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Effect of Squeegee Blade on Solder Paste Print Quality

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Abstract

The solder paste deposition process is viewed by many in the industry as the leading contributor of defects in the Surface Mount Technology (SMT) assembly process. As with all manufacturing processes, solder paste printing is subject to both special and common cause variation. Just like using graduated cylinders from distinctly different manufacturing processes to measure a volume of liquid, using different blades types can contribute significant special cause variation to a process. Understanding the significant differences in print performance between blade types is an important first step to establishing a standard blade for an SMT process.

Over the last 30 years, the SMT assembly process has become increasingly more sophisticated. There are two primary methods of applying solder paste to a circuit board using a stencil printer: squeegee blade printing and enclosed head printing. While each method has its advantages and disadvantages, this study focuses on the squeegee blade printing process and the effects of different types of blades have on the solder paste print deposition quality.

Additionally, solder pastes have been formulated to deliver increased paste deposition volume and consistency for ever decreasing aperture area ratios and increasing print speeds. With squeegee blade printing, only two print parameters can typically be controlled, squeegee speed and downward squeegee pressure. Excessive pressure can result in damaged stencils, coining and breaking of webbing between fine pitch apertures. Too little pressure can result in skips if the stencil is not wiped clean.

This study will report on the effects of squeegee blade thickness along with blade surface finish on solder paste print quality. Print quality is defined here as paste deposit profile, wet bridging and insufficients. Attack angle of the blade, which is considered to be the ultimate factor to be controlled, will be determined using a unique approach as a function of blade thickness, print speed and print pressure. Other aspects of the study will include interaction between the above mentioned factors with various solder paste types. A 3-D Solder Paste Inspection (SPI) system will be used to characterize the print quality in respect to transfer efficiency and deposition profile.

Key words: Squeegee blade, print quality, SPI, transfer efficiency,

Introduction

As the electronics industry evolves, the complexity of the boards and components continues to increase. We are at a point now where the line between SMT and semiconductor packaging is becoming blurry. Miniature components such as 01005 passives and 0.3mm CSP/BGA demand the accuracy and precise deposition of solder paste volume as do the wafer bumping and other semiconductor processes. It is well known that stencil printing is a complex process, influenced by a number of variables that include hardware, software, materials and process related factors. Figure 1 shows some of the main factors affecting a printing process. Squeegee blade assembly is an element of the printing process that can have a significant effect on the print quality. We have seen that almost all of the above mentioned print qualities are affected by squeegee blade type and attack angle of the blade.

Two types of squeegee blade materials are used in the stencil printing process: metal blades and polyurethane blades. Polyurethane blades with a high durameter rating (90-110) have shown success in many applications, but for those applications with denser boards and smaller components, metal blades are more reliable. This is primarily because metal squeegee blades allow a more controlled and consistent print height across the entire board area compared to poly blades. Hence, the focus of this study is restricted to metal blades only.

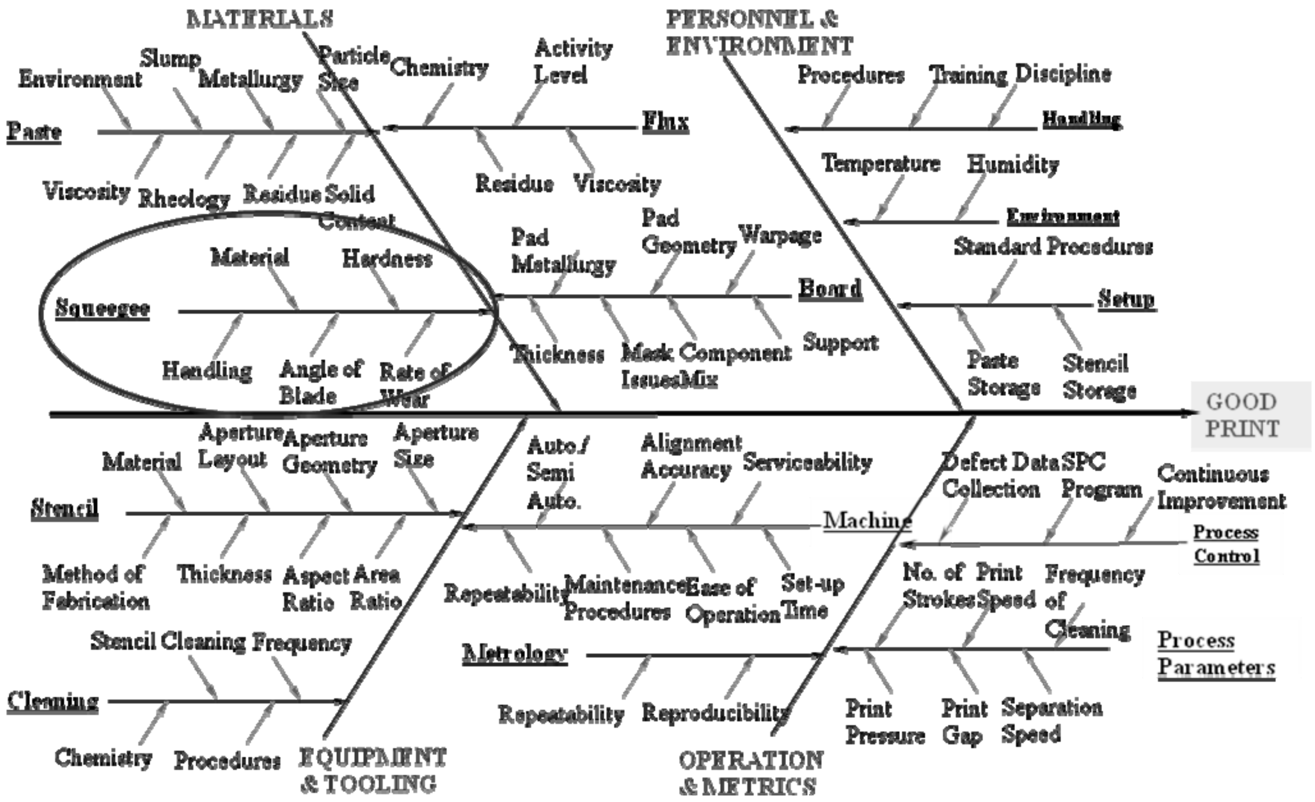


Figure 1. Factors affecting printing process

Metal Blade

In general, only two metal blade printing print parameters which affect aperture filling can be controlled: squeegee speed and downward squeegee pressure. The speed should not be set so high that the paste does not roll as it moves across the stencil or so low that the print cycle time does not keep up with the manufacturing line. The blade pressure is usually set so that no paste remains on the stencil behind the squeegee. Higher pressures will not only damage the stencil, but also shear-thin the paste to such an extent that the flux will separate from the metal and problems such as paste sticking to the blade, lack of tack at placement, or poor solderability will occur further down the assembly line. Figure 2 shows a typical printing process.

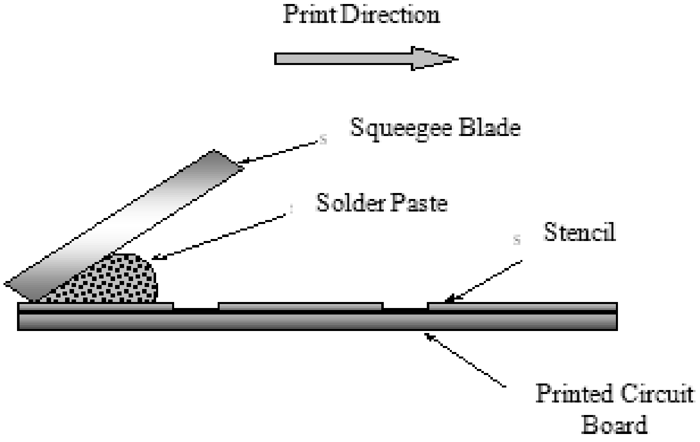


Figure 2. Typical printing process

Contrary to popular belief, in a typical printing process, the paste does not fill the aperture until the paste bead has traveled at least 75% beyond the leading edge of the aperture. The aperture fills from the trailing edge of the aperture backwards. It is the rolling of the solder paste bead that generates the downward force that drives the paste to fill the aperture. This understanding of the aperture filling process is important to understanding why the attack angle of the blade becomes critical.

Blade Angle

While most squeegee blade assemblies are designed to provide a fixed contact angle between the blade and the stencil, in fact, the angle changes as the print process begins. This angle change is due to application of print pressure and speed. The angle between the blade and stencil prior to the print stroke is the contact angle; during the print process (with print pressure and speed in active mode) the angle between the blade and stencil is known as the attack angle. It is the attack angle, not the contact angle, which affects printing and needs to be controlled in order to obtain optimum print quality. Figure 3 demonstrates the difference between contact angle and attack angle. The attack angle is equilibrium angle of the blade during the print stroke.

Figure 3a. Contact angle 60^0 prior to print stroke

Figure 3b. Attack angle $<60^0$ during print stroke

There are different ways to control the attack angle. One option is to design a blade holder that can be fixed at a certain contact angle (figure 3a). Another option is to induce the attack angle by manipulating the blade thickness or compliancy. What actually controls the attack angle of the blade is the deflection of the blade under pressure. The thinner/softer the blade material, the more compliant the blade becomes, which means even with a fixed squeegee holder angle one can achieve a different contact angle as shown in figure 3b.

Working Hypothesis

The working hypothesis behind this effort is that a thinner blade provides a flexible contact angle (based on the blade type, thickness and squeegee pressure) by exhibiting more of a "leaf spring" effect during printing. This effect produces a better pumping action to fill an aperture, allowing the paste to start the filling process earlier than the 75% beyond the beginning of an aperture.

Experimental

Based on the hypothesis above, a series of experiments were designed to understand the effect of blade type on print quality and deflection/attack angle. This study was divided into two parts to address the above mentioned two effects; 1. Deflection/attack angle, 2. Print quality.

Blade Deflection Test

Eight blades were exposed to the deflection test using the method described next. Each blade was held securely by a specially designed blade holder with an attached force indicator dial. The dial indicator was positioned as close to the bottom of the blade as possible without touching the stencil. Figure 4 shows the blade set up. The initial deflection position of the blade was read (in inches) without any applied force.

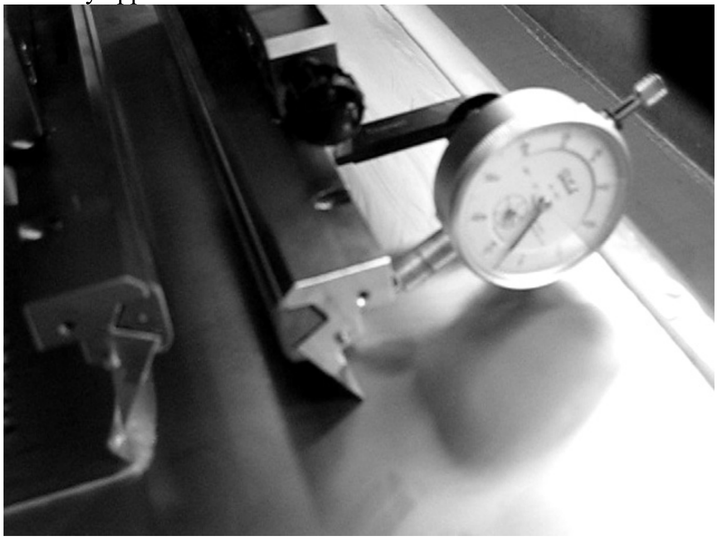


Figure 4. Blade holder set up for 0.007" thick blade. No pressure applied.

The deflection angle during print mode was measured with applied force during static and active state of the blade. The actual deflection angle was measured by applying modeling clay to the end of the blade to capture the static and active angle. Figure 5 shows an example of the modeling clay. Once the modeling clay was hardened in the oven, the deflection angle was measured using a standard compass. In addition to the experimental determination of the deflection angle, Euler model was used to calculate the defection angle employing the material properties. The Euler small defection equation and model (figure 6) is given below[1]:

$$d = \frac{F*L^3}{3EI} \qquad (1)$$

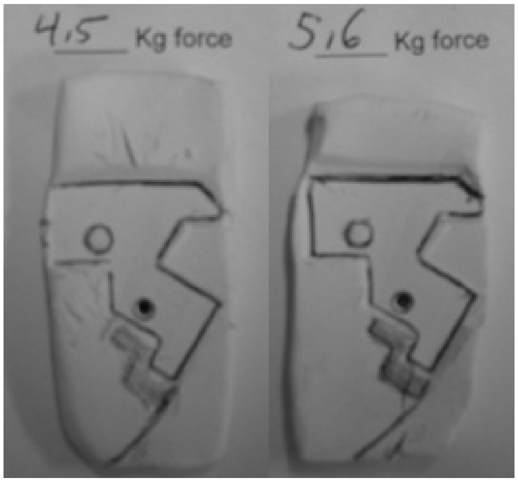


Figure 5. Active print angle for 0.009" thick blade.

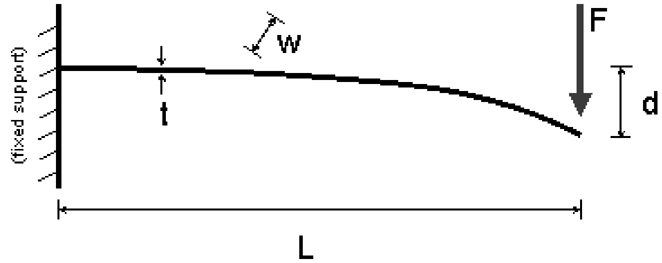


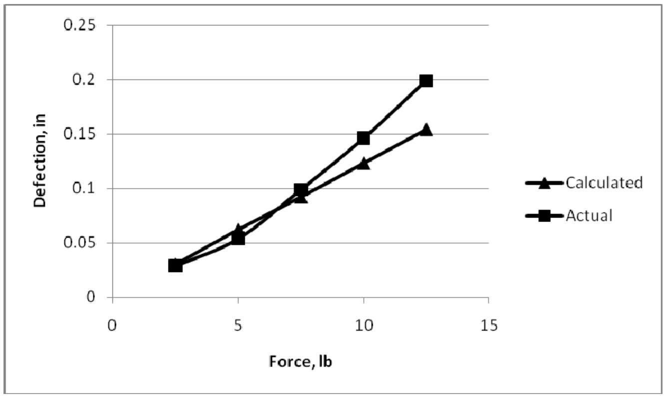
Figure 6. Euler model

Where;

d- deflection at cantilever tip
F-force applied to cantilever tip
L- length of cantilever
W- second moment of area ($wt^3/12$)
E- Young's modulus of cantilever
w- width of cantilever
t- thickness of cantilever

Blade Deflection Result

Figure 7 shows the comparison between experimental deflection angels with Euler model. As it can be seen, the agreement between the model and experimental data is quite comparable, especially in the lower print pressure range. The changes in deflection distance for few selected blades are shown in figure 8. We see from figure 8, depending on the down force, the blade deflection changes. This in turns effect the attach angle.



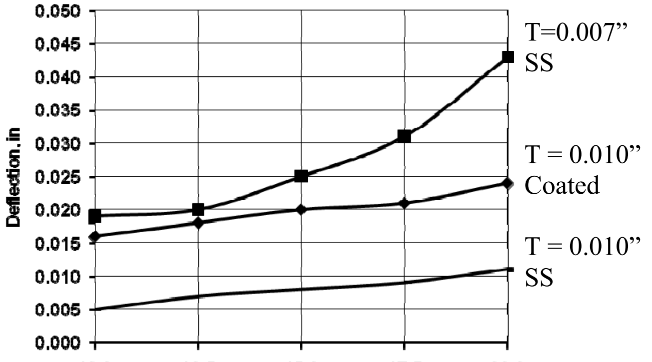


Figure 8. Deflection of blade for different thickness active and static state

Figure 7. Deflection angle comparison

We see that 0.007" blade has higher deflection distance, hence higher attack angle than the 0.010" blades. We also see that blade material effect the absolute attack angle. The 0.010" coated blade which is softer steel, has higher static deflection. But, the active deflection for both 0.010" blades is comparable.

Print Test

The print test was designed to understand the interaction between blade type, paste type and various stencil design factors. A special stencil (5 mil thick) was designed for this study to understand the limit of print capability. Figure 10 shows the stencil layout. The apertures are divided into several groups based on their shape and location on the stencil. Table 2 provides the key to the aperture layout. Each group of apertures consisted of an 8x10 array of apertures and progressively decreased in size while keeping the pitch between adjacent pads the same. Two representative shape layouts are shown in figure 11. All dimentions in figure 11 are in microns. As one would expect, the area ratio associated with each row also progressively decreases from 1.5 to 0.5. Several sequestial DOE's were carried out for this study to understand the factor interaction and ultimately determin the optimal squeegee blade thickness. Initial print study results are presented here only. Remender of the experimental work will be published else where.

Table 2. Aperture layout

Aperture shape	Aperture orientation	Group #
Square	No effect	1,3,9,11
Circular	No effect	5,7,13,15
Rectangular	Vertical	2,4,10,12
Rectangular	Horizontal	6,8,14,16

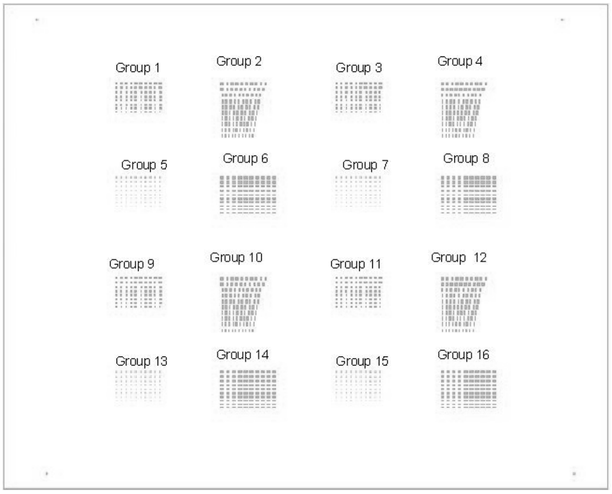


Figure 10. Stencil layout

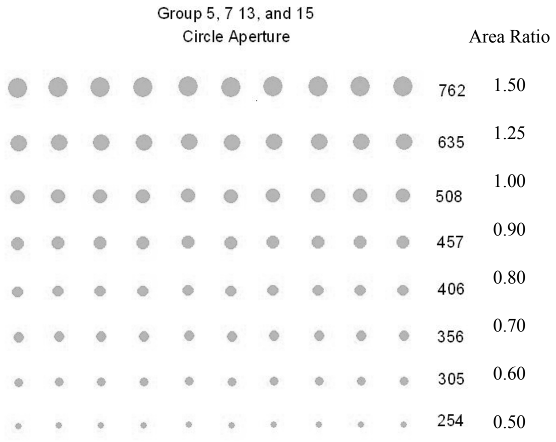


Figure 11a. Circular aperture size

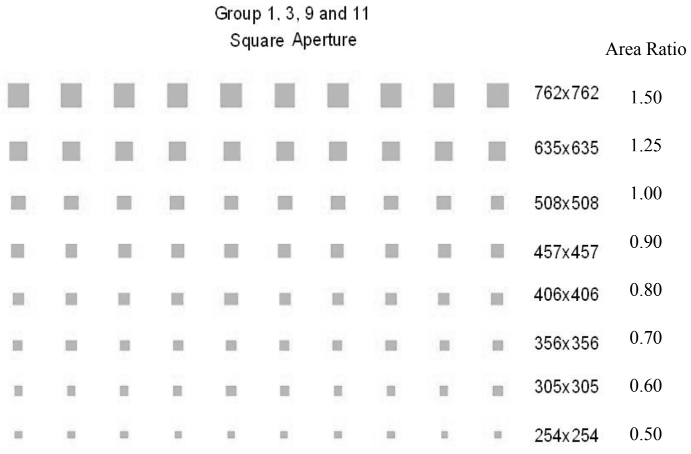


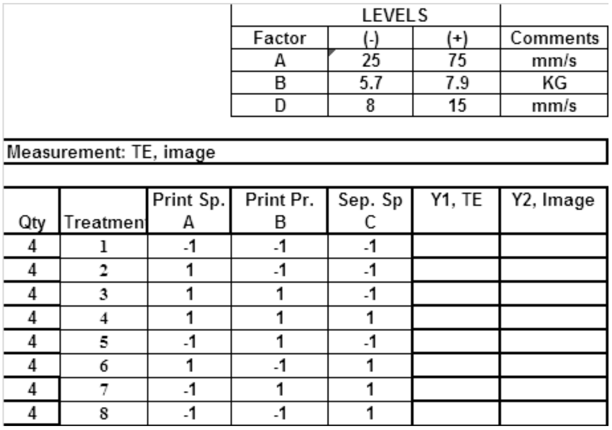
Figure 11b. Square aperture size

Experimental

A full factorial design with 3 factors, at 2 levels, was performed which was blocked over 8 blades. Detail of the experimental set up is given below:

Variable factors:
Print speed
Print pressure
Separation speed
Fixed factors:
Paste type - Alpha OM-338-T45
Stencil type – 5mil, laser cut, electropolished stencil
Printer – MPM Accela
Board support – dedicated tool
Paste inspection – Kho Young SPI machine
Optical microscope – Nikon
Blocked factor:
Blade type

Table 3. Standard order design matrix



	LEVELS		
Factor	(-)	(+)	Comments
A	25	75	mm/s
B	5.7	7.9	KG
D	8	15	mm/s

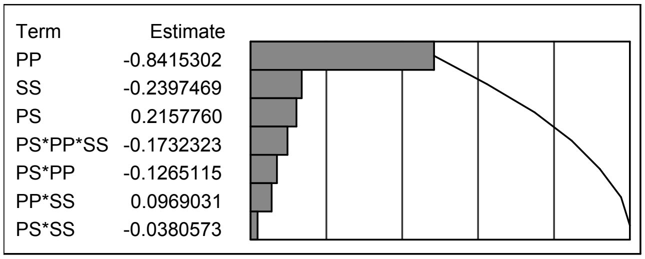
Measurement: TE, image

Qty	Treatmen	Print Sp. A	Print Pr. B	Sep. Sp C	Y1, TE	Y2, Image
4	1	-1	-1	-1		
4	2	1	-1	-1		
4	3	1	1	-1		
4	4	1	1	1		
4	5	-1	1	-1		
4	6	1	-1	1		
4	7	-1	1	1		
4	8	-1	-1	1		

The standard order design table is shown in table 3. The response variable for this study was chosen to be the transfer efficiency and print profile (optical image).

Results and Discussion:

Presenting the detail results and analysis for the current study is beyond the scope of this paper. Hence, selected results are presented here. Figures 12a, 13a and 14a show the Pareto chart obtained from the DOE analysis using JMP software. Figures 12b, 13b, and 14b show the Transfer Efficiency (TE) for the optimum print setting for the given blade. The Pareto chart shows that factor importance depends on the blade type. For example, 0.010” thick blade shows print pressure to be of highest importance while the 0.007” thick blade shows the print speed to be of most importance. We also observe some interaction based on the blade thickness. Additional statistical analysis is underway to fully understand the interaction effect.



Term	Estimate
PP	-0.8415302
SS	-0.2397469
PS	0.2157760
PS*PP*SS	-0.1732323
PS*PP	-0.1265115
PP*SS	0.0969031
PS*SS	-0.0380573

Figure 12a. Blade 1 (0.010”) DOE Pareto chart

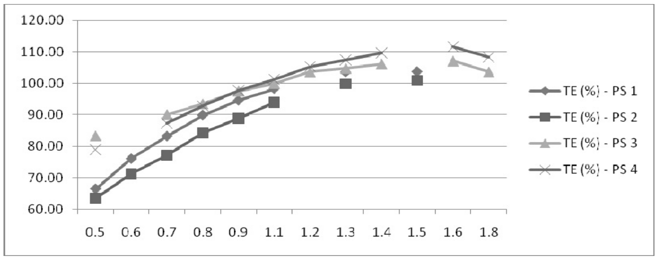
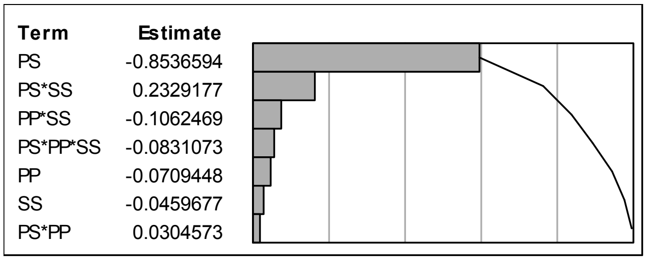


Figure 12b. TE of all aperture shapes at different Area Ratio



Term	Estimate
PS	-0.8536594
PS*SS	0.2329177
PP*SS	-0.1062469
PS*PP*SS	-0.0831073
PP	-0.0709448
SS	-0.0459677
PS*PP	0.0304573

Figure 13a. Blade 3 (0.007”) DOE Pareto chart

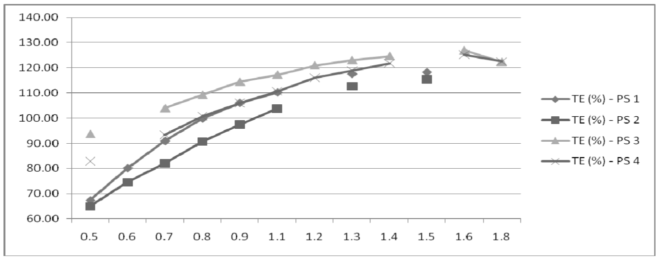
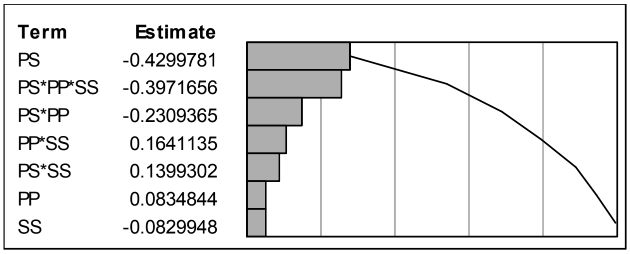


Figure 13b. TE of all aperture shapes at different Area Ratio



Term	Estimate
PS	-0.4299781
PS*PP*SS	-0.3971656
PS*PP	-0.2309365
PP*SS	0.1641135
PS*SS	0.1399302
PP	0.0834844
SS	-0.0829948

Figure 14a. Blade 3 (0.012”) DOE Pareto chart

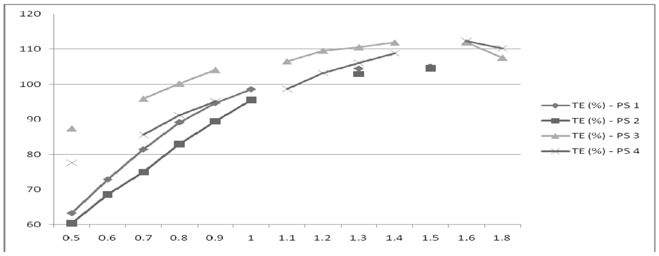


Figure 14b. TE of all aperture shapes at different Area Ratio

As one would expect, TE for all aperture type and blade type increases with increased Area Ratio. We also observe that regardless of blade type, circular (PS2) and square (PS1) apertures give lower TE as compare to the rectangular aperture shapes. Based on this observation, all of the subsequent analyses were restricted to circular and square shape aperture only. The rationale behind this decision was based on the fact that if a certain blade thickness can print these shape apertures, then it will have less of a problem for rectangular shape aperture.

The print profile analysis for two commonly used blade thickness is shown in figure 15. The effect of the blade thickness is not very clear from the optical images presented here. Hence a drawing showing the effect of the blade thickness is presented alongside the optical image. The difference is subtle but important. As we see from the drawing, the volume for both shapes is approximately the same while the shape is very different. Shape 2 is much more desirable due to its almost flat surface. This difference will not be evident in TE data alone. We see from the optical image, a 0.007" blade gives a better fill of the aperture regardless of the aperture shape. This finding is also confirmed by the TE and standard deviation analysis which is presented in figure 16. Figure 16 shows results for the most challenging aperture shape, square, at different Area Ratio. The two 0.007" thick blades presented in this plot refer to two different vendors. As we have seen previously, TE increases with increased Area Ratio. The main observation from this plot is, 0.007" thick blades not only give slightly higher TE, but also shows lower standard deviation. This is primarily due to the better paste deposit shape factor.

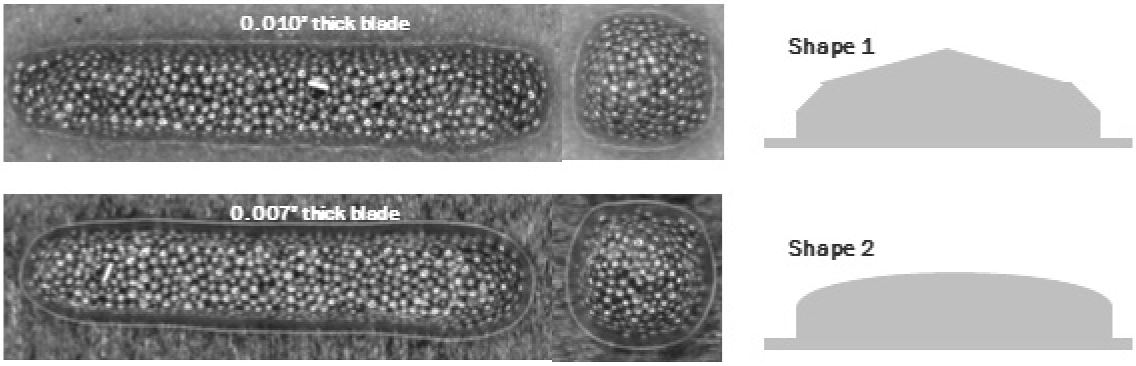


Figure 15. Optical image of rectangular and circular shape aperture showing the paste deposit shape.

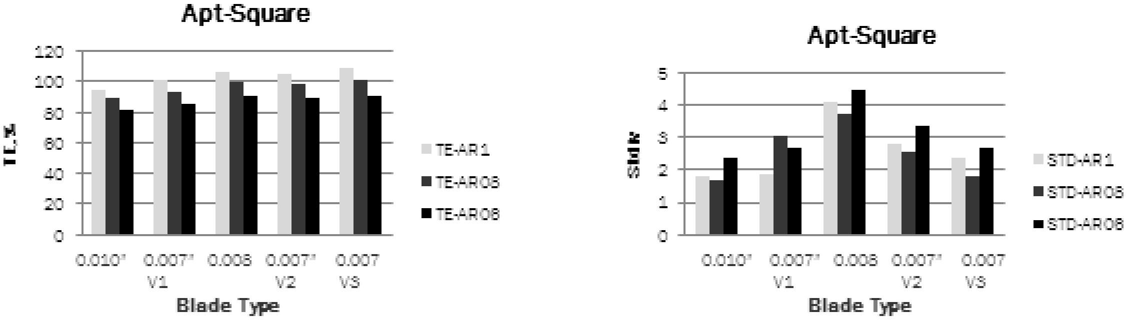


Figure 16. Effect of blade thickness on TE and Standard Deviation for square aperture

Summary & Conclusion

Several experiments were conducted to understand the effect of blade thickness on the overall print quality for fine pitch printing. Based on this study and initial analysis, we can conclude that thinner blades provide more flexibility in regards to attack angle due to a "leaf spring" action. The "leaf spring" action enables us to adjust attack angle by simply changing the print pressure and speed. Preliminary results indicate that thinner blade (0.007") provides higher TE, lower Standard Deviation and better print profile as compared to thicker (0.010") blades.

Future Work

As mentioned earlier, this study is too large and complex to present in its entirety here. Hence a portion of the analysis is presented here. Additional work is underway with new blade design which will be presented at a later date.