Unlocking The Mystery of Aperture Architecture for Fine Line Printing

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Abstract

The art of screen printing solder paste for the surface mount community has been discussed and presented for several decades. However, the impending introduction of passive Metric 0201 devices has reopened the need to re-evaluate the printing process and the influence of stencil architecture.

The impact of introducing apertures with architectural dimensions' sub 150um whilst accommodating the requirements of the standard suite of surface mount connectors, passives and integrated circuits will require a greater knowledge of the solder paste printing process.

The dilemma of including the next generation of surface mount devices into this new heterogeneous environment will create area ratio challenges that fall below todays 0.5 threshold. Within this paper the issues of printing challenging area ratio and their associated aspect ratio will be investigated. The findings will be considered against the next generation of surface mount devices.

Introduction

The electronic assemblies being used in today's mobile devices are pushing the boundaries of what is possible to manufacture at high volumes, low cost and high yields – and it is not going to get any easier.

Passive devices are gearing up for yet another format change, the next generation package sizes which are being touted are Metric 03015 (300um x 150um) and an even smaller package, Metric 0201 (200um x 100um).

The inclusion of these devices alongside traditional surface mount package types, such as Connectors, TANT's, M1005, is starting to raise questions of how to print such devices in one heterogeneous process. Solutions such as stepped stencils and a two print process have been muted but these solutions raise concerns on both the yield and cost aspect of manufacture. The largest roadblock to just printing all aperture geometries with one single thickness of stencil is the Area Ratio (AR) rule. The current limit for high volume, high yield printing is an AR of 0.5.

The latest tool for combating and breaking past the 0.5 area ratio limit has been to employ an active squeegee. In this system, the squeegee assembly contains ultrasonic transducers within its body to assist the deposition process during a print stroke. Previous studies indicate that the technique can enhance the print process with stencil aperture area ratios down to 0.4[1,2,3]. The active squeegee technology increases the action of shear thinning the solder paste material thus allowing the solder paste to flow and fill small apertures more efficiently that passive squeegees [4,5].

However there is one other ratio which has been overlooked in the geometric composition of a regular aperture, this been the Aspect Ratio (AspR). This paper will investigate the impact of the aspect ratio factor within the printing process.

Area Ratio and Aspect Ratio

Stencil printing performance has historically been characterized by the well-known correlation between stencil aperture dimensions and the corresponding solder paste transfer that is predictable. The stability of this relationship has allowed the standardization of stencil design guidelines published by IPC [6].The definition of aperture Area Ratio (AR) is straight-forward – it is simply the ratio between the surface area of an aperture opening to the surface area of the aperture wall, represented by the following equation (Figure 1).

$$AR = \frac{\text{Aperture Open Area}}{\text{Aperture Wall Area}}$$

Figure 1. Area Ratio Formula

Whilst there are many aspects which can influence the stencil printing process, it is the stencil aperture area ratio that fundamentally prescribes what can and what cannot be printed. If the adhesion of solder paste on the aperture wall surface area exceeds that of the aperture opening then the solder paste will want to ‘stick’ to the aperture wall more than the pad, resulting in an aperture which will exhibit blockage and therefore an incomplete solder paste deposit. Conversely, if the adhesion of solder paste on the aperture opening pad contact surface area is greater, then the solder paste will favour adhesion to the pad rather than the aperture wall, leading to a more complete printed deposit. Figure 2 illustrates the concept of how area ratio influences solder paste transfer.

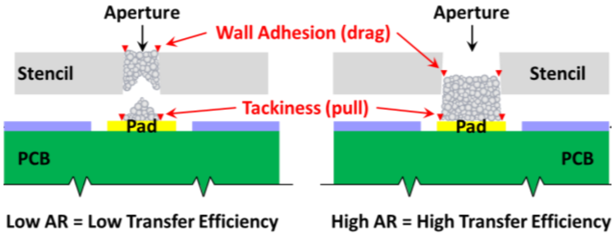


Figure 2. Area Ratio influence on solder paste transfer efficiency.

Therefore, it can be appreciated that as the stencil aperture area ratio decreases then the chances of successful printing with full deposits becomes less likely.

A typical paste transfer efficiency curve representative of where the industry is today is shown in Figure 3 alongside a historical curve from some 20 years ago. The positive shift in transfer efficiency capabilities can be attributed to a number of factors including improvements in solder paste materials, stencil manufacturing techniques together with better understanding of equipment set up and process parameters [7,8,9,10,11].

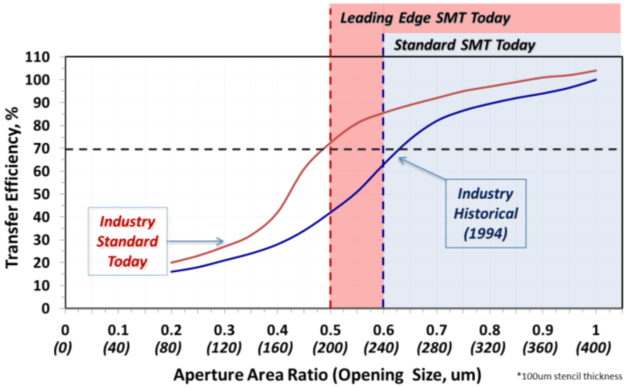


Figure 3. Today’s leading edge solder paste transfer efficiency capabilities compared to 1994.

Metric 03015 and 0201 Requirements

Moving forward, it is clear that there is a very real requirement for print process capabilities down to aperture area ratios of 0.4 to address imminent roadmap challenges. Whilst the industry continues to invest in various material improvements, we have been investigating the benefits of “active” squeegees to fulfil this requirement. In this system, the squeegee assembly contains ultrasonic transducers within its body to assist the deposition process during a print stroke. Previous studies

[1,2,3]indicate that the technique can enhance the print process with stencil aperture area ratios down to the 0.40 mark as shown in Figure 4.

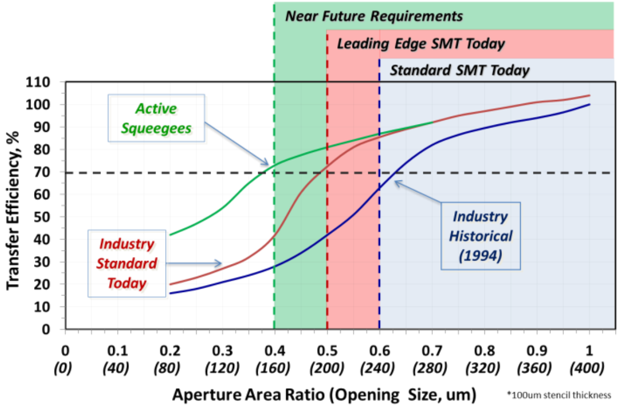


Figure 4. Near future solder paste transfer efficiency requirements.

Aspect Ratio

The aspect ratio of an aperture is defined as:-

$$\text{Aspect Ratio} = \frac{\text{X dimension}}{\text{Y dimension}}$$

Experimental Objective

The objective of this investigation is to discover if the aspect and area ratio of an aperture has an impact on the print efficiency. The investigation will report on the transfer efficiency of the individual designs and draw conclusions on the findings.

SIPOC

The SIPOC Diagram in Figure 5identifies the relevant elements used throughout the investigation.

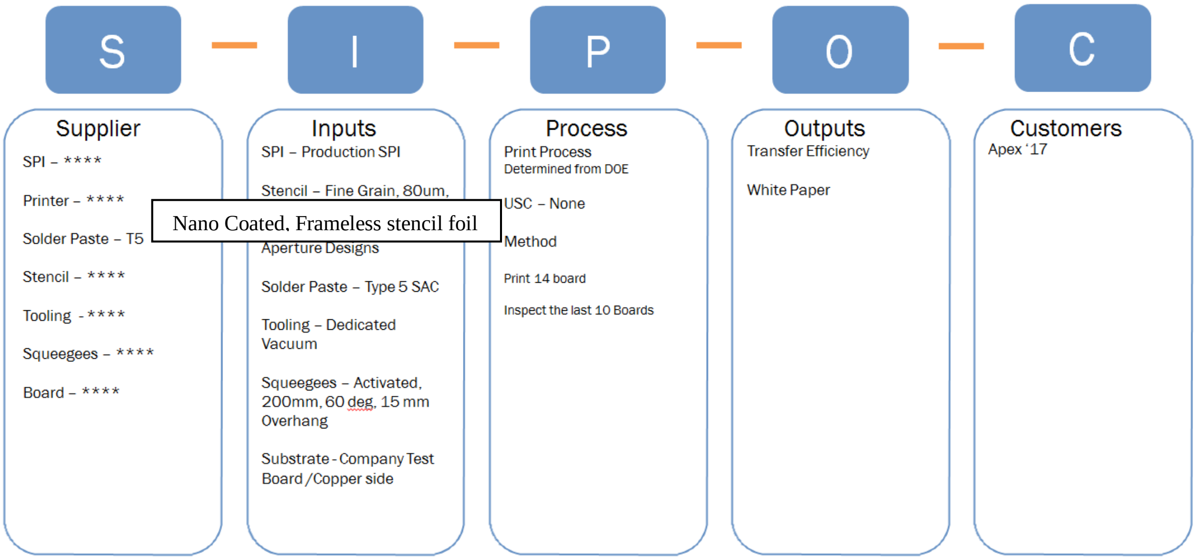


Figure 5. SIPOC Overview

Stencil Design

To achieve the required Aspect Ratio with a given Area Ratio the aperture dimensions were calculated and tabulated (Table 1).

Table 1. Stencil Dimensions

Design Number	1		2		3		4		5	
Aspect Ratio	1.2		1.4		1.6		1.8		2	
Area Ratio	X	Y	X	Y	X	Y	X	Y	X	Y
0.32	0.11	0.092	0.122	0.087	0.138	0.086	0.144	0.08	0.154	0.077
0.36	0.128	0.107	0.14	0.1	0.15	0.094	0.162	0.09	0.174	0.087
0.4	0.142	0.118	0.154	0.11	0.166	0.104	0.18	0.1	0.194	0.097
0.44	0.156	0.13	0.169	0.121	0.182	0.114	0.196	0.109	0.21	0.105
0.48	0.171	0.142	0.183	0.131	0.198	0.124	0.214	0.119	0.23	0.115
0.52	0.184	0.153	0.2	0.143	0.215	0.136	0.232	0.129	0.25	0.125

The stencil designs were laid out as shown in Figure 6. This 5 x 6 array was step and repeated 42 times to create to create the grouping shown in Figure 7. This grouping was then duplicated and used to populate the company miniaturization printing test vehicle board, Figure 8. The final aperture layout provides 84 replicates for each aperture design which are evenly positioned across two large open copper surfaces on the back side of this board.

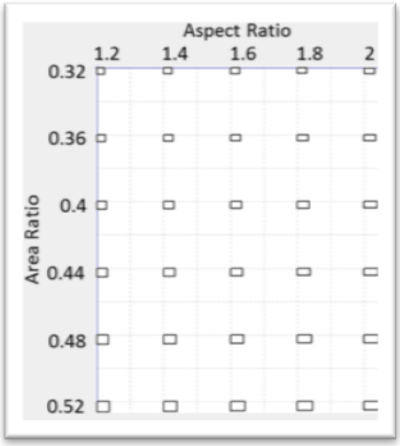


Figure 6. Aperture layout (5 x 6)

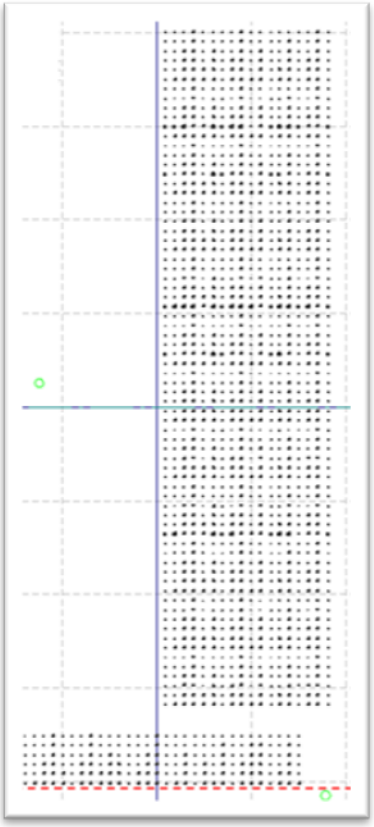


Figure 7. Aperture grouping (42 replicas)

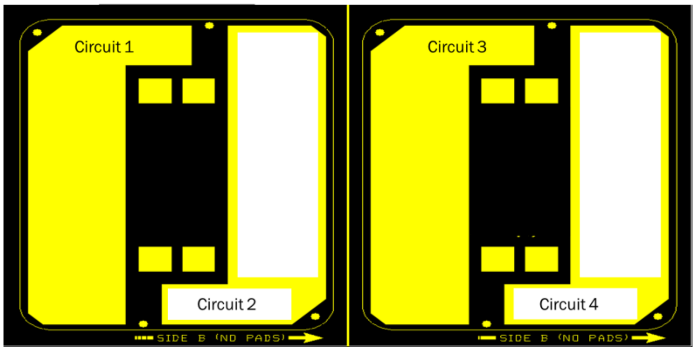


Figure 8.Locations (white) of Test Print Apertures

Design of Experiments

Prior to the experiment the printer was tested against its manufactured specification, in all cases the results were within the specification.

To discover the optimum printer settings a full factorial design of experiments was employed. Table 2 reviews the factors and design.

Table 2. Design of Experiment

Run Order	Print Pressure	Print Speed	Separation Speed
1	5 kg	40 mm/sec	3 mm/sec
2	10 kg	40 mm/sec	20 mm/sec
3	7.4 kg	70 mm/sec	11.5 mm/sec
4	5 kg	100 mm/sec	20 mm/sec
5	10 kg	100 mm/sec	20 mm/sec
6	10 kg	40 mm/sec	3 mm/sec
7	5 kg	100 mm/sec	3 mm/sec
8	10 kg	100 mm/sec	3 mm/sec
9	5 kg	40 mm/sec	20 mm/sec

DOE Discussion

The Cp Index will be used to assess the output from the design of experiment. The formula is shown in Figure 9. The process bandwidth used to calculate the Cp was +/- 40%, a Cp target of ≥1.33 was applied to the analysis.

$$\mathrm{Cp} = \frac{\mathrm{USL} - \mathrm{LSL}}{6 \times \mathrm{Sigma}}$$

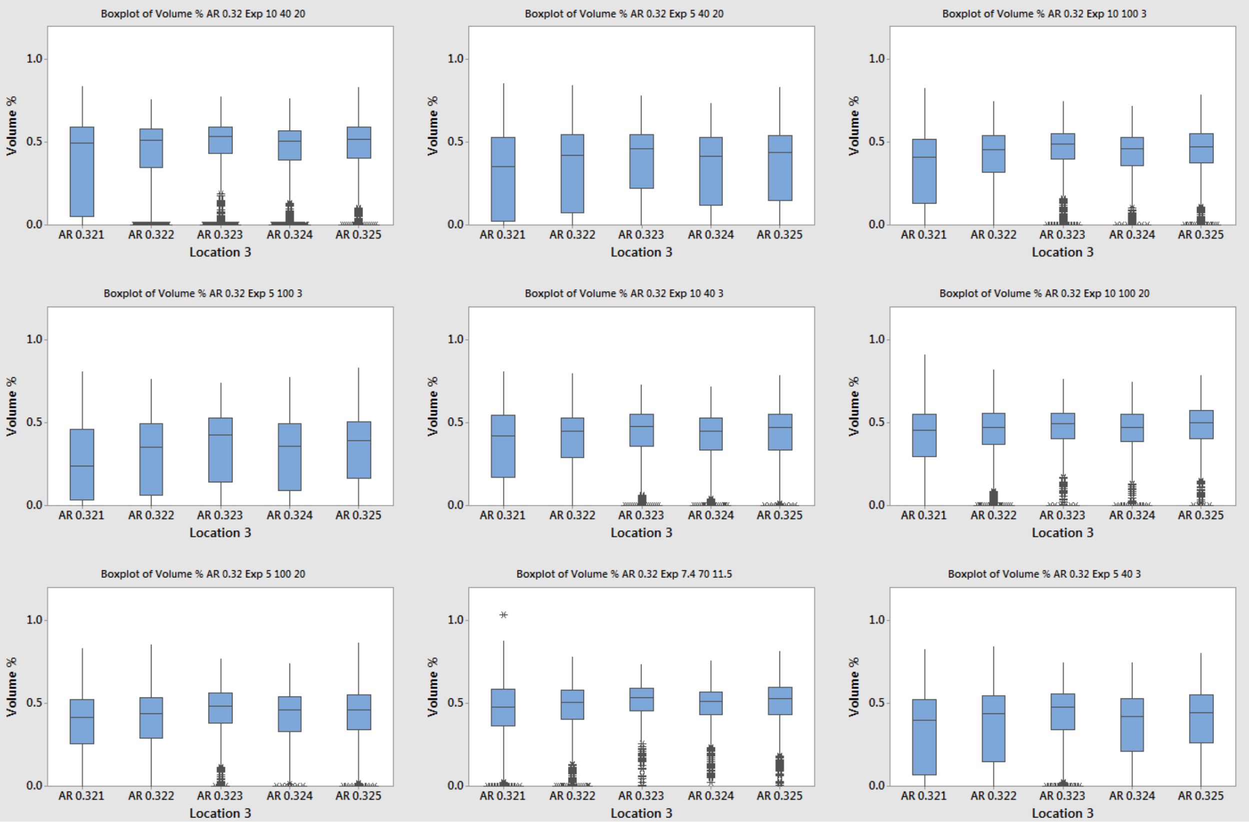
Figure 9.Cp Formula

To aid in the analysis the first review will group together the aspect ratio designs along with aspect ratio designs and the experimental treatments.

The Box plots and data table below show the Cp response for each condition. This method of analysis permits the discovery of the smallest printable area ratio (Cp≥1.33).

Box Plots Analysis

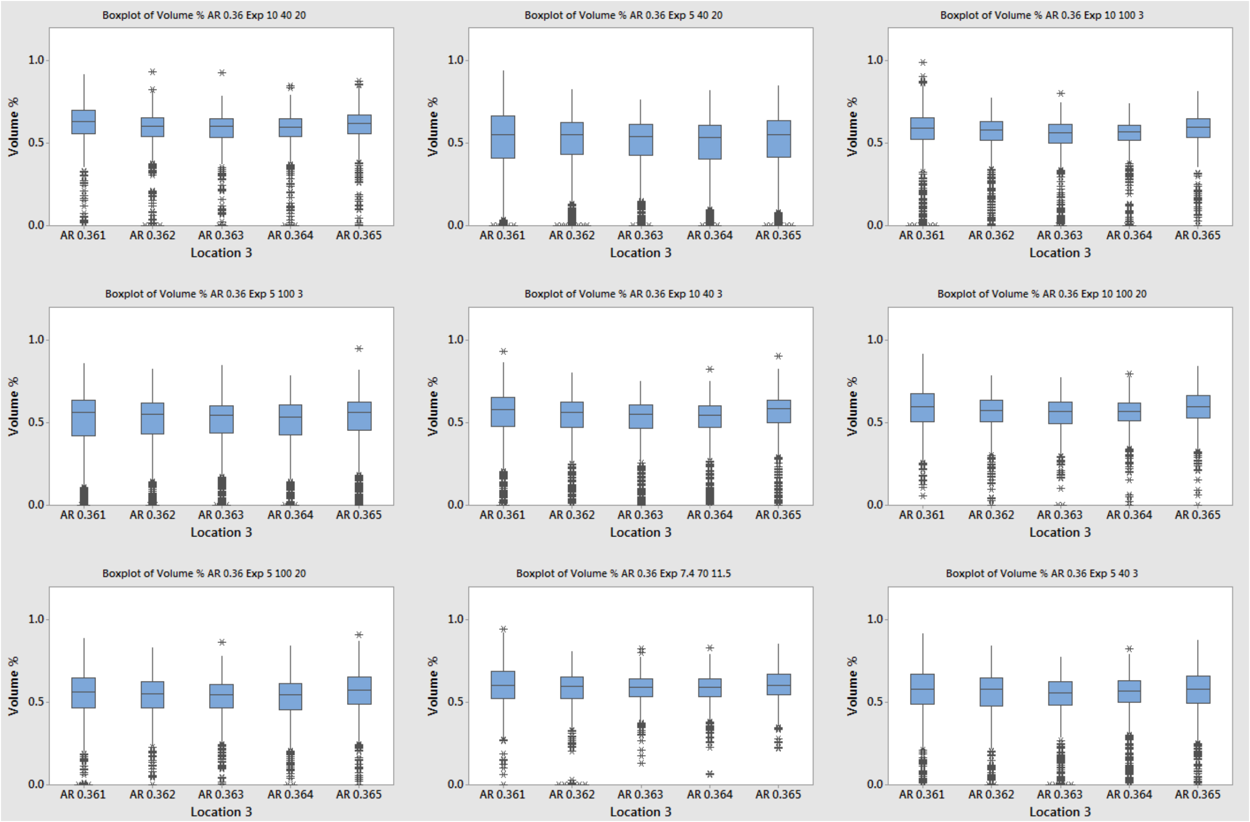
Area Ratio 0.32



AR 0.32 10 100 20	AR 0.32 10 100 3	AR 0.32 10 40 20
0.67	0.61	0.51
0.81	0.70	0.60
0.98	0.82	0.72
0.93	0.81	0.67
0.89	0.78	0.67
AR 0.32 10 40 3	AR 0.32 5 100 20	AR 0.32 5 100 3
0.60	0.70	0.61
0.68	0.72	0.61
0.74	0.89	0.63
0.74	0.82	0.64
0.71	0.76	0.66
AR 0.32 5 40 20	AR 0.32 5 40 3	AR 0.32 7.4 70 11.5
0.52	0.56	0.73
0.56	0.59	0.80
0.63	0.70	1.13
0.61	0.66	1.06
0.59	0.64	0.95

Figure 10. Area Ratio 0.32 Box plot and Data Table (Cp)

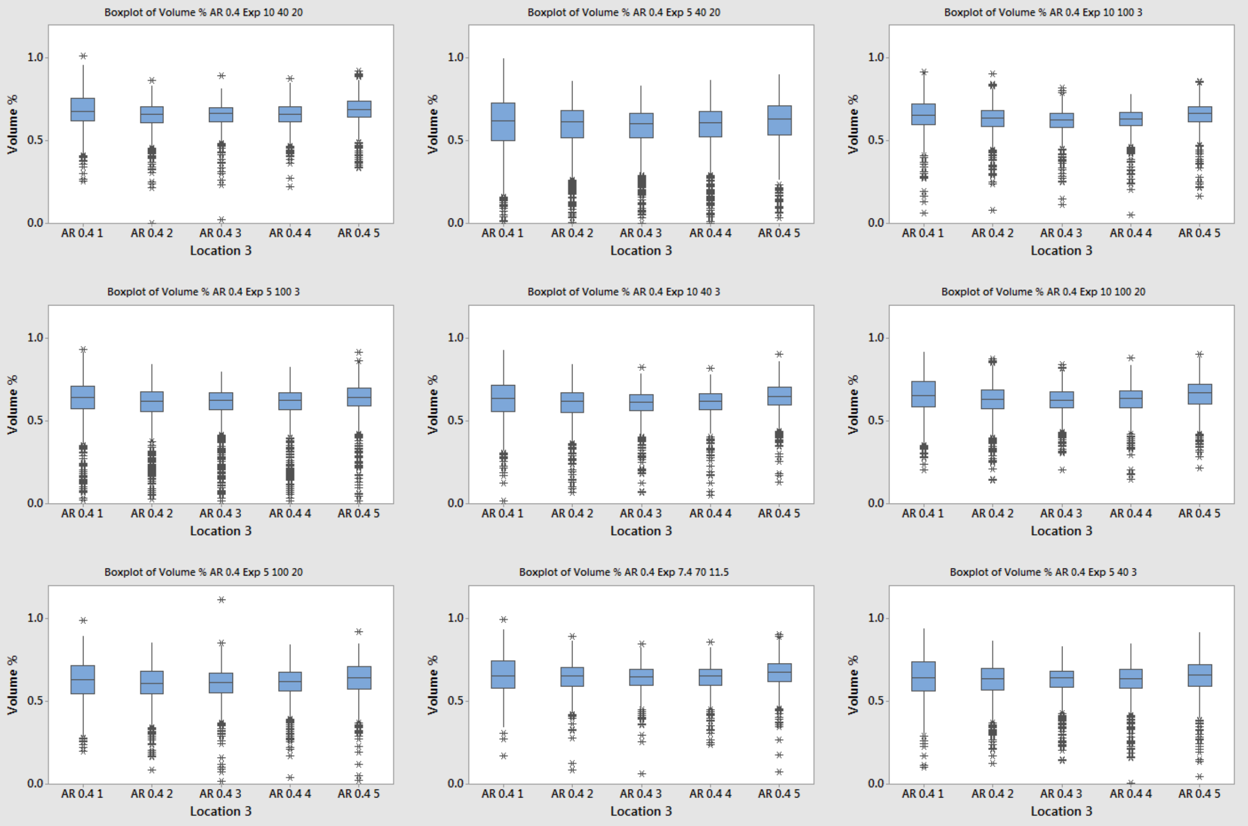
Area Ratio 0.36



AR 0.36 10 100 20	AR 0.36 10 100 3	AR 0.36 10 40 20
1.03	0.81	0.98
1.13	0.99	1.11
1.28	1.04	1.18
1.30	1.13	1.13
1.19	1.08	1.16
AR 0.36 10 40 3	AR 0.36 5 100 20	AR 0.36 5 100 3
0.78	0.89	0.67
0.90	1.01	0.72
0.92	1.04	0.73
0.91	0.99	0.75
0.94	0.98	0.75
AR 0.36 5 40 20	AR 0.36 5 40 3	AR 0.36 7.4 70 11.5
0.61	1.10	1.04
0.69	1.27	1.15
0.71	1.27	1.02
0.71	1.17	1.20
0.67	1.19	1.12

Figure 11. Area Ratio 0.36 Box plot and Data Table(Cp)

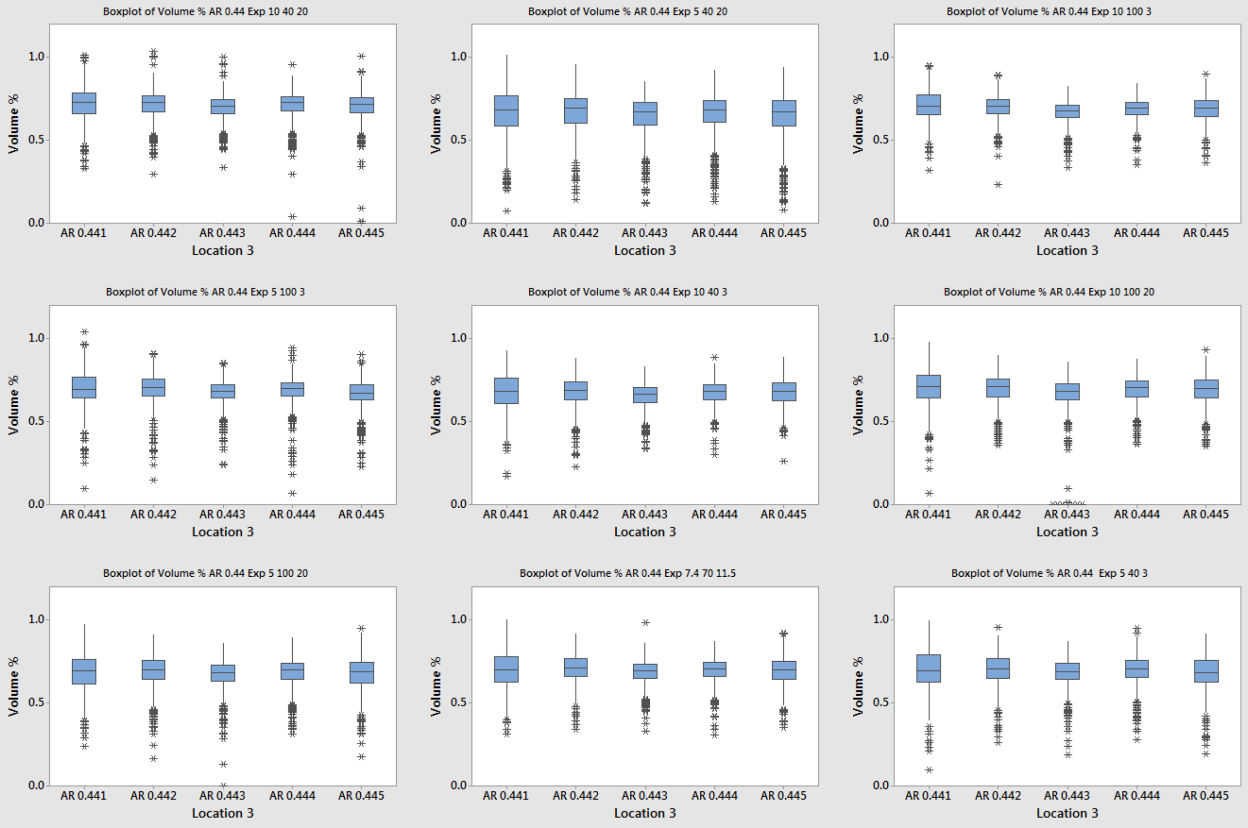
Area Ratio 0.4



AR 0.4 10 100 20	AR 0.4 10 100 3	AR 0.4 10 40 3
1.23	1.17	1.04
1.56	1.33	1.18
1.69	1.58	1.43
1.80	1.50	1.42
1.57	1.38	1.42
AR 0.4 10 40 3	AR 0.4 5 100 20	AR 0.4 5 100 3
1.25	1.04	0.90
1.45	1.20	0.97
1.67	1.26	1.01
1.74	1.33	1.01
1.63	1.18	1.09
AR 0.4 5 40 20	AR 0.4 5 40 3	AR 0.4 7.4 70 11.5
0.74	1.00	1.13
0.86	1.19	1.45
0.91	1.36	1.68
0.92	1.35	1.62
0.89	1.18	1.49

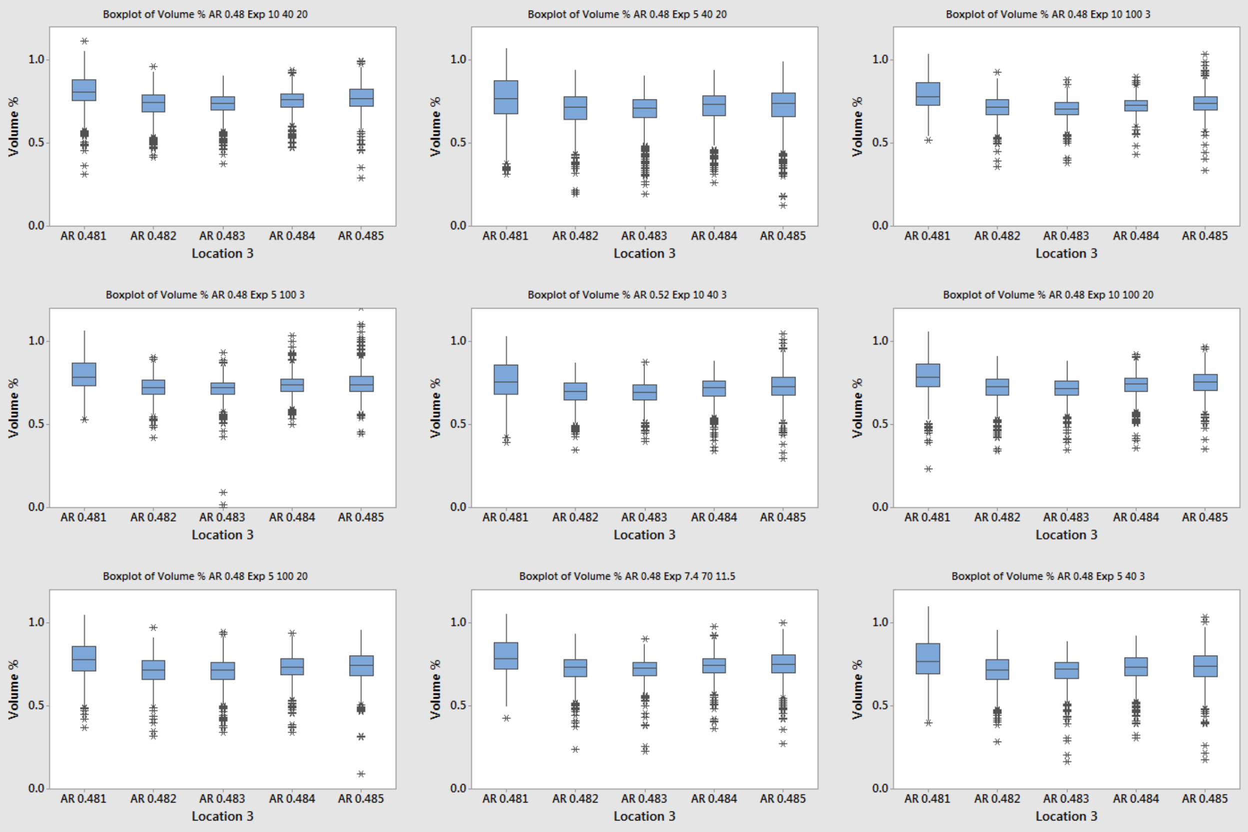
Figure 12. Area Ratio 0.4 Box plot and Data Table(Cp)

Area Ratio 0.44



AR 0.44 10 100 20	AR 0.44 10 100 3	AR 0.44 10 40 20
1.22	1.49	1.31
1.57	1.85	1.59
1.62	2.07	1.77
1.74	2.10	1.66
1.59	1.95	1.51
AR 0.44 10 40 3	AR 0.44 5 100 20	AR 0.44 5 100 3
1.15	1.19	1.30
1.48	1.39	1.51
1.79	1.48	1.80
1.82	1.49	1.63
1.63	1.34	1.57
AR 0.44 5 40 20	AR 0.44 5 40 3	AR 0.44 7.4 70 11.5
0.91	1.08	1.26
1.10	1.37	1.62
1.14	1.55	1.86
1.14	1.55	1.82
0.97	1.31	1.57

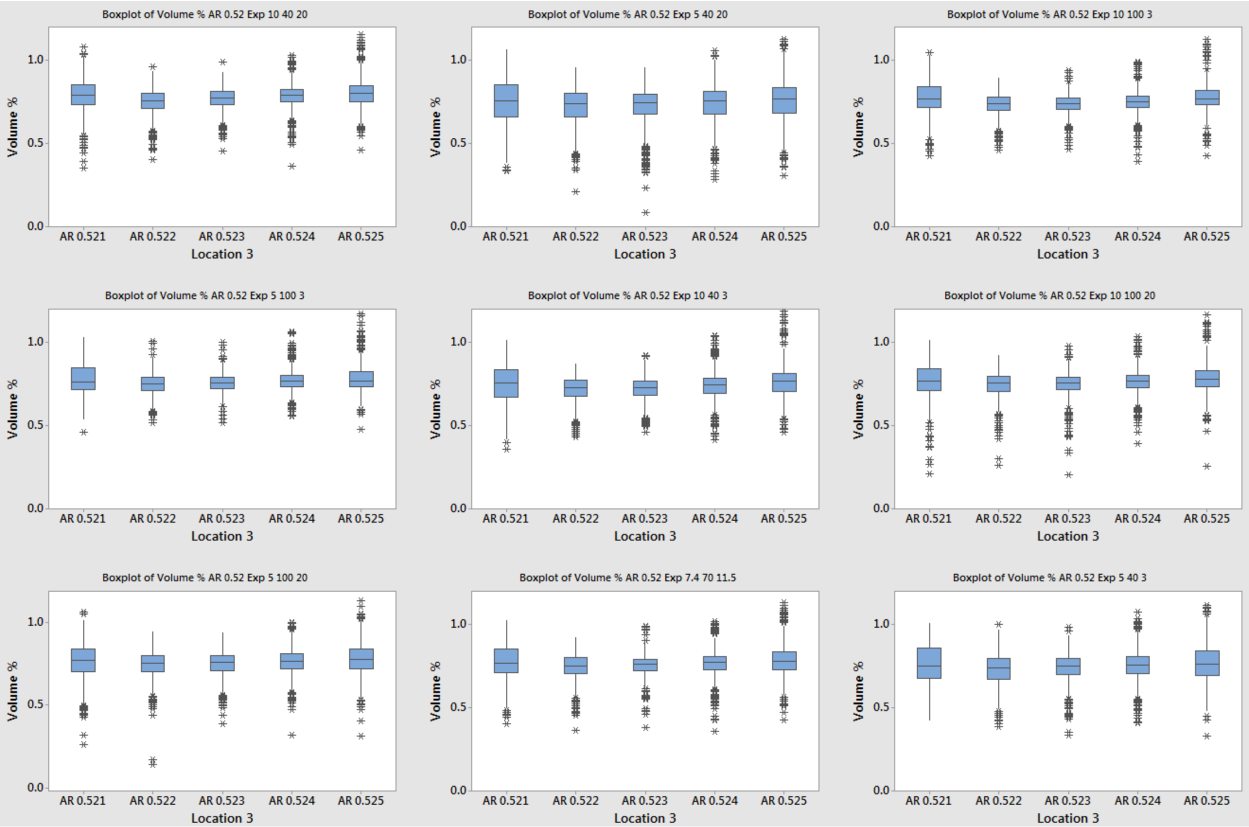
Figure 13. Area Ratio 0.44 Box plot and Data Table(Cp)



AR 0.48 10 100 20	AR 0.48 10 100 3	AR 0.48 10 40 20
1.25	1.46	1.34
1.60	1.99	1.69
1.92	2.33	1.84
1.88	2.50	2.00
1.70	1.88	1.68
AR 0.48 10 40 3	AR 0.48 5 100 20	AR 0.48 5 100 3
1.14	1.24	1.46
1.64	1.55	2.02
1.97	1.62	1.85
1.82	1.62	2.18
1.51	1.44	1.77
AR 0.48 5 40 20	AR 0.48 5 40 3	AR 0.48 7.4 70 11.5
0.91	1.05	1.23
1.18	1.42	1.65
1.25	1.61	1.94
1.27	1.55	1.87
1.06	1.27	1.59

Figure14. Area Ratio 0.48 Box plot and Data Table(Cp)

Area Ratio 0.52



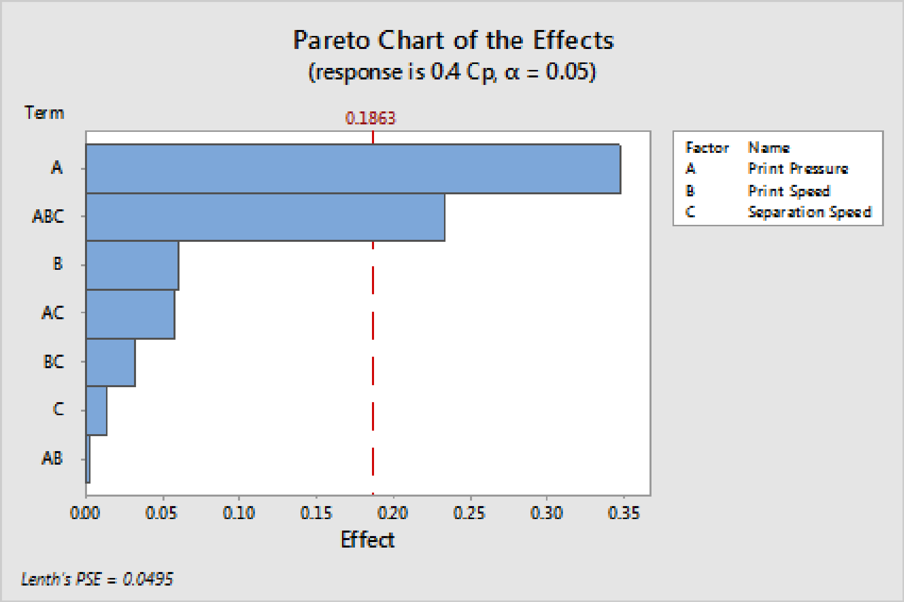
AR 0.52 10 100 20	AR 0.52 10 100 3	AR 0.52 10 40 20
1.31	1.48	1.33
1.77	2.12	1.75
1.86	2.34	2.01
1.84	2.10	1.92
1.55	1.72	1.63
AR 0.52 10 40 3	AR 0.52 5 100 20	AR 0.52 5 100 3
1.19	1.28	1.56
1.77	1.62	2.10
1.84	1.79	2.41
1.73	1.69	2.18
1.41	1.43	1.71
AR 0.52 5 40 20	AR 0.52 5 40 3	AR 0.52 7.4 70 11.5
0.96	1.12	1.36
1.23	1.44	1.76
1.21	1.61	2.16
1.24	1.53	1.80
1.08	1.23	1.51

Figure 15. Area Ratio 0.52 Box plot and Data Table(Cp)

After evaluating Cp results in Figures 10 to 15, it is possible to derive that an area ratio of 0.4 is the minimum printable feature size. The 0.44, 0.48 and 0.52 area ratio results were also reviewed and found to be stable.

The next step of the design of experiments analysis was to understand which factors were significant(Figure 16) and the optimum settings(Figure 17) for the minimum printable feature size (0.4 area ratio design).

Figure 16. Pareto chart of 0.4 Area Ratio design – All Aspect Ratios



- Factor A and ABC have a statistically significant effect on the Cp value.

To understand the “winning” setting from the Design of Experiments a cube plot of the Volumetric transfer efficiency results was constructed (Figure17).

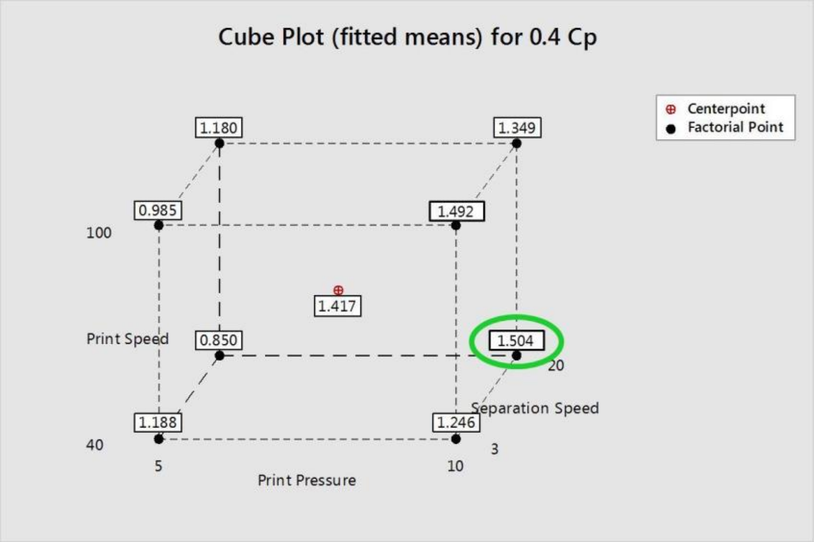


Figure 17. Cube plot of 0.4 Area Ratio (Cp) – All Aspect Ratios

This plot indicates that the highest Cp value occurs with the following settings:-

- Print Pressure = 10kg
- Print Speed = 40mm/s

- Separation Speed = 20mm/s

Aspect Ratio Analysis

So far the minimum printable area ratio and process settings have been discussed, the final step is to use these findings to discover if the aspect ratio has an impact in the process output (capability).Figure 18 illustrates the Cp value for all six area ratio and five associated aspect ratio designs. The process settings are the optimum settings discovered from the design of experiment.

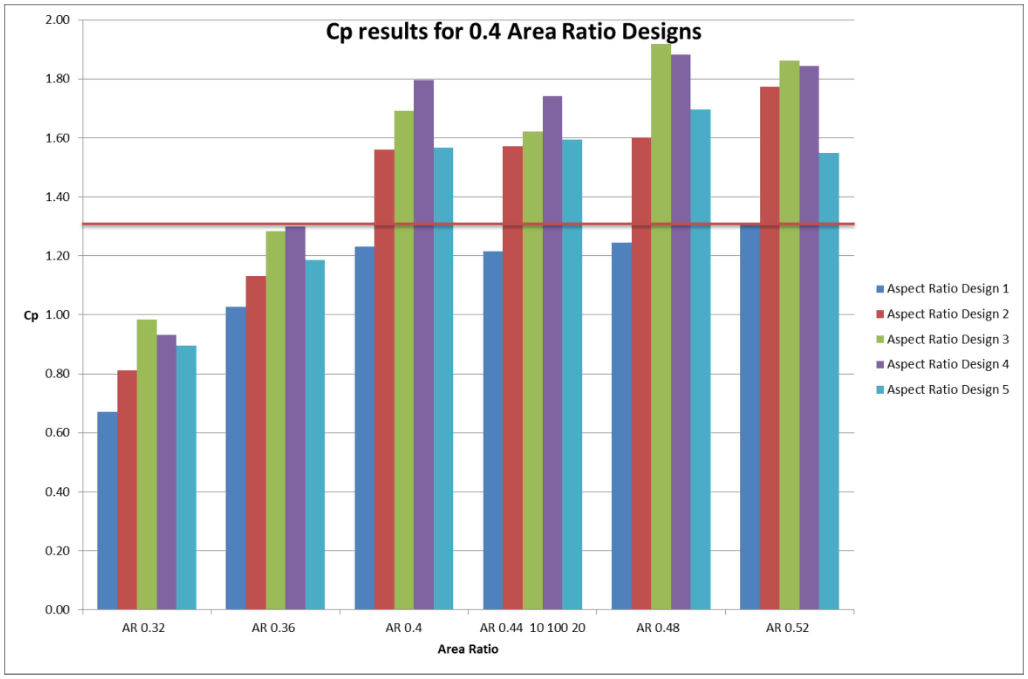


Figure 18. Bar Chart showing the Cp values for all Area and Aspect Ratio designs

From Figure 18 there are two noticeable trends within the data set, as initially observed during the Box plot analysis an area ratio below 0.4 does not achieve a 1.33 Cp value (4 sigma). The second trend which Figure 18 illustrates is the variation of Cp values associated with the aspect ratio designs, designs 3 and 4 produce a higher Cp value than designs 1,2 and 5.

The next section investigates the aspect ratio responses associated with the 0.4 area ratio designs.

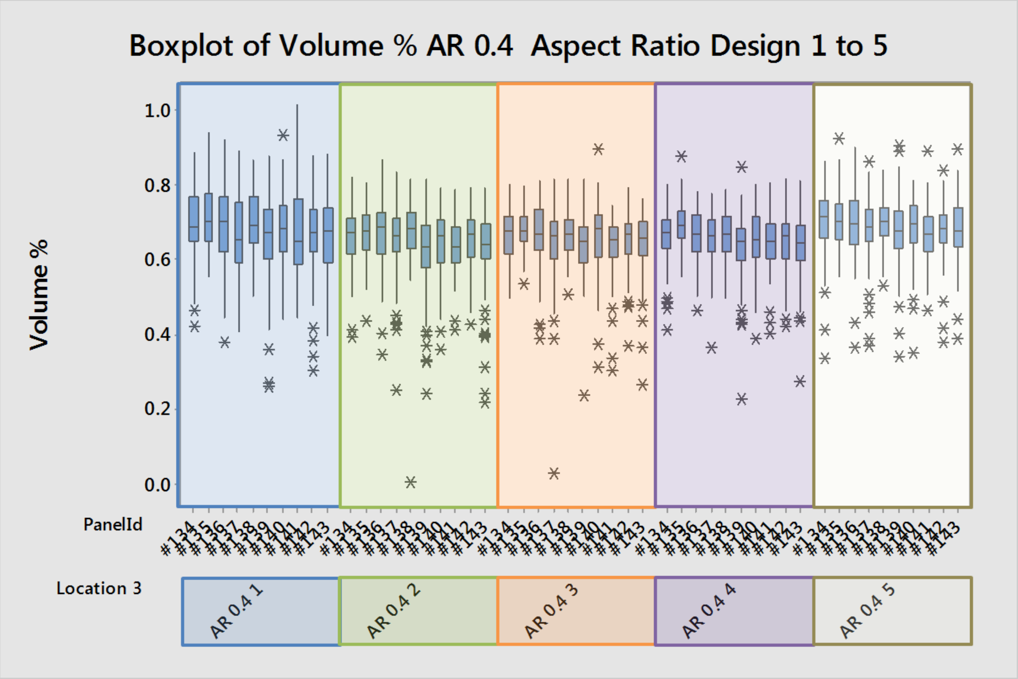


Figure 19. 0.4 Area Ratio Box Plots for all Aspect Ratio designs

Figure 19 displays a series of box plots for the 0.4 area ratio apertures printed with the optimum process settings over the 10 board run. From this set of graphs it is clear to see the differences between the five aspect ratio designs. Design 1exhibits the largest interquartile range (IRQ).Design 2 delivers a smaller IRQ, but an increased occurrence of outliers. Design 5 exhibits a low IRQ, but the incidences of outliers are still numerous. Designs 3 and 4 exhibits a smaller IRQ and a smaller number of outliers, resulting in the highest Cp values. This observation gives the first insight to the significance of aspect ratio as a contributing factor to the process capability.

In view of the results the question is “why do apertures which have the same area ratio but different aspect ratios produce significantly different results?”

To answer this question the following designs will be brought forward for discussion and examination. These designs have been chosen to represent designs which produced high, medium and low Cp values.

Aperture Design Analysis (Area Ratio 0.4)

<u>Design No.1</u>

- Aperture Dimensions 142um x 118um
- Stencil Thickness 80um
- Area Ratio = 0.4
- Aspect Ratio = 1.2

Design 1 delivered high deposit to deposit variability (Cp= 1.23). The opening area and wall surface area associated with design 1 are as follows:-

- Opening area = 16756um3
- Horizontal aperture walls 20% greater area than the Vertical wall geometries.

Design No.4

- Aperture Dimensions 180um x 100um
- Stencil Thickness 80um
- Area Ratio = 0.4
- Aspect Ratio = 1.8

Design 4 delivered low deposit to deposit variability (Cp = 1.8). The opening area and wall surface area associated with design 4 are as follows:-

- Opening area = 18000um3
- Horizontal aperture walls 80% greater area than the Vertical wall geometries.

Design No.5

- Aperture Dimensions 194um x 97um
- Stencil Thickness 80um
- Area Ratio = 0.4
- Aspect Ratio = 2

Design 5delivered medium deposit to deposit variability (Cp = 1.57). The opening area and wall surface area associated with design 5 are as follows:-

- Opening area = 18810um3
- Horizontal aperture walls 100% greater area than the Vertical wall geometries.

Aspect Ratio Design Discussion

Traditional area ratio printing conventions state that as an aperture opening increases so does the adhesive force of the solder paste to land (Figure 2), thus increasing the pull force of the deposit. This increasing pull force enhances the ability to release the solder paste from the aperture walls. However the results illustrated in Figures 18 and 19 indicate that the process response is not linear, therefore the open area is not solely responsible for the process output.

The next step in this investigative process is to explore the interaction of surface area of the aperture walls with respect to the change in aspect ratio designs.

The surface area of the horizontal and vertical walls for the considered aspect ratio designs are illustrated in Table 3. The percentage change for both horizontal and vertical surface areas with respect to the 1.2 aspect ratio design are also shown in Table 3.

Table 3. Table of aperture characteristics

Aspect Ratio	Horizontal Wall Surface Area (North/South) um3	Vertical Wall Surface Area (East/West) um3	Open Area Percentage difference w.r.t 1.2 Aspect Ratio	Horizontal (N/S) Wall Surface Area Percentage Change (%) w.r.t 1.2 Aspect Ratio	Vertical Wall (E/W) Surface Area Percentage Change (%) w.r.t 1.2 Aspect Ratio	Percentage difference between Horizontal and Vertical Wall Surface Area (%)
1.2	11360	9440	0	0	0	20
1.8	14400	8000	7	+ 27	- 15	44
2.0	15520	7760	12	+ 37	- 18	50

From Table 3, the interaction between the aspect ratio and aperture opening versus wall surface area can be observed and examined. The principle outcome from an increase in aspect ratio is the increase of both the opening area and horizontal wall surface area, whereas the vertical wall surface area decreases. Applying these observations and the results so far the following hypothesis can be made:-

<u>Hypothesis</u> - It is proposed that Aspect Ratio designs between 1.6 and 1.8 produce a balance of adhesive and cohesive forces between the surface areas of the aperture opening and wall surface areas for both the horizontal and vertical faces.

To test this hypothesis, Design 1 (Aspect Ratio 1.2) will be considered first as this represents an aperture geometry that did not meet the 1.33 Cp requirements. From Table 3 it can be seen that the 1.2 aspect ratio design has the smallest opening area within the investigation; this implies the lowest adhesive bond between the solder paste and land. The wall surface areas for this design have the closest balance with only a 20% difference between the horizontal and vertical walls, therefore the adhesive force between all four walls will be similar. This comparable balance of bond between the solder paste and the aperture walls causes an internal "tug of war" in which the vertical walls have a slight disadvantage due to being slightly smaller. The combination of a smaller aperture opening area and closely balanced wall surface area creates a situation in which the solder paste does not release completely therefore leading to a low transfer efficiency Cp value.

Design 4 (Aspect Ratio 1.8) represents the optimum design, this aperture design possesses a larger opening area with respect to design 1, therefore the bond of solder paste to pad will correspondingly be higher. In addition, the vertical wall surface area is now 44% less than the horizontal wall area. This proposes a significantly different balance between the horizontal and vertical wall surface area with respect to the 1.2 aspect ratio aperture design. This imbalance in wall surface area could aid the smaller vertical walls breaking their adhesive bond between the solder paste deposit and aperture wall during the separation phase (disrupter). The increased horizontal wall surface area is aided by the increased open area. The balance between the increased open area, the decreased vertical wall surface area and increased horizontal wall surface area produces a "Goldilocks" condition in which the internal adhesive forces are overcome by the pulling force of the land, thus resulting in a repeatable deposit formation.

The repeatability result from the aperture design with an aspect ratio of 2 does not follow the linear improvement bestowed with the aforementioned aspect designs. The proposed reason for this decline in repeatability may possibly be due to the fact that the horizontal wall surface area is now 50% larger than the vertical wall. This increase in surface area may well be too great for the opening area to pull the solder paste out of the aperture in the most repeatable manner. Also the vertical wall has decreased in wall surface area to the point where the solder paste may possibly be "jamming" between the walls during the separation phase, leading to a more varied volumetric solder paste deposit.

Summary/ Conclusions

The findings from this investigation have discovered the following:

- The smallest area ratio which can be printed is 0.4.
- The aspect ratio has an impact on the Cp value of the print deposition.
- An aspect ratio value of 1.6-1.8 produces the most repeatable solder paste deposit.
- The findings have recognised that an interaction between both the horizontal/vertical wall surface area and the aperture opening area exists.
- M03015 solution with 80um stencil thickness = 180um x 100um (Area Ratio 0.4 and Aspect Ratio 1.8) - Tested
- M0201 solution with 60um stencil thickness = 135um x 75um (Area Ratio 0.4 and Aspect Ratio 1.8) – Theoretical

References

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Unlocking The Mystery Of Aperture Architecture For Fine Line Printing

Clive Ashmore

ASM Assembly Systems

Problem Statement

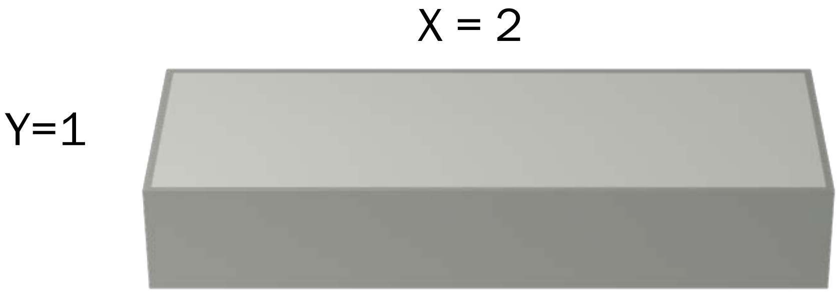
- As the next generation of Surface Mount Devices rolls into the Electronics Community the dimensional features will break into the sub 150um arena. The difficulties facing the printing process (Alignment, Area Ratio, Repeatability etc…) will become evermore challenging.
- Understanding how an apertures construction impacts the resultant printed deposit will help the engineer to design a robust printing process.

Hypothesis

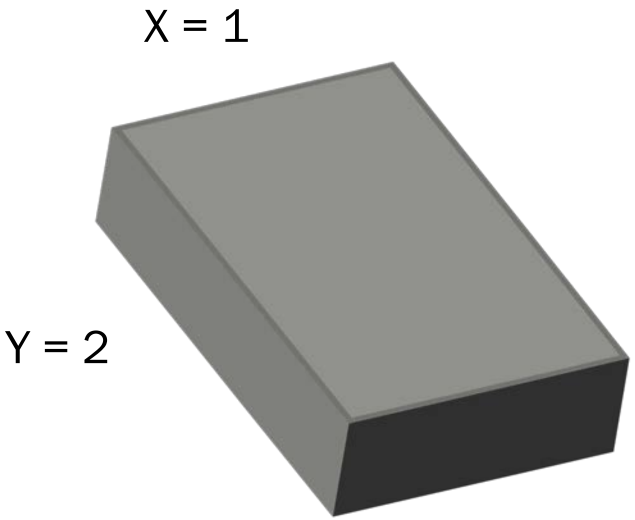
- Does a change in an aperture aspect ratio for a given area ratio influence the resultant solder paste deposit?

TERMS

Aspect Ratio



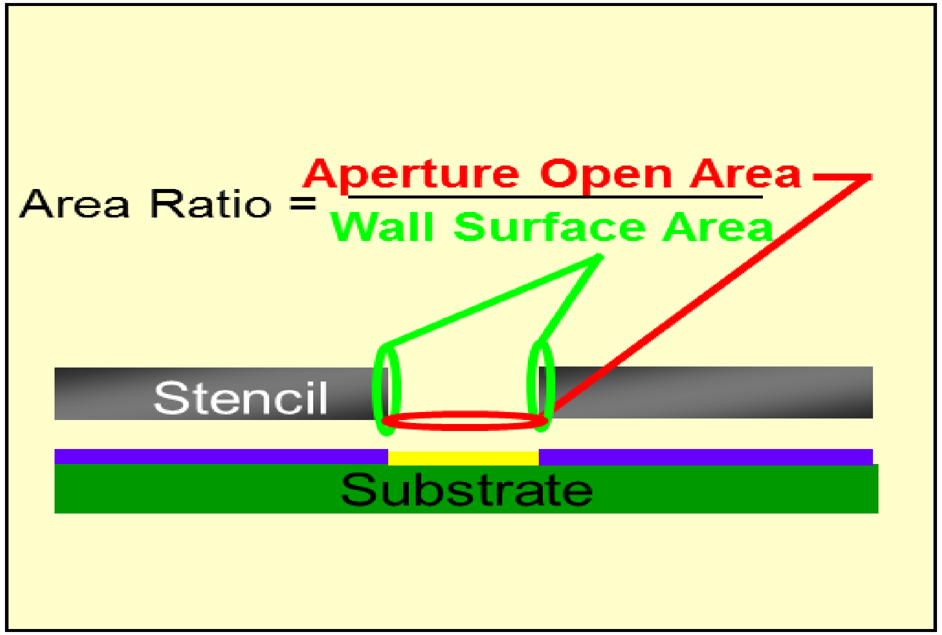
Aspect Ratio = 2



Aspect Ratio = 0.5

$$\text{Aspect Ratio} = \frac{\text{X dimension}}{\text{Y dimension}}$$

Area Ratio



$$\text{Area Ratio} = \frac{\text{Length x Width}}{\text{2 x (Length + Width) x Thickness}}$$

Factors & Responses

- Factors
  - *X & Y Dimensions*

- Responses
  - *Volume: Cp*

Constants

- Printer – Automated platform ±12.5um @ 2 Cpk
- SPI – 10um sensor resolution
- Solder Paste – Type 5
- Squeegee – Activated 200mm, 15mm Overhang and 60 deg
- Tooling – Dedicated Vacuum
- Stencil – Fine Grain Stainless Steel, 80um thick, Nano Coating, 23" Frameless
- Substrate – Company Test Board (Copper side)

S – I – P – O – C

Supplier

SPI – ****

Printer – ****

Solder Paste – T5

Stencil – ****

Tooling - ****

Squeegees – ****

Board – ****

Inputs

SPI – Production SPI

Stencil – Fine Grain, 80um, Nano Coated, Frameless

Aperture Designs

Solder Paste – Type 5 SAC

Tooling – Dedicated Vacuum

Squeegees – Activated, 200mm, 60 deg, 15 mm Overhang

Substrate - Company Test Board /Copper side

Process

Print Process

Determined from DOE

USC – None

Method

Print 14 board

Inspect the last 10 Boards

Outputs

Transfer Efficiency

White Paper

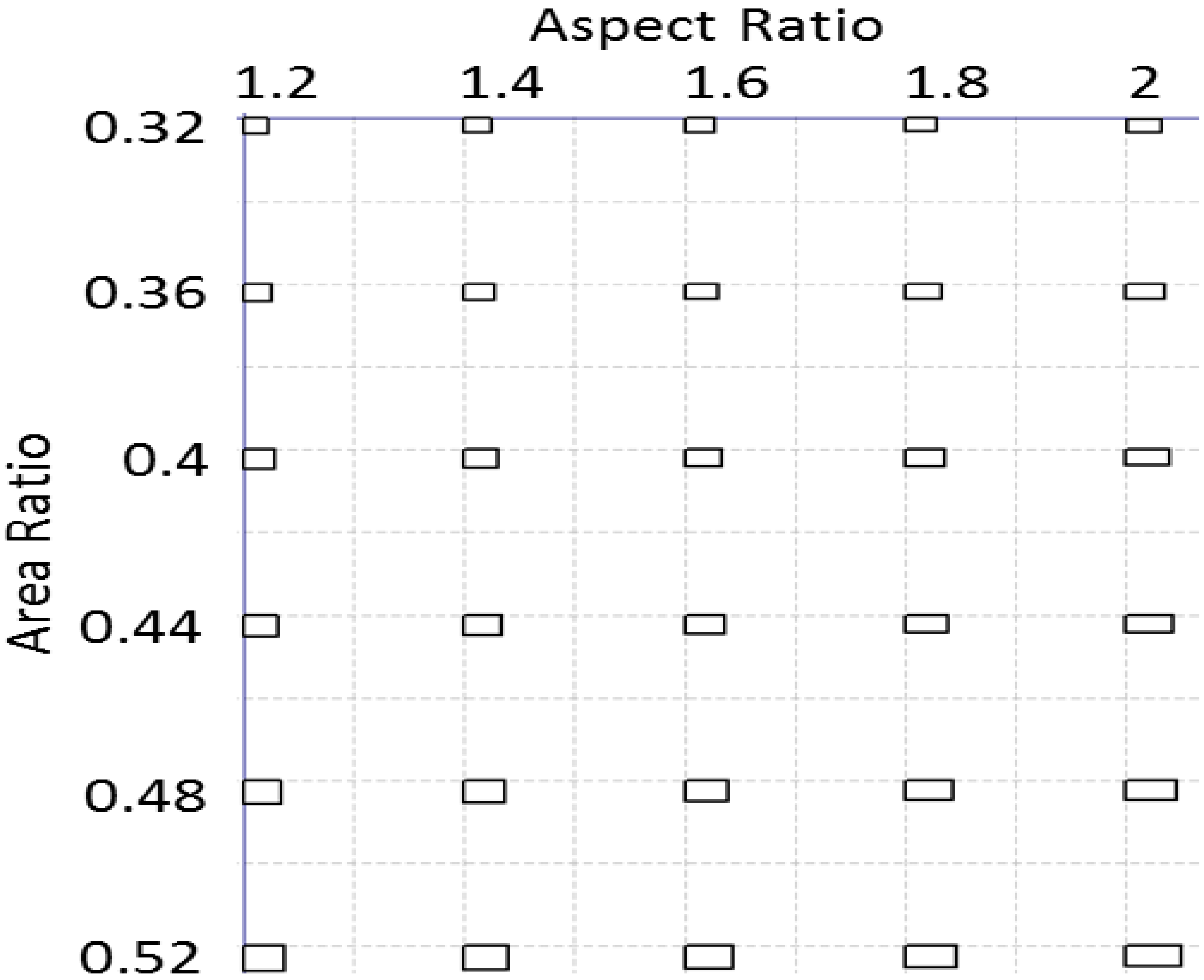
Customers

Apex '17

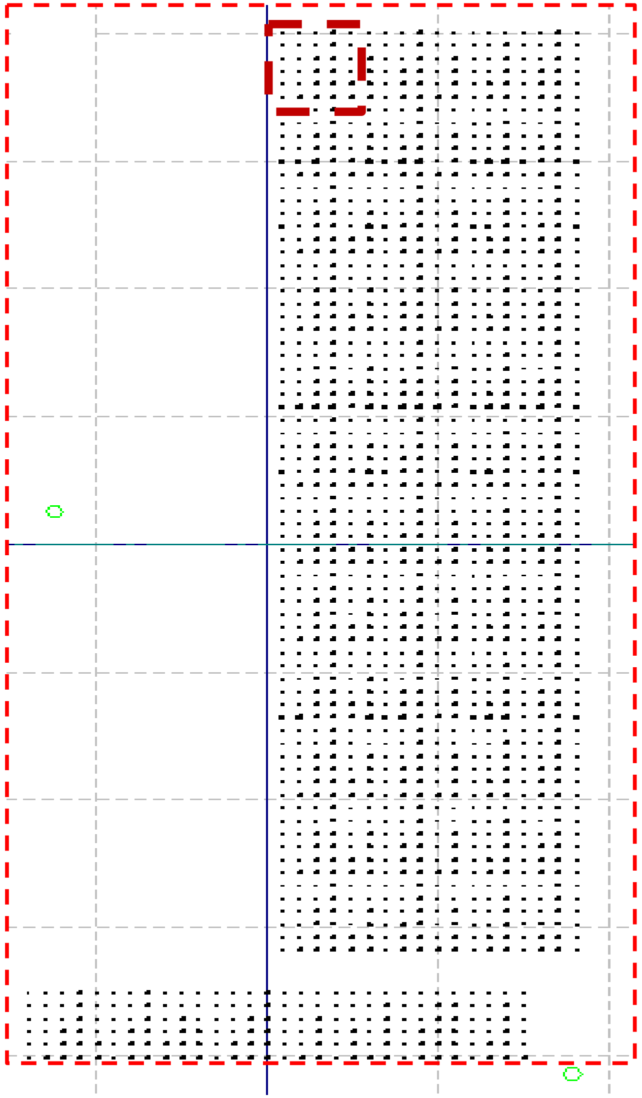
STENCIL DESIGN

Area Ratio/Aspect Ratio

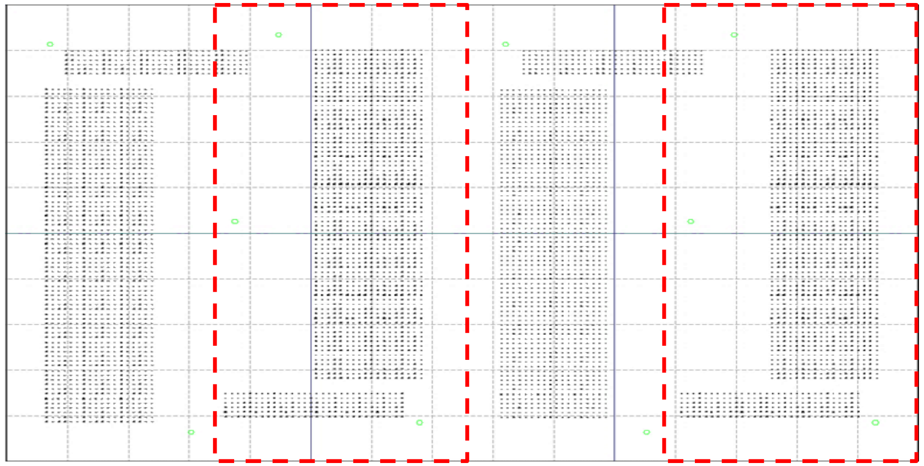
		Aspect Ratio				
Area Ratio	**0.32**	**1.2**	**1.4**	**1.6**	**1.8**	2
	0.36	1.2	1.4	1.6	1.8	2
	0.4	1.2	1.4	1.6	1.8	2
	0.44	1.2	1.4	1.6	1.8	2
	0.48	1.2	1.4	1.6	1.8	2
	0.52	1.2	1.4	1.6	1.8	2
Design		1	2	3	4	5


Aspect Ratio
1.2
1.4
1.6
1.8
2
Area Ratio
0.32
0.36
0.4
0.44
0.48
0.52

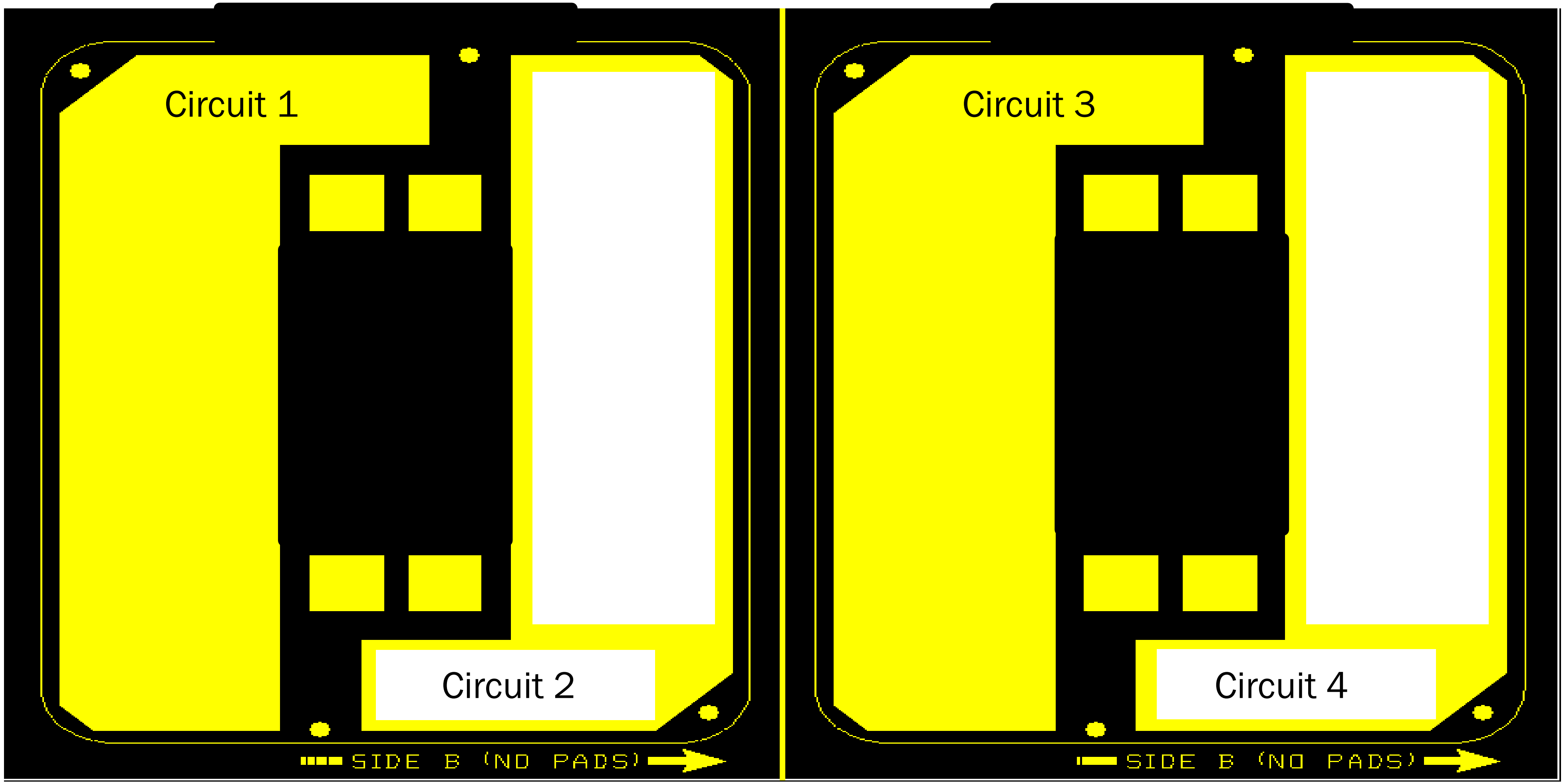
Stencil Artwork



- 42 Replicas per circuit
- 2 Circuits per Board
- 84 Replicas per Board



Substrate –Company Test Board

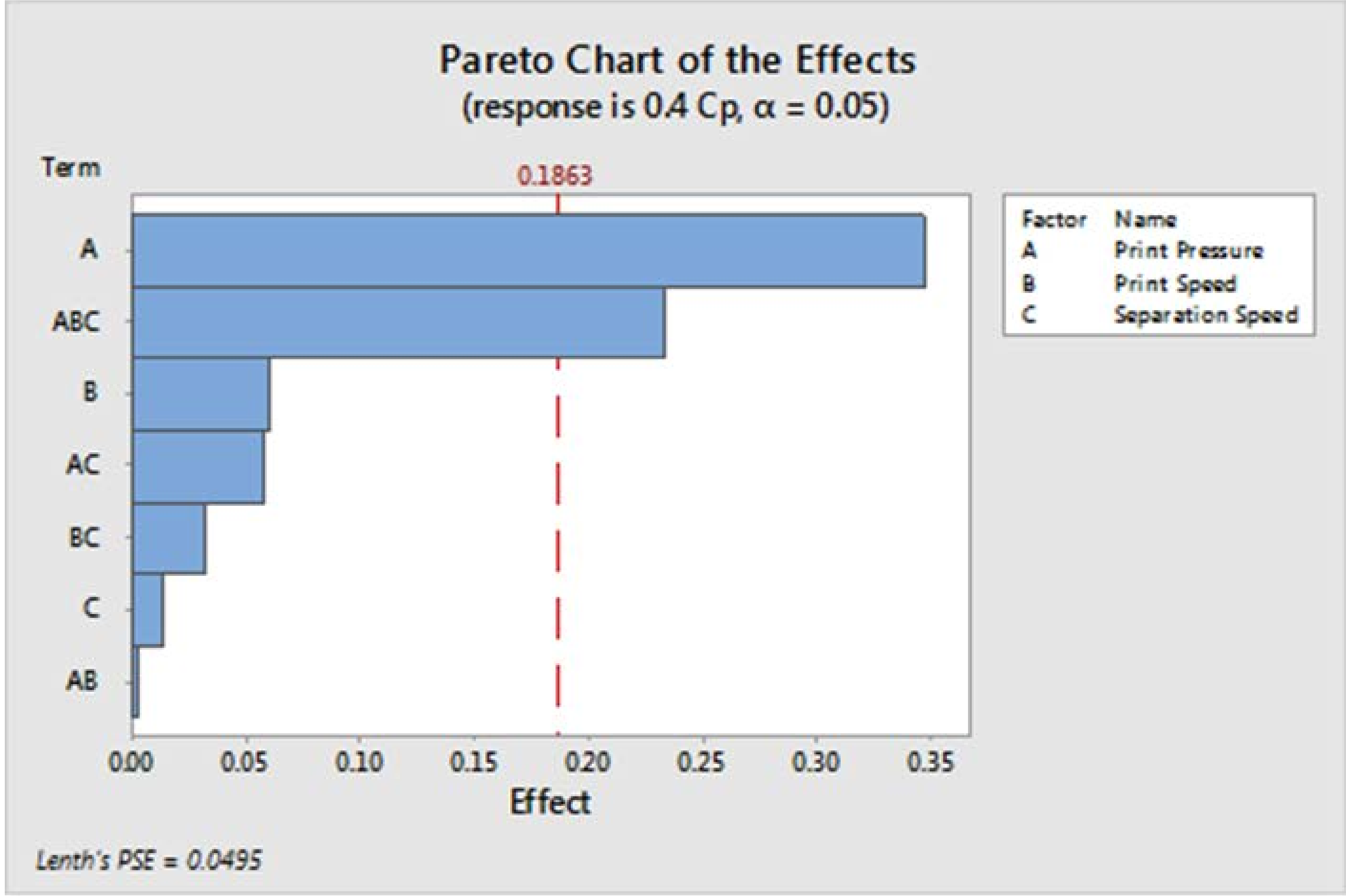


DESIGN OF EXPERIMENTS

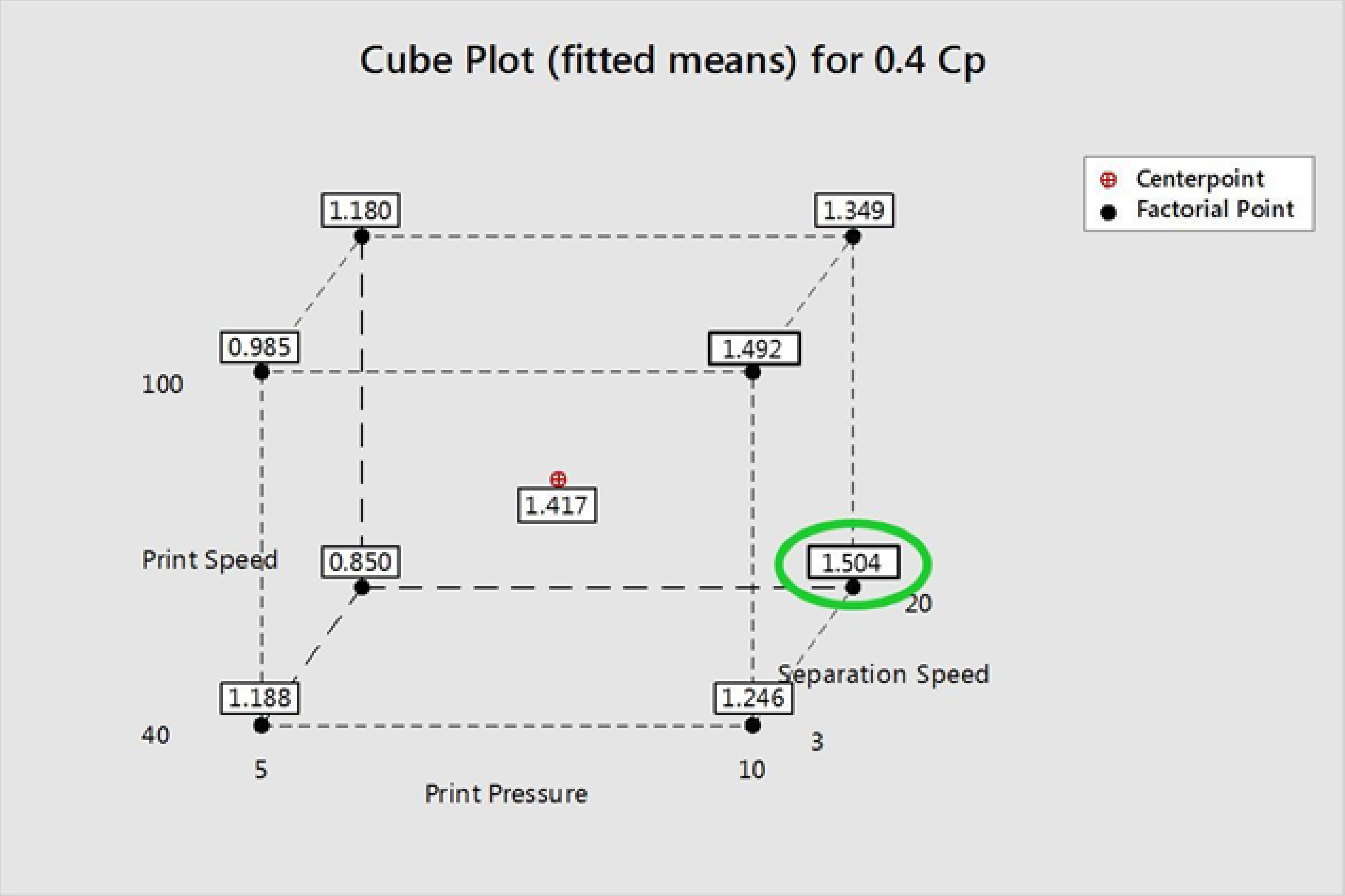
Design of Experiments

Run Order	Print Pressure	Print Speed	Separation Speed
1	5	40	3
2	10	40	20
3	7.4	70	11.5
4	5	100	20
5	10	100	20
6	10	40	3
7	5	100	3
8	10	100	3
9	5	40	20

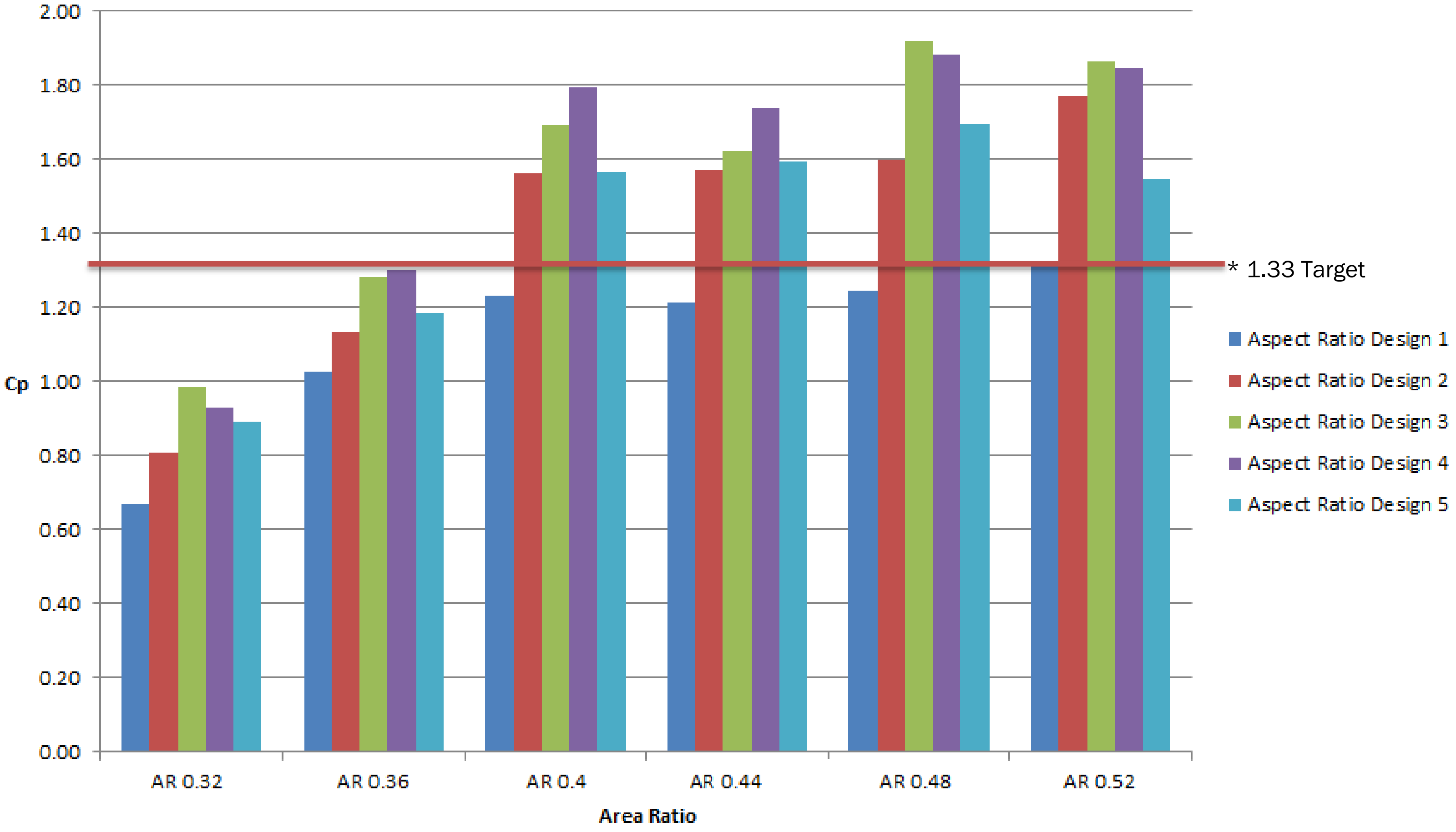
DOE - Pareto Chart



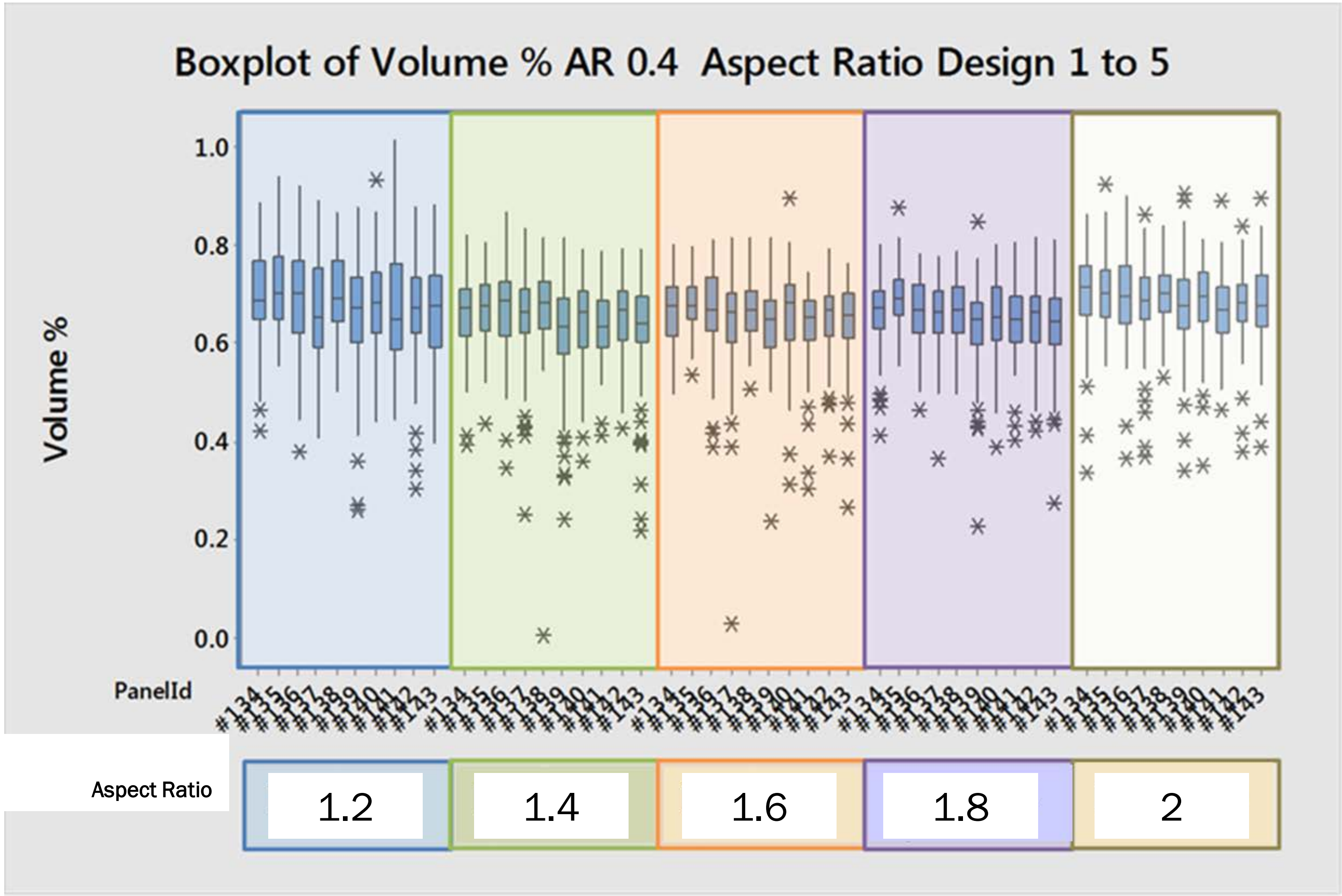
DOE – Cube Plot



DOE – Cp Results



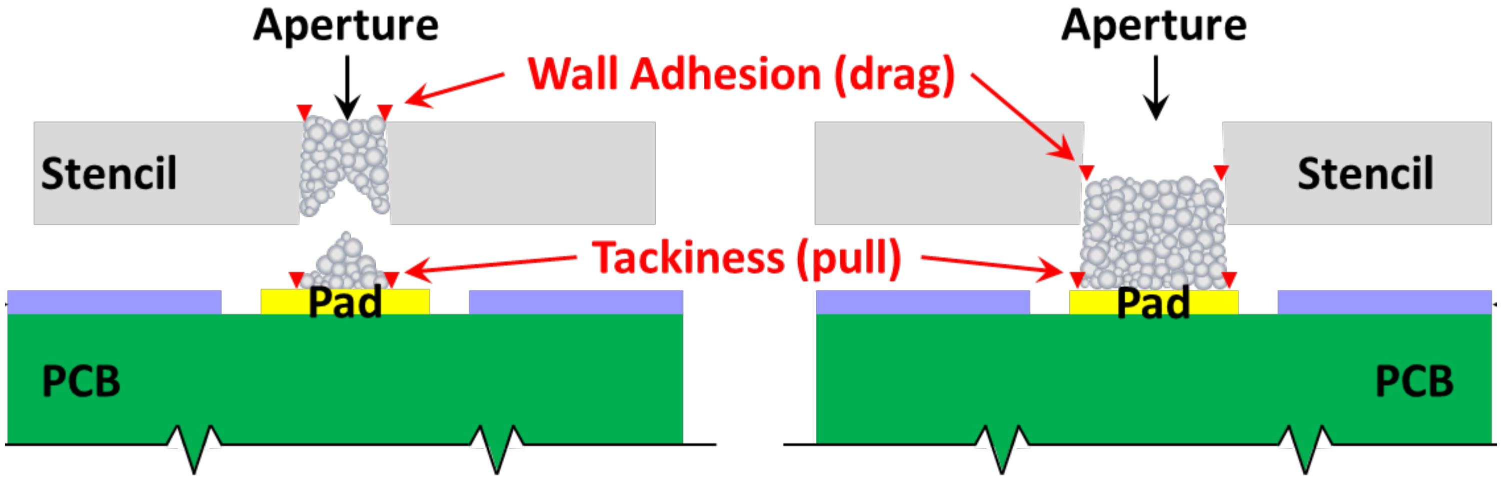
Boxplot Area Ratio 0.4 - Optimum Settings



ANALYSIS AND DISCUSSION

Aspect Ratio/ Design No	Horizontal Wall Surface Area (North/South) um3	Vertical Wall Surface Area (East/West) um3	Open Area Percentage difference w.r.t 1.2 Aspect Ratio	Horizontal (N/S) Wall Surface Area Percentage Change (%) w.r.t 1.2 Aspect Ratio	Vertical Wall (E/W) Surface Area Percentage Change (%) w.r.t 1.2 Aspect Ratio	Percentage difference between Horizontal and Vertical Wall Surface Area (%)
1.2 / 1	11360	9440	0	0	0	-20
1.8 / 4	14400	8000	+7	+ 27	- 15	-44
2.0 / 5	15520	7760	+12	+ 37	- 18	-50

Back to Basics….

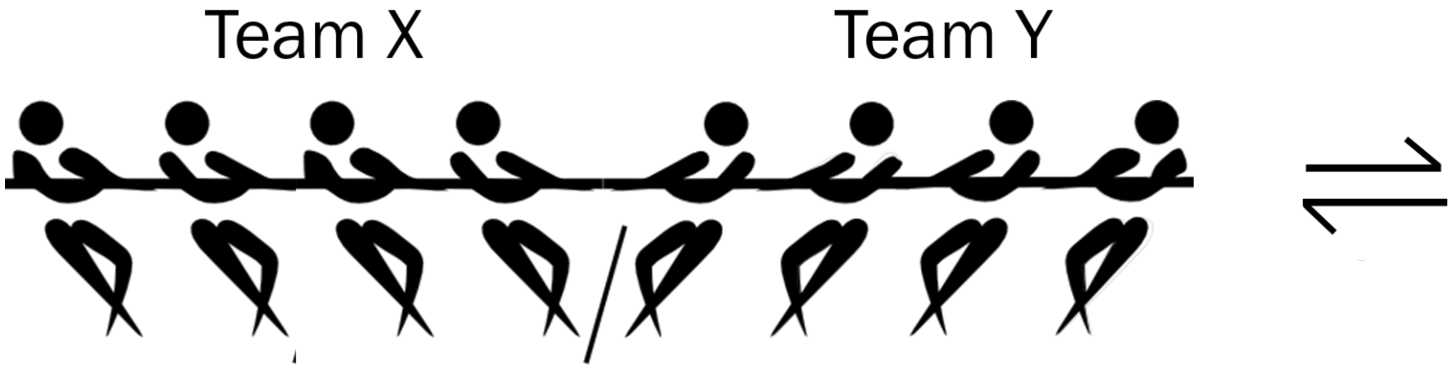


Low AR = Low Transfer Efficiency

High AR = High Transfer Efficiency

$$AR = \frac{\text{Aperture Open Area}}{\text{Aperture Wall Area}}$$

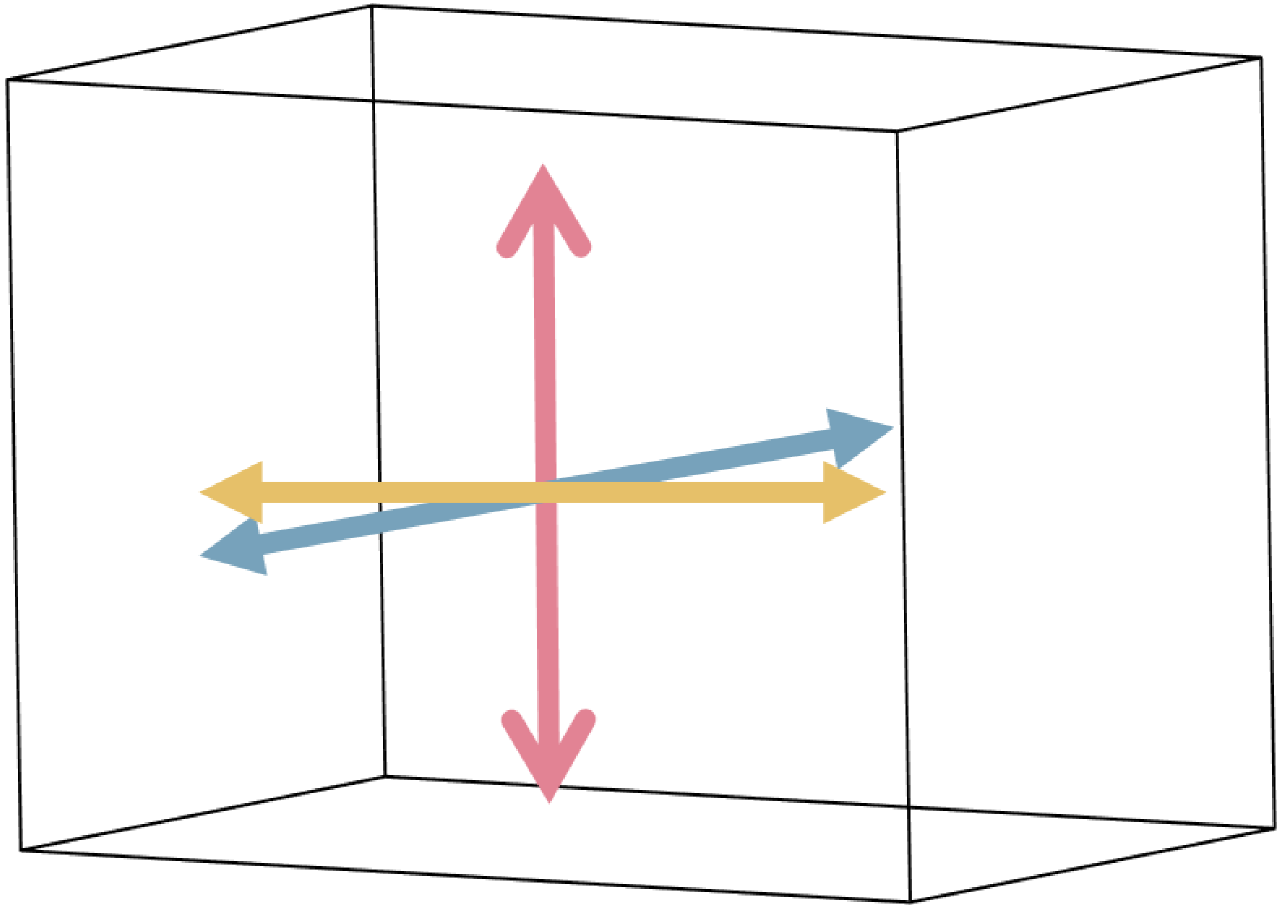
Tug of War



Team Y wins

Aperture Dynamics

Solder paste adheres to the 5 faces of an aperture

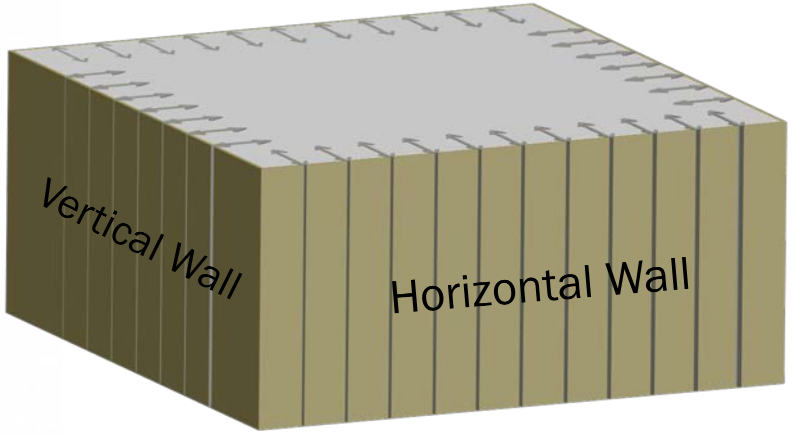


1.2 Aspect Ratio Example

Q. Which wall will loose ?

A. Probably the Vertical walls

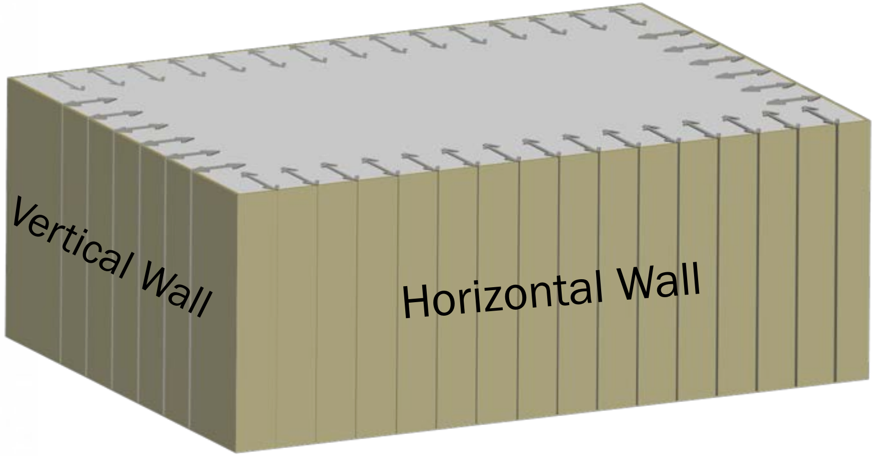
Note – Not much to choose between the two.
The adhesion of deposit to pad is most significant,



1.6 Aspect Example

Q. Which wall will loose ?
A. Certainly the vertical walls

Note – As the Aspect Ratio increases so does the opening area. A break in the vertical wall adhesion will aid the release of the horizontal wall "*Disruptor*"

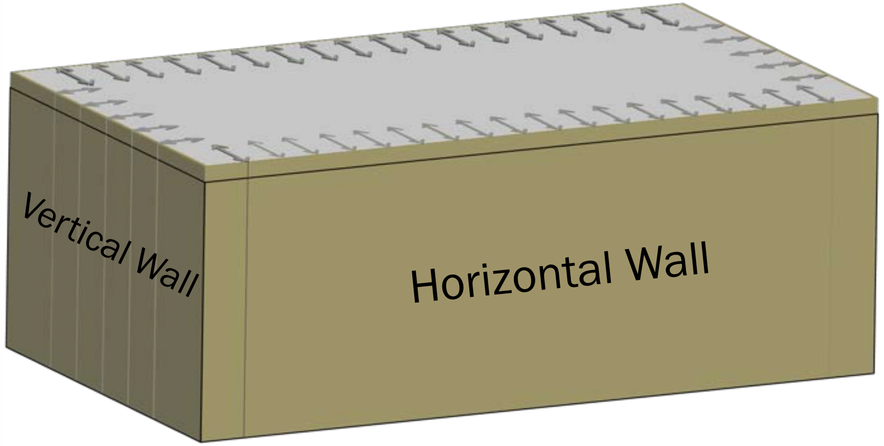


2.0 Aspect Example

Q. Which wall will loose ?
A. Definitely the vertical walls

Note –
The length of the vertical wall has decreased to a point in which the solder paste become jammed

The jamming action does not aid in the solder paste release process.



Conclusion/Thoughts

- The smallest area ratio which can be printed is 0.4
- The aspect ratio has an impact on the Cp value of the print deposition.
- An aspect ratio value of 1.6-1.8 produces the most repeatable solder paste deposit.
- The findings have recognised that an interaction between both the horizontal/vertical wall surface area and the aperture opening area exists.
- M03015 solution with 80um = 180um x 100um (Area Ratio 0.4 & Aspect Ratio 1.8)- Tested
- M0201 solution with 60um = 135 x 75 (Area Ratio 0.4 & Aspect Ratio 1.8) - Theoretical

Many Thanks for Listening…

Any Questions ?

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