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SUSTAINING A ROBUST FINE FEATURE PRINTING PROCESS

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ABSTRACT

With the introduction of 01005 chip components and 0.3 mm pitch CSP devices, electronic component packaging is pushing surface mount technology to the limits of its potential. Miniaturization is driving the electronics industry to implement the smallest and tightest pitch components in order to meet their customer demands. But how much miniaturization is possible before there is a paradigm shift in the technology? At what point is solder paste no longer viable? How small of a feature can be printed with solder paste, and can this process be implemented into a production environment?

Most of the factors and critical parameters in ultra-fine pitch printing have been well understood and documented for over twenty years. Some of these parameters are squeegee speed, squeegee pressure, stencil design (technology, thickness & area ratio), and solder paste. But as the pitch and aperture sizes get smaller and smaller, we begin to see that additional factors start to have an increased effect on the solder paste deposition (transfer efficiency). What are these factors and can we control them in order to obtain acceptable results for transfer efficiency and minimized variability? This paper will evaluate these additional factors and how they affect the transfer efficiency of the paste.

Key words: ultra-fine pitch printing, separation speed, stencil technology, stencil design, pad design, solder powder, tooling, solder paste, area ratio.

INTRODUCTION

There are several challenges in implementing an ultra-fine pitch surface mount process. This paper will focus on the solder paste printing portion. In order to understand all the parameters and effects on solder paste printing, we have developed a cause and effect or "fish-bone" diagram (see Figure 1 below). Using this diagram, there are six identified variables that contribute to the transfer efficiency:

1. Environment
2. Solder paste
3. Tooling
4. PCB design
5. Print process
6. Inspection

To simplify the experiments, we have eliminated several of these variables, such as solder paste, environment, and paste inspection. This allowed us to focus on the PCB design, tooling, and print parameters (such as separation speed and blade angle).

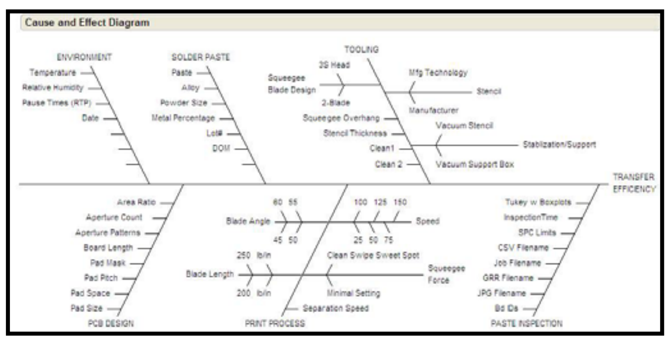


Figure 1 -- Cause & Effect Diagram of the Solder Paste Printing Process

DEFINITIONS

There are several terms that we will use throughout this paper, which should be defined to ensure clarity:

1. **Transfer Efficiency (TE):** The amount of material deposited on the stencil in relation to the theoretical maximum volume of material that could be deposited.

This is typically expressed as a percentage of the maximum volume.

2. **Print Area Ratio or Area Ratio (AR):** The area of the aperture opening divided by the surface area of the inside aperture wall. For a rectangular stencil aperture:

$$Area\ Ratio = \frac{(L \times W)}{(2 \times (L+W) \times T)}$$

3. **Contact Angle:** A function of the squeegee blade holder; the angle formed between the stencil and squeegee blade, as they first make contact with no force between them.
4. **Attack Angle:** This is a function of the contact angle, blade compliancy, print speed and paste rheology. The attack angle is the resultant angle formed by the sum of the static and dynamic forces acting on the squeegee blade during the print stroke.

TEST METHODOLOGY

Several experiments were conducted over the course of a month at Indium Corporation's Process Simulation Lab located in Utica, NY. Printing was conducted on a Yamaha YGP Solder Paste Printer. This machine, sold and supported by Assembléon, uses a servo-driven squeegee motor to change blade contact angle as a process parameter. This greatly widens the process window for printing fine features. It also provides the option to vary the squeegee angle for different process conditions (after an automatic wipe, after a pause in the process, first board printed in a batch, etc.). The net effect is to reduce the overall variation of the process from one board to another.

The solder paste used during the experiments was Indium 8.9HF, a no-clean, lead-free, halide-free material with type 4 powder, designed to meet the current and future challenges of miniaturization.

Tooling was optimized to provide a solid support underneath the stencil and along the entire length of the squeegee blade. Under-side support beyond the length of the board was added to ensure that the applied force of the blade was distributed evenly along the entire length of the squeegee.

Print speed, separation speed, and time between prints were varied. Additionally, the contact angle was varied from 45 – 60° via the servo-driven angle adjustment on the YGP's 3S (Single Swing Squeegee) head.

Volumetric paste print data was taken on a Koh Young 3020T 3D, a semi automatic solder paste inspection system. The data was normalized and analyzed for transfer efficiency (TE) on several sites of interest, namely the 0.45 mm pitch down to the 0.3 mm pitch devices.

For these experiments, a test board was used that incorporated 10x10µ BGA-style pad matrices of varying size (.05mm - 0.5mm) and varying pad spacing (.05mm - 0.5mm). A 3.5mil (89 micron) thick, electroformed stencil, with 1:1 square apertures was used. The board pads and pitch of interest for these experiments are shown in Table 1, below:

Pitch	Aperture/Pad Size (mm)	Aperture/Pad Space (mm)
0.45	0.25	0.20
0.40	0.25	0.15
	0.20	0.20
0.35	0.25	0.10
	0.20	0.15
0.30	0.20	0.10
	0.15	0.15

Table 1 -- Board / Stencil Patterns of Interest

Another variable introduced was the solder mask around the solder pads. For the very small spaces (below 0.2mm), the solder mask was completely removed between the solder pads (see Figures 2 & 3, below).

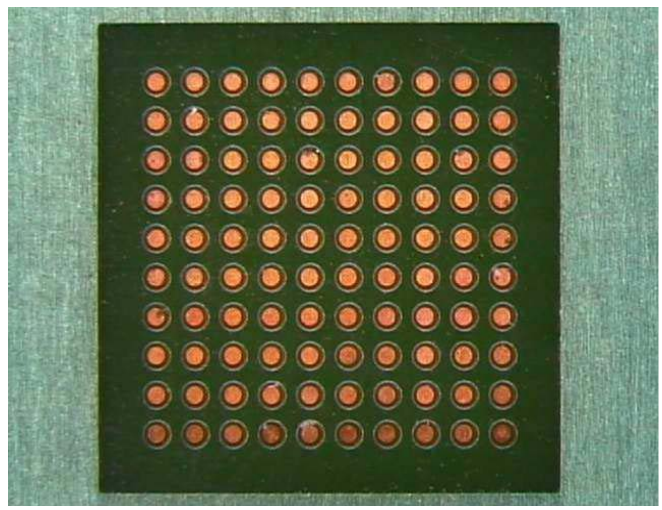


Figure 2 - 0.4mm Pitch Pad Design with 0.20mm Pads (8mils) & 0.20mm (8mils) Spacing

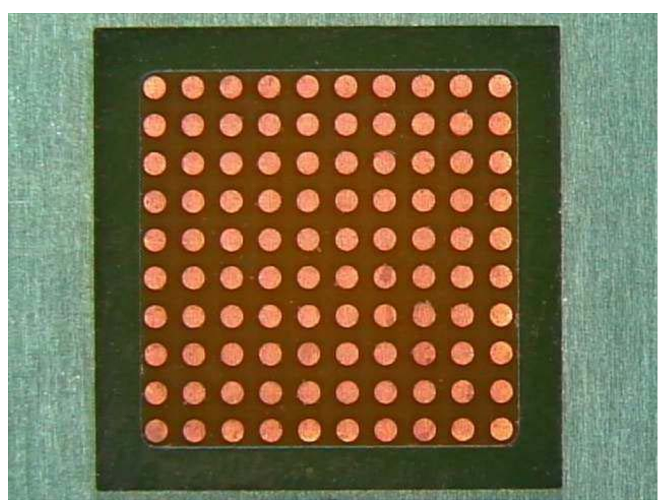


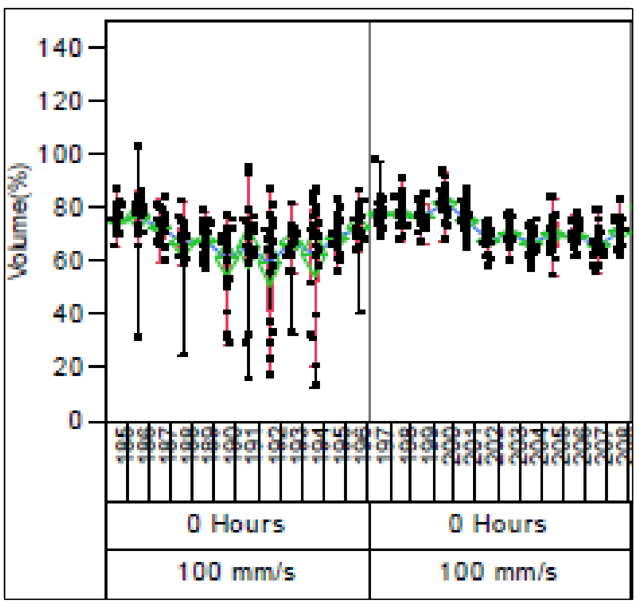
Figure 3 - 0.4mm Pitch Pad Design with 0.25mm Pads (10mils) & 0.15mm (6mils) Spacing

EXPERIMENTATION

Setup Optimization

In a previous experiment performed at Indium Corporation, two different board setups were compared to see how tooling and rail configurations affect the transfer efficiency of the solder paste deposition as area ratios are reduced below 0.66. Figure 4 is a comparison of the transfer efficiency data from these two conditions. Setup A (left) is a standard configuration and Setup B (right) is an optimized configuration, where the focus was to improve the board-to-stencil gasketing. This optimized setup includes the use of vacuum tooling, the elimination of edge board clamps, and a slight drive of the board into the stencil.

From the data, we observe a much tighter distribution of the transfer efficiency for the optimized Setup (B) of the 0.625 area ratio openings. Based on this data, we can conclude that as the fine pitch features are reduced below the standard 0.66 area ratio limit, the board setup and tooling process become more critical to obtaining consistent and repeatable results. This dramatic improvement was the driving force for us to optimize the board setup prior to performing additional print studies.



Setup A Setup B

Figure 4 – Transfer Efficiency Comparison of a 0.625 Area Ratio for Different Printer Setups

Separation Speed and Blade Angle

Once the board setup and fixturing were optimized, the next experiment was designed to observe the effects of separation speed and squeegee angle on the transfer efficiency. The Yamaha printer is capable of varying the squeegee angle from 45 - 60° and these angles were adjusted in 5° increments throughout this experiment. Additionally, two different separation speeds were used - slow and fast. A summary of these conditions is as follows:

Fixed Conditions

- Print Speed: 50 mm/sec (1.97 in/sec)
- Squeegee Force: 40N (4.1kg)
- Blade Length: 350mm

Variables

- Squeegee Angle: 45°, 50°, 55°, 60°
- Separation Speed: Slow (2mm/sec over 2mm), Fast (standard table lift speed)

Total Experiment Conditions = 8

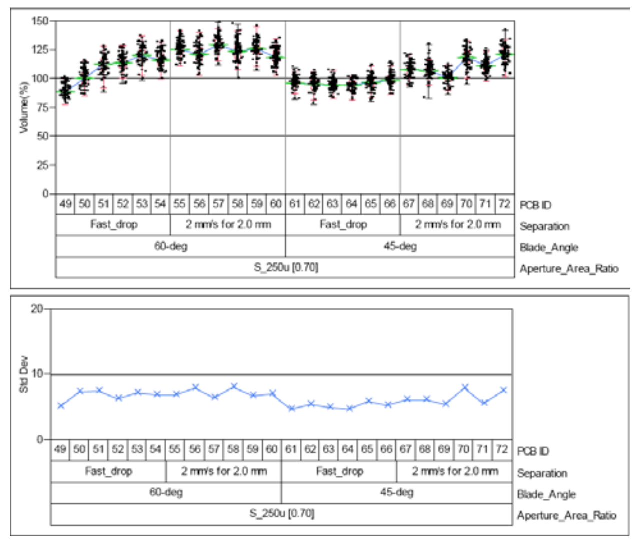


Figure 5 - Variability Chart for Volume % (TE) – Component Pad 0.25 x 0.15 (Area Ratio of 0.70)

The results from the separation speed and squeegee angle experiment show that for the larger pad size (area ratio of 0.70) there was not a significant difference between the different squeegee angles and separation speed (Figure 5). For smaller paste depositions (area ratios below 0.66), the differences become more pronounced (Figure 6 & 7, below).

For short-term decision making, comparing data sets in a box-plot format can be unreasonable, but fortunately a short-cut method can put entire sets together on a single page. Consider that the (100%) target value of the axis setting on the box plots indicates the transfer efficiency data could have a 1:1 relationship with the variance. This is because the standard deviation is the square root of the variance. Consequently, good print quality will have a transfer efficiency variance value less than 100%. To compress the information from multiple print trials, the variance-to-mean ratio (VMR) can be taken from a set of VMR values plotted on a line chart.[1] Points on the line would represent the aperture size and pad design combination. Points that remain below 1.0 indicate that the print quality is good. An entire line below 1.0 will serve to visually indicate that the entire combination of apertures and pad designs has good print quality. Several lines on the VMR line chart can represent an alternate attribute in the process; for example, stencil separation speeds.

Entire VMR lines that remain close will show similar print quality. VMR lines or points on a VMR line that diverge can show precise differences in the stencil printing process. At times, the transfer efficiency specification limits may be unknown. The line chart in Figure 7 indicates a pronounced difference for fast separation speed. In a production setting, an adequate volume of paste is present from a transfer efficiency of 65-85% on 200-250µ (8-10mil) square apertures. The true target may not be 100% transfer efficiency as implied in the box-plot, but instead 65-85% with low variation. The VMR line charts can be used to show qualitative and quantitative differences. The actual volume, SPC specification limits, and other information remain important knowledge to clearly characterize a 0.4mm pitch process. However, the VMR line chart technique for precision stencil print process combination will show its benefits for characterizing attributes for fine feature assembly designs.

We observed that the lower squeegee blade angles (45° & 50°) provided the better and more consistent results compared to the higher angles (55° & 60°). Additionally, the faster separation speed at low angles provided more consistent print volume results compared to a slow separation speed.

The fast drop results were different than what we had expected for a more consistent paste volume. Previously it was thought that if the release of the printed board from the stencil was slow, it would allow the paste to release more completely from the walls. The results from this experiment for these apertures appear to contradict this standard belief.

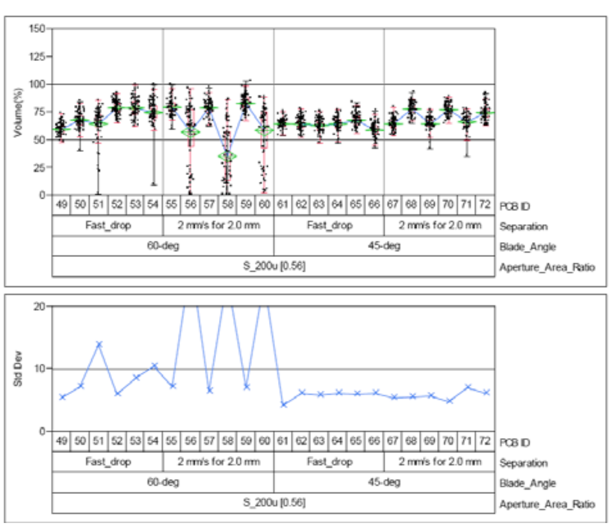


Figure 6 – Variability Chart for Volume % (TE) – Component Pad 0.20 x 0.20 (Area Ratio of 0.56)

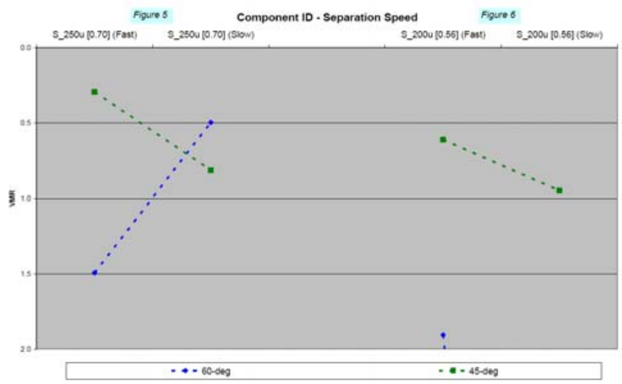


Figure 7 – VMR Chart for Separation Speed and Blade Angle

Blade Angle & Print Speed

For the final experiment, it was decided to vary the squeegee angle from 45 - 60° and the squeegee speed from 25mm/sec to 200mm/sec. The goal of this experiment was to determine the effect on transfer efficiency of the various squeegee angles and squeegee speed on different pad sizes and pitch. A summary of these conditions is as follows:

Fixed Conditions

- Separation Speed: Fast (standard table lift speed)
- Blade Length: 350mm

Variables

- Squeegee Angle: 45°, 50°, 55°, 60°
- Print Speed: 25, 50, 75, 100, 125, 150, 200 mm/sec
- Squeegee Force: Optimized for print speed (see table below)

Total Experiment Conditions = 28

First, the optimum squeegee pressure for each squeegee angle was determined. This was achieved by starting with a very low squeegee pressure (<0.5 lbs per inch of blade length) and then increasing the pressure until a clean wipe of the solder paste across the stencil was obtained. This was completed for each squeegee angle and speed. Table 2 below summarizes the results for the optimum squeegee pressure for each angle.

		Squeegee Speed (mm/sec)						
		25	**50**	**75**	**100**	**125**	**150**	**200**
Angle (deg)	**45**	30	40	45	55	65	75	90
	50	35	45	50	50	65	70	75
	55	30	40	40	55	60	65	70
	60	25	40	40	40	55	55	70

Table 2 - Determining Optimum Squeegee Pressure for Various Print Speeds & Print Angles

The different pad sizes and pitches that were measured for this experiment shown in Figure 8 below:

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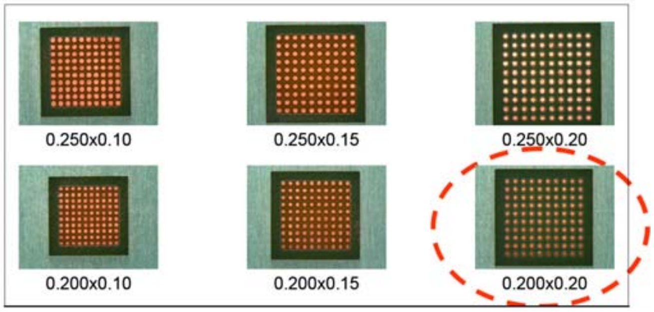


Figure 8 – Patterns of Interest for Measurement [Pad Size (mm) x (Pad Space (mm)]

First, we looked at the print results of the 0.25mm pads (AR = 0.7) and the 0.20mm pads (AR = 0.56) and compared them with the two different spacings (0.2mm and 0.15mm).

Note: As stated previously, the pads with 0.15mm aperture spacing have the solder mask removed between the pads on the board.

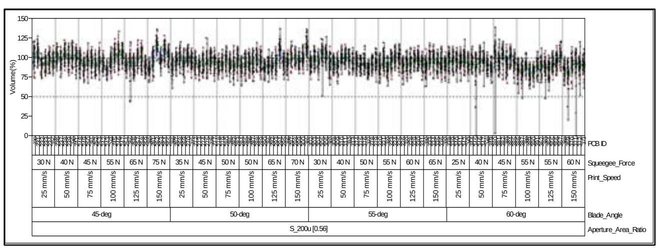


Figure 9 - Variability Chart for Volume (%) Component ID=0.250 x 0.20

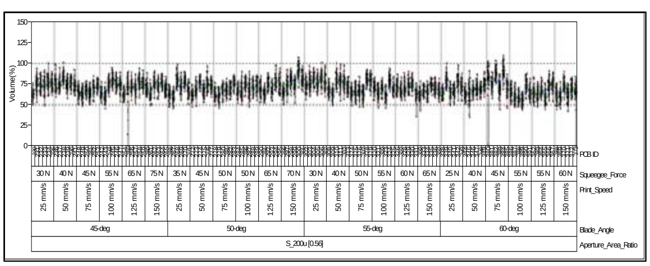


Figure 10 - Variability Chart for Volume (%) Component ID=0.250 x 0.15

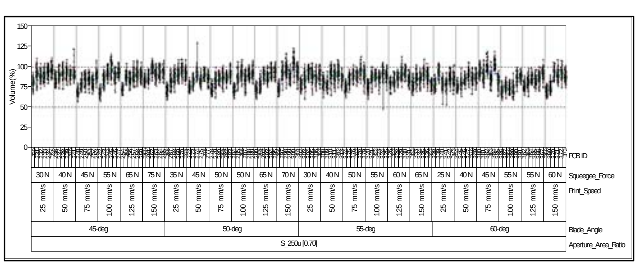


Figure 11 - Variability Chart for Volume (%) Component ID=0.200 x 0.20

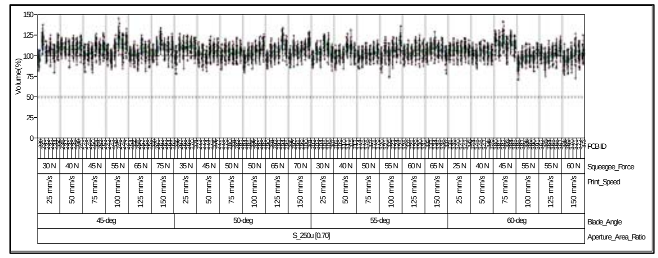


Figure 12 - Variability Chart for Volume (%) Component ID=0.200 x 0.15

The results (Figures 9 – 12 above) show that the variation between prints is not significantly different, but the average transfer efficiency is different. The average print volume for the tighter pitch (0.15mm) is approximately 100%, and is an average of 15% higher than the 0.2mm pitch.

Why does the average volume increase for the same pad aperture openings? The increase in the transfer efficiency is believed to be caused by the absence of the solder mask between the pads. This result suggests that the pads without interstitial solder mask may provide a better local gasket of the stencil to the board and thus increased transfer efficiency.

Additionally, the very nature of how an electroformed stencil is created might be a factor. Electroformed apertures could be created with different dimensional characteristics when the apertures are closer together. The tighter physical space locally can alter the rates of electrodeposition during the hours the mandrel is in the bath. This variance (most likely in the local thickness of the stencil) would affect the overall area ratio and, as a result, the transfer efficiency. Analysis of print height and print volume data (Figures 9-12) further support that local stencil thicknesses differ and enhance volume transfer efficiency.

Next, we observed the transfer efficiency results for the 0.25mm and 0.20mm aperture openings with a 0.10mm aperture spacing (Figure 13 & 14). The data shows that there is a large variation for 45 and 50° squeegee angles compared to the 55 & 60° angles.

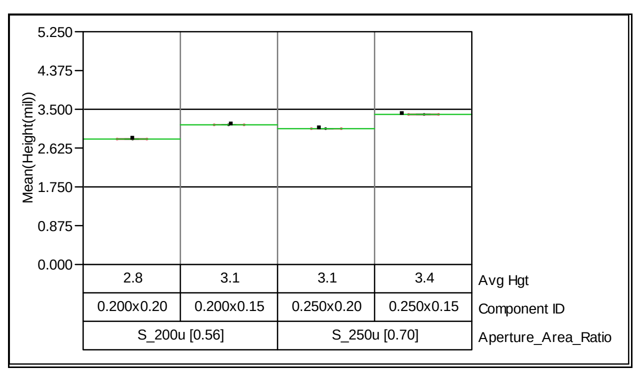


Figure 13 – Local thickness of the stencil would affect the overall area ratio and, as a result, the transfer efficiency. Analysis of the paste height indeed indicates local thickness differs.

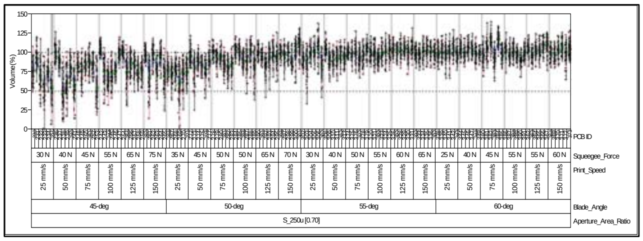


Figure 14 - Variability Chart for Volume (%) Component ID=0.250 x 0.10

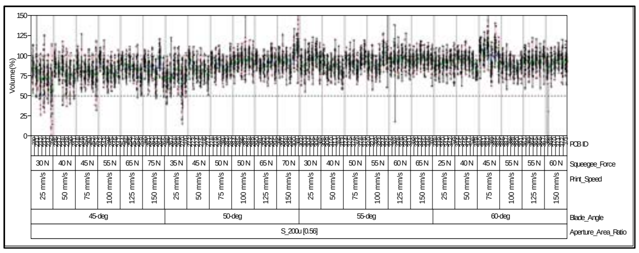


Figure 15 - Variability Chart for Volume (%) Component ID=0.200 x 0.10

In a previous experiment completed at Yamaha, the actual measurements of the squeegee pressure were taken using a pressure transducer mounted into the stencil aperture[2]. The measured results (Table 3) show that as the squeegee angle increases (45 - 65°), the actual paste filling pressure is significantly decreased. In light of this, one possible reason for the increase in the print variation for the lower squeegee angles is that the paste pressures for these angles may be too high. Too high a fill pressure will cause the solder paste to be squeezed out between the pads. This data suggests that that an optimum pressure for printing these apertures might be achieved at angles of 55° and above.

Squeegee Angle	Max Pressure
45	13.05 KPa
50	10.86 KPa
55	9.81 KPa
60	8.18 KPa
65	7.56 KPa

Table 3 – Squeegee Pressure versus Squeegee Angle

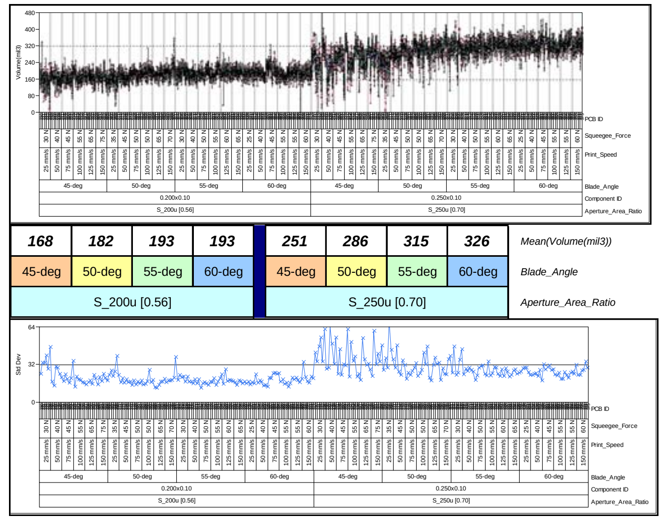


Figure 16 - Analysis of print volume data compares volume variation among blade angle.

CONCLUSION

Throughout the years of solder paste printing, there are well documented reports on what the critical parameters are and how they impact solder paste deposition. These parameters are squeegee speed, squeegee pressure, and stencil design (technology, thickness, and aperture size). The goal of these experiments was to see if other factors have an increased effect on the transfer efficiency as the pad sizes and pitch get smaller.

Our results have shown the following:

1. The board set-up is a critical parameter in printing fine features. Specifically, the board gasketing is improved dramatically by holding the board flat without any topside clamps during the print operation. Additionally, supporting the stencil along the entire length of the squeegee blade improves print definition and transfer efficiency even further,
2. A fast separation speed can have a significant positive effect on reducing transfer efficiency variation. Fine feature pads that are located near the end of the board (close to the rails) may need further investigation on the effect of the separation speed.
3. As the pad size and spacing are decreased, the squeegee angle has a greater effect on transfer efficiency and the consistency of the print deposition.
4. Solder mask in between ultra-fine pitch apertures can be a significant source of variation in the overall transfer efficiency. The effect of solder mask needs to be studied further to draw accurate recommendations for pad design.
5. Lastly, since most printers will not allow the variation of the squeegee angle as a process parameter, until now we have not been able to test the effects of blade angle on process variation throughout the course of the day. Having the ability to change the angle during a print run can offer the end user significantly greater consistency

when faced with events such as a stencil wipe, changeover, or pauses in the print cycle.

This analysis has shown that in studying ultra-fine feature printing, we have revealed several new print parameters that can contribute to the process variation. Previously, these additional parameters have not had a large effect on the printing of standard devices used in the industry today. However, as the pitch and stencil aperture openings decrease, the variables of squeegee blade angle and squeegee speed become an important factor in minimizing insufficient prints and maintaining low print variation.

For an ultra-fine feature assembly, an insufficient deposit can be directly related to rework which is undesirable for optimum end of line yields. Even the smallest variations in the process have significant consequences in these applications. Therefore, the entire printing process must be characterized prior to implementation.

[1] *Anglin, C., "Establishing a Precision Stencil Printing Process for Miniaturized Electronics Assembly," IPC Technical Conference, March 29-April 2, 2009.*

[2] *George Babka, " Moving Towards a Stable Process: Minimizing Variation in Solder Paste Printing," Originally distributed at the International Conference on Soldering and Reliability," Toronto, Ontario, Canada; May 20-22, 2009.*

Figure 1:

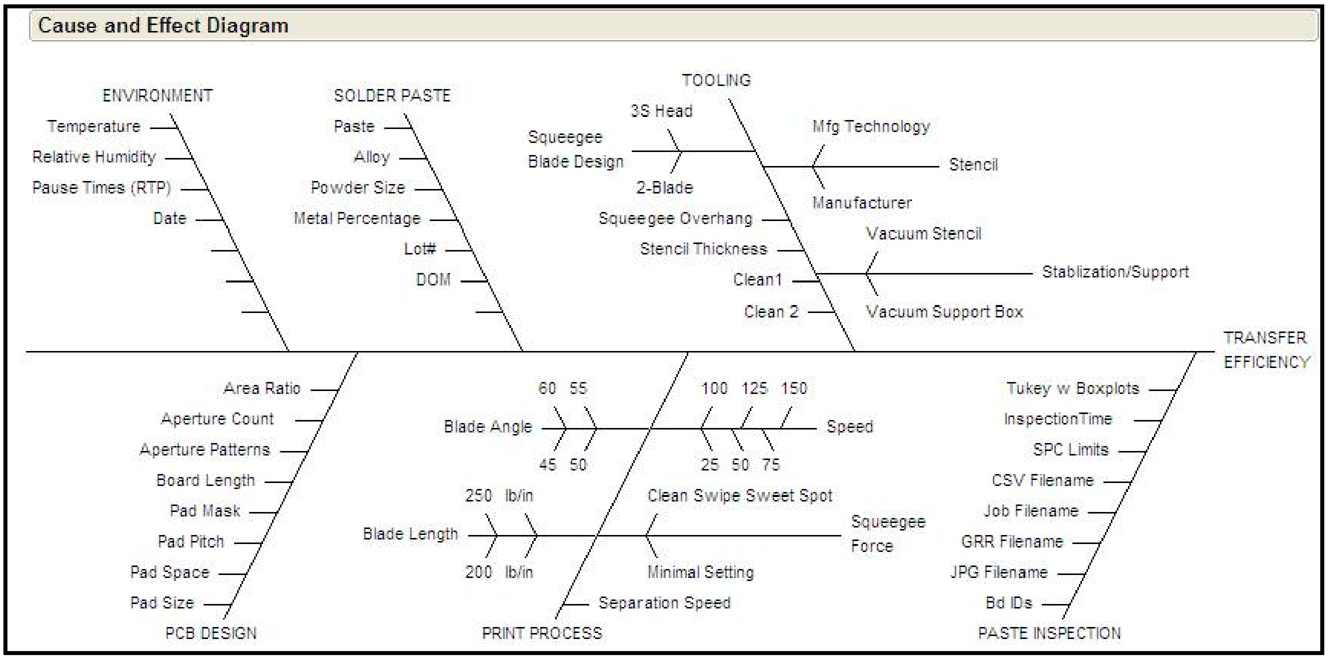
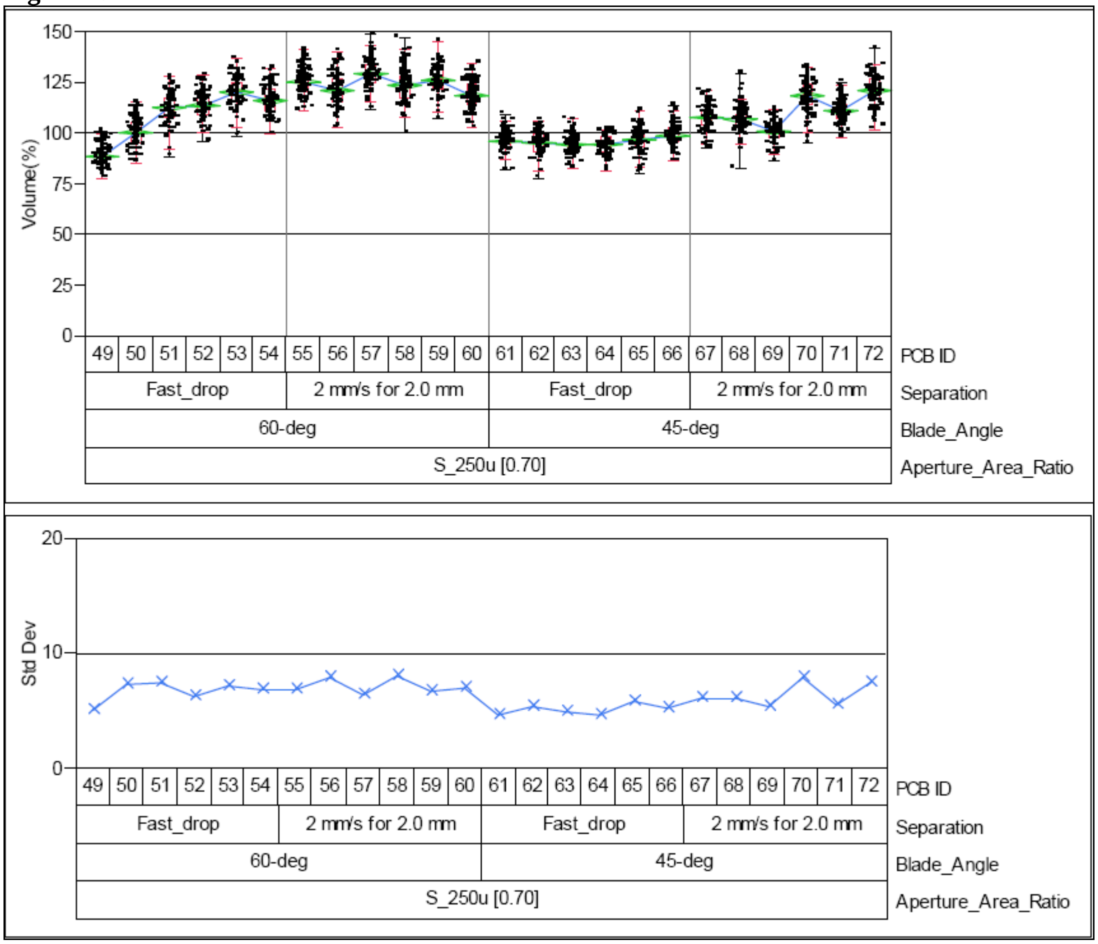


Figure 5:



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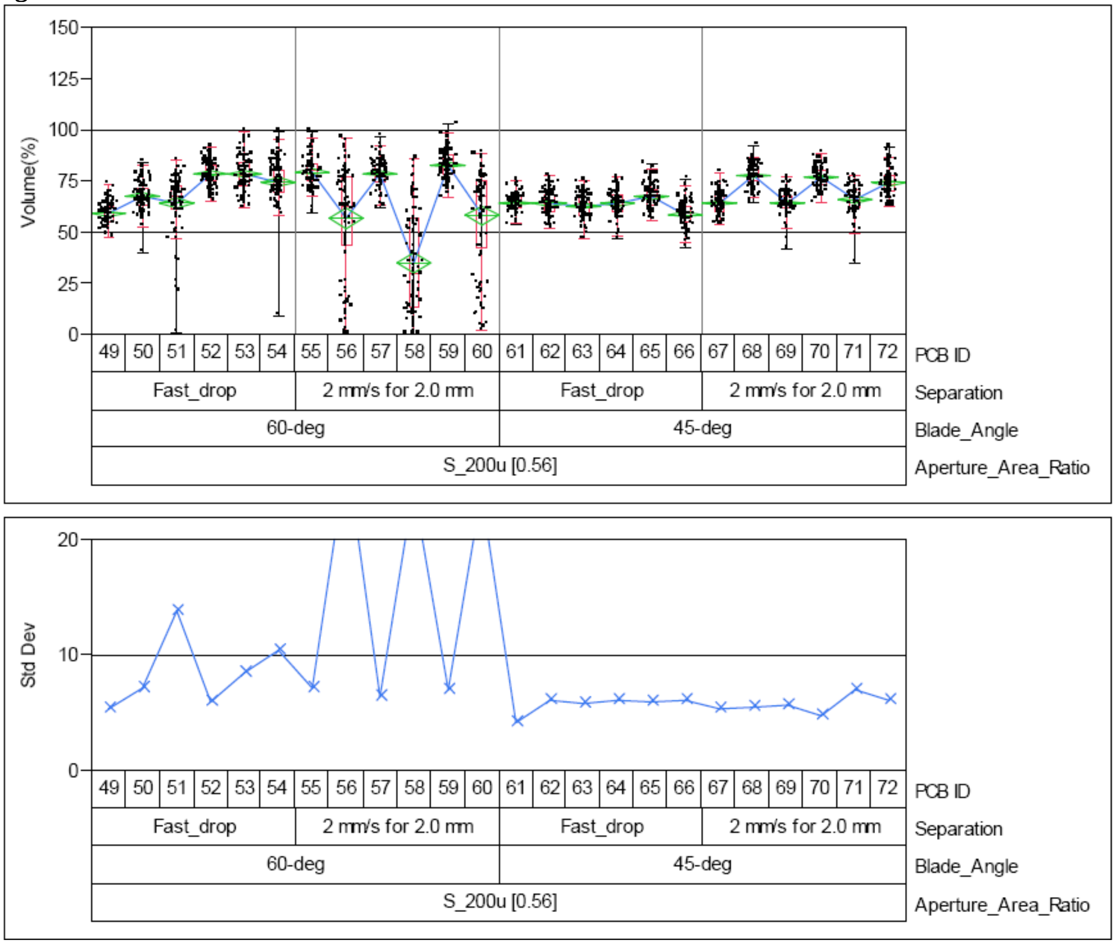


Figure 7:

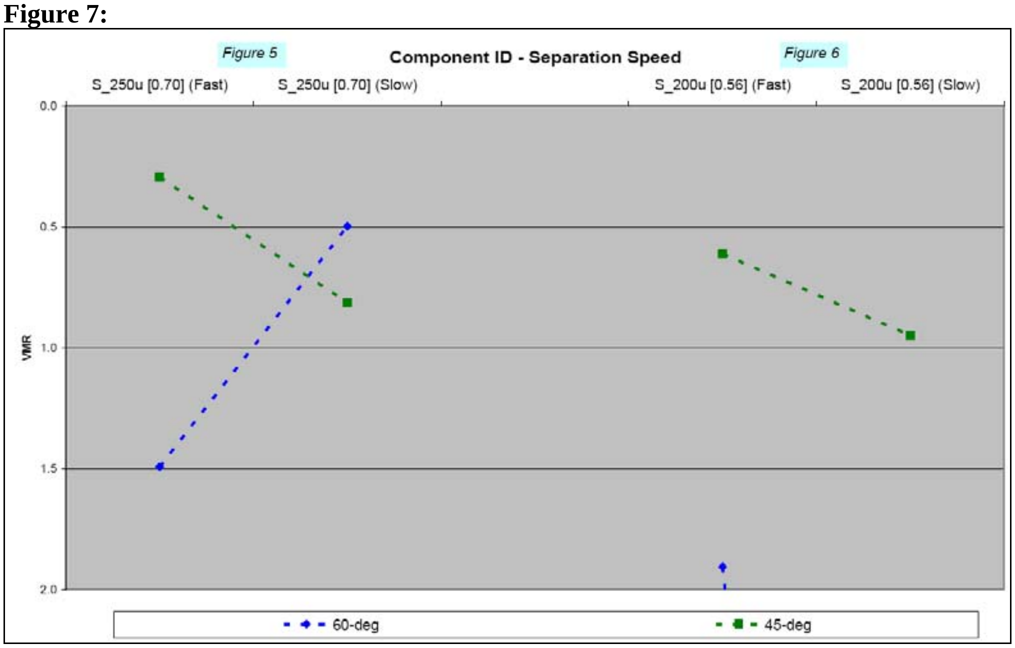


Figure 8:

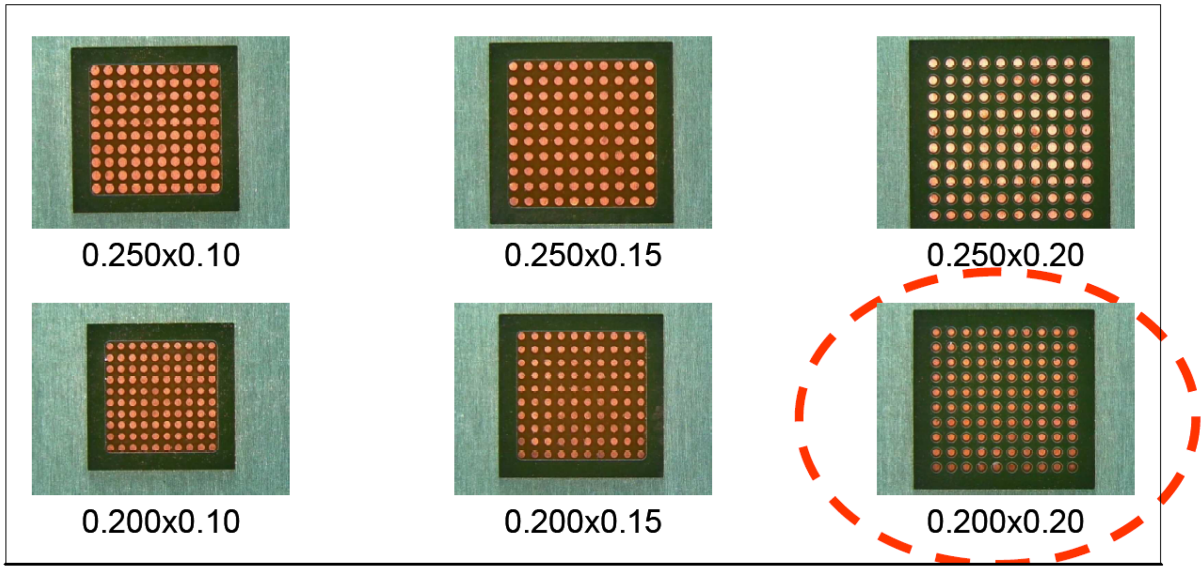
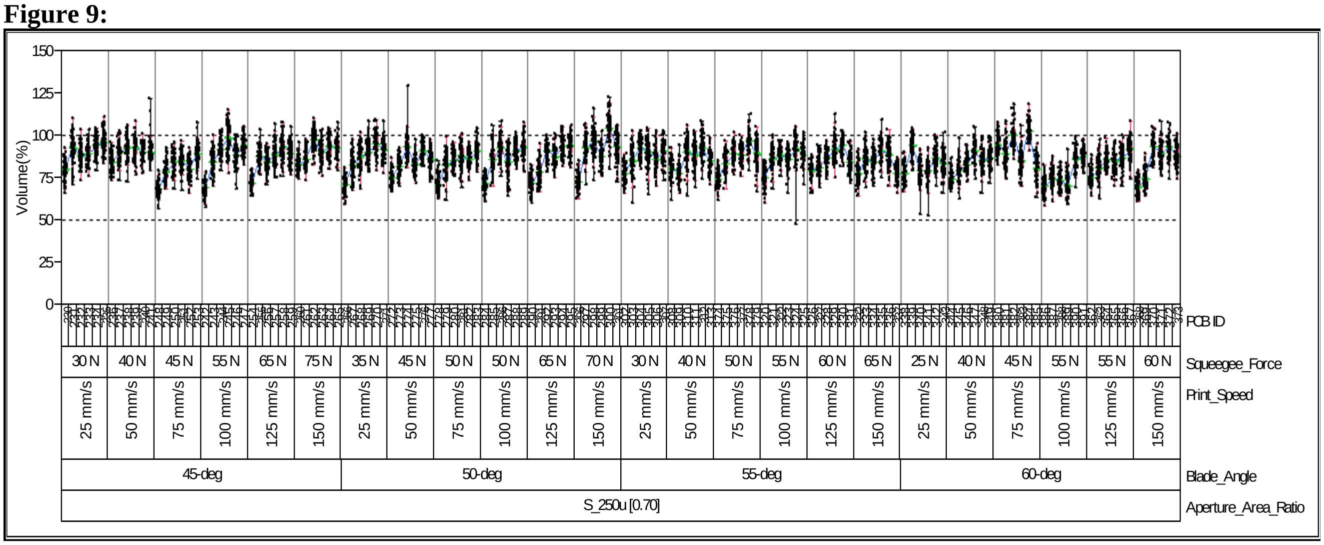


Figure 9:



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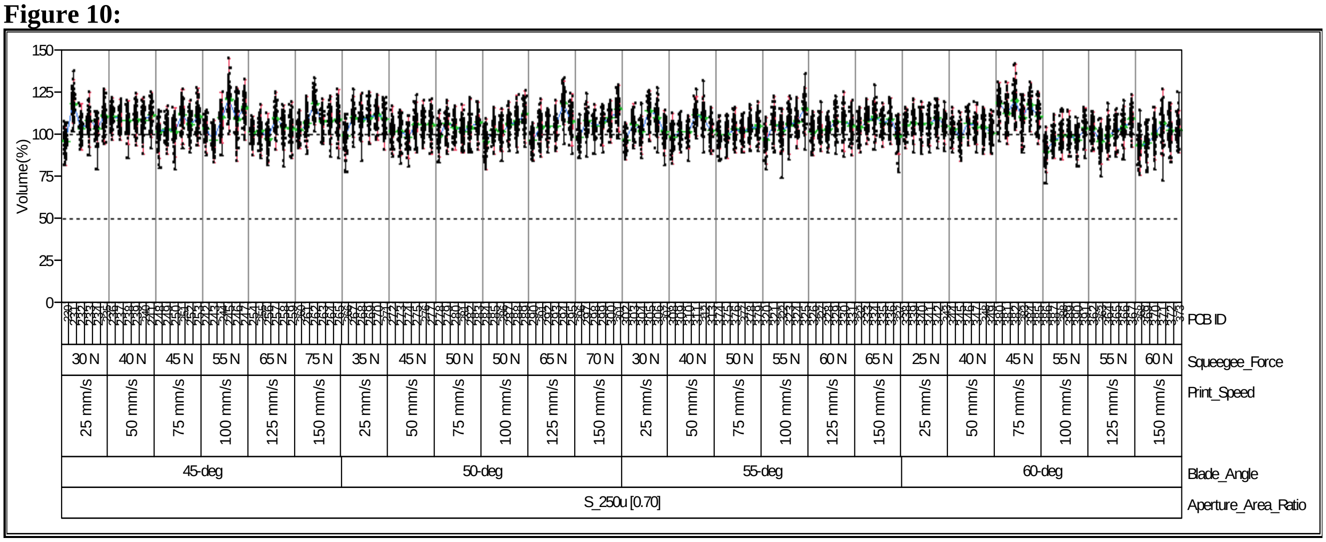

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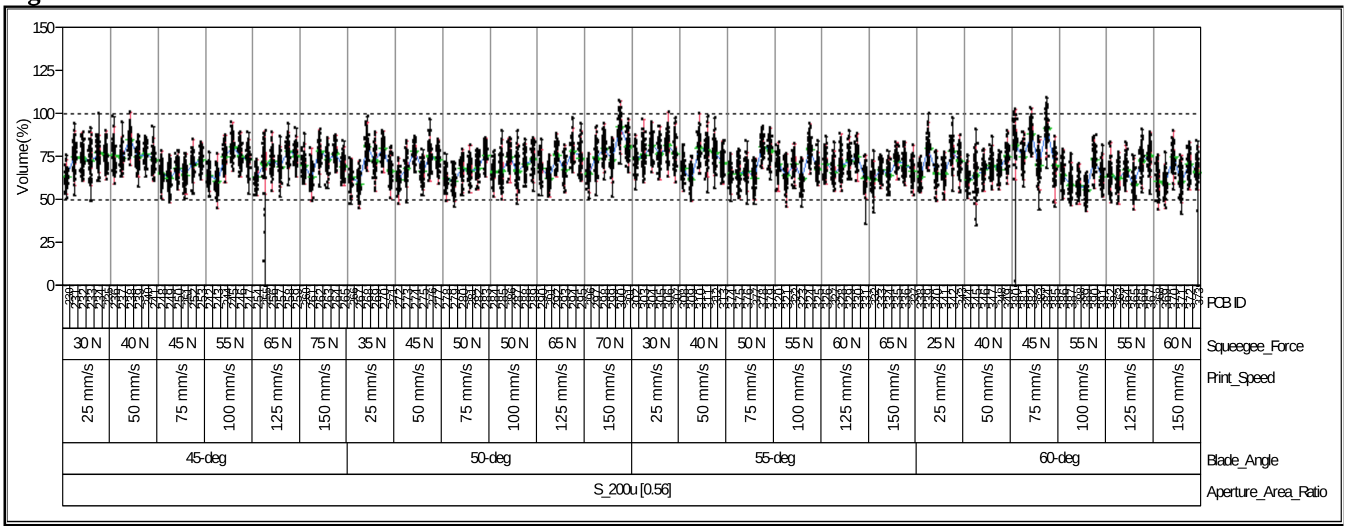

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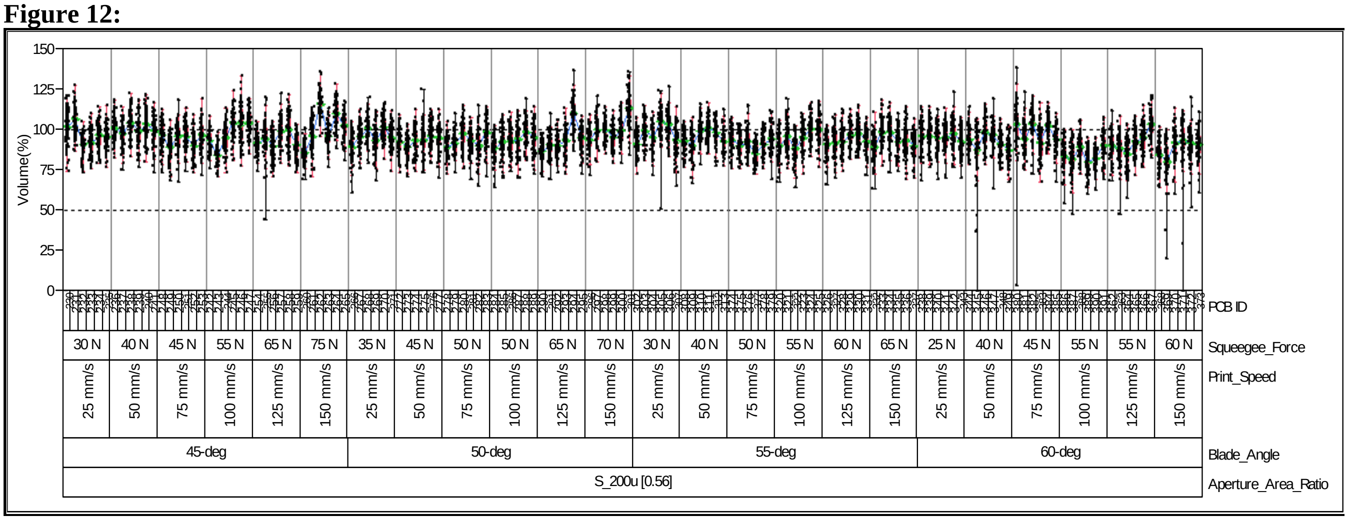
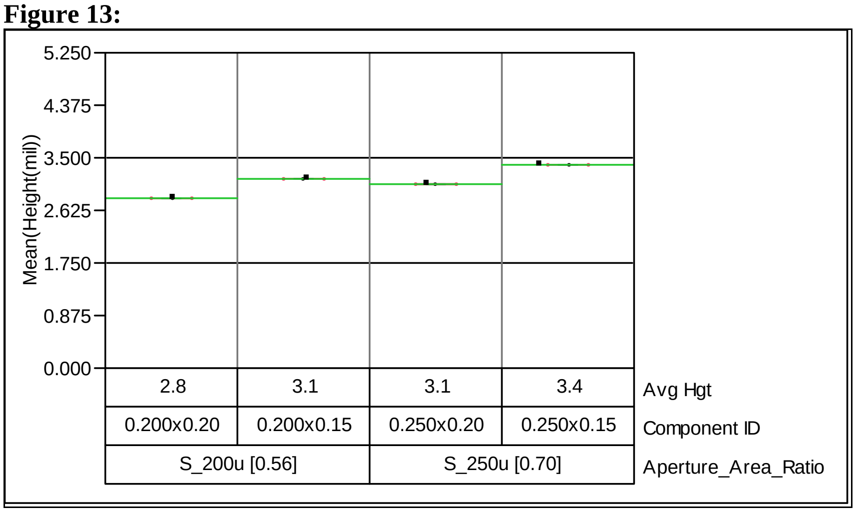


Figure 13:



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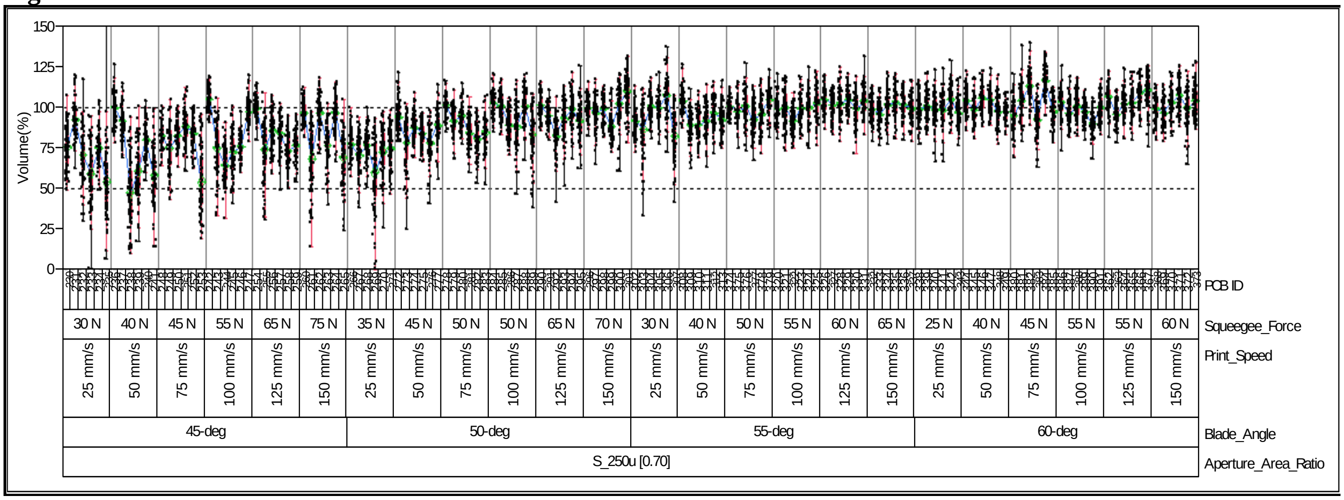

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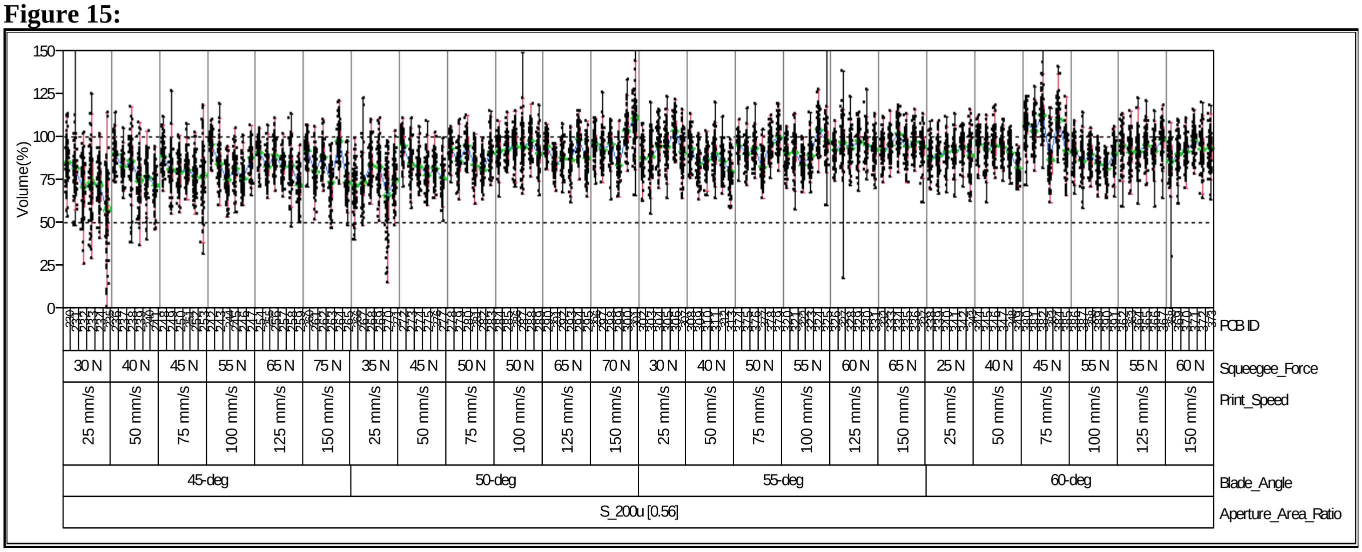
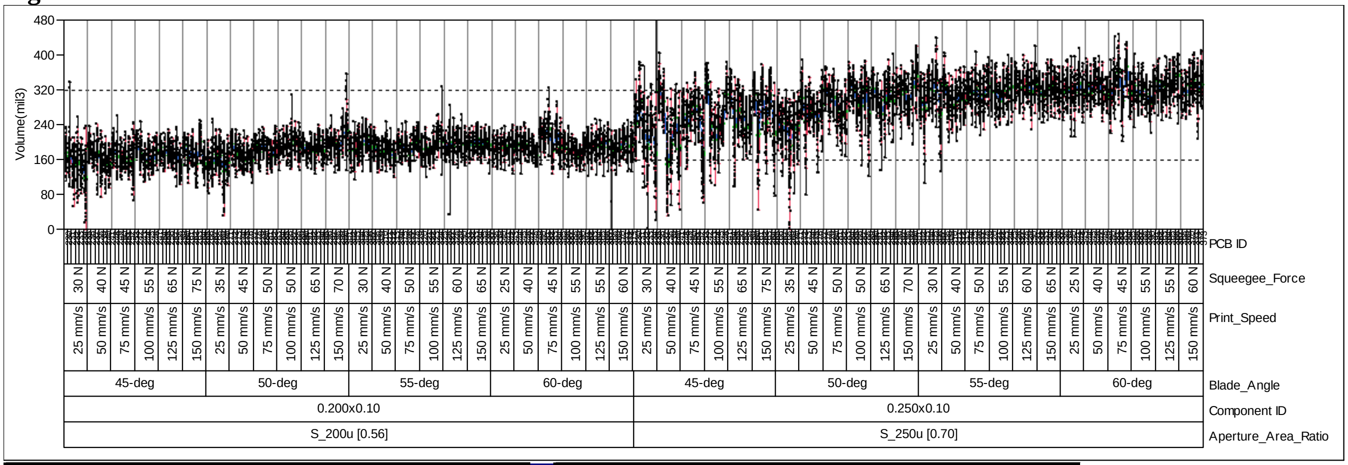


Figure 16:



168	182	193	193	251	286	315	326	*Mean(Volume(mil3))*
45-deg	50-deg	55-deg	60-deg	45-deg	50-deg	55-deg	60-deg	*Blade_Angle*
S_200u [0.56]				S_250u [0.70]				*Aperture_Area_Ratio*