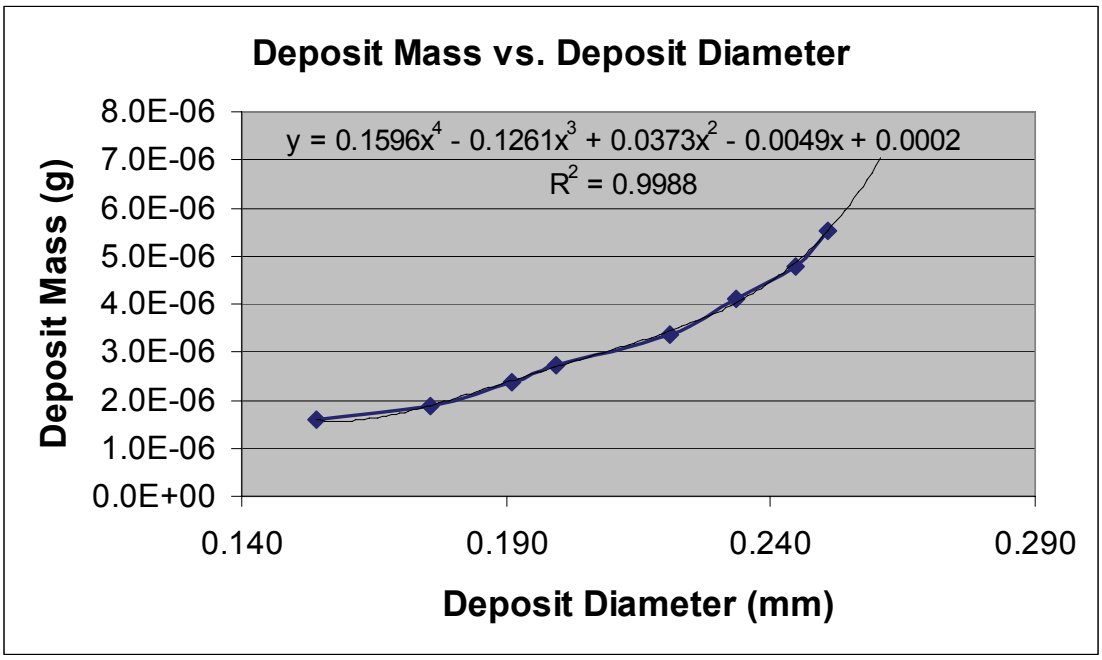

Figure 6 - Deposit Mass vs. Deposit Diameter Graph

Observations: The deposit diameter range over which the relationship between deposit diameter and mass was the closest to linear was from 0.19mm to 0.23mm. This range had been previously identified as optimal for deposit diameter consistency purposes for the Z-gap in use during stage two of the study with a Z-gap to diameter ratio on the order of 1:5 to 1:6.

Attempts at generation of a three dimensional mathematical model were unsuccessful and a third order polynomial regression does not predict the data points well enough to assume a geometrically proportional relationship. The fourth order polynomial regression does a much better job of predicting mass values within the temperature range, reflecting the effect of static Z-gap on deposit shape. The classic assumption that a deposit takes the form of a half sphere does not account for the true relationship between diameter and mass over the full range of diameters tested at the particular Z-gap used. The shape is closer to a spherical section with a small peak on top. Figures 7a and 7b graphically illustrate the change in deposit profile as the quantity of paste deposited increases while Z-gap stays constant.

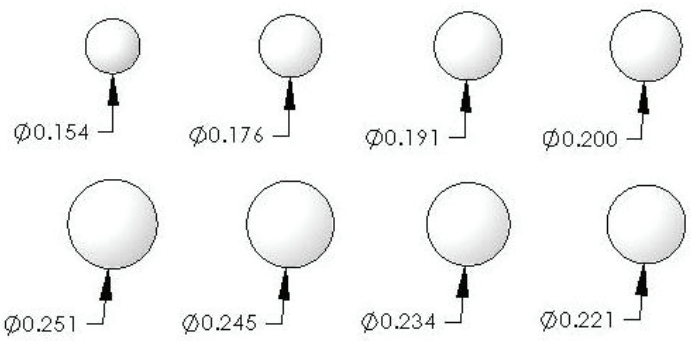

Figure 7a - Deposit Shape, Top Illustration

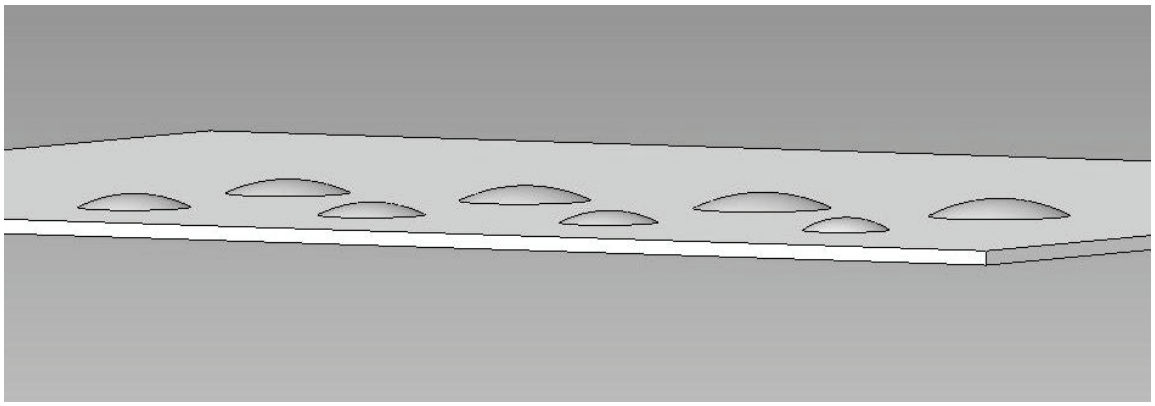

Figure 7b - Deposit Shape, Profile Illustration

Experiment 3: Dispense Gap vs. Deposit Variability
Results: Data sets were collected at five arbitrary deposit diameters. Deposits were generated three or more times at each diameter to identify inherent variability that had to be compensated for in data analysis.

Within each diameter set, calculations were made to determine at what Z-gap range, that is dot to dot difference in Z-gap, that the average deposit size from Z-gap 1 to Z-gap 2 crossed the thresholds of 5% difference and 10% difference. Z-gap was evaluated as both an absolute value and as a ratio relative to diameter.

Z-gap at failure dimensions relative to deposit diameter is graphically illustrated in Figures 8 and 9 for the 10% and 5% thresholds respectively.

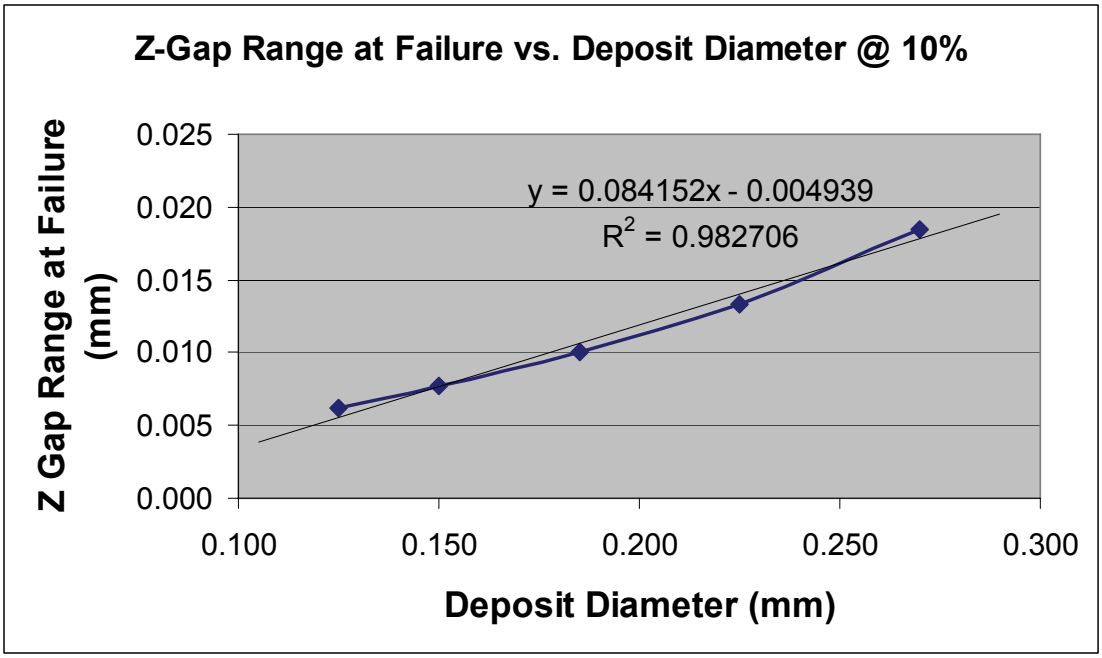

Figure 8 - Z-gap range at failure vs. Deposit Diameter @ 10% Graph

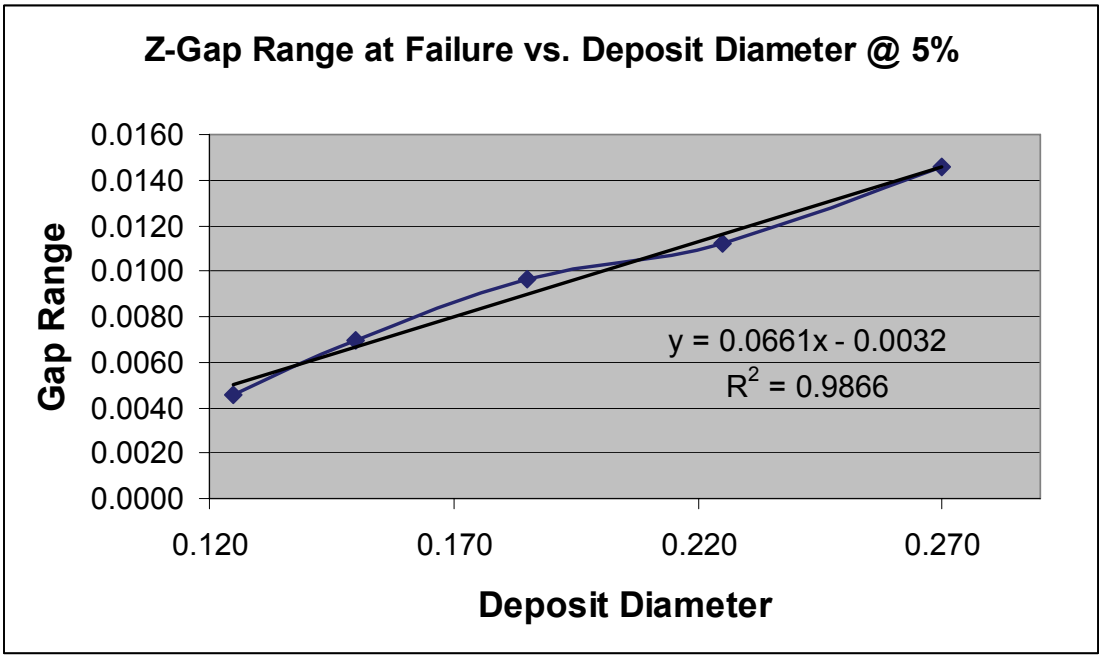

Figure 9 - Z-gap range at failure vs. Deposit Diameter @ 5% Graph

The relationship at both the 5% and 10% levels is remarkably linear. However, for the best fit the data matches higher order polynomials. This behavior is attributed to the relationship of deposit diameter to volume being non-linear. Without a system for absolute Z-gap control using such tools as hard stops and dedicated tooling, the challenge of substrate location and tip location becomes much more severe as we leave the 0.25mm deposit diameter realm and move towards 0.100mm.

To put this in perspective, consider the following… Based on the 5% linear relationship formula and a 0.250mm deposit, the predicted allowable limit for Z-gap variation is 0.0133mm total. Expressed as a tolerance this is +/- 0.00667mm or 6.67 microns. At a diameter of 0.200mm this tolerance drops to +/- 0.005mm or 5 microns. At 0.100 mm the tolerance had dropped to 0.00171mm or 1.71 microns.

At the 10% tolerance level, the allowable Z-gap variation does not change much. For 0.250mm, 0.200mm and 0.100mm diameter deposits the predicted Z-gap tolerance limits are +/-8.00 microns, +/-5.95 microns and +/-1.74 microns respectively. In comparison, the fourth order polynomial best fit, where R^2 approaches 1 to the 11^{th} decimal place, the predicted tolerances for 0.100mm deposits at 5% and 10% are +/-1.48 microns and +/- 2.29 microns respectively.

Conclusions

The combination of observations made for Experiments 1 and 2 point to two significant conclusions. First, with the expectation of maintaining deposit size to within 10% at +/- 3σ, a variation in temperature of as little as +/- 0.25°C can throw a seemingly well-controlled microdot dispensing process out of tolerance. Based on the mass variation data, a +/- 1.0°C process temperature will induce in the order of a +/- 9% to 10% deposit mass variation above and beyond the inherent variation in the process due to equipment and with no variation in Z-gap.

Within the data sets generated at each temperature, the deposit diameter variation at 3σ was between 7.1% and 9.9% for dot sizes appropriate to the Z-gap used. The deposit diameter data establishes that a repeatable process can be achieved at a particular temperature with a particular equipment and material set. The key difference between "conventional" temperature control and that used in the study is the degree to which control is available.

Second, the use of two-dimensional visual inspection criteria does not capture the true variation in a dispense process due to the non-linear relationship between deposit mass and deposit diameter. If the quality of a solder joint is dependent on the volume alloy in the joint, one of two things is required. Either the process needs to be characterized using methods similar to those in this study in order to identify the true range of deposit diameter variation allowable, or a three-dimensional deposit inspection system must be used that has sufficient resolution to detect the difference between acceptable and unacceptable variation in the deposition process.

Experiment 2 characterized Z-gap impact and provides a window to the technical challenges that next generation positioning equipment needs to overcome to meet the demands of deposition processes in the 0.100mm range. With expected tip-to-substrate position consistency limits predicted in the 1 to 2 micron range, new approaches will be required.

References

Vivari, John A., "Automated Dispensing of Lead-free and Leaded Solder Paste," GlobalTRONICS Technology Conference, Singapore, September. 2004.

Vivari, John A., "Dispensing Solder Paste Micro-Deposits to 0.2mm – A Process Solution," Electronics Packaging Technology Conference, Singapore, December. 2005.