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Do We Need to Switch to Type 5 Solder Pastes?
Conducting a Midsize Doe to Find Answers

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ABSTRACT

The design recommendations for the latest chips often contain overprints to handle the small land patterns with common type 4 pastes and 100 µm (4 mil) stencils.

Such workarounds make careful data preparation necessary.
A standardized data processing for the stencil apertures would be preferred.
To match the best practice recommendations for stencil printing, type 5 solder paste, and thinner stencils foils are necessary.

So - what does make more sense: Fiddling or Switching?

To get out of the conflict, a Design of Experiments (DoE) was proceeded to find answers. The experiment should find the optimum printer parameters, compare type 4 vs. 4.5 vs. 5 solder paste and 4 different stencils.

Key words: Area Ratio, Stencil Printing, Type 4.5, Type, DoE, SMT Miniaturization, Nanocoating, SMD Pads

INTRODUCTION

Components and their leads are still getting smaller.
At least every month, one of the new SMD components needs a special treatment at the land pattern and the stencil aperture.

These special treatments are time-consuming and error prone. Recommendations in the datasheets and warning messages can be overseen.

To get back to a standard, a typical misalignment of the solder paste print with 12 µm to 25 µm must be compensated by a reduction of the apertures.

Being close to the magical type 4 borders for round 228 µm diameter or rectangular 190 µm for the shortest edge, a type 5 solder paste is recommended.
Even tough - type 5 solder pastes are more expensive, lead to more complex handling processes and often make the use of (step-) stencils with 80 µm thickness necessary.

EXPERIMENT DESIGN

Design of Experiments

The goals of the experiment were to find to optimal printer parameters as well as comparing different stencil and solder pastes.

To find a first optimum, a Response surface methodology (RSM) Design is mandatory.
A classical or textbook design needs too many runs.
To keep the DoE in budget, the RSM had to be computer generated.

Table 1. Levels of the DoE

Factor	Level			
Printing Speed[mm/sec]	20		70	
Seperation Speed[mm/sec]	1		9	
Printing Pressure[Kg]	6		8.8	
Stencil Vendor	A_brushed	B_brushed	C_brushed	C_nano_coated
Solder Paste Vendor	A_Type_5	B_Type_5	A_Type_4.5	B_Type_4

The final DoE contained 55 runs with 1 repetition, in total 110 runs.

Strength of the design:

- Contains all 2-way interactions terms.
- Contains all second order/quadratic terms.
- Power of main effects is approximately 0.9.
- The power of the 2-way interactions and quadratic terms is between 0.5 to 0.9.

Weaknesses of the design:

- The repetition is done by the backwards printing.
- After the backwards printing, a cleaning cycle is conducted.
- So, there is no real repetition.
- Weak randomization, no real split plot design.
- Unbalanced. No interpretation by e.g., boxplots possible.

PCB Design

A new test vehicle was designed. The PCB includes typical small SMD components, but also upcoming, interesting components.

For most all components the land pattern/cells were designed as Non-Soldermask-Defined (NSMD) and as Soldermask-Defined (SMD) pads.
Components with unsymmetrical leads were placed with a 0° and 90° orientation relative to the printing direction.

The panel consists of six PCBs to provide a realistic – close to series production – behavior. The connectors of the upper row are placed close to the edge, to get a comparison between solder depots close to the rail clamp versus solder depots in the middle of the panel.

The test vehicle has a ENIG finish. It was ordered from a PCB manufacturer for our series production to provide tight copper tolerances (+-10%) and low variations in the solder mask thickness.

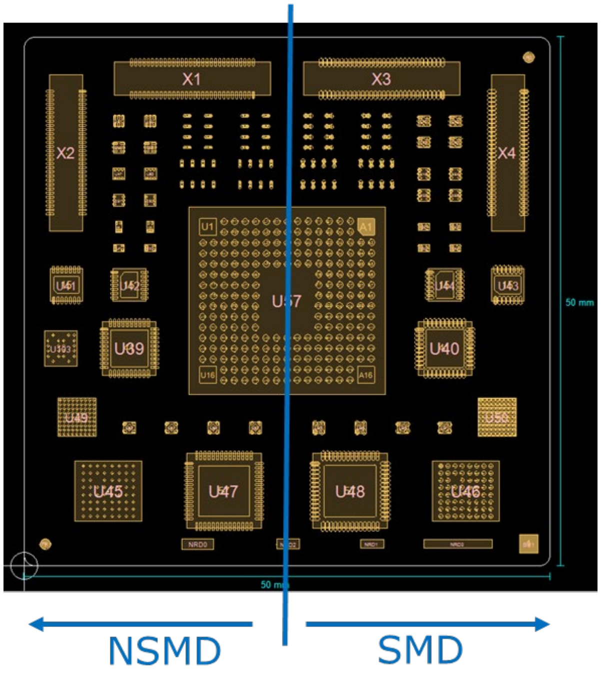


Figure 1. Test vehicle

Area Ratio (AR) Design

Many experts will recommend an AR=0.5 for the apertures of the stencil to see clear the differences between the pastes and the stencils.

The disadvantage is the non-linearity in this AR region.

To find an optimum set of printing parameter, the range of the levels of a DoE should be large as possible, but still linear and stable.

Therefor the low level of this DoE is AR=0.61, the “Center-Point” is AR=0.66 and the high level is AR=0.71.

The panel has a 3x2 matrix, that supports the test design.

Each column has a different AR. The two PCBs in the column, printed with the same AR, add some extra noise and variation to the response.

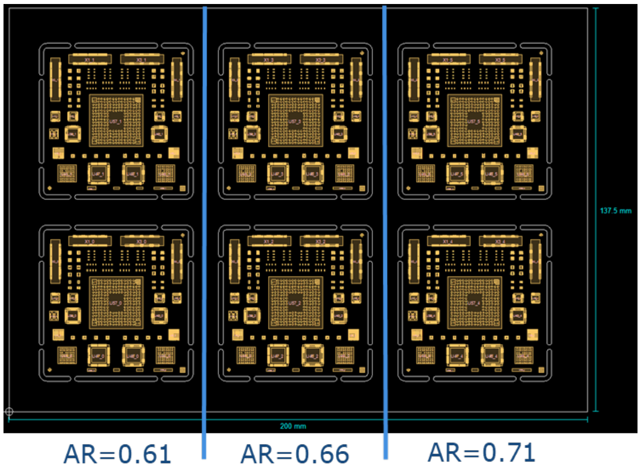


Figure 2. Test vehicle as panel with AR sections

Stencil Design

The ARs were calculated with a circumferential clearance of 12 µm or 25 µm depending on the geometry of the pad.

If that was not senseful, the aperture was calculated with self-coded AR calculator to match the desired AR.

The foil of the stencil as a thickness of 100 µm, but on small components the stencil has steps to 80 µm. This gives a realistic series productions stencil design.

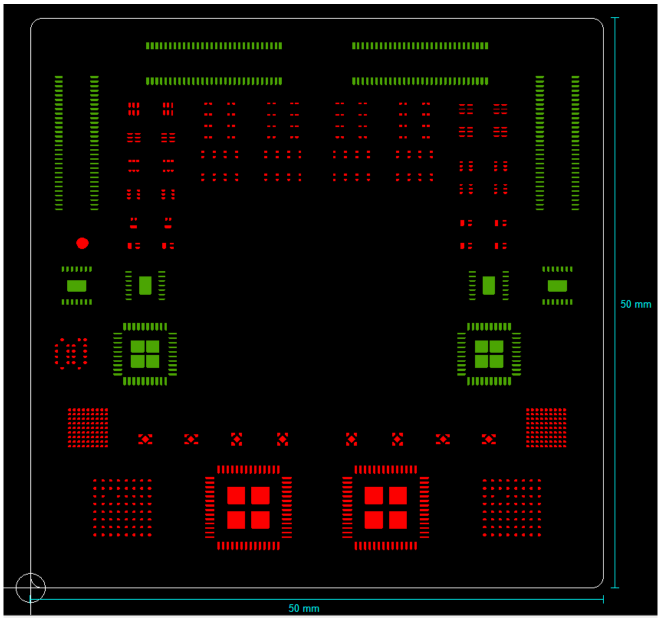


Figure 3. Green = 100 µm and red = 80 µm thickness

Depending on the vendor, the steps were realized by honing or welding. All stencils are stainless steel. The vendors had to cut the apertures exactly by the gerber file. No changes or optimizations were allowed.

The dimensions of the apertures were checked by random samples. All apertures were matching the ordered dimensions within the typical tolerances.

The Land Grid Array (LGA) in the middle of the PCB, was only used for preselecting the pastes. Its apertures are far to large to be relevant for the type 5 test. Therefor the DoE stencil has no apertures for this component/cell.

Paste Selection

We started with four paste suppliers.
The DoE plan just provides space for two suppliers for the type 5 paste. And at least one of them must also provide a type 4.5, to fit all needs of the plan. So, we proceeded a screening test to shorten the list.

Note:

- Solder pastes from vendor B have same flux mixture for type 4.5 and type 5.
- For the confirmation trials we had to exchange one paste, because the original paste got too dry.

Solder Paste Inspection (SPI)

We used a Parmi Sigma X as seen Figure 4 to measure the volume, height and area of the paste deposit of each pad of each land pattern/component/cell and exported the results as a *.xlsx.
The real volume is not important for the response of the DoE. It is just important, that all measurements are done the same way, so the results can be compared. Therefore, no units will be used in the further discussions.

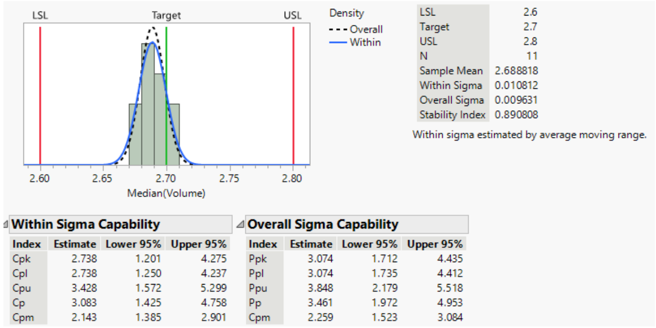
Figure 4. Volume measurement by SPI

General settings:

- Freshly adjusted DEK Horizon 03.
- Full metal board support system.
- 300 mm Squeegee blade.
- 60° wiping angle.
- Pastes got softened 4 minutes.
- Cleaning cycles every second print (details see DoE plan in the appendix).
- All stencils were cleaned by the machine one time, before they got used.

Gage R&R and Capability

No real Gage R&R was proceeded.
To get an idea we inspected the same printed PCB eleven times. The capability of the measured volume seems to be 'good enough', but for a few cases it was foreseeable, that it would be hard to discriminate between signal and noise.



LSL	2.6
Target	2.7
USL	2.8
N	11
Sample Mean	2.688818
Within Sigma	0.010812
Overall Sigma	0.009631
Stability Index	0.890808

Within sigma estimated by average moving range.

Within Sigma Capability

Index	Estimate	Lower 95%	Upper 95%
Cpk	2.738	1.201	4.275
Cpl	2.738	1.250	4.237
Cpu	3.428	1.572	5.299
Cp	3.083	1.425	4.758
Cpm	2.143	1.385	2.901

Overall Sigma Capability

Index	Estimate	Lower 95%	Upper 95%
Ppk	3.074	1.712	4.435
Ppl	3.074	1.735	4.412
Ppu	3.848	2.179	5.518
Pp	3.461	1.972	4.953
Cpm	2.259	1.523	3.084

Figure 5. Capability plot and Cpk

Execute the design

The whole main DoE was conducted in one eight hours shift. There were no special issues during the test.

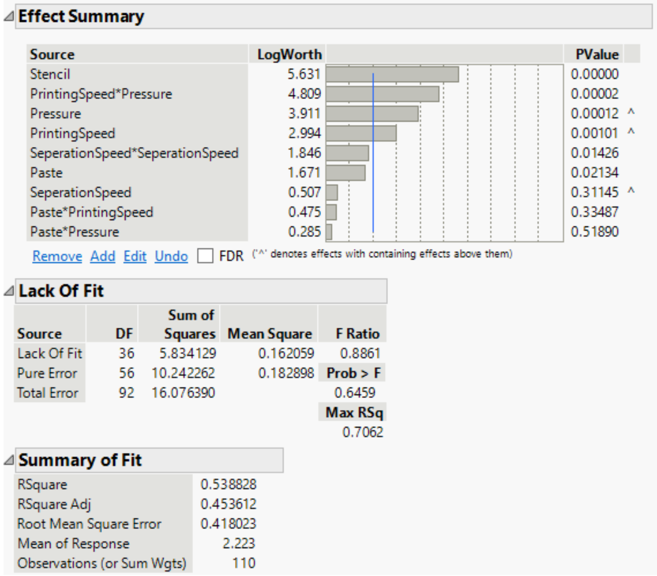
Analysis

The responses of the DoE are the median and the interquartile range (IQR) of the volumes of all pads of the land pattern in the scope (data filtered).

The computer-generated DoE is not interpretable without advanced statistic tools. Hence linear regression was used. To harden the model, different models got compared by significance of coefficients, (adjusted) R² and Lack Of Fit. Finally, one model that fits for all components and all ARs was set.

This final, reduced regression model includes:

- Main factors:
    - Paste.
    - Stencil.
    - Separation speed.
    - Printing speed.
    - Printing pressure.
- 2-way interactions:
    - Paste vs. Printing speed.
    - Pressure vs. Printing speed.
    - Paste vs. Separation speed.
- Quadratic:
    - Separation speed.



Effect Summary

Source	LogWorth	PValue
Stencil	5.631	0.00000
PrintingSpeed*Pressure	4.809	0.00002
Pressure	3.911	0.00012 ^
PrintingSpeed	2.994	0.00101 ^
SeperationSpeed*SeperationSpeed	1.846	0.01426
Paste	1.671	0.02134
SeperationSpeed	0.507	0.31145 ^
Paste*PrintingSpeed	0.475	0.33487
Paste*Pressure	0.285	0.51890

Remove Add Edit Undo ☐ FDR ('^' denotes effects with containing effects above them)

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	36	5.834129	0.162059	0.8861
Pure Error	56	10.242262	0.182898	**Prob > F**
Total Error	92	16.076390		0.6459
				Max RSq
				0.7062

Summary of Fit

RSquare	0.538828
RSquare Adj	0.453612
Root Mean Square Error	0.418023
Mean of Response	2.223
Observations (or Sum Wgts)	110

Figure 6. Example linear regression analysis

Standard DoE analyzing tools like main effect plots, interaction plots and response surface plots are inconvenient for a design with two additional categorial factors. Hence, the interactive prediction profiler of SAS JMP® was used to analyze the differences.

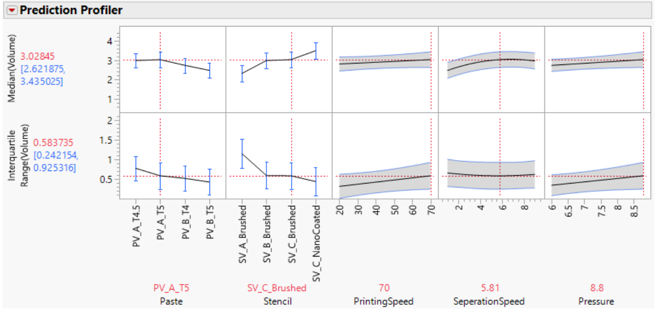
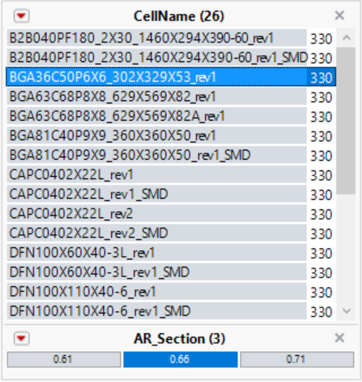


Figure 7. Median and IQR Vol. @BGA36C50... AR=0.66

The complexity of the data made it necessary to explore the data cell by cell and AR by AR using a filter.



CellName (26)

B2B040PF180_2X30_1460X294X390-60_rev1	330
B2B040PF180_2X30_1460X294X390-60_rev1_SMD	330
BGA36C50P6X6_302X329X53_rev1	330
BGA63C68P8X8_629X569X82_rev1	330
BGA63C68P8X8_629X569X82A_rev1	330
BGA81C40P9X9_360X360X50_rev1	330
BGA81C40P9X9_360X360X50_rev1_SMD	330
CAPC0402X22L_rev1	330
CAPC0402X22L_rev1_SMD	330
CAPC0402X22L_rev2	330
CAPC0402X22L_rev2_SMD	330
DFN100X60X40-3L_rev1	330
DFN100X60X40-3L_rev1_SMD	330
DFN100X110X40-6_rev1	330
DFN100X110X40-6_rev1_SMD	330

AR_Section (3)

0.61	0.66	0.71

Figure 8. Filter widget

The confidence intervals are very important in this analysis. In the examples below (Figure 9 and Figure 10) you can see an example of confidence intervals/bands for the Cell *BGA36C50P6X6_302X329X53_rev1*@AR=0.66.

In Figure 10 all confidence intervals of the pastes overlapping. That means - by the rule of thumb - there is no statistical significance between the volumes of the pastes. An ANOVA shows the same results, of course.

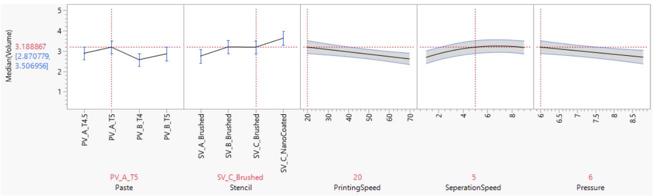


Figure 9. CI Example Low Printing Speed and Pressure

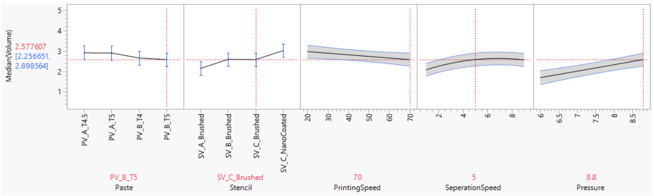


Figure 10. CI Example High Printing Speed and Pressure

Results of DoE

You learn from the DoE, that:

- The differences of the median volume between the paste types are often not significant. Hence, there is no significant advantage of pastes with type 5 powder shown by this DoE.
- With the same flux mixture, type 4.5 shows less variation at higher printing speed, than the type 5.
- The optimal separation speed depends on the size of the pad aperture.
- The nano stencil provides the best volume, but not always the best deviation.
- All stencils bring unexpected variation between different aperture designs.
- The optimal separation speed for a maximum volume is slightly different to the optimal separation speed for a minimum of volume deviation. A separation speed of 5 mm/sec to 6 mm/sec is an optimum.
- The stencil of Vendor A is significantly worst.

Discussion of the DoE

It is hard to see statistically significant differences between type 4, type 4.5 und type 5. The cause is the DoE Design. It is neither at the cutting edge of the paste nor of the AR.

However – a robust stencil design will not exhaust what is possible. The goal is a stable printing process with a low deviation. Therefore, it was the right approach.

With an AR=0.61 the results got clearer - what statistically makes sense because the differences in the deposit are bigger, too. But even with an AR=0.71, clear differences between stencils and printer settings can be seen.

The right stencil had very often a bigger leverage on the median volume than the type 5 paste, followed by the separation speed.

Why is the stencil of Vendor A always worse?
The measurements of the apertures were inconspicuous. Coincidentally we found slag from the laser processing in the insides of the apertures. This diameter reduction might be the root cause, for the bad results.

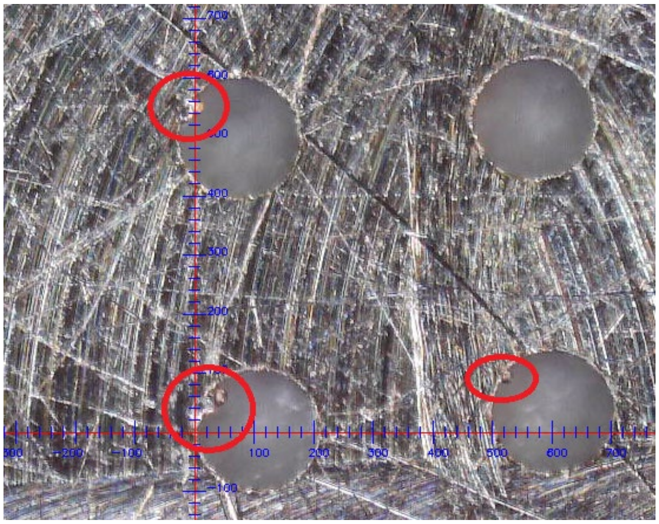


Figure 11. Slag at stencil from Vendor A, Dimension [µm]

CONFIRMATION RUN

It is best practice to run a confirmation run to prove the insides from a DoE.

Design of confirmation run

10 prints with a different pairing of paste and stencil with the same printer settings should be enough as a first confirmation.

Because the stencil of Vendor A performed bad, it was discarded. Vendor B has an interesting new coating technology, so it took over the place from the bad stencil.
Type 4.5 was dropped, too. The – possibly – lower variation on higher printing speed was no advantage for our production concept.

The type 5 paste of Vendor A got too dry. A highly optimized DoE approved the first bare eye impression. It was not possible to get a replacement within the trial period. So, it could not be used for the confirmation run.
In exchange we used a different type 5 paste from Vendor C.

Our standard type 4 paste from Vendor B worked as a facilitator. If there were differences between the stencils, they should also occur with a type 4 paste.

The printer settings were predetermined as

- Separation speed = 6mm/sec.
- Printing speed = 20mm/sec.
- Printing pressure = 6 kg.
- Cleaning Cycle after 5 prints.

Table 2. Stencil-paste pairings:

Paste Vendor (PV) / Stencil Vendor (SV)	B Type 4	B Type 5 (preaged)	C Type 5
B brushed	X		
B coated	X		X
C brushed	X		
C nano-coated	X	X	

Analysis

With the data plotted in a control chart (Figure 12), the volumes of all printed cells at all AR are instable.

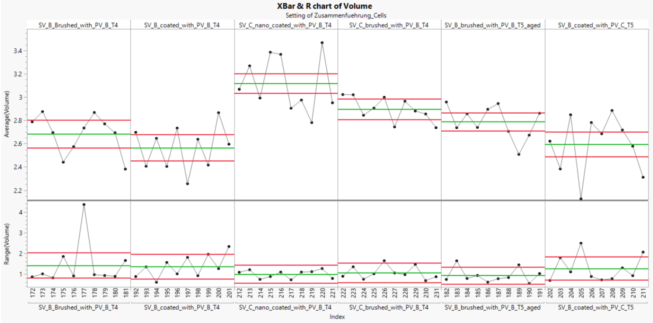


Figure 12. Control Chart for CAPC0402X22L, AR=0.66

Using a Three Way Control Chart (Figure 13), it is getting obvious, that there is a variation between the groups – means – printing cycles.

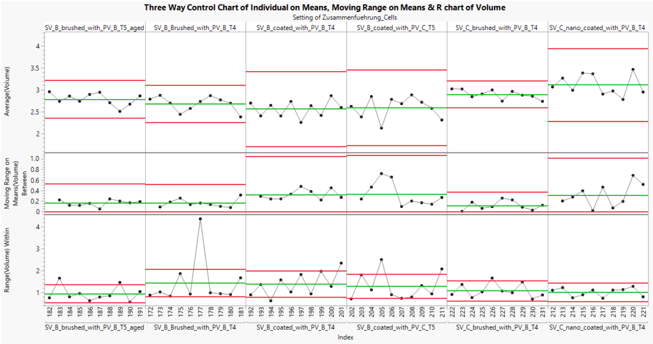


Figure 13. Three Way Control Chart for CAP0402...

Further adjustments of the printer might reduce the problem. One hypothesis is, that the separation process is not capable.

Coefficient of Variation

To compare the predictability of the stencil-paste pairings the coefficient of variation (CV) is a good indicator.

Using the CV definitions for stencils, see Chrys Shea et al.[1],

- *<10%: preferred*
- *10-15%: acceptable*
- *>15%: unacceptable*

the picture getting clearer.

- Like expected, the nano-coated stencil from Vendor C performs very well, even with a type 4 paste.
- More surprising is that brushed stencils often show a *desired* variation with type 4 and type 5 pastes.
- Surprisingly the new coating of Vendor B is very often in section of *unacceptable* and almost never below *desired* with type 4 and type 5!

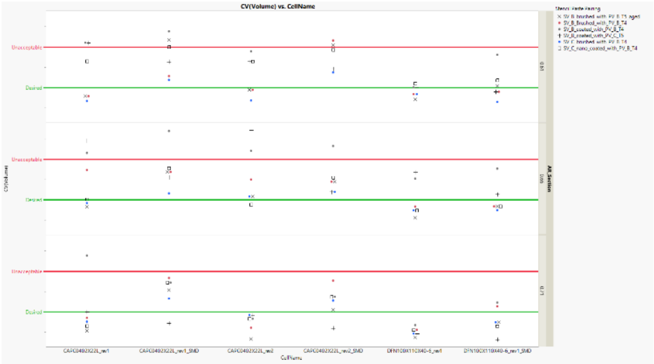


Figure 14. CV vs. Stencil-Paste-Pairing (for large plot see Appendix)

Outlier

A different quality indicator is the proportion/percentage of pads, which are having a volume below a certain percentage of the volume's median of the cell-pairing-AR group.
Or in short words: "How many percent of the solder depots will be misprinted?"

Following the typical thresholds for the transfer efficiency, a deposit with less than 75% of the median of the group, will be defined as misprinted.

A visualization for the concept is shown in Figure 15.

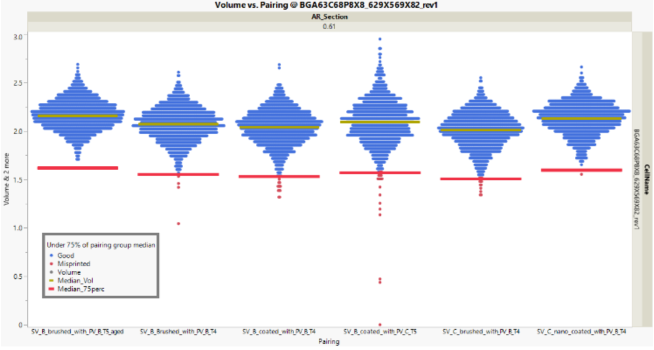
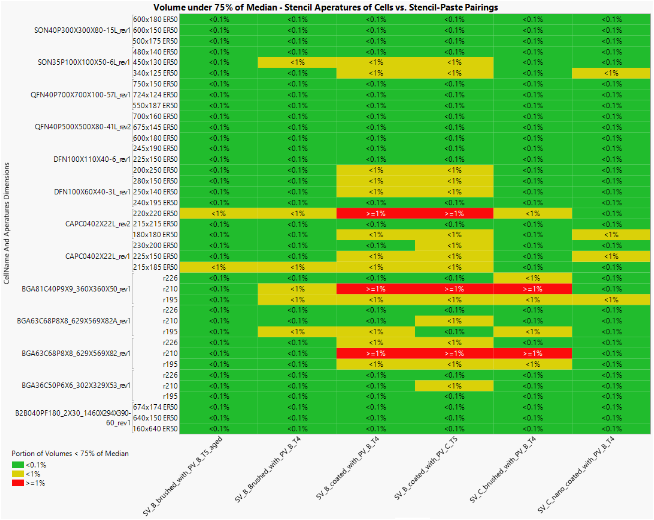


Figure 15. Vol. < 75% of cell-pairing-AR median = red

The three categories were used to rate the quantity of misprinted pads

- more or equal 1%,
- between 0.1% and 1%,
- less than 0.1%.

Here the result for the NSMD land pattern is very clear.



Volume under 75% of Median - Stencil Aperatures of Cells vs. Stencil-Paste Pairings

CellName And Aperatures Dimensions		SV_B_brushed_with_PV_B_T5_aged	SV_B_Brushed_with_PV_B_T4	SV_B_coated_with_PV_B_T4	SV_B_coated_with_PV_C_T5	SV_C_brushed_with_PV_B_T4	SV_C_nano_coated_with_PV_B_T4
SON40P300X300X80-15L_rev1	600x180 ER50	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
	600x150 ER50	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
	500x175 ER50	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
SON35P100X100X50-6L_rev1	480x140 ER50	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
	450x130 ER50	<0.1%	<1%	<1%	<1%	<0.1%	<0.1%
	340x125 ER50	<0.1%	<0.1%	<1%	<1%	<0.1%	<1%
QFN40P700X700X100-57L_rev1	750x150 ER50	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
	724x124 ER50	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
	550x187 ER50	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
QFN40P500X500X80-41L_rev2	700x160 ER50	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
	675x145 ER50	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
	600x180 ER50	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
DFN100X110X40-6_rev1	245x190 ER50	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
	225x150 ER50	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
	200x250 ER50	<0.1%	<0.1%	<1%	<1%	<0.1%	<0.1%
DFN100X60X40-3L_rev1	280x150 ER50	<0.1%	<0.1%	<1%	<1%	<0.1%	<0.1%
	250x140 ER50	<0.1%	<0.1%	<1%	<1%	<0.1%	<0.1%
	240x195 ER50	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
CAPC0402X22L_rev2	220x220 ER50	<1%	<1%	>=1%	>=1%	<1%	<0.1%
	215x215 ER50	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
	180x180 ER50	<0.1%	<0.1%	<1%	<1%	<0.1%	<1%
CAPC0402X22L_rev1	230x200 ER50	<0.1%	<0.1%	<0.1%	<1%	<0.1%	<0.1%
	225x150 ER50	<0.1%	<0.1%	<1%	<1%	<0.1%	<1%
	215x185 ER50	<1%	<1%	<1%	<1%	<0.1%	<0.1%
BGA81C40P9X9_360X360X50_rev1	r226	<0.1%	<0.1%	<0.1%	<0.1%	<1%	<0.1%
	r210	<0.1%	<1%	>=1%	>=1%	>=1%	<0.1%
	r195	<0.1%	<1%	<1%	<1%	<1%	<1%
BGA63C68P8X8_629X569X82A_rev1	r226	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
	r210	<0.1%	<0.1%	<0.1%	<1%	<0.1%	<0.1%
	r195	<0.1%	<1%	<1%	<0.1%	<1%	<0.1%
BGA63C68P8X8_629X569X82_rev1	r226	<0.1%	<0.1%	<1%	<1%	<0.1%	<0.1%
	r210	<0.1%	<0.1%	>=1%	>=1%	>=1%	<0.1%
	r195	<0.1%	<0.1%	<1%	<1%	<1%	<0.1%
BGA36C50P6X6_302X329X53_rev1	r226	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
	r210	<0.1%	<0.1%	<0.1%	<1%	<0.1%	<0.1%
	r195	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
B2B040PF180_2X30_1460X294X390-60_rev1	674x174 ER50	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
	640x150 ER50	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
	160x640 ER50	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%

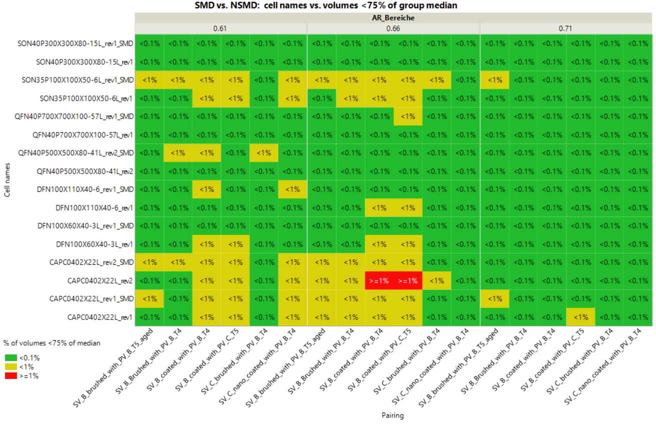
Portion of Volumes < 75% of Median
🟩 <0.1%
🟨 <1%
🟥 >=1%

Figure 16. NSMD - Percentage Volume < 75% of Median

The (preaged) type 5 paste on the brushed stencil shows almost no misprints at all apertures, followed by the type 4 paste on the nano coated stencil.

The new coating of stencil supplier B has many misprints, no matter which paste was used.

Comparing SMD vs. NSMD:



SMD vs. NSMD: cell names vs. volumes <75% of group median

	AR_Bereiche																	
	0.61						0.66						0.71					
Cell names	SV_B_brushed_with_PV_B_T5_aged	SV_B_Brushed_with_PV_B_T4	SV_B_coated_with_PV_B_T4	SV_B_coated_with_PV_C_T5	SV_C_brushed_with_PV_B_T4	SV_C_nano_coated_with_PV_B_T4	SV_B_brushed_with_PV_B_T5_aged	SV_B_Brushed_with_PV_B_T4	SV_B_coated_with_PV_B_T4	SV_B_coated_with_PV_C_T5	SV_C_brushed_with_PV_B_T4	SV_C_nano_coated_with_PV_B_T4	SV_B_brushed_with_PV_B_T5_aged	SV_B_Brushed_with_PV_B_T4	SV_B_coated_with_PV_B_T4	SV_B_coated_with_PV_C_T5	SV_C_brushed_with_PV_B_T4	SV_C_nano_coated_with_PV_B_T4
SON40P300X300X80-15L_rev1_SMD	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
SON40P300X300X80-15L_rev1	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
SON35P100X100X50-6L_rev1_SMD	<1%	<1%	<1%	<1%	<0.1%	<1%	<1%	<1%	<1%	<1%	<1%	<0.1%	<1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
SON35P100X100X50-6L_rev1	<0.1%	<0.1%	<1%	<1%	<0.1%	<1%	<0.1%	<1%	<1%	<1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
QFN40P700X700X100-57L_rev1_SMD	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
QFN40P700X700X100-57L_rev1	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
QFN40P500X500X80-41L_rev2_SMD	<0.1%	<1%	<1%	<0.1%	<1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
QFN40P500X500X80-41L_rev2	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
DFN100X110X40-6_rev1_SMD	<0.1%	<0.1%	<1%	<0.1%	<0.1%	<1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
DFN100X110X40-6_rev1	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<1%	<1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
DFN100X60X40-3L_rev1_SMD	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
DFN100X60X40-3L_rev1	<0.1%	<0.1%	<1%	<1%	<0.1%	<0.1%	<0.1%	<0.1%	<1%	<1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
CAPC0402X22L_rev2_SMD	<1%	<1%	<1%	<1%	<0.1%	<1%	<1%	<1%	<1%	<1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
CAPC0402X22L_rev2	<0.1%	<0.1%	<1%	<1%	<0.1%	<1%	<1%	<1%	>=1%	>=1%	<1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
CAPC0402X22L_rev1_SMD	<1%	<0.1%	<1%	<1%	<0.1%	<1%	<1%	<1%	<1%	<1%	<0.1%	<0.1%	<1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
CAPC0402X22L_rev1	<0.1%	<0.1%	<1%	<1%	<0.1%	<1%	<1%	<1%	<1%	<1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<1%	<0.1%	<0.1%

Pairing

% of volumes <75% of median
🟩 <0.1%
🟨 <1%
🟥 >=1%

Figure 17. Volume <75% NSMD vs. SMD

Using a Soldermask Design (SMD), the variation of the solder mask thickness typically leads to more deviation in solder paste printing. Analyzing the summarized data, this typical assumption is not always true.

Prediction Interval

The Prediction Interval (PI) is also an interesting capability indicator.
It gives the predicted confidence interval for one single pad.

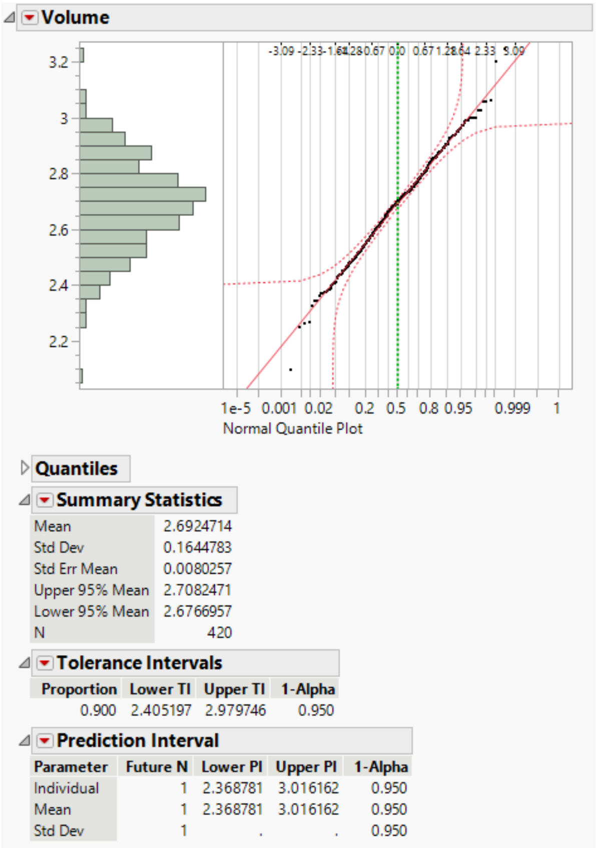
For the cell BGA36C50P6X6_302X329X53_rev1 @AR=0.66 with a brushed stencil the PI is
Volume type 5: 2.692 ± 0.32
Volume type 4: 2.424 ± 0.39

To correct the different means - caused by the different pastes -, the volumes and intervals can be divided by their means.

Upper PI type5 / mean type 5 = 1.12
Upper PI type4 / mean type 4 = 1.16

This calculation give as a half PI differences of ~3.5% or a (full) PI difference of 7%. This proofs, that the printing results of the type 5 paste will have a lower variation.

For e.g., 01005 cells the difference in the PI is even bigger.



Summary Statistics

Mean	2.6924714
Std Dev	0.1644783
Std Err Mean	0.0080257
Upper 95% Mean	2.7082471
Lower 95% Mean	2.6766957
N	420

Tolerance Intervals

Proportion	Lower TI	Upper TI	1-Alpha
0.900	2.405197	2.979746	0.950

Prediction Interval

Parameter	Future N	Lower PI	Upper PI	1-Alpha
Individual	1	2.368781	3.016162	0.950
Mean	1	2.368781	3.016162	0.950
Std Dev	1	.	.	0.950

Figure 18. BGA36C50… AR=0.66 type 5

Results of the confirmation run

- The type 5 paste at a brushed steel stencil performs best at small apertures.
- The nano coated stencil with type 4 paste and an AR=0.66 beats the type 5 on a brushed stencil. So, it is an excellent bridge technology.
- The new coating technology from stencil supplier B is often worse, than the same – just brushed – stencil without coating. Surprisingly, if it was paired with type 5 paste, it was worse than a (different) type 5 paste on a standard stencil from the same supplier!

Discussion confirmation run

Even if the design of the confirmation run was a bit 'tuned', it was a full success.

Thanks to performing the main DoE before the confirmation run, all prints used the optimal settings for the test vehicle and the stencils. This is a big advantage compared to tests that just use the "typical" settings or the recommendations from the solder paste vendors. The test showed that the printing process is not stable between the printing cycles, what might serve as a starting point for further optimizations. However, with this variation it was possible to proof the differences between the stencil technologies as well as the solder powder size with three different indicators, the CV, the percentage of misprinted pads and the prediction interval. All results show that the type 5 is an advantage. Furthermore, it shows that even a good coating technology can be beaten by the right solder paste type. The new coating technology of supplier B cannot be recommended. It is not only worse than their own uncoated stencil, but furthermore the capability of the coating seems to vary with the paste. Otherwise, it would not be explainable, why the same stencil performs worse with a type 5 than with a type 4 solder paste.

Conclusion

We asked many experts about the different stencil technologies used by our production. There were many different opinions, but statistically robust evidence was absent. Thanks to the DoE we have now answers and know that the extra effort of introducing a type 5 will be worth it. And that the fiddling can end, too. The typical AR=0.66 recommendations can already be critical for a capable printing process. Using an AR~0.7, the printing process is by far better under control. The main DoE created 890,000 data points and the confirmation run a another 475,000 data points. With this massive amount of data, more research and prediction can be done. By example: The result of the printing quality depends not only on the area and the foil thickness, but also on the shape and – for a rectangular – on the aspect ratio of the edges. Hence, linear regression is not the best prediction tool. Neural networks are better in finding and predicting "spots". A simple example is shown in Figure 19. In this neural neutral with five hidden nodes, you can – carefully using domain knowledge – predict the percentage of misprinted pads.

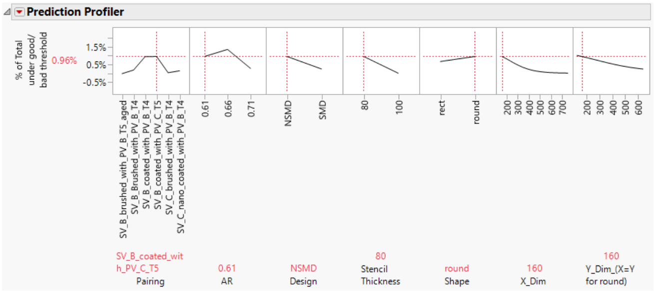
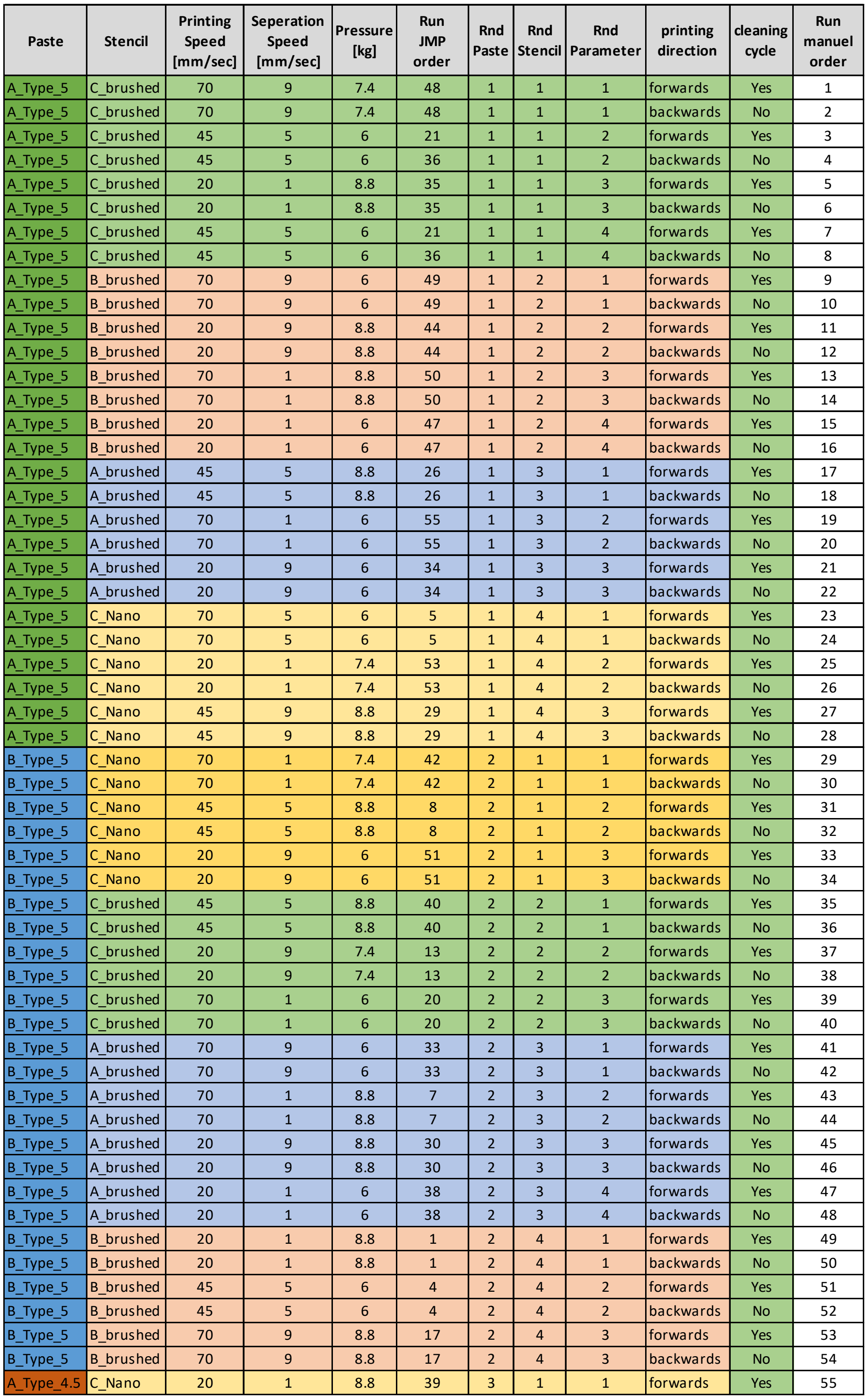


Figure 19. Example Neural network

REFERENCES

[1] C.Shea et al.,"Thin Foil Printing in Today's Miniaturized World: Do Printing Rules Change?", Proceedings of SMTA International, 2021

APPENDIX



Paste	Stencil	Printing Speed [mm/sec]	Seperation Speed [mm/sec]	Pressure [kg]	Run JMP order	Rnd Paste	Rnd Stencil	Rnd Parameter	printing direction	cleaning cycle	Run manuel order
A_Type_5	C_brushed	70	9	7.4	48	1	1	1	forwards	Yes	1
A_Type_5	C_brushed	70	9	7.4	48	1	1	1	backwards	No	2
A_Type_5	C_brushed	45	5	6	21	1	1	2	forwards	Yes	3
A_Type_5	C_brushed	45	5	6	36	1	1	2	backwards	No	4
A_Type_5	C_brushed	20	1	8.8	35	1	1	3	forwards	Yes	5
A_Type_5	C_brushed	20	1	8.8	35	1	1	3	backwards	No	6
A_Type_5	C_brushed	45	5	6	21	1	1	4	forwards	Yes	7
A_Type_5	C_brushed	45	5	6	36	1	1	4	backwards	No	8
A_Type_5	B_brushed	70	9	6	49	1	2	1	forwards	Yes	9
A_Type_5	B_brushed	70	9	6	49	1	2	1	backwards	No	10
A_Type_5	B_brushed	20	9	8.8	44	1	2	2	forwards	Yes	11
A_Type_5	B_brushed	20	9	8.8	44	1	2	2	backwards	No	12
A_Type_5	B_brushed	70	1	8.8	50	1	2	3	forwards	Yes	13
A_Type_5	B_brushed	70	1	8.8	50	1	2	3	backwards	No	14
A_Type_5	B_brushed	20	1	6	47	1	2	4	forwards	Yes	15
A_Type_5	B_brushed	20	1	6	47	1	2	4	backwards	No	16
A_Type_5	A_brushed	45	5	8.8	26	1	3	1	forwards	Yes	17
A_Type_5	A_brushed	45	5	8.8	26	1	3	1	backwards	No	18
A_Type_5	A_brushed	70	1	6	55	1	3	2	forwards	Yes	19
A_Type_5	A_brushed	70	1	6	55	1	3	2	backwards	No	20
A_Type_5	A_brushed	20	9	6	34	1	3	3	forwards	Yes	21
A_Type_5	A_brushed	20	9	6	34	1	3	3	backwards	No	22
A_Type_5	C_Nano	70	5	6	5	1	4	1	forwards	Yes	23
A_Type_5	C_Nano	70	5	6	5	1	4	1	backwards	No	24
A_Type_5	C_Nano	20	1	7.4	53	1	4	2	forwards	Yes	25
A_Type_5	C_Nano	20	1	7.4	53	1	4	2	backwards	No	26
A_Type_5	C_Nano	45	9	8.8	29	1	4	3	forwards	Yes	27
A_Type_5	C_Nano	45	9	8.8	29	1	4	3	backwards	No	28
B_Type_5	C_Nano	70	1	7.4	42	2	1	1	forwards	Yes	29
B_Type_5	C_Nano	70	1	7.4	42	2	1	1	backwards	No	30
B_Type_5	C_Nano	45	5	8.8	8	2	1	2	forwards	Yes	31
B_Type_5	C_Nano	45	5	8.8	8	2	1	2	backwards	No	32
B_Type_5	C_Nano	20	9	6	51	2	1	3	forwards	Yes	33
B_Type_5	C_Nano	20	9	6	51	2	1	3	backwards	No	34
B_Type_5	C_brushed	45	5	8.8	40	2	2	1	forwards	Yes	35
B_Type_5	C_brushed	45	5	8.8	40	2	2	1	backwards	No	36
B_Type_5	C_brushed	20	9	7.4	13	2	2	2	forwards	Yes	37
B_Type_5	C_brushed	20	9	7.4	13	2	2	2	backwards	No	38
B_Type_5	C_brushed	70	1	6	20	2	2	3	forwards	Yes	39
B_Type_5	C_brushed	70	1	6	20	2	2	3	backwards	No	40
B_Type_5	A_brushed	70	9	6	33	2	3	1	forwards	Yes	41
B_Type_5	A_brushed	70	9	6	33	2	3	1	backwards	No	42
B_Type_5	A_brushed	70	1	8.8	7	2	3	2	forwards	Yes	43
B_Type_5	A_brushed	70	1	8.8	7	2	3	2	backwards	No	44
B_Type_5	A_brushed	20	9	8.8	30	2	3	3	forwards	Yes	45
B_Type_5	A_brushed	20	9	8.8	30	2	3	3	backwards	No	46
B_Type_5	A_brushed	20	1	6	38	2	3	4	forwards	Yes	47
B_Type_5	A_brushed	20	1	6	38	2	3	4	backwards	No	48
B_Type_5	B_brushed	20	1	8.8	1	2	4	1	forwards	Yes	49
B_Type_5	B_brushed	20	1	8.8	1	2	4	1	backwards	No	50
B_Type_5	B_brushed	45	5	6	4	2	4	2	forwards	Yes	51
B_Type_5	B_brushed	45	5	6	4	2	4	2	backwards	No	52
B_Type_5	B_brushed	70	9	8.8	17	2	4	3	forwards	Yes	53
B_Type_5	B_brushed	70	9	8.8	17	2	4	3	backwards	No	54
A_Type_4.5	C_Nano	20	1	8.8	39	3	1	1	forwards	Yes	55

Figure 20. Main DoE run table – run 1 to 55

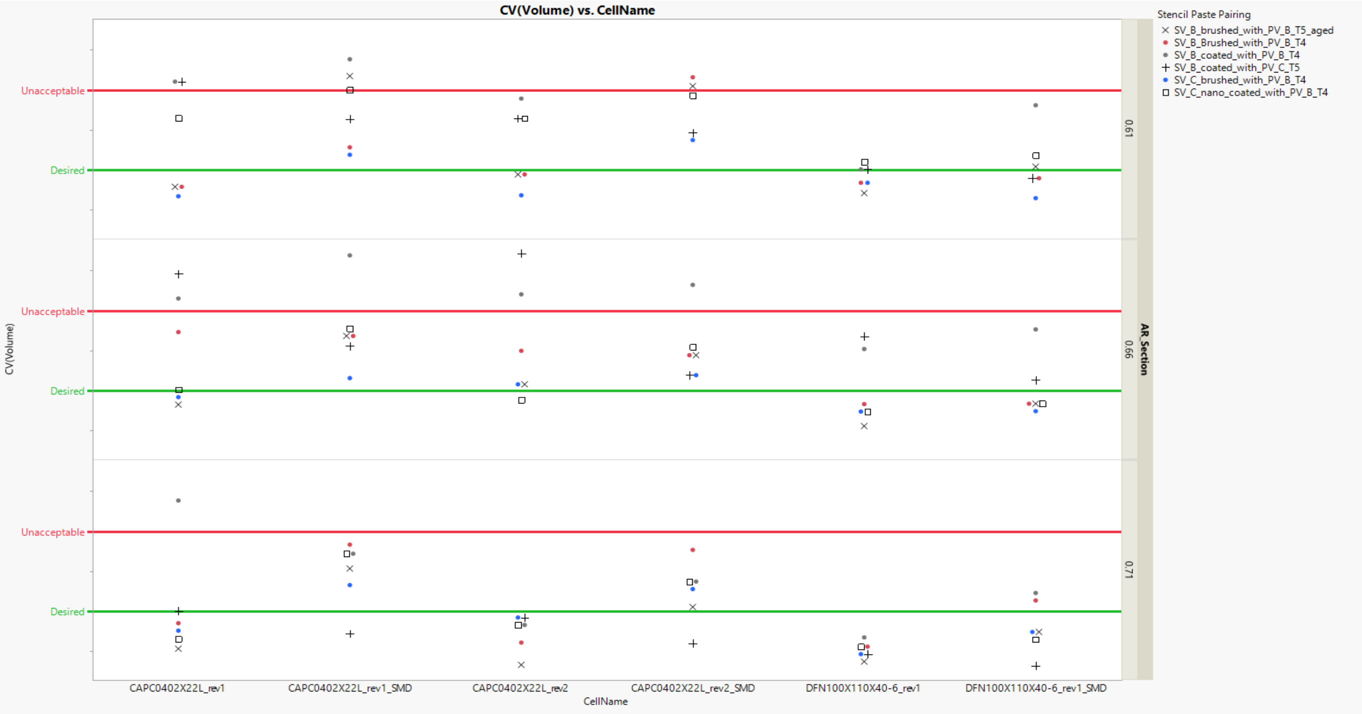
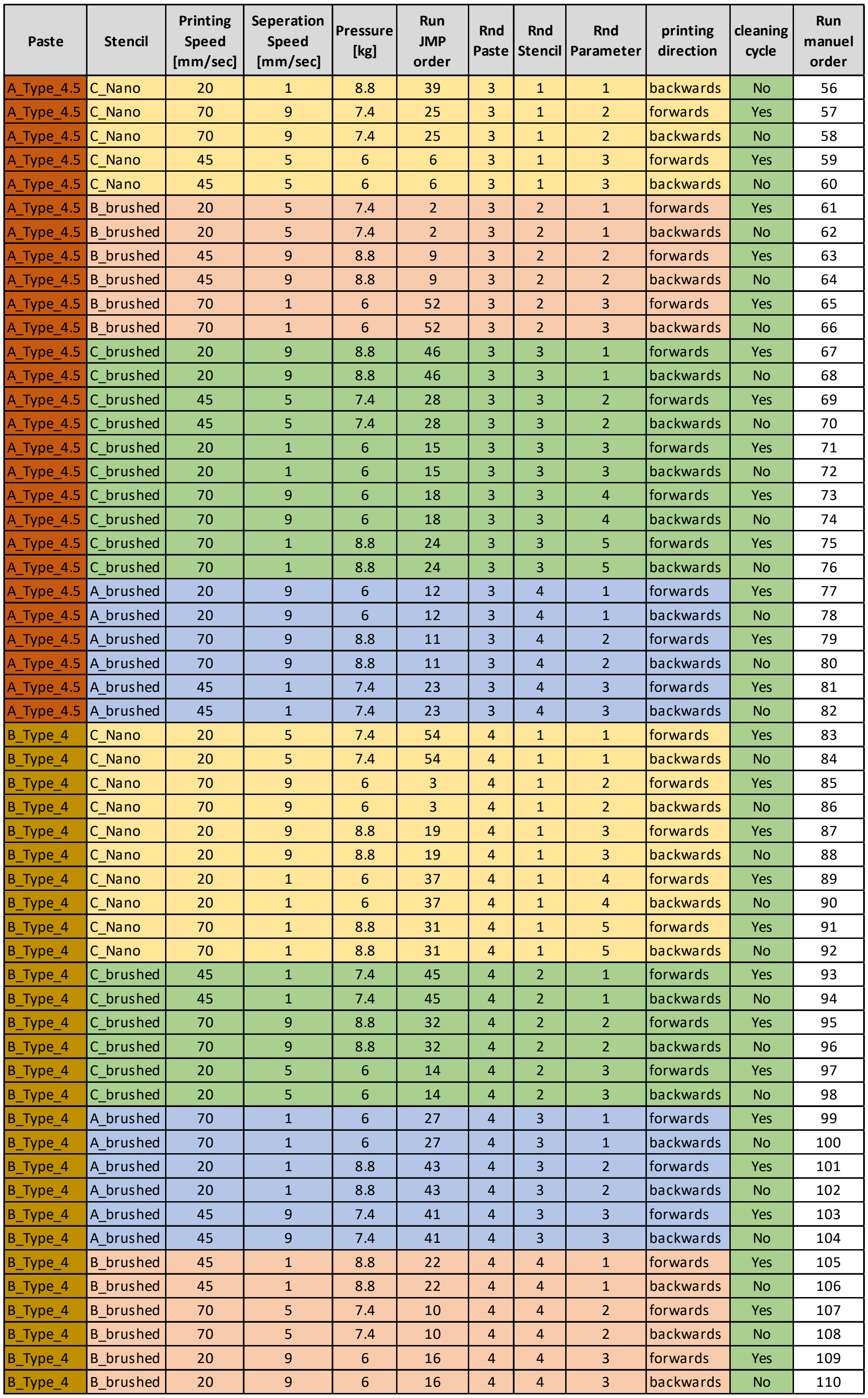


Figure 21. CV vs. Cells vs. Stencil-Paste-Pairing vs. AR



Paste	Stencil	Printing Speed [mm/sec]	Seperation Speed [mm/sec]	Pressure [kg]	Run JMP order	Rnd Paste	Rnd Stencil	Rnd Parameter	printing direction	cleaning cycle	Run manuel order
A_Type_4.5	C_Nano	20	1	8.8	39	3	1	1	backwards	No	56
A_Type_4.5	C_Nano	70	9	7.4	25	3	1	2	forwards	Yes	57
A_Type_4.5	C_Nano	70	9	7.4	25	3	1	2	backwards	No	58
A_Type_4.5	C_Nano	45	5	6	6	3	1	3	forwards	Yes	59
A_Type_4.5	C_Nano	45	5	6	6	3	1	3	backwards	No	60
A_Type_4.5	B_brushed	20	5	7.4	2	3	2	1	forwards	Yes	61
A_Type_4.5	B_brushed	20	5	7.4	2	3	2	1	backwards	No	62
A_Type_4.5	B_brushed	45	9	8.8	9	3	2	2	forwards	Yes	63
A_Type_4.5	B_brushed	45	9	8.8	9	3	2	2	backwards	No	64
A_Type_4.5	B_brushed	70	1	6	52	3	2	3	forwards	Yes	65
A_Type_4.5	B_brushed	70	1	6	52	3	2	3	backwards	No	66
A_Type_4.5	C_brushed	20	9	8.8	46	3	3	1	forwards	Yes	67
A_Type_4.5	C_brushed	20	9	8.8	46	3	3	1	backwards	No	68
A_Type_4.5	C_brushed	45	5	7.4	28	3	3	2	forwards	Yes	69
A_Type_4.5	C_brushed	45	5	7.4	28	3	3	2	backwards	No	70
A_Type_4.5	C_brushed	20	1	6	15	3	3	3	forwards	Yes	71
A_Type_4.5	C_brushed	20	1	6	15	3	3	3	backwards	No	72
A_Type_4.5	C_brushed	70	9	6	18	3	3	4	forwards	Yes	73
A_Type_4.5	C_brushed	70	9	6	18	3	3	4	backwards	No	74
A_Type_4.5	C_brushed	70	1	8.8	24	3	3	5	forwards	Yes	75
A_Type_4.5	C_brushed	70	1	8.8	24	3	3	5	backwards	No	76
A_Type_4.5	A_brushed	20	9	6	12	3	4	1	forwards	Yes	77
A_Type_4.5	A_brushed	20	9	6	12	3	4	1	backwards	No	78
A_Type_4.5	A_brushed	70	9	8.8	11	3	4	2	forwards	Yes	79
A_Type_4.5	A_brushed	70	9	8.8	11	3	4	2	backwards	No	80
A_Type_4.5	A_brushed	45	1	7.4	23	3	4	3	forwards	Yes	81
A_Type_4.5	A_brushed	45	1	7.4	23	3	4	3	backwards	No	82
B_Type_4	C_Nano	20	5	7.4	54	4	1	1	forwards	Yes	83
B_Type_4	C_Nano	20	5	7.4	54	4	1	1	backwards	No	84
B_Type_4	C_Nano	70	9	6	3	4	1	2	forwards	Yes	85
B_Type_4	C_Nano	70	9	6	3	4	1	2	backwards	No	86
B_Type_4	C_Nano	20	9	8.8	19	4	1	3	forwards	Yes	87
B_Type_4	C_Nano	20	9	8.8	19	4	1	3	backwards	No	88
B_Type_4	C_Nano	20	1	6	37	4	1	4	forwards	Yes	89
B_Type_4	C_Nano	20	1	6	37	4	1	4	backwards	No	90
B_Type_4	C_Nano	70	1	8.8	31	4	1	5	forwards	Yes	91
B_Type_4	C_Nano	70	1	8.8	31	4	1	5	backwards	No	92
B_Type_4	C_brushed	45	1	7.4	45	4	2	1	forwards	Yes	93
B_Type_4	C_brushed	45	1	7.4	45	4	2	1	backwards	No	94
B_Type_4	C_brushed	70	9	8.8	32	4	2	2	forwards	Yes	95
B_Type_4	C_brushed	70	9	8.8	32	4	2	2	backwards	No	96
B_Type_4	C_brushed	20	5	6	14	4	2	3	forwards	Yes	97
B_Type_4	C_brushed	20	5	6	14	4	2	3	backwards	No	98
B_Type_4	A_brushed	70	1	6	27	4	3	1	forwards	Yes	99
B_Type_4	A_brushed	70	1	6	27	4	3	1	backwards	No	100
B_Type_4	A_brushed	20	1	8.8	43	4	3	2	forwards	Yes	101
B_Type_4	A_brushed	20	1	8.8	43	4	3	2	backwards	No	102
B_Type_4	A_brushed	45	9	7.4	41	4	3	3	forwards	Yes	103
B_Type_4	A_brushed	45	9	7.4	41	4	3	3	backwards	No	104
B_Type_4	B_brushed	45	1	8.8	22	4	4	1	forwards	Yes	105
B_Type_4	B_brushed	45	1	8.8	22	4	4	1	backwards	No	106
B_Type_4	B_brushed	70	5	7.4	10	4	4	2	forwards	Yes	107
B_Type_4	B_brushed	70	5	7.4	10	4	4	2	backwards	No	108
B_Type_4	B_brushed	20	9	6	16	4	4	3	forwards	Yes	109
B_Type_4	B_brushed	20	9	6	16	4	4	3	backwards	No	110

Figure 22. Main DoE run table - run 56 to 110

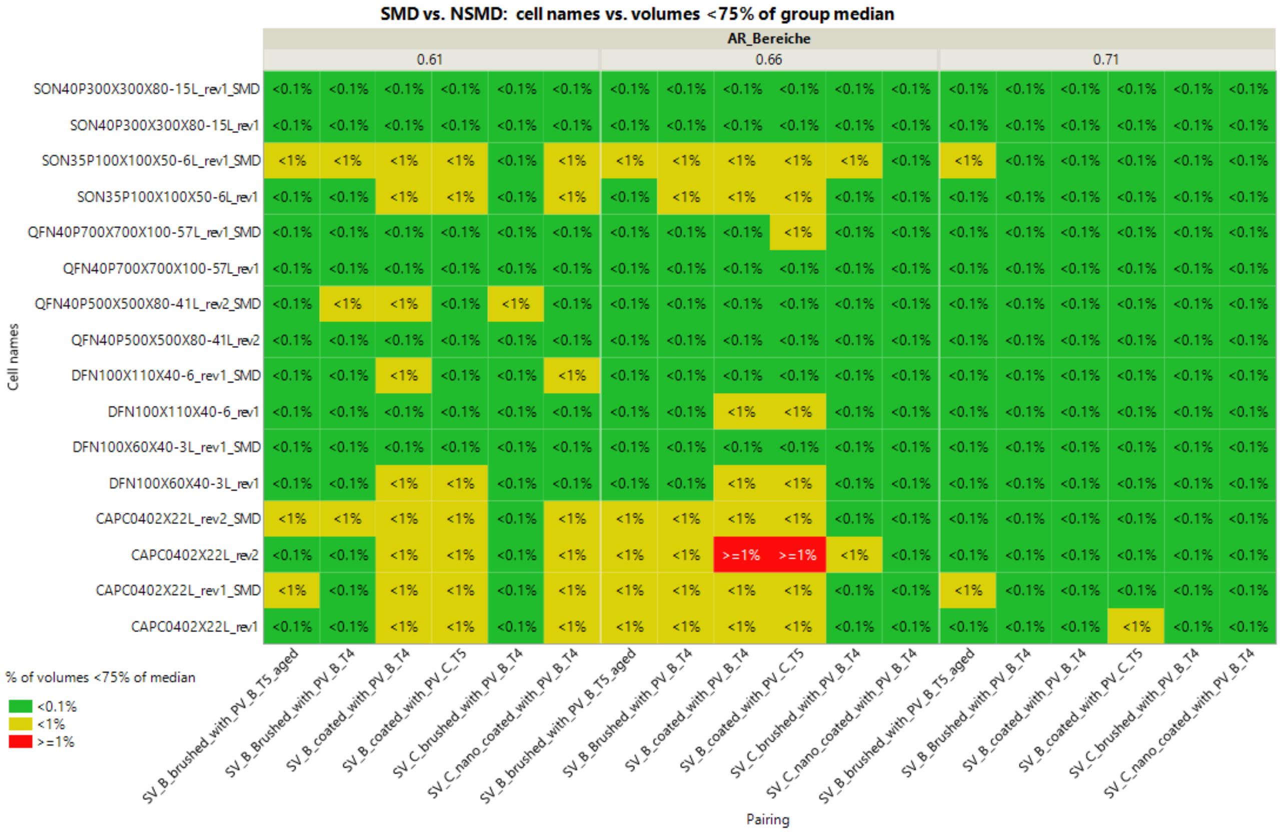
Volume under 75% of Median - Stencil Aperatures of Cells vs. Stencil-Paste Pairings

CellName And Aperatures Dimensions		SV_B_brushed_with_PV_B_T5_aged	SV_B_Brushed_with_PV_B_T4	SV_B_coated_with_PV_B_T4	SV_B_coated_with_PV_C_T5	SV_C_brushed_with_PV_B_T4	SV_C_nano_coated_with_PV_B_T4
SON40P300X300X80-15L_rev1	600x180 ER50	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
	600x150 ER50	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
	500x175 ER50	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
SON35P100X100X50-6L_rev1	480x140 ER50	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
	450x130 ER50	<0.1%	<1%	<1%	<1%	<0.1%	<0.1%
	340x125 ER50	<0.1%	<0.1%	<1%	<1%	<0.1%	<1%
QFN40P700X700X100-57L_rev1	750x150 ER50	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
	724x124 ER50	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
	550x187 ER50	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
QFN40P500X500X80-41L_rev2	700x160 ER50	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
	675x145 ER50	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
	600x180 ER50	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
DFN100X110X40-6_rev1	245x190 ER50	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
	225x150 ER50	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
	200x250 ER50	<0.1%	<0.1%	<1%	<1%	<0.1%	<0.1%
DFN100X60X40-3L_rev1	280x150 ER50	<0.1%	<0.1%	<1%	<1%	<0.1%	<0.1%
	250x140 ER50	<0.1%	<0.1%	<1%	<1%	<0.1%	<0.1%
	240x195 ER50	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
CAPC0402X22L_rev2	220x220 ER50	<1%	<1%	>=1%	>=1%	<1%	<0.1%
	215x215 ER50	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
	180x180 ER50	<0.1%	<0.1%	<1%	<1%	<0.1%	<1%
CAPC0402X22L_rev1	230x200 ER50	<0.1%	<0.1%	<0.1%	<1%	<0.1%	<0.1%
	225x150 ER50	<0.1%	<0.1%	<1%	<1%	<0.1%	<1%
	215x185 ER50	<1%	<1%	<1%	<1%	<0.1%	<0.1%
BGA81C40P9X9_360X360X50_rev1	r226	<0.1%	<0.1%	<0.1%	<0.1%	<1%	<0.1%
	r210	<0.1%	<1%	>=1%	>=1%	>=1%	<0.1%
	r195	<0.1%	<1%	<1%	<1%	<1%	<1%
BGA63C68P8X8_629X569X82A_rev1	r226	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
	r210	<0.1%	<0.1%	<0.1%	<1%	<0.1%	<0.1%
	r195	<0.1%	<1%	<1%	<0.1%	<1%	<0.1%
BGA63C68P8X8_629X569X82_rev1	r226	<0.1%	<0.1%	<1%	<1%	<0.1%	<0.1%
	r210	<0.1%	<0.1%	>=1%	>=1%	>=1%	<0.1%
	r195	<0.1%	<0.1%	<1%	<1%	<1%	<0.1%
BGA36C50P6X6_302X329X53_rev1	r226	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
	r210	<0.1%	<0.1%	<0.1%	<1%	<0.1%	<0.1%
	r195	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
B2B040PF180_2X30_1460X294X390-60_rev1	674x174 ER50	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
	640x150 ER50	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
	160x640 ER50	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%

Portion of Volumes < 75% of Median

🟩 <0.1%
🟨 <1%
🟥 >=1%

Figure 23. NSMD - Percentage Volume < 75% of Median, Dimensions of the apertures in [µm]



SMD vs. NSMD: cell names vs. volumes <75% of group median

Cell names	AR_Bereiche 0.61						AR_Bereiche 0.66						AR_Bereiche 0.71					
Pairing	SV_B_brushed_with_PV_B_T5_aged	SV_B_Brushed_with_PV_B_T4	SV_B_coated_with_PV_B_T4	SV_B_coated_with_PV_C_T5	SV_C_brushed_with_PV_B_T4	SV_C_nano_coated_with_PV_B_T4	SV_B_brushed_with_PV_B_T5_aged	SV_B_Brushed_with_PV_B_T4	SV_B_coated_with_PV_B_T4	SV_B_coated_with_PV_C_T5	SV_C_brushed_with_PV_B_T4	SV_C_nano_coated_with_PV_B_T4	SV_B_brushed_with_PV_B_T5_aged	SV_B_Brushed_with_PV_B_T4	SV_B_coated_with_PV_B_T4	SV_B_coated_with_PV_C_T5	SV_C_brushed_with_PV_B_T4	SV_C_nano_coated_with_PV_B_T4
SON40P300X300X80-15L_rev1_SMD	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
SON40P300X300X80-15L_rev1	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
SON35P100X100X50-6L_rev1_SMD	<1%	<1%	<1%	<1%	<0.1%	<1%	<1%	<1%	<1%	<1%	<1%	<0.1%	<1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
SON35P100X100X50-6L_rev1	<0.1%	<0.1%	<1%	<1%	<0.1%	<1%	<0.1%	<1%	<1%	<1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
QFN40P700X700X100-57L_rev1_SMD	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
QFN40P700X700X100-57L_rev1	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
QFN40P500X500X80-41L_rev2_SMD	<0.1%	<1%	<1%	<0.1%	<1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
QFN40P500X500X80-41L_rev2	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
DFN100X110X40-6_rev1_SMD	<0.1%	<0.1%	<1%	<0.1%	<0.1%	<1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
DFN100X110X40-6_rev1	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<1%	<1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
DFN100X60X40-3L_rev1_SMD	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
DFN100X60X40-3L_rev1	<0.1%	<0.1%	<1%	<1%	<0.1%	<0.1%	<0.1%	<0.1%	<1%	<1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
CAPC0402X22L_rev2_SMD	<1%	<1%	<1%	<1%	<0.1%	<1%	<1%	<1%	<1%	<1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
CAPC0402X22L_rev2	<0.1%	<0.1%	<1%	<1%	<0.1%	<1%	<1%	<1%	>=1%	>=1%	<1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
CAPC0402X22L_rev1_SMD	<1%	<0.1%	<1%	<1%	<0.1%	<1%	<1%	<1%	<1%	<1%	<0.1%	<0.1%	<1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%
CAPC0402X22L_rev1	<0.1%	<0.1%	<1%	<1%	<0.1%	<1%	<1%	<1%	<1%	<1%	<0.1%	<0.1%	<0.1%	<0.1%	<0.1%	<1%	<0.1%	<0.1%

% of volumes <75% of median

- 🟩 <0.1%
- 🟨 <1%
- 🟥 >=1%

Figure 24. Volume <75% NSMD vs. SMD